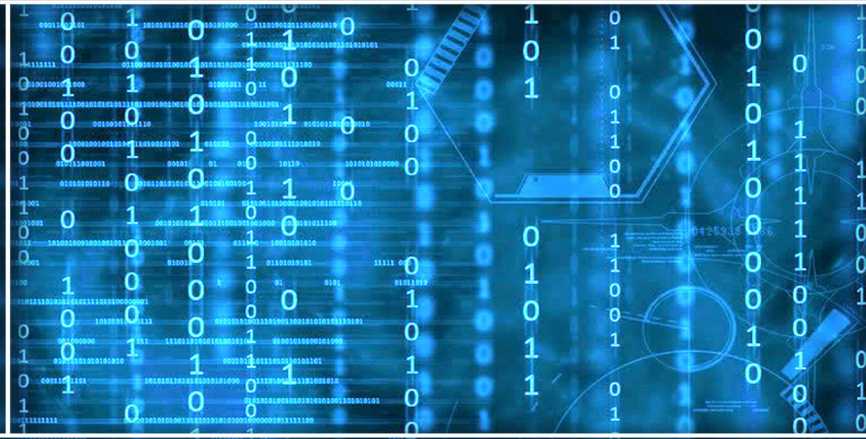


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Editorial Preface

From the Desk of Managing Editor...

It may be difficult to imagine that almost half a century ago we used computers far less sophisticated than current home desktop computers to put a man on the moon. In that 50 year span, the field of computer science has exploded.

Computer science has opened new avenues for thought and experimentation. What began as a way to simplify the calculation process has given birth to technology once only imagined by the human mind. The ability to communicate and share ideas even though collaborators are half a world away and exploration of not just the stars above but the internal workings of the human genome are some of the ways that this field has moved at an exponential pace.

At the International Journal of Advanced Computer Science and Applications it is our mission to provide an outlet for quality research. We want to promote universal access and opportunities for the international scientific community to share and disseminate scientific and technical information.

We believe in spreading knowledge of computer science and its applications to all classes of audiences. That is why we deliver up-to-date, authoritative coverage and offer open access of all our articles. Our archives have served as a place to provoke philosophical, theoretical, and empirical ideas from some of the finest minds in the field.

We utilize the talents and experience of editor and reviewers working at Universities and Institutions from around the world. We would like to express our gratitude to all authors, whose research results have been published in our journal, as well as our referees for their in-depth evaluations. Our high standards are maintained through a double blind review process.

We hope that this edition of IJACSA inspires and entices you to submit your own contributions in upcoming issues. Thank you for sharing wisdom.

Thank you for Sharing Wisdom!

Kohei Arai
Editor-in-Chief
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Spatio-Temporal Features based Human Action Recognition using Convolutional Long Short-Term Deep Neural Network

A F M Saifuddin Saif, Ebisa D. Wollega, Sylvester A. Kalevela
School of Engineering, Colorado State University Pueblo, CO 81001, USA

Abstract—Recognition of human intention is crucial and challenging due to subtle motion patterns of a series of action evolutions. Understanding of human actions is the foundation of many applications, i.e., human robot interaction, smart video monitoring and autonomous driving etc. Existing deep learning methods use either spatial or temporal features during training. This research focuses on developing a lightweight method using both spatial and temporal features to predict human intention correctly. This research proposes Convolutional Long Short-Term Deep Network (CLSTDN) consists of Convolutional Neural Network (CNN) and Recurrent Neural Network (RNN). CNN uses Inception-ResNet-v2 to classify object specific class categories by extracting spatial features and RNN uses Long Short-Term Memory (LSTM) for final prediction based on temporal features. Proposed method was validated on four challenging benchmark dataset, i.e., UCF Sports, UCF-11, KTH and UCF-50. Performance of the proposed method was evaluated using seven performance metrics, i.e., accuracy, precision, recall, f-measure, error rate, loss and confusion matrix. Proposed method showed better results comparing with existing research results. Proposed method is expected to encourage researchers to use in future for real time implications to predict human intentions more robustly.

Keywords—Convolutional neural network; recurrent neural network; long short-term memory; human action recognition

I. INTRODUCTION

The recognition and understanding of human activities on video streams have now become crucial in many applications for instance smart video monitoring, automobiles driving, somatic gaming, etc. This task is extremely difficult if both accuracy and robustness are taken into consideration. In the field of human behavior recognition, substantial research is needed. Recognition and prediction of actions are two key tasks in the field of computer vision and action recognition. Understanding the actions of others is the foundation of human social interaction. It is difficult to predict the intent of others from their acts but it's necessary. Recognition of human activities plays a significant role in people's daily lives, for example in applications for medical, protection, and law enforcement fields. Observation of human intentions through motions was introduced to many instances of Human-Robot Interaction. Recognition of actions and prediction of actions can be very different among the different classes of action. Intention prediction, however, infers from the subtle motion patterns of a series of action evolutions of the same action. This makes the prediction of intention a more challenging

task. Recognition of action can essentially be categorized at various abstraction levels depending on the nature of the visual information. It varies from simple actions like activity concepts, interaction with objects and human beings to complex acts as a group activity.

In recent years, one of the popular deep learning models, Convolutional Neural Networks (CNNs), has shown great success in many computer vision's tasks, such as image recognition, image segmentation, object tracking and so on [1] [2]. CNN appears to learn a hierarchy of features from low-level to high-level and researchers find the features that CNN automatically learns are typically better than the handcrafted features. Researchers have put a great effort to develop neural networks capable of capturing spatial-temporal features in recognition of human activities. Most of the researchers have taken advantage of the deep learning approach for the recognition of human activities. Because deep learning techniques allow automated extraction and learning of hierarchical features by human behavior recognition systems, several of these systems have been developed and have shown promising results. Deep Learning (DL) methods have gained significant attention recently due to their remarkable performance in various fields. It is, therefore, not surprising that DL-based methods for identification, prediction and prediction of intention have also increased. Particularly Deep Learning models based on the Recurrent Neural Network have brought much success in the field of behavior analysis in recent years. The most widely used model in RNN is usually the Long Short-Term Memory (LSTM). It is an extension of the RNN structure that essentially allows long-term temporal dependencies by replacing hidden nodes with gated memory cells.

Focusing on that, this research proposes a Deep Learning approach for recognizing human intention. In videos with complex scenarios, proposed method called Convolutional Long Short-Term Deep Network (CLSTDN) can identify human intentions with a good amount of precision. Pre-trained convolutional neural network, Inception-ResNet-v2 is used for extracting spatial features from video sequence and then using LSTM temporal features are extracted from the video sequence. With some more dense layers, training and classification are done to recognize intention from videos. In this task, this research evaluates proposed method on the human action datasets such as UCF Sports dataset, UCF-11 dataset, UCF-50 dataset and KTH dataset where variety of actions of different situations was found. These datasets are

very complex and challenging because of wide variations in camera motion, conditions of lighting, object appearance and posture, size of object, view, cluttered background, etc. Regardless of the point of view, background, inter-class and intra-class similarities are found in image frames, proposed method performed very well with very small data sequences in all the datasets. Experiment results show that the proposed method achieved state-of-the-art performance with low computational resources for action intentions recognition from human behavior. Overall contribution of this research is summarized as below.

1) This research proposes a news method called Convolutional Long Short-Term Deep Network (CLSTDN) consists of a Convolutional Neural Network (CNN) and Recurrent Neural Network (RNN) for efficient human intention prediction. Proposed CLSTDN serves following two purposes:

a) Convolutional Neural Network (CNN) uses Inception-ResNet-v2 to classify scenes to categorize class specific objects by extracting spatial features.

b) Recurrent Neural Network (RNN) uses Long Short-Term Memory (LSTM) for final prediction based on temporal features.

Thus, this research ensures to use spatial and temporal features for improved human intention prediction. Previous research methods used either spatial or temporal features for human intention prediction; however, proposed CLSTDN used spatial-temporal features for human intention prediction.

2) Massive experimental results are demonstrated on four benchmark datasets to validate the proposed method. Four publicly available datasets were used for validation, i.e., UCF Sports, UCF-11, KTH and UCF-50. Seven evaluation metrics were estimated for each dataset, i.e., accuracy, precision, recall, f-measure, error rate, loss and confusion matrix.

3) Proposed CLSTDN performed efficiently based on all the evaluation metrics with limited number of data sequence irrespective of viewpoint, background, inter-class and intra-class similarities present in the image frames in all the datasets which is very promising comparing with previous research methods.

4) Previous research methods provide the evidence that deep learning architectures require huge computational power and GPU clusters which imply the fact that it is wise to consider not only the accuracy but also the cost of a method for implementation. By considering this fact to implicate new research methodology with limited computation resources in lieu of achieving satisfactory computation time, this research proposed Convolutional Long Short-Term Deep Network (CLSTDN) to recognize the human action based on intention. Rest of this research is organized as follows, Section II illustrates existing research methods, Section III reflects proposed research methodology, Section IV reflects comprehensive experimental results for robust validation of the proposed methodology and finally, conclusion section presents concluding remarks.

II. PREVIOUS RESEARCH STUDY

There are essentially two types of human activity recognition approaches, i.e., video-based models and sensor-based models. High-dimensional features are derived from videos or images [3][5][10][13][14][35], whereas sensor-based systems rely on motion information captured by sensing devices [44]. Researchers have focused on analyzing human behavior through radar backscattering echoes with the development of new sensing technology. It is understood that the carrier frequency of the radar signal would be changed when reflected from any moving target which is known as the Doppler Effect. A point network can learn more efficiently about structural features from the micro motion trajectory than it can directly process the raw point cloud and it also shows that the temporal range-Doppler PointNet approach performs better on most behaviors [18]. This uses radar to emit signals, while very high frequency reflected signal analysis captures very fine dynamic behavior. Radar can be used for extreme climates, meaning that it is immune to light and weather conditions, as this system uses radar, human beings can be identified via walls, making radar useful in more situations. For researchers, the hierarchical model is superior to its base counterpart (P-Net). Sensor-based technologies may be a trigger for mental and physical discomfort [43] and wearable technology is not ideal for applications where complex motor activity needs to be monitored and interpreted [15][23][24][25][26][27].

YOLOv3 object detector [8] and SSD [29] can accurately detect a group of people with a high degree of confidence by only taking a few frames from video-based models. There is also a pipeline of Generative Adversarial Networks (GANs), which jointly learns latent information for estimating and group identification of pedestrian trajectories [2]. GAN suggests a learning mechanism for task-specific loss function where a minimum game between the generative and discriminatory models is an objective of training. In the area of computer vision, significant progress has been made concerning recent developments in deep learning methodologies due to the advancement of deeper CNN, parallel computer hardware and wide-ranged annotated datasets. Various approaches have been put on places to address the recognition of action problems. Actions recognition systems can be classified into representations based on shape and appearance, representations based on optical flow and representations based on the point of interest depending on the representations of the feature. The most successful methods of classifying the action involve using CNNs. Deep CNN models achieved state-of-the-art results with tasks of object identification, classification, generation and segmentation. In deep learning, there are two primary strategies used to extract features from the video frames. First, by expanding traditional 2D CNN architectures to 3D, 3D CNN learns convolution kernels in space and time domains [17]. The second strategy is a two-stream CNN [55] that delivers state-of-the-art results in [56][57][58]. A Convolutional Neural Network (CNN) with YOLO is used together for an IoT detection that enables suspicious human behavior with minimal effort [20]. A Deep Neural Network (DNN) is followed by a time-domain classifier method for automatic violent behavior detection designed for video sensor

networks [40]. One distinguishing characteristic of the proposed solution is that it relies entirely on motion characteristics by completely disregarding appearance details. Asymptotically the tests are like optical flow-based approaches and often better than the others. This method is ideally suited for low computing devices and used by researchers for improvement in the future. Researchers achieved state-of-the-art efficiency, using Raspberry-Pi sensor nodes to run on low computational embedded architecture. This approach works perfectly well with low-computing devices and a potential area for enhancement work. Research in [22] compared state-of-the-art machine learning and deep learning approaches suitable for detecting early changes in human behavior, where support vector machine (SVM) and Convolutional neural network (CNN) from the supervised method, One-class support vector machine (OCSVM) and Stacked auto-encoders (SAE) from Semi-Supervised and K-means clustering (KM) and Convolutional auto-encoder (CAE) from Unsupervised is used. Methods based on CNN take many parameters for model learning. This takes hours to months to optimize. In the meantime, using a GPU with parallel architecture significantly reduces the processing time. The more GPUs, the less computational time it takes to train. These factors have given much importance to the transition of transfer learning [11] [12] [32] [38] [41]. Researchers proposed a pre-trained model of a convolutional neural network (CNN) based on Visual Geometry Group network 19 (VGGNet-19) which is used to extract descriptive features [41]. An abnormal event detection system using pre-trained VGGNet-19 and Binary Support Vector Machine (BSVM) videos demonstrates higher detection accuracy than other pre-trained networks: GoogleNet, ResNet50, AlexNet, and VGGNet-16. BSVM needs only a few abnormal detection training patterns and provides reasonable detection accuracy for new patterns with the same features. Several researchers use Deep convolutional neural networks (CNN) to detect violent scenes by transfer learning to classify aggressive human behaviors [28][31][50]. Research in [30] recognized basic human activities using the Deep Belief Network (DBN) method which is a good candidate to the model activity recognition system. DBN is a robust, deep learning method used during training using Restricted Boltzmann Machines (RBMs). At first, they extracted efficient features from the raw data. Then they used kernel principal component analysis (KPCA) and linear discriminant analysis (LDA) to make the data more robust. Research in [16] proposed a Real-time Multi-Person 2D Pose Estimation using Part Affinity Fields (PAFs). The OpenPose program recognizes the key human points better than other methods. The program identifies and generates a student report every three seconds in the classroom. It utilizes a non-parametric representation called PAFs to learn to connect the body components with individuals in the image. Via this approach, the OpenPose system recognizes the human key points better than other approaches. This also operates on the low computational device slowly, leading to a lack of input in real-time and considering only six gestures. Long-term memory networks (LSTM) are another technology which is used in various approaches like in [32] to predict human movements accurately. To send visual signals, they used a deep learning

model that explored combining CNN with LSTM. LSTM is used to derive temporal patterns of human motion outputting the prediction result immediately before movement occurs. LSTM is used by research in [45] for the simulation of spatial-temporal sequences obtained from smart home sensors. They mentioned that approaches based on LSTM yield higher results than the existing DL and ML methods. For pattern recognition, LSTM is also used for anomaly detection with the Recurrent Neural Network (RNN) and Multi-Layer Perceptron (MLP) [21,60]. Different researchers used models to explain human emotion, sentiment, stress, and fatigue using GRU [6][9] and LSTM [19]. GRU is LSTM-like, which has shown that it operates well on smaller datasets. GRU has less operation compared to LSTM and thus it can be trained much faster than LSTMs, while LSTM is more accurate in the long sequence datasets. A method was proposed by research in [43] to identify such behaviors in which humans interact with various objects, considering object-oriented knowledge of the operation, using a hybrid approach to combine deep convolutional neural networks with multi-class support vector machines (multi-class SVM). An Adaptive feature recalibration residual network (AFRRNet) and Quaternion Spatio-Temporal Convolutional Neural Network (QST-CNN) based model is proposed by research in [47] to recognize human behavior. In predicting human action or behavior, the temporal network works much better than other related networks. It also makes use of optical flow representation for the input flow. The pre-processing of the optical flow image corresponds to the spatial flow. Optical flow suppresses horizon details and displays series motion fields. The motion fields highlighted encode motion information between adjacent frames which contribute significantly to the prediction of intention. This essentially improves the ability of the network to derive functionality and accuracy of recognition of behaviors.

Research in [35] proposed a multi-stream model for a better understanding of human activities through 3-channel Depth MHI and Skeleton based ST-GCN. The model defines contextual awareness, global and local intervention recognition motions. These two models have a fusion performance that exceeds each model and is comparable with state-of-the-art results. Researchers proposed an architecture with the multi-stream convolutional neural network (HR-MSCNN) based on a human-related region that encodes the presence, motion and captured tubes of regions with human relations [36]. The improved version of B-RPCA (IB-RPCA) can be defined reliably as the main actor in complex realistic circumstances including vibration, specific luminous conditions and partial occlusions. Human emotions also make a significant contribution to understand human intention. A deep learning approach is focused on the multimodal detection of stress through Convolutional Autoencoders and Recurrent Neural Networks. This also contained a recurrent unit called Gated Recurrent Unit (GRU) [9]. Some researchers use a lightweight CNN model for recognition of facial expression from a given input image [7]. CNN generates a matrix using the input image. After that the pooling process takes place then, the flattening process starts. Finally, the system predicts the facial expression. Using Convolutional Neural Network (CNN) fused with Extreme Learning Machines (ELMs), it can

classify emotions where two layers of the ELM to the fusion make calculation fast. It is found that the fusion based on ELM performed better than the combination of the classifiers [17]. With respect to local feature descriptors, there has been a lot of work to extract and explain useful and robust information. Several feature descriptors have been successfully adapted to enhance the accuracy of human action recognition from the image domain to the video domain. In addition to human-robot interaction, prediction of human intention plays an important role in a wide variety of applications, such as driving assistance systems on cars to predict the lane changes intentions of drivers [4] [34], prediction of pedestrian or cyclist intention [49], as well as monitoring to predict the intentions underlying detected suspicious activities and giving security [20][21].

There were many methods and frameworks with various types of limitations or drawbacks that are needed to overcome to develop a perfect method for human activity recognition. Many of the methods and frameworks were simple to implement and develop but offered considerable computational time. The more GPUs there are, the less computational time it needs for training. However, the solution is costly. It is wise to consider not only the accuracy but also the cost of a method when choosing a method for any implementation, as this can influence the time to build a production-ready method and the operating costs for running it.

III. PROPOSED RESEARCH METHODOLOGY

Previous research provides the evidence that deep learning architectures require huge computational power and GPU clusters to perform in low computational time. By considering this fact to implicate new research methodology with limited computation resources in lieu of achieving satisfactory computation time, this research proposed Convolutional Long Short-Term Deep Network (CLSTDN) to recognize the Human Action based Intention. Proposed method used both spatial and temporal features from a video and predicted intentions robustly. Pre-trained convolutional neural network (CNN), Inception-Resnet-v2 extracts spatial features from a video frame and makes a feature sequence. After that, features are given as input into the LSTM network. LSTM network extracts the temporal features from the sequence and with dense layer and SoftMax activation function, proposed method predicts an intention from the video. Overall proposed method was very resource friendly as this research did not use any external GPUs and only 8 gigabytes of RAM. Later, proposed method was validated with real-world environment videos and performed robustly to identify human intentions.

Proposed CLSTDN by this research consists of a convolutional neural network and a Long-short-term Memory network. Proposed methodology consists of three main parts, i.e., data preprocessing, feature extraction and intention recognition. This research used video-based datasets to train and test the method. In the data processing section, frames are extracted from the video data first and then reshaped those images to 224 x 224. For KTH dataset, this research calibrated images into 120 x 120 as the image dimension of the KTH dataset was smaller than the other datasets used by this

research. Second significant part of the proposed methodology is feature extraction. This research used a pre-trained Inception-ResNet-v2 model to extract an image encoding. In this section, this research stacks the frames to provide a three-channel image to meet the specifications of Inception-ResNet-v2 and after that, this research reshaped images into 299 x 299 and made sequences by extracting features from the image frames for training and testing purpose. The third part of the proposed methodology is training and testing the model from the extracted features using LSTM deep learning method. Here, this research fed the extracted spatial feature into the LSTM model and extracts temporal features and the last layer output using the SoftMax activation function. Overall proposed methodology is shown in Fig. 1 and comprehensively explained in the subsequent sections.

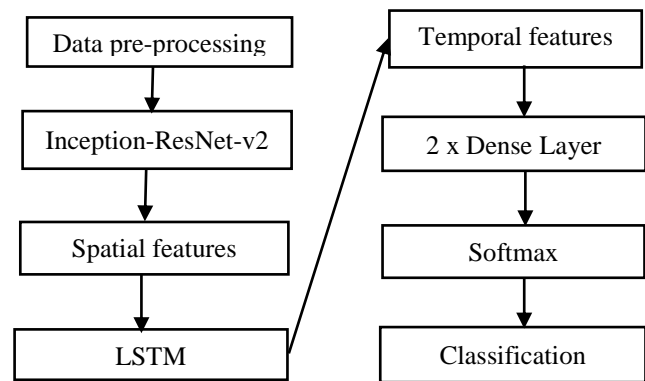


Fig. 1. Components of proposed methodology.

A. Data Processing

This research used UCF Sports, UCF11, UCF50 and KTH dataset to train and test proposed CLSTDN. As these datasets are video-based dataset so this research first extracted image frames from these datasets followed by splitting the data into train and test data and saved each video's number of frames into a CSV file by which extraction of spatial features were done by Inception-ResNet-v2 model. As imbalanced dataset may lead to wrong accuracy and over-fitting problems, this research removed blank image frames from the dataset. After that, this research reshaped images size to decrease computation time. Next, these images are used as input to Inception-Resnet-v2 to extract features.

B. Backbone

To utilize depth features as guidance of 2D convolutions, this research formulates backbone as a two-branch network: the first branch is the feature extraction network using RGB images and the other is the filter generation network to produce convolutional kernels for feature extraction network using the estimated depth as input. These two networks process the two inputs separately and their outputs of each block are merged by the depth guided filtering approach.

The backbone of the feature extraction network is Inception-ResNet-v2[54] without its final FC and pooling layers and is pre-trained on the ImageNet classification dataset [63]. To obtain a larger field-of-view and keep the network stride at 16, this research finds the last convolutional layer (conv5 1, block4) that decreases resolution and set its stride to

1 to avoid signal decimation and replace all subsequent convolutional layers with dilated convolutional layers (the dilation rate is 2). For the filter generation network, we only use the first three blocks of Inception-ResNet-v2 to reduce computational costs. Note the two branches have the same number of channels of each block for the depth guided filtering task. More about Inception-ResNet-v2 is illustrated in the next section.

C. Inception-ResNet-V2

For extracting spatial features from input images, this research used pre-trained Inception-ResNet-v2 model. This architecture is trained on more than a million images from the ImageNet database. The network is 164 layers deep and can classify images into 1000 object categories. Inception-ResNet-v2[54] is from the Inception family convolutional neural network (CNN) architecture which gradually evolved from GoogleNet and was the first Inception neural network through Inception v2 and Inception v3, and finally, Inception v4 [54]. Every one of the architectures brought changes primarily with respect to the Inception module, Inception networks building block. Research in [54] motivated by the results obtained by residual neural networks, experimented with integrating residual connections, key features of residual networks, with the Inception module. The result, Inception-ResNet-v2 is a very deep network, which in a lower number of epochs can achieve high accuracy which motivates proposed method by this research to use Inception-ResNet-v2 model for spatial feature extraction.

Inception-ResNet-v2 architecture contains three separate types of Residual Inception modules, called A, B, and C, and two distinct blocks of reduction. In Residual Inception module, residual connections play significant role for overall manipulation. Residual connection is a simple concept that has been invented as a way of solving the problems of the vanishing gradient and exploding gradient that may appear in a very deep neural network. The theory behind is that residual block only measures the adjustments that will make the input perfect, apply them to the input, and present it as its output, instead of calculating the output from scratch. Residual Inception blends residual learning with the Inception modules by incorporating a residual connection to it. The concept on which the Inception module operates is to expand rather than deeper neural network. The expanded width enables complex patterns to be recorded at different scales. The initial 1x1 convolutions are only used to reduce dimensionality on the axis of the channel to lighten the following convolutions. All convolutions use zero padding for the preservation of height and width. This is important since the outputs are concatenated along the depth dimension after each separate calculation in the module, which would not be possible if the heights and widths differed. The split of a $n \times n$ convolution into two $-1 \times n$ and $n \times 1$ convolution stored one on top of each other is another feature of the Inception module. An important feature of the Residual Inception module is that after the concatenation, there is a 1x1 convolution to allow the addition of identity passed by the residual relation and the actual output by aligning its dimensions [54]. Inception-ResNet-v2 contains reduction modules which are slightly changed Inception modules. Unlike those mentioned earlier, these modules

contain an average pooling on one of the branches followed by a 1x1 convolution. This research extracted spatial features from the Average Pooling layer of Inception-ResNet-v2 architecture (Fig. 1 Top) and fed it as an input to the LSTM model for training the model.

D. Training LSTM Model

After extracting the spatial features, this research uses Long Short-Term Memory (LSTM) network to extract temporal features from a sequence. LSTM is a recurrent neural network (RNN) architecture designed more accurately than conventional RNNs for modeling temporal sequences and long-term dependencies. In the recurring hidden layer, LSTM has special units known as memory blocks. Fig. 2 shows that memory blocks contain a memory cell with self-connections to store the network's temporal state, as well as special multiplication units called information flow gates. An input gate and an output gate were included in each memory block of the initial architecture. Input Gate controls the memory cell flow of the activations. Output gate controls cell activation output flow into the rest of the network. Forget gate was added to the memory block later. The forgotten gate measures the inner cell state before connecting it to the cell through the self-recurring connection of the cell, thereby forgetting or resetting the cell's memory adaptively.

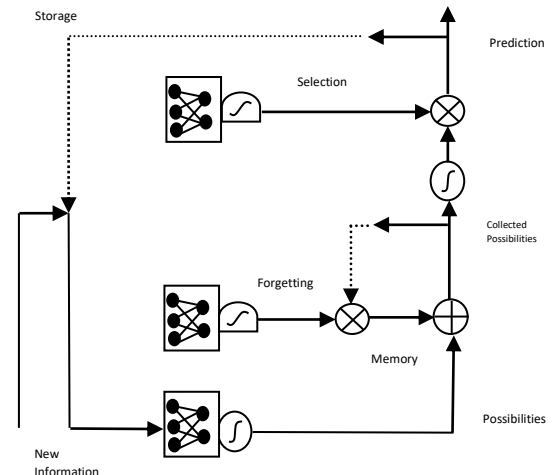


Fig. 2. Long Short-Term Memory (LSTM) network.

For training purpose this research used Long Short-Term Memory Deep Learning approach. During implementation, this research changed learning rate, decay rate, dropout and momentum to find the optimal value of these hyper parameters. A low learning rate helps overall methodology to avoid overfitting problem, where proposed method performs well on both training and test data. In this context, this research tuned parameters into four steps, i.e., tuning LSTM size, tuning batch size, tuning number of epochs and tuning for LSTM and Dense layers for four different datasets.

1) *Tuning for LSTM size:* This research initially fixed number of LSTM and Dense layers to 3, batch size to 32 and number of epochs to 50 and tuned LSTM size over these parameters. This research trained LSTM model with size 512,

1024 and 2048 for every dataset used for experimentation. With size 2048, proposed method generated the highest accuracy for tuning LSTM size. This research also used a fixed dense layer of size 512 and a classification dense layer to classify overall result.

2) *Tuning batch size and no. of epochs:* After tuning LSTM size, this research fixed its size to 2048 and number of LSTM and Dense layers to 3 and tuned batch size and number of epochs. This research performs training with a batch size of 8, 16, 32, 64, 128, 256 and number of epochs of 20, 50, 75 and 100. This research performs training for each set of batch sizes and number of epochs respectively. Here, this research found different batch sizes and number of epochs sets for different datasets which are explained in more details in experimental results section.

3) *Tuning No. of LSTM and dense layers:* For the final step of parameter tuning, proposed method fixed LSTM size to 2048 and different batch sizes and number of epochs for the different datasets and tuned number of LSTM and Dense layers. In this context, this research performs training with one fixed LSTM layers and 2, 3, and 4 Dense layers. This research also tuned the model by changing dense layer size of 256, 512 and 1024. Proposed method generated the best result for 3 layers with different sizes for the different datasets.

In summary, this research proposed a new method called Convolutional Long Short-Term Deep Network (CLSTDN) to recognize human action-based intention. Proposed CLSTDN consists of convolutional neural network and recurrent neural network. For convolutional neural network, this research used pre-trained network which was Inception-ResNet-v2 which is trained on more than a million images from ImageNet database. This network contains 164 layers to classify images into 1000 object categories. For recurrent neural network, this research used Long Short-Term Memory (LSTM) network. Overall proposed methodology consists of three main parts, i.e., data preprocessing, feature extraction, intention recognition. At first, video frames were extracted followed by preprocessing frames according to Inception-ResNet-v2. Then, images are passed to the Inception-ResNet-v2 network to extract the spatial features and create a sequence of the video. After that, the sequences are passed to the LSTM network which extracts temporal features from the sequence. Then dense layers and SoftMax activation function are used in the proposed method to predict the intention from the video. This research performs training with low computational resources by using both spatial-temporal features. Proposed method predicted intentions accurately which was revealed robustly during experimental validation demonstrated in the next section. In addition, implication of the proposed method is resource friendly.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

Evaluation for the proposed Convolutional Long Short-Term Deep Network (CLSTDN) was done by experimenting four publicly available datasets, i.e., UCF Sports, UCF-11, KTH and UCF-50. This research plotted actual and predicted data for each intention into a confusion matrix after

experimentation. From the confusion matrix, this research estimated True Positive (TP), False Positive (FP), True Negative (TN), False Negative (FN) which helped to find out the evaluation metrics. This research estimated accuracy, precision, recall, f-measure and error rate for each dataset. After 62 epochs, this research received best result for UCF Sports dataset which gives an accuracy of 95.74%, precision of 95.83%, recall of 97.49%, F-measure of 96.23%, and an error rate of 4.26%. After 43 epochs, proposed method received best results for UCF 11 dataset which gives an accuracy of 95.44%, precision of 95.3%, recall of 95.33%, F-measure of 95.26%, and error rate of 4.66%. After 45 epochs, proposed method found best result for KTH dataset which gives an accuracy of 90.1%, precision of 90.1%, recall of 90.54%, F-measure of 90.2% and an error rate of 9.9%. After 20 epochs, proposed method received best results for UCF 50 dataset which gives an accuracy of 80.80%, precision of 80.27%, recall of 80.27%, F-measure of 79.68%, and error rate of 19.2%.

A. Hardware and Software Set Up

1) *Hardware set up:* For experimental validation, this research used two different computers with similar configurations. Both computers were running on windows 10x64 platforms with an Intel Core i5-7200U CPU 2.5GHz with turbo boost up to 3.1 GHz and both with 8 Gigabytes of RAM and with no external Graphics Processing Unit (GPU).

2) *Software set up:* This research used python 3.7.1 on Jupyter Notebook 6.0.3 Integrated Development Environment (IDE) on Anaconda Navigator 2, Atom 1.51.0 x64 IDE. This research used different types of python libraries OpenCV 3.4.2, Tensorflow 2.1.0, Keras 2.3.1, Matplotlib 3.2.2 for line graph, Seaborn 0.10.1 for confusion matrix, FFMpeg 4.2.2, NumPy 1.19.1, Pandas 1.0.5, Scikit Learn 0.23.1 for evaluation metrics, Tqdm 4.47.0, CSV, and Glob.

B. Evaluation Parameters

To evaluate the performance of the proposed method, evaluation was done by finding the accuracy, precision, recall, f-measure, and error rate on various datasets. In this context, TP, FP, FN, TN are used to calculate accuracy, precision, recall, f-measure and error rate [67]. True Positive (TP) is the number of correct predictions that an instance is negative. False Positive (FP) is the number of incorrect predictions that an instance is positive. False Negative (FN) is the number of incorrect of predictions that an instance negative. True Negative (TN) is the number of correct predictions that an instance is positive [69].

1) *Accuracy:* Accuracy is the most natural measure of performance which refers a ratio between correctly predicted observation and total observations expressed using following equation [63, 67].

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{FP} + \text{FN} + \text{TN}} \quad (1)$$

2) *Precision:* Precision is the proportion of positive observations accurately predicted to the overall predicted

positive observations which is expressed using following equation [64, 67].

$$\text{Precision} = \frac{TP}{TP+FP} \quad (2)$$

3) *Recall*: Recall is the proportion of positive observations accurately predicted to all observations in actual class which is expressed using following equation [65, 67].

$$\text{Recall} = \frac{TP}{TP+FN} \quad (3)$$

4) *F-Measure*: F-Measure is the weighted average of Recall and Precision which takes both false positives and false negatives into account and is expressed using following equation [67, 68].

$$\text{F Measure} = 2 * \frac{\text{Recall} * \text{Precision}}{\text{Recall} + \text{Precision}} \quad (4)$$

5) *Error rate*: Error rate is simply a ratio of wrongly predicted observation to the total observations which is expressed using following equation [67].

$$\text{Error rate} = \frac{FP+FN}{TP+FP+FN+TN} \quad (5)$$

6) *Loss*: Loss is a number that indicates how poor a prediction of the model was in one particular case [59,60,61,62,66]. Loss is zero if the assumption of the model is right or else the loss is greater. Loss functions are intended to measure how much a method requires to minimize value in training. This research used the categorical_crossentropy as the loss function. The value measured by the loss function is simply called a loss which is usually used when there are two or more than two label classes.

7) *Confusion matrix*: For deep learning classification perspectives, confusion matrix is a performance measurement where two or more classes generate output [59, 60, 61, 62, 66, 69]. Confusion matrix is a table with four different predicted and actual value combinations which is very useful for measuring accuracy, precision, recall, f- measure, and error rate. This research found predicted percentage value comparing to the actual value and inserted the value for that class in the confusion matrix.

C. Datasets

In order to evaluate the performance of the proposed Convolutional Long Short-Term Deep Network (CLSTDN) for Intention recognition, this research evaluated the performance of the network with the publicly accessible datasets like: UCF-Sports [31, 36, 60, 66], UCF-11 [60, 66], KTH [8,31,47,62], and UCF-50 [31,36]. Such challenging datasets are commonly used for benchmarking. Later, this research compared experimental results with state-of-the-art approaches. Details for each of the datasets are illustrated below.

1) *UCF-Sport*: UCF Sport is one of the oldest datasets for action's recognition which consists of a sequence of acts from different sports activities. The dataset consists of 150 videos for 10 human actions with a resolution of 720x480. This

dataset's frame numbers vary from video to video. Frame rate of the UCF Sports dataset was 10 frames per second and on average each video contains 30 to 130 frames in total.

2) *UCF-11*: UCF-11 dataset includes 11 types of action categories. Due to broad variations in camera movement, object appearance and posture, object size, view, cluttering background, lighting conditions, etc. This dataset is very complex and challenging comparing than YouTube video-based dataset.

3) *KTH*: The KTH is the most widely used human behavior public dataset which contains 6 different types of video action with a resolution of 160x120. 25 participants in four different scenarios performed actions multiple times. For each combination of 25 subjects, 6 actions, and 4 scenarios, there are total of 600 video files. All sequences with a static camera with a 25fps frame rate had been taken over homogenous backgrounds.

4) *UCF-50*: UCF50 is a collection of action recognition data with 50 categories of action, consisting of realistic videos taken from YouTube. This dataset is an extension of the YouTube Action dataset (UCF-11). The videos are grouped into 25 groups for all the 50 categories, where each group consisting of more than four action clips with a resolution of 320x240.

This research splits all datasets into 70% for training and 30% for testing. The training and testing data split are shown in Table I.

TABLE I. DESCRIPTION OF TRAIN AND TEST SPLIT OF VIDEOS OF DATASETS

Dataset	Training Data	Testing Data
UCF Sports	103	47
UCF-11	1084	439
KTH	407	192
UCF-50	4636	1839

In the UCF Sports dataset, this research extracted 15 frames from per second of the video. For UCF-11 dataset, this research extracted 10 frames per second of the video as there are more videos. Also, for the UCF-50 dataset, this research extracted 10 frames from per second of the video as the dataset is very big in size and the images are loaded into a resolution of 224x224x3. For the KTH dataset, this research extracted 25 frames per second of the video and images are loaded into a resolution of 120x120x3 as the videos were of low resolution. This research ignored the frames mentioned to be ignored from the official site of the KTH dataset so there is no ambiguous data. This research reshaped images into a resolution of 299x299 because pre-trained Inception-ResNet-v2 network accepts an input of size 299x299 only. Inception-ResNet-v2 is a pre-trained convolutional neural network which was used to extract the spatial features from frames of a video.

To train the model, this research used batch size of 32 for the UCF Sports dataset, 32 for the UCF-11 dataset, 64 for KTH and 128 for the UCF-50 dataset. This research used

LSTM of size 2048 and two more dense layers size of 1024 and 512 with the most common Rectified Linear Unit (ReLU) activation function. This research used dropout probability of 0.1 to reduce any overfitting issues in all layers for UCF sports and UCF-11 dataset. In addition, this research used a dropout of 0.1 on the dense layer size of 512 for KTH and UCF-50 dataset and no dropout on other layers. Finally, this research used SoftMax activation function on the last dense layer of the size of the output class to achieve output. This research used Adam optimizer with a learning rate of 1×10^{-5} , a decay rate of 1×10^{-6} and a momentum of 0.2 for all the datasets. This research sets the model to train for 100 epochs but if the validation loss of the model does not improve for 10 consecutive epochs, this research used early stopper function to stop epochs.

D. Experimental Results

Proposed method received best results for UCF Sports dataset after 62 epochs which needed 2336 seconds with accuracy of 95.74%, precision of 95.83%, recall of 97.49%, F measure of 96.23% and error rate of 4.26% shown in Table II. After 43 epochs that needed 4970 seconds, proposed method received best results for UCF 11 dataset which gives an accuracy of 95.44%, precision of 95.3%, recall of 95.33%, F-measure of 95.26%, and error rate of 4.66%. After 45 epochs that needed 10556 seconds, proposed method achieved best results for the KTH dataset which gives an accuracy of 90.1%, precision of 90.1%, recall of 90.54%, F-measure of 90.2%, and error rate of 9.9%. After 20 epochs which needed 5146 seconds, proposed method received best results for UCF 50 dataset which gives an accuracy of 80.80%, precision of 80.27%, recall of 80.27%, F-measure of 79.68% and an error rate of 19.2%.

TABLE II. EXPERIMENTAL RESULTS FOR THE PROPOSED METHOD IN FOUR DATASETS

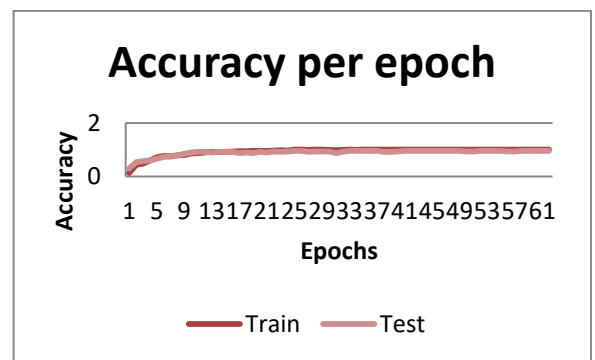
Dataset	Accuracy	Precision	Recall	F-Measure	Error rate
UCF Sports	95.74	95.83	97.49	96.23	4.26
UCF-11	95.44	95.3	95.33	95.26	4.66
KTH	90.1	90.1	90.54	90.2	9.9
UCF-50	80.8	80.27	80.27	79.68	19.2

Line graph as Accuracy per epochs of the UCF-Sports dataset is shown in Fig. 3(a) where yellow line indicates testing accuracy and blue line indicates training accuracy. As this research uses deep learning architecture to train and test data, proposed method learns gradually from the train data. From test data proposed method validates performance in each epoch. Fig. 3(a) states that after 62 epochs, training accuracy increased gradually and finally reached 1.0 which is 100%. Test accuracy also increased gradually with each epoch and reached a maximum value of 0.9574 which is 95.74%.

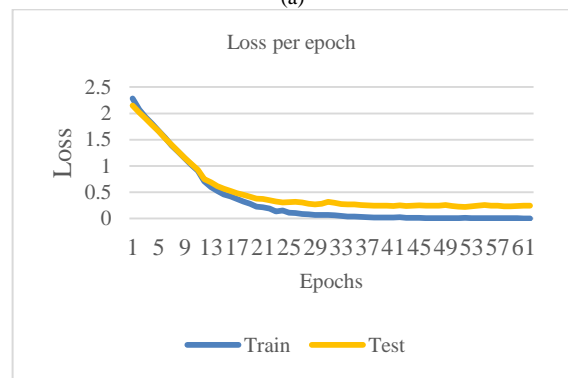
Line graph as Loss per epochs of the UCF Sports dataset is shown in Fig. 3(b) where yellow line is the test loss and blue line is the train loss. Loss is zero if the assumption of the proposed method is right or else the loss is greater. Loss will gradually decrease with each epoch. If test loss value does not decrease for 10 consecutive epochs, then this research stopped

the epoch. Following this, this research receives best result with minimum test loss which is targeted for minimizing overfitting. Fig. 3(b) states that minimum train loss is 0.0042 and the minimum test loss is 0.22254.

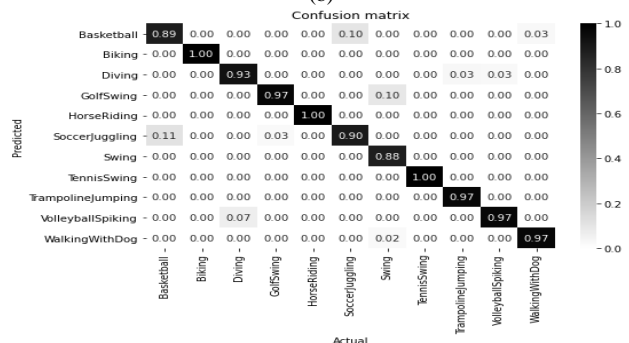
Confusion matrix for UCF Sports dataset is shown in Fig. 3(c) which states that proposed method faced problems in predicting actions like Golf swing and Run side. Running sideways is one time predicted as kicking by the proposed method. On the other hand, Golf-swing is predicted as kicking for one time by the proposed method. For the rest of the activities, proposed method model predicted intentions accurately. After analyzing various actions in videos for which proposed method predicted wrong, this research observed that some frames from the video of golf swing make the intention of kicking due to similarity of patterns. Also, for the running activity, the videos were a bit unclear and made the proposed method predicting it as kicking due to the same reason.



(a)



(b)



(c)

Fig. 3. (a). Line graph as accuracy of UCF sports dataset, (b). Line graph as loss of UCF sports dataset, (c) Confusion matrix of UCF sports dataset.

Line graph as accuracy per epochs of the UCF-11 dataset is shown in Fig. 4(a) where yellow line indicates testing accuracy and blue line indicates training accuracy. Fig. 4(a) states that after 43 epochs, training accuracy increased gradually and finally reached 1.0 which is 100%. Testing accuracy also increased gradually with each epoch and reached a maximum value of 0.9544 which is 95.44%. Line graph as the Loss per epochs of the UCF-11 dataset is shown in Fig. 4(b) where yellow line is the test loss and the blue line is the train loss. Loss is zero if the assumption of the proposed method is right or else loss is greater. Best results were achieved with minimum test loss which is targeted for minimizing overfitting. Fig. 4(b) states that the minimum train loss is 0.0012 and minimum test loss is 0.1557.

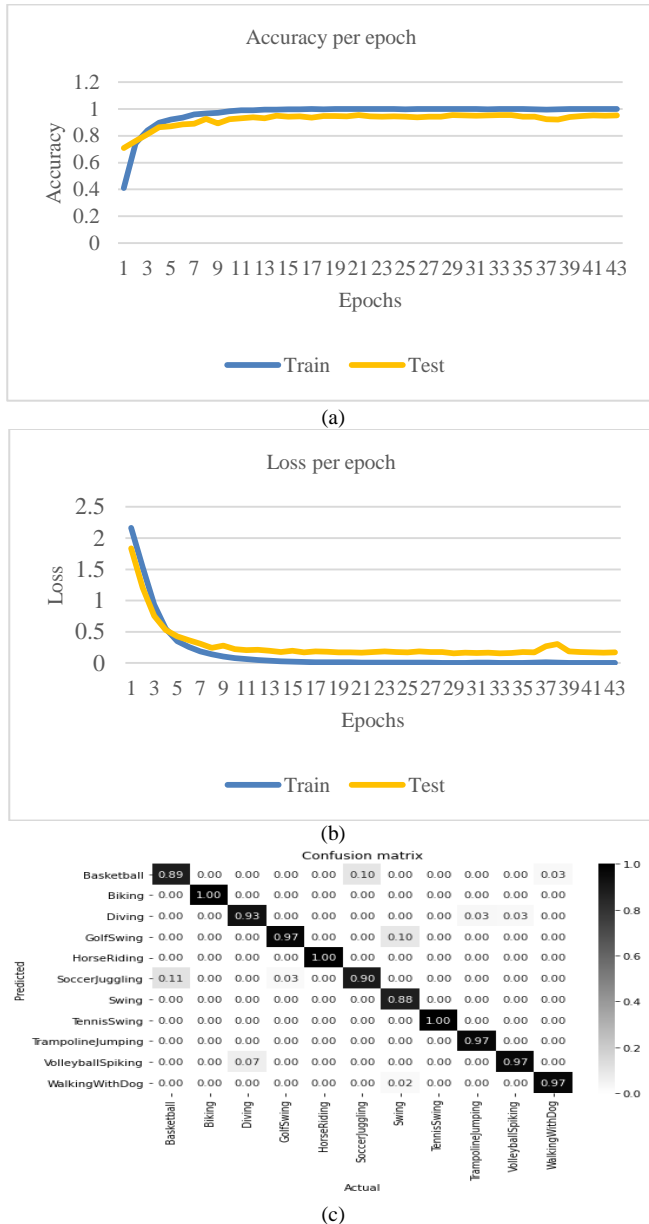


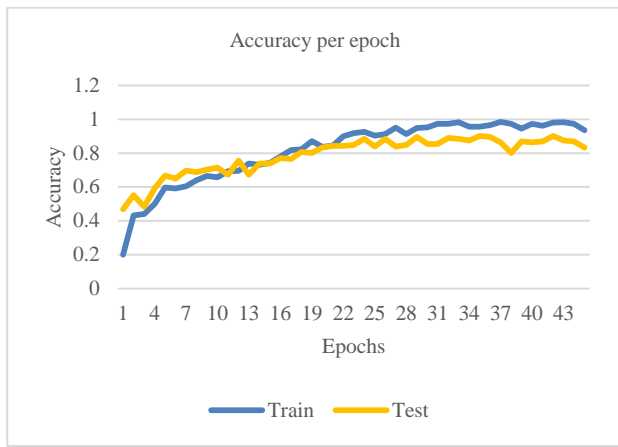
Fig. 4. (a) Line graph as accuracy of UCF-11 dataset, (b) Line graph as loss of UCF-11 dataset, (c) Line graph as confusion matrix of UCF-11 dataset.

Confusion matrix of UCF-11 dataset is shown in Fig. 4(c). From the confusion matrix, this research observed that proposed method almost predicted all the intentions perfectly where for almost all the activities prediction was robust. In some activities like Basketball playing, proposed method predicted some video sequences as soccer as there is a common object which is a ball. In this context, accuracy can be increased if more training is done with these activities. Also, for swing, there were some video angles in which proposed method was not trained which causes wrong prediction for those angles as golf swings.

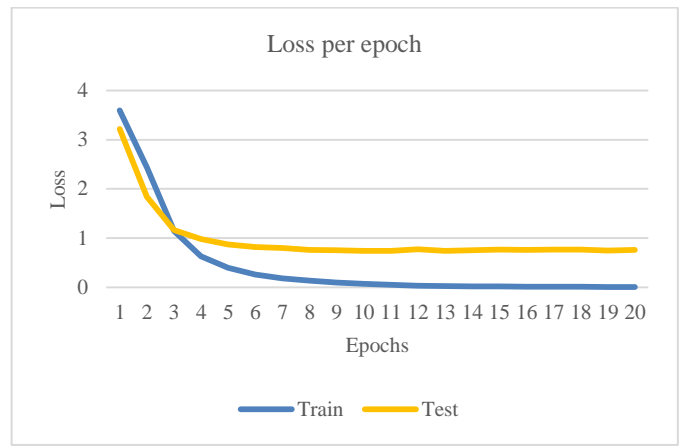
Line graph as the Accuracy per epochs of the KTH dataset is shown in Fig. 5(a) where yellow line indicates testing accuracy and blue line indicates training accuracy. Fig. 5(a) states that after 45 epochs, training accuracy increased gradually and finally reached 0.9853 which is 98.53%. Test accuracy also increased gradually with each epoch and reached a maximum value of 0.9010 which is 90.10%.

Line graph as the Loss per epochs of the KTH dataset is shown in Fig. 5(b) where yellow line indicates test loss and blue line indicates train loss. Proposed method receives best results with minimum test loss which was targeted for minimizing the overfitting. Fig. 5(b) shows that the minimum train loss is 0.0645 and the minimum test loss is 0.3179. Confusion matrix of the KTH dataset is shown in Fig. 5(c). KTH dataset is robust datasets which contains similar kinds of activities like jogging, running and walking. Confusion matrix states that proposed method by this research predicted the intentions accurately enough. Although, proposed method faced problems for running activity which was predicted as jogging, which is also tough for a normal human being to differentiate between, them due to the similarity of the pattern.

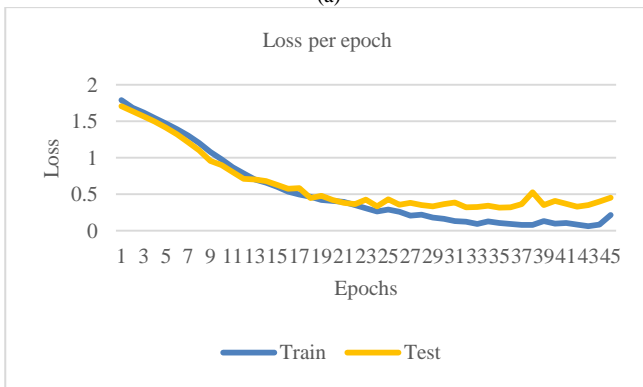
Line graph as the Accuracy per epochs of the UCF-50 dataset is shown in Fig. 6(a) where yellow line indicates testing accuracy and blue line indicates training accuracy. Fig. 6(a) states that after 20 epochs, training accuracy increased gradually and finally reached 1.0 which is 100%. Testing accuracy also increased gradually with each epoch and reached a maximum value of 0.8113 which is 81.13%. Line graph as the Loss per epochs of the UCF-50 dataset is shown in Fig. 6(b) where yellow line indicates test loss and blue line indicates train loss. Proposed method received accuracy was 81.13%, best test loss was achieved with accuracy of 80.8%. Fig. 6(b) states that minimum train loss is 0.0098 and the minimum test loss is 0.7413. Confusion matrix of UCF-50 datasets states that proposed method faced problems in predicting the actions like nunchucks, jumping jack, and javelin throw. In these actions, there are some positions or frames which are like other activities. Nunchucks is often considered as golf swing or swing because it has some position like these two activities. For jumping jacks, it has some frames which make the proposed method predicting other activities like lunges, jumping rope or pullups. In javelin throwing, the actor often jumps to throw the javelin which was predicted as high jump by our proposed method often due to similarity of the pattern.



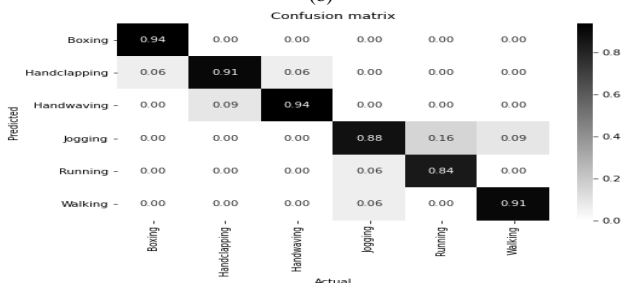
(a)



(b)

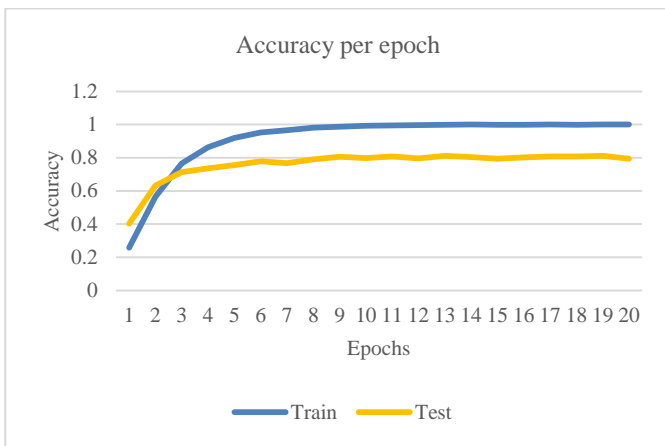


(b)

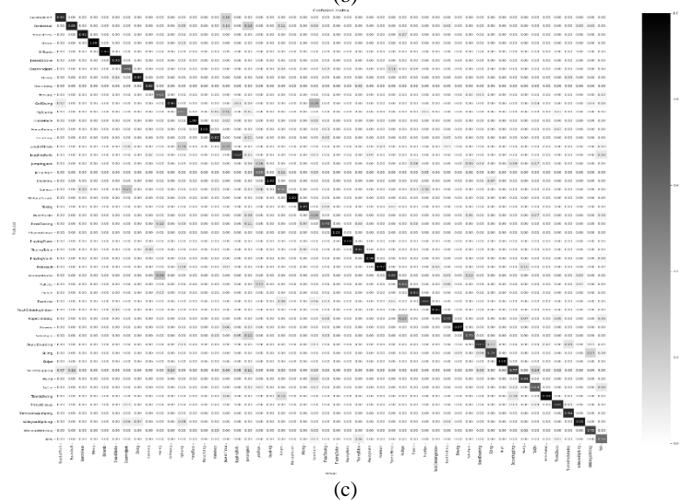


(c)

Fig. 5. (a) Line graph as accuracy of KTH dataset, (b) Line graph as loss of KTH dataset, (c) Confusion matrix of KTH dataset.



(a)



(c)

Fig. 6. (a) Line graph as accuracy of UCF-50 dataset, (b) Line graph as loss of UCF-50 dataset, (c) Confusion matrix of UCF-50 dataset.

E. Comparison with Previous Research Results

After experimenting on four different datasets, this research compared proposed method with state-of-the-art methods and found that proposed method performed very well using spatial-temporal features compared to other method with a good amount of accuracy, precision, recall and f-measure.

Proposed CLSTDN received accuracy rate of 95.74% which is higher than previous research methods shown in Fig. 7(a). Research in [59] received accuracy of 93.1% using Convolutional Neural Network and Support Vector Machine. They used three frames of a video instead of the all the frames to understand the human action. Besides, they extracted conceptual features to recognize objects and worked with sports-based dataset only. Whereas proposed CLSTDN used spatial-temporal features caused better performance than research in [59]. Research in [60] received accuracy rate of an accuracy of 93.67% using same method as research in [60]. They used only first and last frames of a video instead of the all the frames to understand human action. Like in research [59], they used conceptual features to recognize objects and used SVM to classify high level and stationary features obtained from CNN; whereas usage of spatial-temporal features by the proposed CLSTDN resulted better performance than research in [60]. Research in [61] received

accuracy rate of 86.67% using action-history and histogram of oriented gradient. They used Motion History Image (MHI), Local Binary Pattern (LBP) and Histogram of Oriented Gradient (HOG) approaches for action recognition. Proposed CLSTDN by this research pre-trained CNN used Inception-ResNet-v2 to extract features from deep inside the image to create sequence. For this reason, proposed CLSTDN achieved better performance comparing with research in [61]. Research in [62] received accuracy rate of 93.7% using fully connected-to-LSTM. They used VGG-16 as pre-trained CNN network and fused the result with LSTM to recognize human actions whereas proposed CLSTDN extract spatial features from average pooling layer and passed the data sequence to LSTM to extract temporal features to recognize human intentions. Also, research in [62] used spatial features only to recognize human actions whereas proposed CLSTDN used both spatial and temporal features to recognize human intention and achieved better accuracy. Research in [66] received accuracy rate of 92.4% using motion history images of frame sequences with spatial information extraction. They used Motion History frame sequence to understand the temporal changes. However, proposed CLSTDN passed spatial feature sequences to LSTM for temporal understanding of the whole video caused higher accuracy than research in [66]. In overall, previous methods used spatial or temporal data for understanding video whereas proposed CLSTDN uses both spatial-temporal understanding of a video which helps for a better understanding of human intention.

Proposed CLSTDN received precision rate of 95.83% which is higher than previous methods shown in Fig. 7(b). Research in [59] received precision rate of 93.27% using Convolutional Neural Network and Support Vector Machine. Precision rate indicates the proportion of positive observations accurately predicted to the overall predicted positive observations. As research in [59] used only three frames of a video instead of the all the frames to understand the human action, their overall positive classifications were less than proposed method by this research. Research in [60] received precision rate of 93.91% using Convolutional Neural Network and Support Vector Machine. As they used first and last frames only of a video instead of the all the frames to understand the human action caused their positive classifications less than proposed CLSTDN by this research. As accurately predicted positive observation by research in [60] is less than proposed CLSTDN, precision is also less than proposed CLSTDN. They used spatial-temporal understanding of an image but they are still unable to learn from an image due to lack of depth features which causes lower accurately predicted positive observations than proposed CLSTDN and precision is also higher than research in [61]. Research in [62] received precision rate of 95% and 89% using fully connected-to-LSTM and Convolutional-to-LSTM respectively. They used VGG-16 as pre-trained CNN network caused number predicted positive observations less than proposed method and finally resulted in better precision rate than in research [62]. Research in [66] received precision rate of 92.46% using frame sequences and spatial features extraction. Like other previous methods, research in [66] used the VGG-16 pre-trained network which caused less accurate predictions than proposed method by this research and

resulted in lower precision rate than by the proposed CLSTDN.

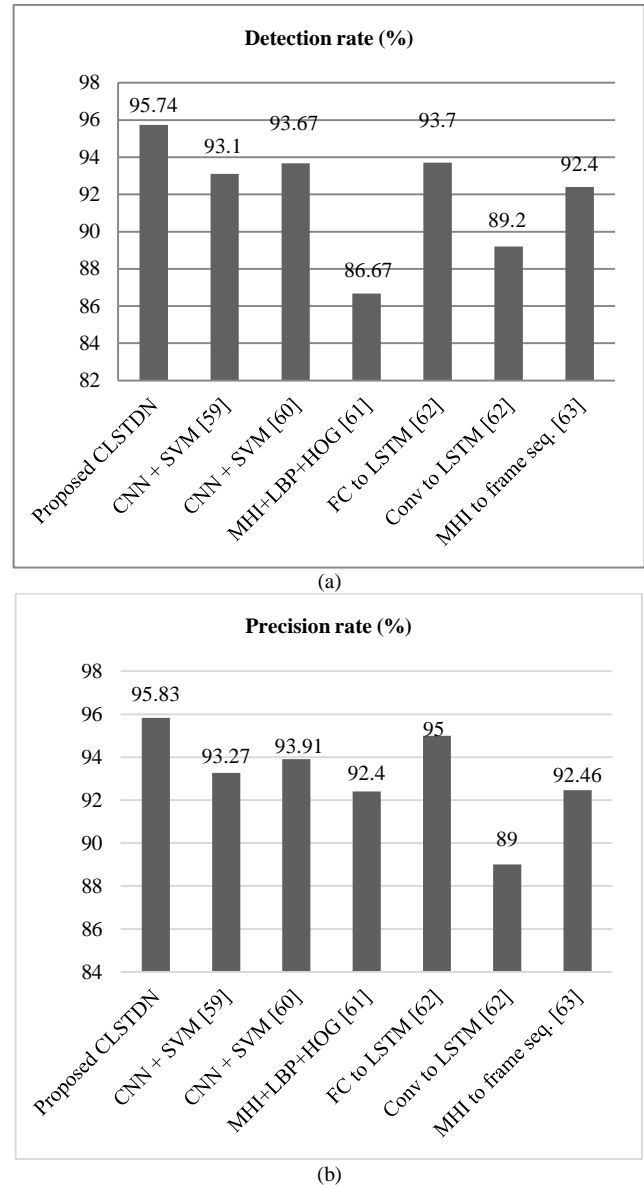


Fig. 7. (a) Detection rate comparison with previous research., (b) Precision rate comparison with previous research.

Proposed CLSTDN received recall rate of 97.5% which is higher than previous methods shown in Fig. 8(a). Research in [59] received recall rate of 93.11% using Convolutional Neural Network and Support Vector Machine which is lower than proposed CLSTDN due to usage of randomly three frames only to understand the overall video. Research in [60] received recall rate of 93.66% using Convolutional Neural Network and Support Vector Machine. However, due to usage of first and last frame to understand overall video without Spatio-temporal features, research in [60] produced lower recall rate comparing with the proposed CLSTDN. Research in [61] received recall rate of 86.67% using Binary patterns of action-history and histogram of oriented gradient. Similarly, research in [62] received recall rate of 93% using

both fully connected-to-LSTM and Convolutional-to-LSTM and research in [66] received recall rate of 92.36% using frame sequences and spatial features extraction. Proposed CLSTDN achieved better recall rate than research in [61], [62] and [66] due to usage of Inception-ResNet-v2 for deep Spatio-temporal features extraction instead of VGG-16.

Proposed CLSTDN received F-Measure value of 96.23% which is higher than previous methods shown in Fig. 8(b). Research in [59] received F-Measure value of 93.18% using Convolutional Neural Network and Support Vector Machine. Similarly, research in [60] received F-Measure value of 93.78% using Convolutional Neural Network and Support Vector Machine. F measure indicates the weighted average of recall and precision which considers both false positives and negative into account. As proposed CLSTDN understands spatial-temporal features of the video sequence and human motion in video, better F-Measure was achieved by this research comparing with research in [59] and [60]. Research in [61] received F-Measure value of 89.44% using Binary patterns of action-history and histogram of oriented gradient. As proposed method used Inception-ResNet-V2 to understand video sequence, better F-Measure rate was achieved than research in [61]. Research in [62] received F-Measure rate of 94% and 91% using fully connected-to-LSTM and Convolutional-to-LSTM respectively. As number of features extraction by VGG-16 is less and not deep as Inception-ResNet-V2 which used by proposed CLSTDN, F measure by research in [62] is not promising like proposed method by this research. Research in [66] received recall rate of F-Measure rate of 92.41% using frame sequences and spatial features extraction. They used VGG-16 pre-trained network to understand temporal changes from Motion History Images. However, proposed CLSTDN used Inception-ResNet-V2 to model spatial features which were passed to LSTM and caused understanding patterns better than research in [66]. For this reason, better F-Measure was achieved by this research comparing with research in [66].

Proposed CLSTDN received error rate of 4.26% which is lower than previous methods shown in Fig. 8(c). Research in [59] and [60] received error rate of 6.9% and 6.33% respectively using Convolutional Neural Network and Support Vector Machine. Error rate by research in [59] and [60] is higher than proposed CLSTDN due to usage of random frames to identify objects in the video scenes. Research in [61] received error rate of 13.33% which is very high comparing with the proposed CLSTDN due to learn features more deeply using Inception-ResNet-V2. Research in [62] received error rate of 6.3% and 10.8% using fully connected-to-LSTM and Convolutional-to-LSTM respectively which made their proposed approach computationally heavy and resulted in higher error rate comparing with the proposed CLSTDN. Research in [66] received error rate of 7.6% using frame sequences and spatial features extraction which is also higher than proposed CLSTDN due to extract more depth features using Inception-ResNet-V2.

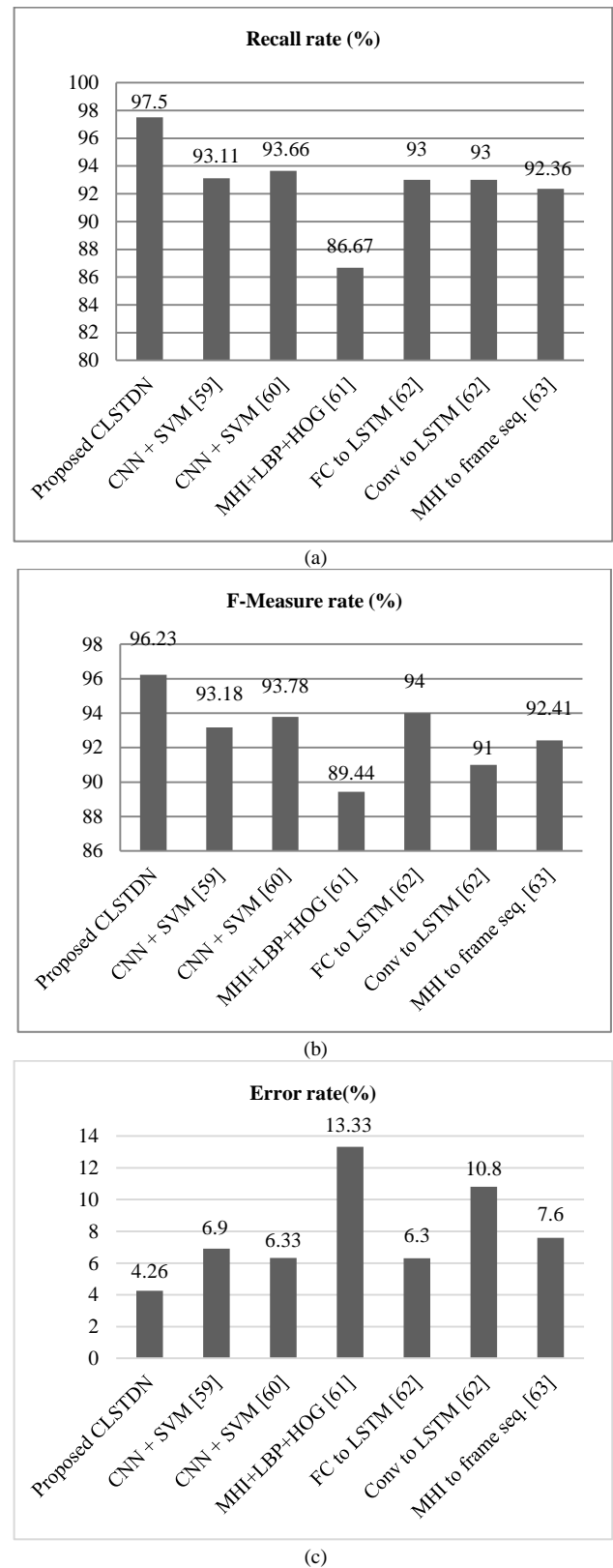


Fig. 8. (a) Recall rate in comparison with previous research, (b) F- Measure rate in comparison with previous research., (c) Error rate in comparison with previous research.

In overall, results from experimenting on different datasets showed that proposed Convolutional Long Short-Term Deep Network (CLSTDN) using both spatial and temporal features can lead to a viable solution for significantly improving recognition performance of human intentions of various activities. Proposed method performed well on UCF Sports, KTH, and UCF-11 dataset with low computation power. However, proposed method lacks in performance in the UCF-50 dataset due to the number of frames extracted from the video which was very low.

Proposed CLSTDN was evaluated on four publicly available datasets where accuracy, precision, recall, f-measure, and error rate were estimated for each dataset. To validate the proposed method, satisfactory accurate results were achieved on determining the intention on real time videos. After 62 epochs that needed 2336 seconds, proposed method received best results for UCF Sports dataset which gives an accuracy of 95.74%, precision of 95.83%, recall of 97.49%, f-measure of 96.23%, and an error rate of 4.26%. Previous methods used either spatial or temporal data for understanding the scene [33][37][39][42][46][48][51][52][53], whereas proposed method used both spatial-temporal understanding of a video which helps for a better understanding of an intention. To extract spatial features, proposed method used pre-trained convolutional neural network which was Inception ResNet V2 and passed the sequence to long short-term memory for the temporal understanding of the sequence. Also, this research dealt with limited data sequences whereas other methods used full data which causes the proposed method be faster comparing with previous methods. In addition, another benefit of the proposed method is that it runs on low computational power and resources. As this research illustrated earlier, because of taking both spatial and temporal features, proposed method gives more accurate results.

V. CONCLUSION

This research proposed Convolutional Long Short-Term Deep Network (CLSTDN) to recognize human action-based intention. Proposed CLSTDN consists of Convolutional Neural Network (CNN) and Recurrent Neural Network (RNN). Inception-ResNet-v2 was used as pre-trained network for CNN which contains 164 deep layers deep to classify class specific object categories. Long Short-Term Memory (LSTM) network was used for Recurrent Neural Network. Proposed CLSTDN extracted spatial features by Convolutional Neural Network and temporal features by Recurrent Neural Network to ensure the usage of Spatio-temporal features for efficient human intention prediction. Overall proposed methodology consists of three main phases, i.e., data preprocessing, feature extraction and final classification. Data preprocessing involves reshape, handling of blank image frames and overfitting to prepare the data to feed into Inception-ResNet-v2. Feature extraction phase involves implication of Convolutional Neural Network (CNN) and Recurrent Neural Network (RNN). Finally, dense layers and SoftMax activation function predicts human intention based on spatial-temporal features. Training of the proposed methodology was done on low computation resources and achieved better performance comparing with existing research results. Four publicly available datasets were used for validation, i.e., UCF Sports, UCF-11, KTH and UCF-

50. Validation of the proposed CLSTDN was done based seven evaluation metrics, i.e., accuracy, precision, recall, f-measure, error rate, confusion matrix and loss. Previous research methods used either spatial or temporal features for human intention prediction, however, proposed method used spatial-temporal features for human intention prediction caused more improved performance than previous research methods. In addition, proposed CLSTDN performed efficiently based on all the evaluation metric with a limited number of data sequence irrespective of viewpoint, background, inter-class and intra-class similarities present in the image frames with very small data sequences in almost all the datasets. However, proposed method produced some errors for several activities, i.e., jogging and running in KTH dataset, basketball and soccer game in UCF-11 dataset, nunchucks, jumping jack, and javelin throw in UCF-50 dataset due to similarity of patterns. In future, proposed CLSTDN will be investigated more comprehensively for more similar types of human actions.

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REFERENCES

- [1] T.D. Nguyen, S. Marchal, M. Miettinen, H. Fereidooni, N. Asokan, A.-R. Sadeghi, D²IoT: A federated self-learning anomaly detection system for IoT, in: 2019 IEEE 39th International conference on distributed computing systems (ICDCS), IEEE, 2019, pp. 756-767.
- [2] T. Fernando, S. Denman, S. Sridharan, C. Fookes, Gd-gan: Generative adversarial networks for trajectory prediction and group detection in crowds, in: Asian conference on computer vision, Springer, 2018, pp. 314-330.
- [3] G.K. Gudur, P. Sundaramoorthy, V. Umaashankar, ActiveHARNet: Towards on-device deep Bayesian active learning for human activity recognition, in: The 3rd International Workshop on Deep Learning for Mobile Systems and Applications, 2019, pp. 7-12.
- [4] Z. Wei, C. Wang, P. Hao, M.J. Barth, Vision-based lane-changing behavior detection using deep residual neural network, in: 2019 IEEE Intelligent Transportation Systems Conference (ITSC), IEEE, 2019, pp. 3108-3113.
- [5] M. Munir, M.A. Chattha, A. Dengel, S. Ahmed, A comparative analysis of traditional and deep learning-based anomaly detection methods for streaming data, in: 2019 18th IEEE International Conference On Machine Learning And Applications (ICMLA), IEEE, 2019, pp. 561-566.
- [6] C. Soh, S. Yu, A. Narayanan, S. Duraisamy, L. Chen, Employee profiling via aspect-based sentiment and network for insider threats detection, Expert Systems with Applications, 135, 2019, pp.351-361.
- [7] C.-M. Kuo, S.-H. Lai, M. Sarkis, A compact deep learning model for robust facial expression recognition, in: Proceedings of the IEEE conference on computer vision and pattern recognition workshops, 2018, pp. 2121-2129.
- [8] B. Padmaja, M.B. Myneni, E.K.R. Patro, A comparison on visual prediction models for MAMO (multi activity-multi object) recognition using deep learning, Journal of Big Data, 7,2020, pp.1-15.
- [9] C.-P. Bara, M. Papakostas, R. Mihalcea, A Deep Learning Approach Towards Multimodal Stress Detection, in: AffCon@ AAAI, 2020, pp. 67-81.

- [10] Z. Tariq, S.K. Shah, Y. Lee, Speech emotion detection using iot based deep learning for health care, in: 2019 IEEE International Conference on Big Data (Big Data), IEEE, 2019, pp. 4191-4196.
- [11] Y. Gao, Y. Zhang, H. Wang, X. Guo, J. Zhang, Decoding behavior tasks from brain activity using deep transfer learning, *IEEE Access*, 7 (2019) 43222-43232.
- [12] Y. Xing, C. Lv, H. Wang, D. Cao, E. Velenis, F.-Y. Wang, Driver activity recognition for intelligent vehicles: A deep learning approach, *IEEE transactions on Vehicular Technology*, 68 (2019) 5379-5390.
- [13] P. Venuprasad, T. Dobhal, A. Paul, T.N. Nguyen, A. Gilman, P. Cosman, L. Chukoskie, Characterizing joint attention behavior during real world interactions using automated object and gaze detection, in: *Proceedings of the 11th ACM Symposium on Eye Tracking Research & Applications*, 2019, pp. 1-8.
- [14] W. Shi, J. Li, Y. Yang, Face fatigue detection method based on MTCNN and machine vision, in: *International Conference on Applications and Techniques in Cyber Security and Intelligence*, Springer, 2019, pp. 233-240.
- [15] W. Fang, Y. Ding, F. Zhang, J. Sheng, Gesture recognition based on CNN and DCGAN for calculation and text output, *IEEE access*, 7 (2019) 28230-28237.
- [16] T. Zhang, Gesture Recognition Based on Deep Learning, *Journal of Physics: Conference Series*, 1449 (2020).
- [17] M.S. Hossain, G. Muhammad, Emotion recognition using deep learning approach from audio-visual emotional big data, *Information Fusion*, 49 (2019) 69-78.
- [18] A. Saif, Z.R. Mahayuddin, Robust Drowsiness Detection for Vehicle Driver using Deep Convolutional Neural Network, *International Journal of Advanced Computer Science and Applications*, (2020).
- [19] A. Saif, Z.R. Mahayuddin, Fast and Effective Motion Model for Moving Object Detection Using Aerial Images, *International Journal of Advanced Computer Science and Applications*, (2018).
- [20] V.R. Mali, A.R. Surve, V. Ghorpade, IoT Enabled Detection of Suspicious Human Behavior for ATM Environment, in: *Advances in Cybernetics, Cognition, and Machine Learning for Communication Technologies*, Springer, 2020, pp. 269-277.
- [21] A.A. Sukor, A. Zakaria, N.A. Rahim, L. Kamarudin, H. Nishizaki, Abnormality detection approach using deep learning models in smart home environments, in: *Proceedings of the 7th International Conference on Communications and Broadband Networking*, 2019, pp. 22-27.
- [22] G. Diraco, A. Leone, A. Caroppo, P. Siciliano, Deep Learning and Machine Learning Techniques for Change Detection in Behavior Monitoring, in: *AI* AAL@ AI* IA*, 2019, pp. 38-50.
- [23] B. Rezaei, Y. Christakis, B. Ho, K. Thomas, K. Erb, S. Ostadabbas, S. Patel, Target-specific action classification for automated assessment of human motor behavior from video, *Sensors*, 19 (2019) 4266.
- [24] A.A.Q. Mohammed, J. Lv, M. Islam, A deep learning-based end-to-end composite system for hand detection and gesture recognition, *Sensors*, 19 (2019) 5282.
- [25] Y. Gu, H. Zhang, S. Kamijo, Multi-person pose estimation using an orientation and occlusion aware deep learning network, *Sensors*, 20 (2020) 1593.
- [26] K. Slimani, K. Lekdioui, R. Messoussi, R. Touahni, Compound facial expression recognition based on highway cnn, in: *Proceedings of the New Challenges in Data Sciences: Acts of the Second Conference of the Moroccan Classification Society*, 2019, pp. 1-7.
- [27] V. Raudonis, A. Paulauskaite-Taraseviciene, K. Sutiene, D. Jonaitis, Towards the automation of early-stage human embryo development detection, *Biomedical engineering online*, 18 (2019) 1-20.
- [28] A. Saif, Z.R. Mahayuddin, Vision based 3D Gesture Tracking using Augmented Reality and Virtual Reality for Improved Learning Applications, *International Journal of Advanced Computer Science and Applications*, (2021).
- [29] I. Condés, J.M. Cañas, Person Following Robot Behavior Using Deep Learning, in: *Workshop of Physical Agents*, Springer, 2018, pp. 147-161.
- [30] M.M. Hassan, M.Z. Uddin, A. Mohamed, A. Almogren, A robust human activity recognition system using smartphone sensors and deep learning, *Future Generation Computer Systems*, 81 (2018) 307-313.
- [31] N. Jaouedi, N. Boujnah, M.S. Boulhel, A new hybrid deep learning model for human action recognition, *Journal of King Saud University-Computer and Information Sciences*, 32 (2020) 447-453.
- [32] Z. Liu, Q. Liu, W. Xu, Z. Liu, Z. Zhou, J. Chen, Deep learning-based human motion prediction considering context awareness for human-robot collaboration in manufacturing, *Procedia CIRP*, 83 (2019) 272-278.
- [33] X. Qin, Y. Ge, J. Feng, D. Yang, F. Chen, S. Huang, L. Xu, DTMMN: Deep transfer multi-metric network for RGB-D action recognition, *Neurocomputing*, 406 (2020) 127-134.
- [34] H. Fujiyoshi, T. Hirakawa, T. Yamashita, Deep learning-based image recognition for autonomous driving, *IATSS research*, 43 (2019) 244-252.
- [35] Y. Gu, X. Ye, W. Sheng, Y. Ou, Y. Li, Multiple stream deep learning model for human action recognition, *Image and Vision Computing*, 93 (2020) 103818.
- [36] Z. Tu, W. Xie, Q. Qin, R. Poppe, R.C. Velkamp, B. Li, J. Yuan, Multi-stream CNN: Learning representations based on human-related regions for action recognition, *Pattern Recognition*, 79 (2018) 32-43.
- [37] J. Guo, Z. Lei, J. Wan, E. Avots, N. Hajarolasvadi, B. Knyazev, A. Kuharenko, J.C.S.J. Junior, X. Baró, H. Demirel, Dominant and complementary emotion recognition from still images of faces, *IEEE Access*, 6 (2018) 26391-26403.
- [38] A. Othmani, A.R. Taleb, H. Abdelkawy, A. Hadid, Age estimation from faces using deep learning: A comparative analysis, *Computer Vision and Image Understanding*, 196 (2020) 102961.
- [39] F. You, Y. Gong, H. Tu, J. Liang, H. Wang, A fatigue driving detection algorithm based on facial motion information entropy, *Journal of advanced transportation*, 2020 (2020).
- [40] M. Baba, V. Gui, C. Cernazanu, D. Pescaru, A sensor network approach for violence detection in smart cities using deep learning, *Sensors*, 19 (2019) 1676.
- [41] A. Al-Dhamari, R. Sudirman, N.H. Mahmood, Transfer deep learning along with binary support vector machine for abnormal behavior detection, *IEEE Access*, 8 (2020) 61085-61095.
- [42] S. Ruan, C. Tang, X. Zhou, Z. Jin, S. Chen, H. Wen, H. Liu, D. Tang, Multi-pose face recognition based on deep learning in unconstrained scene, *Applied Sciences*, 10 (2020) 4669.
- [43] C.N. Phyo, T.T. Zin, P. Tin, Complex human-object interactions analyzer using a DCNN and SVM hybrid approach, *Applied Sciences*, 9 (2019) 1869.
- [44] D. Liciotti, M. Bernardini, L. Romeo, E. Frontoni, A sequential deep learning application for recognising human activities in smart homes, *Neurocomputing*, 396 (2020) 501-513.
- [45] P. Wang, H. Liu, L. Wang, R.X. Gao, Deep learning-based human motion recognition for predictive context-aware human-robot collaboration, *CIRP annals*, 67 (2018) 17-20.
- [46] L. Zhang, S. Li, H. Xiong, X. Diao, O. Ma, An application of convolutional neural networks on human intention prediction, *Int. J. Artif. Intell. Appl.*, 10 (2019) 1-11.
- [47] F. Yao, RETRACTED ARTICLE: Deep learning analysis of human behaviour recognition based on convolutional neural network analysis, *Behaviour & Information Technology*, 40 (2021) LXXXVI-LXXXIV.
- [48] Z. Liu, J. Hao, Intention recognition in physical human-robot interaction based on radial basis function neural network, *Journal of Robotics*, 2019 (2019).
- [49] Z. Fang, A.M. López, Intention recognition of pedestrians and cyclists by 2d pose estimation, *IEEE Transactions on Intelligent Transportation Systems*, 21 (2019) 4773-4783.
- [50] W. Huang, X. Liu, M. Luo, P. Zhang, W. Wang, J. Wang, Video-based abnormal driving behavior detection via deep learning fusions, *IEEE Access*, 7 (2019) 64571-64582.
- [51] S. Mirjalili, H. Faris, I. Aljarah, Introduction to evolutionary machine learning techniques, in: *Evolutionary Machine Learning Techniques*, Springer, 2020, pp. 1-7.

- [52] M.Z. Alom, T.M. Taha, C. Yakopcic, S. Westberg, P. Sidike, M.S. Nasrin, M. Hasan, B.C. Van Essen, A.A. Awwal, V.K. Asari, A state-of-the-art survey on deep learning theory and architectures, *Electronics*, 8 (2019) 292.
- [53] J. Schmidhuber, Deep learning in neural networks: An overview, *Neural networks*, 61 (2015) 85-117.
- [54] C. Szegedy, S. Ioffe, V. Vanhoucke, A.A. Alemi, Inception-v4, inception-resnet and the impact of residual connections on learning, in: *Thirty-first AAAI conference on artificial intelligence*, 2017.
- [55] K. Simonyan, A. Zisserman, Two-stream convolutional networks for action recognition in videos, *Advances in neural information processing systems*, 27 (2014).
- [56] L. Wang, Y. Qiao, X. Tang, Action recognition with trajectory-pooled deep-convolutional descriptors, in: *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2015, pp. 4305-4314.
- [57] C. Feichtenhofer, A. Pinz, A. Zisserman, Convolutional two-stream network fusion for video action recognition, in: *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2016, pp. 1933-1941.
- [58] L. Wang, Y. Xiong, Z. Wang, Y. Qiao, D. Lin, X. Tang, L.V. Gool, Temporal segment networks: Towards good practices for deep action recognition, in: *European conference on computer vision*, Springer, 2016, pp. 20-36.
- [59] G. Shamsipour, J. Shanbehzadeh, H. Sarrafzadeh, Human action recognition by conceptual features, (2017).
- [60] A. Saif, Z.R. Mahayuddin, Moving Object Detection Using Semantic Convolutional Features, *Journal of Information System and Technology Management*, (2022), pp. 24-41.
- [61] M. Rahman Ahad, M. Islam, I. Jahan, Action recognition based on binary patterns of action-history and histogram of oriented gradient, *Journal on Multimodal User Interfaces*, 10 (2016) 335-344.
- [62] H. Gammulle, S. Denman, S. Sridharan, C. Fookes, Two stream lstm: A deep fusion framework for human action recognition, in: *2017 IEEE Winter Conference on Applications of Computer Vision (WACV)*, IEEE, 2017, pp. 177-186.
- [63] A. Saif, Z.R. Mahayuddin, Moment features based violence action detection using optical flow, *International Journal of Advanced Computer Science and Applications*, 11 (2020).
- [64] A. Saif, Z.R. Mahayuddin, Crowd Density Estimation from Autonomous Drones Using Deep Learning: Challenges and Applications, *Journal of Engineering and Science Research*, (2021), pp.01-06.
- [65] A. Saif, Z.R. Mahayuddin, An Efficient Method for Hand Gesture Recognition using Robust Features Vector, *Journal Information System and Technology Management (JISTM)*, (2021), pp.25-35.
- [66] S. Zebhi, S. Almodarresi, V. Abootalebi, Human activity recognition by using MHIs of frame sequences, *Turkish Journal of Electrical Engineering & Computer Sciences*, 28 (2020) 1716-1730.
- [67] M. Hossin, M.N. Sulaiman, A review on evaluation metrics for data classification evaluations, *International journal of data mining & knowledge management process*, 5 (2015) 1.
- [68] A. Saif, Z.R. Mahayuddin, Vision based 3D Object Detection using Deep Learning: Methods with Challenges and Applications towards Future Directions, *International Journal of Advanced Computer Science and Applications*, (2022).
- [69] A. Santra, C.J. Christy, Genetic algorithm and confusion matrix for document clustering, *International Journal of Computer Science Issues (IJCSI)*, 9 (2012) 322.

Usability and Security of Knowledge-based Authentication Systems: A State-of-the-Art Review

Hassan Wasfi

Iowa State University HCI Department
Iowa, USA

Richard Stone

Iowa State University Industrial and
Manufacturing Systems Engineering Department,
Iowa, USA

Abstract—Knowledge-based passwords are still the most dominant authentication method for securing digital platforms and services, in spite of the emergence of alternative systems such as token-based and biometric systems. This method has remained the most popular one mostly because of its usability, compatibility, affordability of implementation, and user familiarity. However, the main challenge of knowledge-based password schemes lies in creating passwords that provide a balance between memorability and security. This research aimed to compare various knowledge-based schemes in order to establish a strategy that provided high memorability and resilience to most cyberattacks. The overview of this research identifies areas of knowledge-based passwords for further research and enhances the methodology that helps to offer insight into usable, secure, and sustainable authentication approaches. Future work has been recommended to explore the major features and drawbacks of recognition-based textual passwords because this method provides the usability and security benefits of graphical passwords with the familiarity of textual passwords.

Keywords—Knowledge-based authentication; recognition; recall; usability; security; memorability

I. INTRODUCTION

The biggest challenge for several companies is to establish an authentication technique that offers a high level of usability and security. Authentication systems can be classified into three main types: knowledge-based, token-based, and biometric [1], [2]. Large corporations and banks have recently switched to the use of biometrics or token passwords to verify individuals' identities, but these passwords require expensive hardware and high-complexity algorithms [3]–[5]. However, the most usable password is the knowledge-based one, particularly the textual passwords, because it is easy to use and user-friendly and has an extendable security feature [6]. Different researchers have extensively investigated the most common password schemes, as shown in Fig. 1, including usability, security, and deployability benefits. Thus, none of the stated methods converge to the benefits of textual passwords [7], [8]. The text password security requirements have increased dramatically in the last ten years because most people are not aware of the fundamentals of creating a strong password [9]. Users tend to create weak passwords with personal information and predictable patterns, which could be easily guessed by the password owner's close people or attackers [10]. Another scheme called a passphrase has been proposed as an alternative to text-based passwords; it offers better memorability and security [11], [12]. Though, the typing of long passphrases has shown an increase in typographical errors, thus reducing the successful login rate [13]–[15]. Researchers have suggested

algorithms that help avoid small typographical errors but still do not fully mitigate this issue (correct up to 57.7%) [16]. A recent study also found that 8.8% of users' passwords are vulnerable to attacks because of the typo-tolerance software [17]. There is another method considered a competitive strategy to recall passphrases called recognition-based textual passwords. The most usability-centered advantage of this scheme is to reduce the cognitive load and enhance the retrieval performance [18], [19]. Different studies have stated that a recognition passphrase has a better memorability rate than a recall scheme [19], [20]. The main usability and security challenges for recognition-based textual passwords are system design, user login performance, and resistance against guessing, brute-force, and shoulder-surfing attacks [21]. Nowadays, the knowledge-based password scheme needs further research to help to produce a system with large security entropy, low cognitive load, low cost, and resistance to common attacks. The main contribution of this paper is to analyze and evaluate the features and drawbacks of knowledge-based password schemes. We have aimed to present detailed information about the existing knowledge-based methods adopted thus far to critically investigate possible issues and, thus, help to propose ways to establish a new secure and usable knowledge-based authentication approach. This paper argues that the existing authentication systems must thoroughly address users' cognitive limitations or leverage humans', particularly for the recognition of textual passwords. Consequently, despite considerable research, establishing the recognition of textual passwords suggests a low cognition load, high memorability, and resistance to the most common attacks.

II. RELATED WORK

This part will compare the main types of knowledge-based authentication systems, namely textual and graphical passwords.

A. Textual Passwords

1) *Text-Based Passwords*: The traditional text-based password has been the most common authentication method for the past two decades [22]. It has several usability characteristics, such as ease of use and low cost to establish [23]. The password's strength depends on its complexity, length, and unpredictability against a guessing attack [24]. However, people tend to use insecure strategies for password creation, such as the use of common phrases, personal information, or predictable patterns [25]. These behaviors enforce businesses to set strict password policies [26]. Unfortunately, prior research has found

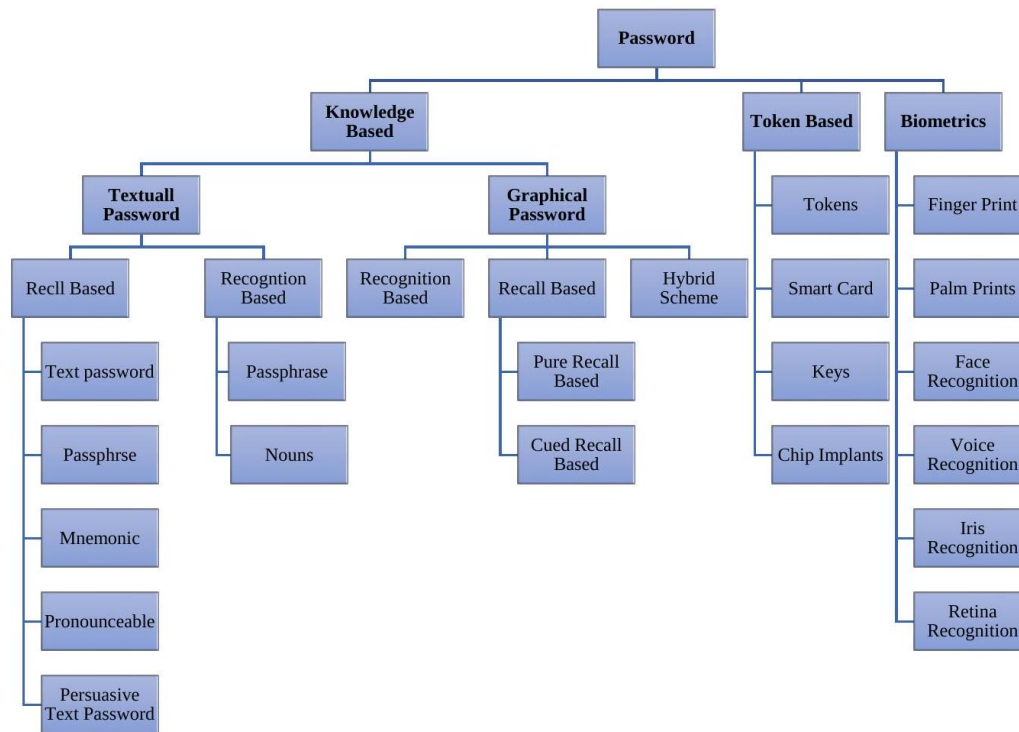


Fig. 1. Taxonomy of authentication systems.

that password policies are not sufficiently effective to form a strong password [10]. Additionally, a majority of people reuse the same passwords for different accounts because of cognitive challenges; thus, this practice might be risky as if one account is compromised, the attacker could use the same password to access the other accounts [27]. A survey result reported that 94% of the participants reused at least one password for more than one account [28].

2) *Passphrases*: A passphrase is a type of password that contains a series of words or text to authenticate an individual identity [29]. Long passphrases provide better security against brute-force attacks and frequently require less cognitive load than traditional passwords [30]. It was found that users spent less time on password activities such as retries and resets when using passphrases than when using traditional passwords [13]. However, a passphrase result in a usability issue related to typographical errors [13], [14], [31]. The typographical errors significantly increased when the passphrase was very lengthy [13], [19], [25] or when the guidelines and policies were followed strictly [8], [32]. In addition, people tend to create passphrases from common words with predictable patterns; this method is vulnerable to guessing attacks [33]. Regarding the previous usability and security issues of the passphrase approach, several studies have suggested the following:

- Tolerate spelling errors by applying a validation algorithm that accepts small typing errors without any influence on security entropy [34]. Still, these algorithms have a significant security degradation, not as previously understood [17].
- Create a long passphrase with specific security policies [12], [14].

- Systemically generate random words to reduce the predictability level [20], [31]. Table I lists the differences between users and system-generated passphrases.

3) *Mnemonic Passwords*: A mnemonic is a concept of sentence abbreviation that assists or is intended to assist memory by utilizing patterns of letters (often, the first letter), numbers, or relevant associations [35]. An analysis of mnemonics and passphrases created based on entire words shows that mnemonics offer a superior memorability rate [36]. Different mnemonic strategies are often utilized, such as sentence substitution “**I**went**H**K4&**h**ya” or special character insertion “**H**e,**l**lo&&**w**orld!” [37], [38]. Moreover, simulating the letters on keyboard buttons with different patterns to produce a mnemonic, such as “**H**” is equal to “**UHBijnhj**” [39]. Consequently, it provides a slight resistance against brute-force attacks as compared to traditional passwords [37].

4) *Pronounceable Passwords*: In 1975, it was established to systemically produce complex and memorable pronounceable passwords [40], [41]. The old version of the pronounceable password algorithm was vulnerable to guessing attacks if an attacker could analyze the pattern of the generated password [40]. Although systemically generated pronounceable passwords are intended to be easier to remember than random sequences of letters, but they still need further strategies. To address this issue, a study[42] suggested a method that partially combines two words while considering the phonotactic and syllabic restrictions of verbal English, which plays a role in determining the memorability rate. A new approach called “ProSemPass” is based on user-chosen pronounceable and semantically meaningful passwords; thus, it has 30% higher memorability than the systemically generated pronounceable

TABLE I. USABILITY AND SECURITY OF RECALL PASSPHRASE

Recall Passphrase			
	Memorability	Security	Comment/Limitation
User Generated	High	Low/Medium	<ul style="list-style-type: none">• Needs guidelines and policies for security enhancement [14], [32]• Is easier to remember than text passwords [13]• Is easy to guess [43], [44]
System Generated	Low	High	<ul style="list-style-type: none">• Is difficult to remember because of the unmeaningful passphrase structure [45].• Is most likely to be written down[46]• Has guaranteed robustness against guessing attacks [30]

methods and is more resilient against guessing attacks [41]. Recently, a new study suggested converting a user-chosen password into phonemes and measuring their pronounceability to enhance the password's usability and security and compared this method with different pronounceable strategies, including the "ProSemPass" scheme; however, on the basis of the findings, the author recommended the use of a passphrase instead of the proposed approach because it promises better usability and security standards [47].

5) *Persuasive Text Passwords (PTP)*: PTP is a user-chosen text password system with a random guideline to create a secure password. It is based on selecting one word, whose security will be enhanced by the system by placing a few randomly selected characters at randomly assigned positions [48]. For instance, users can select the word "security", and the PTP system will generate random changes, such as inserting or replacing the characters as "use>curity". Users can shuffle for repositioning characters until they are persuaded with a memorable password. However, the PTP does not deliver a high security level, particular after insertion, because PTP does not assess the password's strength [49].

6) *Recognition-based Textual Passwords (Human Memory and Words Memorability)*: The human capacity to memorize large amounts of information is limited. Psychological researchers have discussed how the human brain works and how to exploit its features to transfer data from the short- to the long-term memory [50]. In 1956, Miller argued the range of items that individuals can hold for the short-term memory is approximately seven [51]. Different strategies explain how human memory pays attention to information through a human's five senses (sight, hearing, taste, smell, and touch) and is transferred from the sensory register to the short-term memory. Moreover, with rehearsal the information will be transferred to the long-term memory [52]. The capacity of the human brain to store words for a long period differs from person to person, but the stimulus to the human memory has a critical role in how information is effectively stored and retrieved [53]. In general, the major factors in the English language that have a direct impact on the memorability rate are as follows:

- **Word Frequency**: Several research studies have examined the memorability of high-frequency (HF) or common words versus low-frequency (LF) or uncommon words and found that the HF-word versus the LF-word memorability is complex and depends on many aspects, such as recall versus recognition, word familiarity, task nature, mixed lists, pure lists and subsequent memory [54].
- **Concreteness and imageability**: Concrete words are words

that "refer to tangible objects, materials, or persons and can be easily perceived with the senses" and thus, stimulate the mental image [55].

- **Valence**: This belongs to emotional words, which are divided into two main categories: attractiveness/"good"-ness (positive valence) or averseness/"bad"-ness (negative valence) of an object, circumstance, or event [56].
- **Arousal**: Arousal is related to the personal experience of feelings (emotion words), including tension and high energy [57].

Word memorability in education is complex because various physiological factors play a role, such as individual memory capacity, culture, and age [58]. In authentication systems, the English words are established with different strategies as compared to the learning criteria as follows:

- 1) Recall or recognition strategy
- 2) Word-generated methodology: user-generated, system-generated, or both
- 3) Grid design (word presentation)
- 4) Word type
- 5) Word structure (phrase, semantic meaning, etc.)

Previous researchers have attempted to implement a recognition mechanism for different types of passwords to enhance their retrieval performance. A majority of the authentication systems based on recognition methods used graphical passwords to leverage human memory through visual information (images) [59], as discussed in Section 2.2. In contrast, the recognition approach has been used with English words but has still not yet been fully investigated. Word recognition passwords are a relatively challenging area of authentication systems because they are a less common form of authentication. They typically require the users to select specific words as passwords, which can be easier to memorize than complex text-based passwords. In the last decade, several studies have examined the recognition of words with different types of passwords, as shown in Table II.

7) *User-Chosen vs. System-Assigned Passwords*: User-chosen passwords are vulnerable to various attacks because users tend to create easy passwords to remember with predictable patterns [64]. Most websites force their users to create passwords conforming to specific policies; however, these policies are not sufficiently effective to generate secure passwords [65]. Extant research has proven that users have a misconception about creating strong passwords for various reasons, such as using common keyboard patterns, words, phrases, or personal information [66]. To partially

TABLE II. USABILITY AND SECURITY OF RECOGNITION OF TEXTUAL PASSWORDS

Recognition-Based Textual Passwords				
Source	Condition	Memorability	Security	Comments/Limitations
Study [20]	system-generated (a) recall password (b) recall passphrase (c) recognition passphrase	- recognition passphrase > recall passphrase, letter, password - letter recall > passphrase recall	4 words out of 156 (29.14 bits)	<ul style="list-style-type: none"> Some participants commented that their passphrase did not include a verb or semantic meaning (“throat” and “tongue”), which negatively affected the retrieval of the correct password. Recognition method has significantly fewer password resets than word recall. Takes a long time to log in because the GUI contains six groups of words.
Study [18]	system-generated recognition (a) objects (b) image (c) words	- objects > image and words - words = image	5 words out of 48 (27.9 bits)	<ul style="list-style-type: none"> No balance exists between word types presented to users in the registration phase (adjectives less than other types). Word set contains words with the same first letters, which might confuse users in long-term memory such as “Camp” and “Lamp”. Memorizing time for words is less than that for objects and significantly less than that for images.
Study [60]	system-generated (a) recognition nouns (b) text-based password	- text-based password > recognition nouns	3 words out of 104 (20.1 bits)	<ul style="list-style-type: none"> Noun recognition has significantly shorter login times on a mobile and a comparable login time on a desktop computer than text-based passwords.
Study [61]	(a) self-selection of system-generated recognition passphrase (b) system-generated recognition passphrase	- self-selection of generated system passphrase > system-generated recognition passphrase	6 words out of 20 or 100 (25.93 to 39.86 bits)	<ul style="list-style-type: none"> The dictionary used contains a majority of uncommon words; thus, it is not applicable to users with different backgrounds. The experiment was not conducted in a controlled environment such as a lab. Typing the recognized words slightly reduces the successful login rate.
Study [19]	(a) self-selection of system-generated recognition nouns with pure recall nouns (b) self-selection of system-generated recognition passphrase with pure recall passphrase	- recognition nouns and passphrase > recall nouns and passphrase - recognition and recall passphrase > recognition and recall nouns	4 words or more out of 26 words (18.8 bits)	<ul style="list-style-type: none"> The login time for noun recall is less than that for recognition. The login time for a recognition passphrase is almost similar to that for a recall passphrase. Words with the same categorization such as “YouTube” and “Facebook” confuse users to log in successfully. Word set with words with almost the same first letters such as “store” and “story” negatively affects the participants’ retrieval of the correct password. Also, the Unmeaningful structure of passphrases has a negative impact on memorability.
Study [62]	(a) user-selection passphrase (b) conventional password	- passphrase > conventional password	4 words (crossword puzzle with 625 cells)	<ul style="list-style-type: none"> Takes a long time to log in than a conventional password. Is a complex approach and needs more training for users to accomplish the authentication process. Is invulnerable to several attacks such as dictionary attacks, brute-force attacks, and shoulder surfing attacks.
Study [21]	system-assigned recognition (a) nouns (b) nouns with verbal cues (c) nouns with verbal and spatial cues	- nouns with verbal and spatial cues > nouns - nouns with (verbal and spatial) cues > nouns with verbal	words out of 80 (20 bits)	<ul style="list-style-type: none"> The registration time for nouns with verbal and noun (spatial and verbal) cues is significantly higher than that for nouns. The login time for nouns and nouns with (spatial and verbal) cues is significantly less than that for nouns with verbal cues. Nouns with verbal cues have a significantly higher login rate than just nouns. There is no significant difference in the memorability rate between nouns with verbal cues, 94.23 %, and nouns with (spatial and verbal) cues, 96.15 %.
Study [63]	system-assigned passphrases (a) CC-SP is a condition with training features (fixed location of the words, repetition, exposure time, and/or the words with semantic relations) (b) other four conditions	- CC-SP > all conditions	4 words out of 128 (28 bits)	<ul style="list-style-type: none"> This study is based on Implicit learning techniques such as contextual cueing and semantic priming CC-SP method significantly improves the usability of system-assigned passphrases, in terms of recall rates and login time. It includes different training sessions.

cover weak password patterns, several companies have suggested password meters to determine whether the created password is strong, but the results of popular website meters have revealed many weak passwords as very strong [67]. The final goal of password meters has not comprehensively solved the problem of creating a strong password. However, a system-assigned password has been proposed as a solution to the security issue of user-chosen passwords. Different studies have reported that randomly assigned passwords are secure but difficult to remember [68]. Moreover, another study has proven a significantly low memorability rate of system-assigned passphrases than that of user-generated and mnemonic-guided passphrases [43]. A systemic review article of different composition strategies of textual passwords includes text-based, pronounceable, mnemonic, passphrase, system, and user-generated passwords; thus, user-generated passwords are more memorable than system-generated passwords [69]. Additional research attempted to reach a compromise between user-chosen and system-assigned passwords by applying a PTP approach, which requires users to select a password and then the system will perform some modifications to the actual password, as discussed in Section 2.1.5, but the study was not conducted for several sessions that evaluate the memorability rate. Overall, a recent psychological study proved that self-generated passphrases have fewer cognitive load stressors on the working memory than system-generated passphrases [70].

B. Graphical Passwords

Graphical passwords were proposed by Blonder in 1991 and are presented in a certain visual format (as opposed to the text password format). Humans remember pictures better than text, so graphical authentication passwords are possible alternatives to text-based passwords [71]. Graphical passwords have been categorized into four main schemes: drawmetric (pure-recall-based), locimetric (cued-recall-based), cognometric (recognition-based), and hybrid [72]. In general, graphical password systems have various usability and security advantages such as being easy to remember and difficult to guess, higher security level, being human-friendly, and mitigating dictionary attacks; however, they are vulnerable to shoulder-surfing attacks and brute-force attacks (which reduce the common areas in the images) [73].

1) *Drawmetric (Pure-Recall-Based) and Locimetric (Cued-Recall-Based)*: The recall graphical password is divided into pure and cued recall-based methods [74]. The pure recall technique is called drawmetric; users generate their passwords without any clues to remember these passwords. It mainly depends on drawing a secret on a blank canvas or a grid as a simple picture, such as Draw a Secret Algorithm (DAS) Fig. 2(a) and Background Draw a Secret (BDAS) Fig. 2(b) [75]. The users must draw their secrets in an exact manner, which would require help remembering the exact stroke order [76]. These methods have a memorability range of 50%–80% [77]; however, they have less password space and no resistance against shoulder-surfing attacks [78].

The cued-recall-based graphical password, also known as locimetric, is based on displaying an image to the users to choose different points on it [75]. The most common schemes of cued recall are blonder and pass-point. Users are required

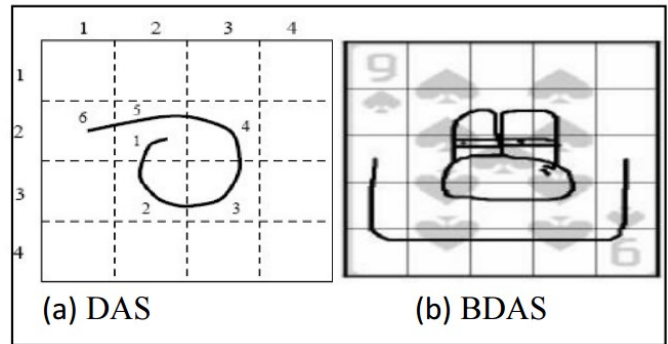


Fig. 2. Draw a secret algorithm.

in the login phase to select the same regions in a specific order, as shown in Fig. 3(a) [79]. The blonder method resists brute-force attacks because it contains millions of regions that can be selected as passwords [80]. Nevertheless, the main disadvantage of this method is that users cannot arbitrarily click on the background [78], [81]. Another mechanism called pass-point was proposed to overcome the limitation of the blonder method [82]. It allows users to select any natural image sufficiently rich to have many possible click points, which would be a hint for the users to remember their click points, as shown in Fig. 3(b) [83].

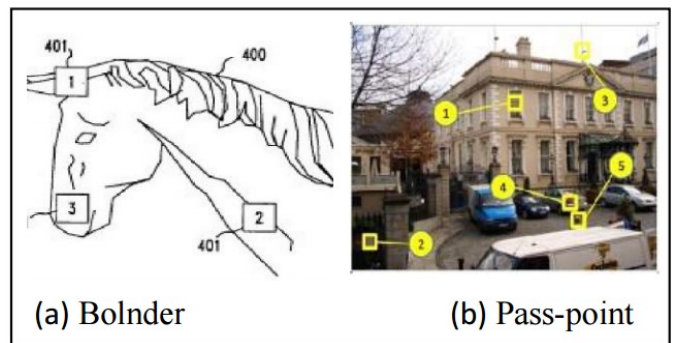


Fig. 3. Blonder and pass-point method.

2) *Cognometric (recognition-based)*: A recognition-based graphical password scheme creates a platform for the user that contains visual passwords, and the user can select some of them as a password [18], [84]. Several image formats have been proposed for this recognition-based scheme: faces, random art pictures, icons, and daily objects [85]. Passfaces is a common method that uses human faces as a verification tool for the authentication procedure [86]. Passface is very memorable for a long period, but it is somehow predictable and vulnerable to a variety of attacks, as a majority of the users tend to select a person's face on the basis of apparent behavioral patterns, as shown in Fig. 4(a) [87]. Another version of Passface was proposed called S-Passface, which is based on replacing some characters by entering random characters corresponding to each face instead of selecting the face by the mouse, as shown in Fig. 4(b). Therefore, S-Passface is 100% resistant to shoulder surfing as compared to the original Passface version, but the security improvement has decreased

some of the usability features [88].

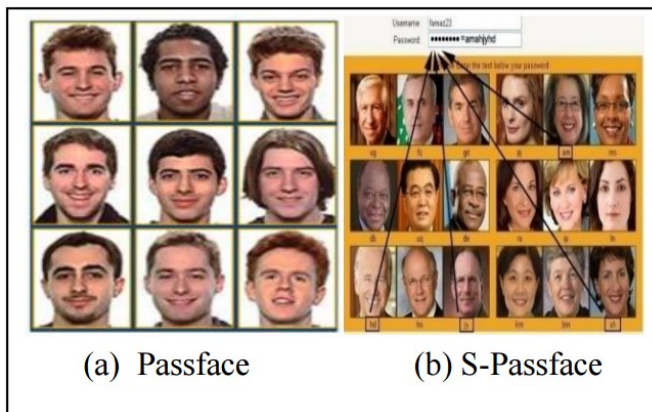


Fig. 4. Passfaces authentication systems.

Furthermore, other common recognition-based methods, Déjà Vu and story, are based on recognizing images with different principles. Déjà Vu is an algorithm that uses the technology of hash visualization of the images, as shown in Fig. 5(a) [89]. This approach showed that 90% of the participants succeeded in the authentication by using this technique, while only 70% succeeded by using text-based passwords [90]. The main disadvantage of this technique is that it takes a long time to log in because storing a large number of pictures causes a delay in transferring over the network, thus delaying the authentication process [79]. The story mechanism is comparable to the Passfaces method; it presents images of places, people, or everyday objects, as shown in Fig. 5(b). Users are instructed to mentally create linked images as a story to quickly and easily remember their passwords. The memorability result revealed that from 236 failed attempts, more than 75% were correct pictures in a wrong order [91]. Moreover, this scheme suffers from guessing and shoulder-surfing attacks [78].

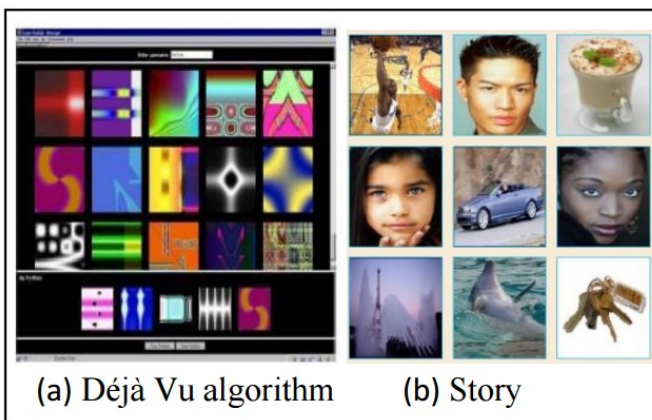


Fig. 5. Déjà Vu and story schemes.

3) *Hybrid Schemes*: A hybrid scheme combines two or more different types of graphical passwords or other authentication techniques for usability and security improvement [92]. According to recent studies, hybrid techniques can be classi-

fied into two categories: hybrid systems with only graphical password methods[72] and a hybrid system with a graphical and textual password [93]. Recent studies have combined recognition-based and cued-recall-based graphical passwords with images and drawn a pattern, as shown in Fig. 6(a) [94].

Moreover, the Passface scheme has been combined with traditional text passwords, as shown in Fig. 6(b) [95]. The hybrid system is utilized to overcome the limitations of graphical password schemes by creating a new system that provides a robust authentication system against spyware and shoulder-surfing attacks [96]. A recent study comprehensively deliberated hybrid graphical passwords' security levels and compared them with other graphical password systems against different attacks; thus, revealing that they had a high level of security against shoulder-surface attacks but were still vulnerable to the others [78]. However, the hybrid graphical password can provide an additional layer of security, but it could also be complex and require users to spend more time creating and entering their passwords [97]. It is critical to consider interaction while creating a hybrid graphical password system to maximize the system's effectiveness [98].

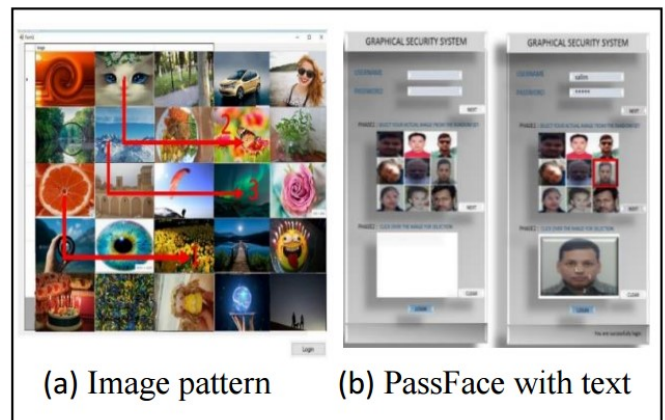


Fig. 6. Hybrid authentication system.

III. COMPARATIVE ANALYSIS OF KNOWLEDGE-BASED PASSWORDS, TOKENS, AND BIOMETRICS

An alternative solution has been discussed to overcome the security issue of a knowledge-based password, which are tokens and biometrics. A token password is a widely used authentication mechanism that enables users to access website resources by verifying their identity by submitting a token produced for one-time use only [99]. However, it primarily depends on third-party providers to produce tokens or one-time passwords, which makes them susceptible to the man-in-the-middle attack [100]. Moreover, researchers have reported that token passwords have a safety issue: time wastage and delays before accessing services [101]. Additionally, losing the token devices and lengthy authentication time are the main issues of this technique [102]. Thus, token passwords have a high computational cost and are expensive to implement [103].

Biometric passwords are based on people's unique behavioral and physiological characteristics and use these features as a password by using different technologies [104]. Recent studies have indicated that biometric passwords provide better

security than most of the other password types [105]. Nevertheless, biometric passwords are expensive to establish because they need high-quality devices and have a high complexity of implementation [106]. There is another concern about biometric methods, which is that no person can regulate the biometric differences caused by injury or aging [107]. The biggest security concern of biometric passwords is deceiving a security system by using copied or fake information [108]. These disadvantages of biometric methods reduce their efficiency as compared to the other types of passwords.

The knowledge-based password still provides extendable usability and security features. It can be comparable to the token and biometrics security levels with respect to mitigating most of the usability issues and security threats [1], [109]. Textual passwords are relatively still the most usable passwords because their ease of use, lack of hardware required, and less required storage [110]. A comparison of textual passwords with graphical passwords revealed a huge difference in the storage space and time consumption to login [98]. Furthermore, the shoulder-surfing attack is the most pressing security concern of graphical passwords because of their visual interface [76]. Regarding the storage problem of graphical passwords, a colored image requires a storage space of around 23.98 MB, which is significantly higher than that required by textual passwords with eight characters (57 bits) [111]. The huge size of images of graphical passwords lead to the maximization of the network latency [112]. Increasing the data transmission over the network costs more because of the complex computation and communication [113]. Furthermore, graphical passwords have an issue with communication speed as compared to textual passwords because of the picture sizes, long configuration size of registration and logging in, as well as the complexity of the encryption process [114]. Overall, graphical passwords are more expensive than textual passwords because they require large storage space to store a large number of images [115].

IV. OPEN CHALLENGE AND FUTURE TRENDS

Authentication systems typically involve different types of credentials, such as tokens, biometrics, textual passwords, or graphical passwords. The main challenges with these systems are related to security, usability, and scalability. Each authentication method has its strengths and weaknesses, and organizations need to consider the benefits and drawbacks of each approach on the basis of their specific needs and security requirements. Biometrics and tokens offer high security, but they are costly and require particular hardware and software. Furthermore, graphical passwords require a large storage space to store large numbers of images, which causes delays in transferring the pictures over the network; therefore, they are not as widely used as textual passwords. Textual passwords are the most common type of passwords used and are regularly required to encounter certain complexity requirements. Recently, companies and government sectors (Microsoft, Canadian Government, FBI, etc.) have encouraged users to create long passphrases with the same complexity as traditional passwords to enhance security and memorability. The biggest challenge of using a long passphrase with policies as the password is the typographical errors, particularly when people need to gain experience with English as a primary language. Therefore, increasing the length of the password

or passphrase helps to increase the security level, but it will make it difficult for users to login successfully. The future trend is establishing user-chosen recognition textual passwords with a high memorability rate and mitigating common attacks. This approach will be the alternated scheme for textual and graphical password schemes. It can solve several issues related to recall textual passwords such as memorization burden, lack of diversity, reuse across multiple accounts, and difficulty of password creation. Moreover, it does not require high storage space, complex implementation, and high load over the network (causing delay to login) as a graphical password scheme.

The main novelty of this paper was that specify the limitations of previous studies of recognition of textual passwords to establish a new strategy that is more competitive with other textual and graphical password, as shown in Table II. The majority of prior research on the recognition of textual passwords is based on system generated approach which results in several drawbacks. Firstly, a recent study stated that system-assigned recognition words have low memorability rates and need spatial cues (pictures) to improve word memorability; thus, they require considerable storage space, which will be costly and delay the login process [21]. Secondly, this approach needs more training to enhance password retrieval performance [63]. Finally, the word selection is limited between 4 and 5 words which cause a low password space as shown in Table II. There are different strategies that can be applied to user-chosen recognition textual passwords to enhance the usability and security level by applying a hybrid system that combines user-chosen recognition textual passwords with recall techniques or using cued recall strategies.

REFERENCES

- [1] M. Ali et al., "A Simple and Secure Reformation-Based Password Scheme," *IEEE Access*, vol. 9, pp. 11655-11674, 2021, doi:10.1109/ACCESS.2020.3049052.
- [2] P. C. Golar, "An Approach Towards Usability Parameter for Graphical Based Authentication System Turkish Journal of Computer and Mathematics Education," vol. 12, no. 12, pp. 831-836, 2021.
- [3] T. Haque, Md. A.; Ahmad, "A concept of captcha based dynamic password," *Recent Advances in Computer Science and Communications*, vol. 14, no. 5, pp. 1633-1640, 2021."
- [4] S. S. Almohamade, "Continuous Authentication of Users to Robotic Technologies Using Behavioural Biometrics," no. November, 2022.
- [5] A. Henricks and H. Kettani, "On Data Protection Using MultiFactor Authentication," *ACM International Conference Proceeding Series*, no. October 2019, pp. 1-4, 2019, doi:10.1145/3394788.3394789.
- [6] M. S. Kaiser, J. Xie, and V. S. Rathore, *New Text-Based User Authentication Scheme Using CAPTCHA*. 2023. [Online]. Available: <https://app.dimensions.ai/details/publication/pub.1148546790>
- [7] S. Ghorbani Lyastani, M. Schilling, M. Neumayr, M. Backes, and S. Bugiel, "Is FIDO2 the kingslayer of user authentication? a comparative usability study of FIDO2 passwordless authentication," *Proc IEEE Symp Secur Priv*, vol. 2020-May, pp. 268-285, 2020, doi:10.1109/SP40000.2020.00047.
- [8] V. Zimmermann and N. Gerber, "The password is dead, long live the password - A laboratory study on user perceptions of authentication schemes," *International Journal of Human Computer Studies*, vol. 133, no. August 2019, pp. 26-44, 2020, doi: 10.1016/j.ijhcs.2019.08.006.
- [9] M. Awad, Z. Al-Qudah, S. Idwan, and A. H. Jallad, "Password security: Password behavior analysis at a small university," *International Conference on Electronic Devices, Systems, and Applications*, no. May 2020, 2017, doi:10.1109/ICEDSA.2016.7818558.
- [10] M. Yildirim and I. Mackie, "Encouraging users to improve password security and memorability," *Int J Inf Secur*, vol. 18, no. 6, pp. 741-759, 2019, doi: 10.1007/s10207-019-00429-y.

- [11] Australian Cyber Security Centre, "Creating Strong Passphrases Principles for strong passphrases Protect your passphrases Secure your passphrases," no. December 2020, pp. 1-3, 2021.
- [12] Microsoft, "Create and use strong passwords," 2022. <https://support.microsoft.com/en-us/windows/create-and-use-strong-passwords-c5cebb49-8c53-4f5e-2bc4-fe357ca048eb> (accessed Sep. 07, 2022).
- [13] B. Bhana and S. V. Flowerday, "Usability of the login authentication process: passphrases and passwords," *Information and Computer Security*, vol. 30, no. 2, pp. 280-305, 2022, doi: 10.1108/ICS-07-2021-0093.
- [14] C. Bonk, Z. Parish, J. Thorpe, and A. Salehi-Abari, "Long Passphrases: Potentials and Limits," 2021 18th International Conference on Privacy, Security and Trust, PST 2021, 2021, doi: 10.1109/PST52912.2021.9647800
- [15] K. Schiller and F. Adamsky, "Work in Progress: Can Johnny Encrypt E-Mails on Smartphones?," *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 13176 LNCS, pp. 182-193, 2022, doi: 10.1007/978-3-031-10183-0_9.
- [16] E. Blanchard, "Client-Side Hashing for Efficient Typo-Tolerant Password Checkers," *International Journal of Systems and Software Security and Protection*, vol. 13, no. 1, pp. 1-24, 2022, doi:10.4018/ijsssp.302622.
- [17] S. Sahin and F. Li, "Don't Forget the Stuffing! Revisiting the Security Impact of Typo-Tolerant Password Authentication," vol. 1, no. 1. Association for Computing Machinery, 2021. doi:10.1145/3460120.3484791.
- [18] H. Assal, A. Imran, and S. Chiasson, "An exploration of graphical password authentication for children," *Int J Child Comput Interact*, vol. 18, pp.37-46, 2018, doi:10.1016/j.ijcci.2018.06.003.
- [19] H. Wasfi and R. Stone, "The Effectiveness of Applying Different Strategies on Recognition and Recall Textual Password," *International Journal of Network Security & Its Applications*, vol. 14, no. 2, pp. 15-29, 2022, doi:10.5121/ijnsa.2022.14202.
- [20] N. Wright, A. S. Patrick, and R. Biddle, "Do you see your password? Applying recognition to textual passwords," *SOUPS 2012 - Proceedings of the 8th Symposium on Usable Privacy and Security*, 2012, doi:10.1145/2335356.2335367.
- [21] M. N. Al-Ameen, S. T. Marne, K. Fatema, M. Wright, and S. Scielzo, "On improving the memorability of system-assigned recognition-based passwords," *Behaviour and Information Technology*, vol. 41, no. 5, pp.1115-1131, 2022, doi:10.1080/0144929X.2020.1858161.
- [22] L. Zhou, K. Wang, J. Lai, and D. Zhang, "A Comparison of a Touch-Gesture- and a KeystrokeBased Password Method: Toward Shoulder-Surfing Resistant Mobile User Authentication," *IEEE Trans Hum Mach Syst*, no. February, 2023, doi:10.1109/THMS.2023.3236328.
- [23] R. Dillon, S. Chawla, D. Hristova, B. Gobl, and S. Jovicic, "Password policies vs. usability: When do users go 'bananas'?", *Proceedings - 2020 IEEE 19th International Conference on Trust, Security and Privacy in Computing and Communications, TrustCom 2020*, pp. 148-153, 2020, doi:10.1109/TrustCom50675.2020.00032.
- [24] D. Sangrey and P. Wang, "Password Change Requirements and the Effective Strength of Passwords," *Issues In Information Systems*, vol. 23, no. 2, pp. 29-41, 2022, doi:10.48009/2_iis_2022_103.
- [25] B. Bhana and S. Flowerday, "Passphrase and keystroke dynamics authentication: Usable security," *Comput Secur*, vol. 96, p. 101925, 2020, doi:10.1016/j.cose.2020.101925.
- [26] Y. Guo, Z. Zhang, Y. Guo, and X. Guo, "Nudging personalized password policies by understanding users' personality," *Comput Secur*, vol. 94, 2020, doi:10.1016/j.cose.2020.101801.
- [27] Y. Abdrabou et al., "Your Eyes Tell You Have Used This Password Before: Identifying Password Reuse from Gaze and Keystroke Dynamics," *Conference on Human Factors in Computing Systems Proceedings*, no. May, 2022, doi: 10.1145/491102.3517531.
- [28] B. Merdenyan and H. Petrie, "Two studies of the perceptions of risk, benefits and likelihood of undertaking password management behaviours," *Behaviour and Information Technology*, vol. 41, no. 12, pp. 2514-2527, 2022, doi: 10.1080/0144929X.2021.2019832.
- [29] J.R. Nirmal, R.B. Kiran, and V.Hemamalini, "Improved multifactor user authentication mechanism using defense in depth strategy with integration of passphrase and keystroke dynamics," vol. 62, no. 7, pp. 4837-4843, 2022, doi: doi.org/10.1016/j.matpr.2022.03439.
- [30] A. Nosenko, Y. Cheng, and H. Chen, "Password and Passphrase Guessing with Recurrent Neural Networks," *Information Systems Frontiers*, no. August, 2022, doi: 10.1007/s10796-022-10325-x.
- [31] M. V. Martin, "Assessing the Memorability of Familiar Vocabulary for System Assigned Passphrases," no. August, 2021.
- [32] P. B. Maoneke, S. Flowerday, and M. Warkentin, "Evaluating the usability of a multilingual passphrase policy," *26th Americas Conference on Information Systems, AMCIS 2020*, pp. 0-10, 2020.
- [33] N. Jagadeesh and M. V. Martin, "Alice in Passphraseland: Assessing the Memorability of Familiar Vocabularies for System-Assigned Passphrases," arXiv, 2021.
- [34] T. Pongmorakot and R. Chatterjee, "tPAKE: Typo-Tolerant Password-Authenticated Key Exchange," *International Conference on Security, Privacy, and Applied Cryptography Engineering*. Springer, Cham, 2020.
- [35] A. Mukherjee, K. Murali, S. K. Jha, N. Ganguly, R. Chatterjee, and M. Mondal, *MASCARA: Systematically Generating Memorability And Secure Passphrases*, vol. 1, no. 1. Association for Computing Machinery, 2023. [Online]. Available: <http://arxiv.org/abs/2303.09150>
- [36] Y. Al-Slais and W. El-Medany, "User-Centric Adaptive Password Policies to Combat Password Fatigue," *International Arab Journal of Information Technology*, vol. 19, no. 1, pp. 55-62, 2022, doi: 10.34028/iajit/19/1/7.
- [37] B. Ye, Y. Guo, L. Zhang, and X. Guo, "An empirical study of mnemonic password creation tips," *Comput Secur*, vol. 85, pp. 41-50, 2019, doi: 10.1016/j.cose.2019.04.009.
- [38] M. Hanna, "Assisting Seniors with Technology Challenges: Video Tutorials for Password Development and Management," 2021.
- [39] J. Song, D. Wang, Z. Yun, and X. Han, "Alphapwd: A Password Generation Strategy Based on Mnemonic Shape," *IEEE Access*, vol. 7, pp. 119052-119059, 2019, doi: 10.1109/ACCESS.2019.2937030.
- [40] R. P. A. Lioy, I. Andrea, A. Candidato, and F. Sarti, "Toward a usable system-generated authentication mechanism," 2019.
- [41] S. S. Woo, "How Do We Create a Fantabulous Password?," *The Web Conference 2020 Proceedings of the World Wide Web Conference, WWW 2020*, pp. 1491-1501, 2020, doi: 10.1145/3366423.3380222.
- [42] A. M. White, K. Shaw, F. Monrose, and E. Moreton, "Isn't that Fantabulous," pp. 25-38, 2014, doi: 10.1145/2683467.2683470.
- [43] S. S. Woo and J. Mirkovic, "Memorability and Security of Different Passphrase Generation Methods," *Review of KIISC*, vol.28, no. 1, pp. 29-35, 2018.
- [44] A. Addas, J. Thorpe, and A. SalehiAbari, "Geographic Hints for Passphrase Authentication," 2019 17th International Conference on Privacy, Security and Trust, PST 2019 - Proceedings, 2019, doi: 10.1109/PST47121.2019.8949033
- [45] A. Kanta, S. Coray, I. Coisel, and M. Scanlon, "How viable is password cracking in digital forensic investigation? Analyzing the guessability of over 3.9 billion real-world accounts," *Forensic Science International: Digital Investigation*, vol. 37, p. 301186, 2021, doi: 10.1016/j.fsi.2021.301186.
- [46] Z. Joudaki, J. Thorpe, and M. Vargas Martin, "Enhanced Tacit Secrets: System-assigned passwords you can't write down, but don't need to," *Int J Inf Secur*, vol. 18, no. 2, pp. 239-255, Apr. 2019, doi: 10.1007/s10207-0180408-2.
- [47] K. S. Wallia, S. Shenoy, and Y. Cheng, "An Empirical Analysis on the Usability and Security of Passwords," *Proceedings - 2020 IEEE 21st International Conference on Information Reuse and Integration for Data Science, IRI 2020*, pp. 1-8, 2020, doi: 10.1109/IRI49571.2020.00009.
- [48] Y. Cheng, C. Xu, Z. Hai, and Y. Li, "DeepMnemonic: Password Mnemonic Generation via Deep Attentive Encoder-Decoder Model," *IEEE Trans Dependable Secure Comput*, vol. 19, no. 1, pp. 77-90, 2022, doi: 10.1109/TDSC.2020.2987025.
- [49] D. He, X. Yang, B. Zhou, Y. Wu, Y. Cheng, and N. Guizani, "Password Enhancement Based on Semantic Transformation," *IEEE Netw*, vol. 34, no. 1, pp. 116-121, 2020, doi: 10.1109/MNET.2019.1900033.
- [50] A. P. Burgoyne and R. W. Engle, "Attention Control: A Cornerstone of Higher-Order Cognition," *Curr Dir Psychol Sci*, vol. 29, no. 6, pp. 624-630, 2020, doi: 10.1177/0963721420969371.
- [51] H. Feng, "Memory studies of chunking and decay of memory," vol. 36, pp. 709-714, 2023.
- [52] D. Ševerdija, "Working Memory in Word Recall," pp. 2-29, 2023, [Online]. Available: <https://urn.nsk.hr/urn:nbn:hr:131:382156>
- [53] W. Xie, W. A. Bainbridge, S. K. Inati, C. I. Baker, and K. A. Zaghoul, "Memorability of words in arbitrary verbal associations modulates memory retrieval in the anterior temporal lobe," *Nat Hum Behav*, vol. 4, no. 9, pp. 937-948, 2020.
- [54] V. Popov and L. Reder, "Frequency effects in recognition and recall," *Handbook of Human Memory*, pp. 1-31, 2021.
- [55] J. Verhagen, M. van Stiphout, and E. Blom, "Determinants of early lexical acquisition: Effects of word- and child-level factors on Dutch

- children's acquisition of words," *J Child Lang*, vol. 49, no. 6, pp. 1193-1213, 2022, doi: 10.1017/S0305000921000635.
- [56] M. Ponari, C. Frazier Norbury, and G. Vigliocco, "The role of emotional valence in learning novel abstract concepts Marta Ponari," *Dev Psychol*, vol. 56, no. 10, pp. 1855-1865, 2020.
- [57] J. Kaleńska-Rodzaj, "Preperformance emotions and music performance anxiety beliefs in young musicians," *Research Studies in Music Education*, vol. 42, no. 1, pp. 77-93, 2020, doi: 10.1177/1321103 × 19830098.
- [58] S. M. Mohammad, "Obtaining reliable human ratings of valence, arousal, and dominance for 20,000 English words," *ACL 2018 56th Annual Meeting of the Association for Computational Linguistics, Proceedings of the Conference (Long Papers)*, vol. 1, pp. 174-184, 2018, doi: 10.18653/v1/p18 – 1017.
- [59] A. Jha, K. R. Bhatele, P. Philip, and K. Mishra, "Graphical Password Authentication System for Web and Mobile Applications in JavaScript," pp. 160-185, 2022, doi: 10.4018/978-1-6684-58273.ch011.
- [60] U. Cil and K. Bicakci, "gridwordx: Design, implementation, and usability evaluation of an authentication scheme supporting both desktops and mobile devices," *Workshop on Mobile Security Technologies (MoST 13)*, 2013.
- [61] N. K. Blanchard, C. Malaingre, and T. Selker, "Improving security and usability of passphrases with guided word choice," pp. 723732, 2018, doi: 10.1145/3274694.3274734.
- [62] B. B. B. and T. T. H. Tazawa, T. Katoh, "A user authentication scheme using multiple passphrases and its arrangement," 2010.
- [63] Z. Joudaki, J. Thorpe, and M. V. Martin, "Reinforcing system assigned passphrases through implicit learning," *Proceedings of the ACM Conference on Computer and Communications Security*, pp. 1533-1548, 2018, doi: 10.1145/3243734.3243764.
- [64] U. Farooq, "Real Time Password Strength Analysis on a Web Application Using Multiple Machine Learning Approaches," *International Journal of Engineering Research & Technology (IJERT)*, vol. 9, no. 12, pp. 359-364, 2020.
- [65] D. K. Davis, M. M. Chowdhury, and N. Rifat, "Password Security: What Are We Doing Wrong?," *IEEE International Conference on Electro Information Technology*, vol. 2022-May, pp. 562-567, 2022, doi: 10.1109/eIT53891.2022.9814059.
- [66] R. Alomari, M. V. Martin, S. MacDonald, A. Maraj, R. Liscano, and C. Bellman, "Inside out - A study of users' perceptions of password memorability and recall," *Journal of Information Security and Applications*, vol. 47, pp. 223-234, 2019, doi: 10.1016/j.jisa.2019.05.009.
- [67] J. M. Pittman and N. Robinson, "Shades of Perception- User Factors in Identifying Password Strength," 2020, [Online]. Available: <http://arxiv.org/abs/2001.04930>
- [68] J. Kävrestad, M. Lennartsson, M. Birath, and M. Nohlberg, "Constructing secure and memorable passwords," *Information and Computer Security*, vol. 28, no. 5, pp. 701717, 2020, doi: 10.1108/ICS-072019-0077.
- [69] M. Lennartsson, "Evaluating the Memorability of Different Password Creation Strategies: A Systematic Literature Review," 2019.
- [70] L. A. Loos, Minas. K, R. Crosby., and M. E. M.-B C. Ogawa, "Passphrase Authentication and Individual Physiological Differences," vol. 12776 LNAI. Cham: Springer International Publishing, 2021. doi: 10.1007/978-3-030-78114-9_19.
- [71] T. Khodadadi, Y. Javadianasl, F. Rabiei, M. Alizadeh, M. Zamani, and S. S. Chaeikar, "A Novel Graphical Password Authentication Scheme with Improved Usability," 2021 4th International Symposium on Advanced Electrical and Communication Technologies, ISAECT 2021, no. December, 2021, doi: 10.1109/ISAECT53699.2021.9668 599.
- [72] S. Z. Nizamani, S. R. Hassan, R. A. Shaikh, E. A. Abozinadah, and R. Mehmood, "A novel hybrid textual-graphical authentication scheme with better security, memorability, and usability," *IEEE Access*, vol. 9, pp. 51294-51312, 2021, doi: 10.1109/ACCESS.2021.3069164.
- [73] S. W. Jirjees, A. M. Mahmood, and A. R. Nasser, "Passnumbers: An Approach of Graphical Password Authentication Based on Grid Selection," *International Journal of Safety and Security Engineering*, vol. 12, no. 1, pp. 21-29, 2022, doi: 10.18280/ijss.120103.
- [74] K.Lapin and M.Šiurkus, "Balancing Usability and Security of Graphical Passwords," vol. 440. 2022. [Online]. Available: <https://link.springer.com/10.1007/978-3-031-11432-8>
- [75] A. Khan and A. G. Chefranov, "A Captcha-Based Graphical Password with Strong Password Space and Usability Study," 2nd International Conference on Electrical, Communication and Computer Engineering, ICECCE 2020, no. June, pp. 12-13, 2020, doi: 10.1109/ICECCE49384.2020.9179 265.
- [76] O. Osunade, I. A. Oloyede, and T. O. Azeze, "Graphical User Authentication System Resistant to Shoulder Surfing Attack," *Adv Res*, vol. 19, no. 4, pp. 1-8, 2019, doi: 10.9734/air/2019/v19i430126.
- [77] B. Robert, S. Chiasson, and P. C. van Oorschot, "Graphical passwords: Learning from the first twelve years," *ACM Comput Surv*, vol. 44, no. 4, pp. 1-41, 2012, doi: 10.1145/2333112.2333114.
- [78] T. I. Shamme, T. Akter, M. Mou, F. Chowdhury, and M. S. Ferdous, "A Systematic Literature Review of Graphical Password Schemes," *Journal of Computing Science and Engineering*, vol. 16, no. 4, pp. 163-185, 2020, doi: 10.5626/JCSE.2020.14.4.163.
- [79] F. Ghiyamipour, "Secure graphical password based on cued click points using fuzzy logic," *Security and Privacy*, vol. 4, no. 2, pp. 1– 26, 2021, doi: 10.1002/spy2.140.
- [80] A. F. MUAFLAH, "A Secure Shoulder Surfing Resistant Hybrid Graphical User Authentication Scheme," *Ayan*, vol. 8, no. 5, p. 55, 2019.
- [81] N. A. Bi. M. Fazil, "Graphical Password Authentication Using Cued Click Point Technique," *Universiti Sultan Zainal Abidin*, 2021.
- [82] I. Journal, O. F. Advance, and E. Trends, "Graphical Systems Authentication Using Ascii," vol. 4, no. 6, pp. 24-30, 2020.
- [83] J. A. Herrera-macias, C. M. Legónpérez, L. Suárez-plasencia, L. R. Piñero-díaz, O. Rojas, and G. Sosa-gómez, "SS symmetry Test for Detection of Weak Graphic Passwords in Password Based on the Mean Distance between Points †," pp. 1-19, 2021.
- [84] J. G. Kaka and O. J. O, "Recognition Based Graphical Password Algorithms: A Survey," 2021.
- [85] P. U. Gujare, A. S. Kapse, and A. S. Kapse, "Three way authentication technique using User Defined Graphical Authentication System," vol. 5, no. 6, pp. 185188, 2020.
- [86] Prof. P. S. Gayke, Shradha Thorat, Gayatri Nagarkar, Priyanka Kusalkar, and Priyanka Waditake, "Secure Data Access using Steganography and Image Based Password," *Int J Sci Res Sci Technol*, pp. 193-198, 2022, doi: 10.32628/ijrsr229343.
- [87] U. Bedekar and G. Bhatia, "A Novel Approach to Recommend Skincare Products Using Text Analysis of Product Reviews", vol. 191, no. Ictcs. 2022. doi: 10.1007/978-981-16-0739-4_24.
- [88] P. Jitibumrungrak and N. Hongwarittorm, "A preliminary study to evaluate graphical passwords for older adults," *ACM International Conference Proceeding Series*, pp. 88-95, 2019, doi: 10.1145/3328243.3328255.
- [89] H. U. Suru, A. A. Muslim, S. U. Suru, and H. U. Suru, "A Review of Graphical, Hybrid and Multifactor Authentication Systems," vol. 10, no. 1, pp. 1447-1475, 2019.
- [90] H. Umar Suru and P. Murano, "Security and User Interface Usability of Graphical Authentication Systems - A Review," *International Journal of Computer Trends and Technology*, vol. 67, no. 2, pp. 17-36, 2019, doi: 10.14445/22312803/ ijctv67i2p104.
- [91] H. M. Aljahdali and R. Poet, "The affect of familiarity on the usability of recognition-based graphical passwords: Cross cultural study between Saudi Arabia and the United Kingdom," *Proceedings - 12th IEEE International Conference on Trust, Security and Privacy in Computing and Communications, TrustCom 2013*, pp. 1528-1534, 2013, doi: 10.1109/TrustCom.2013.187.
- [92] N. Kausar, I. U. Din, M. A. Khan, A. Almogren, and B. S. Kim, "GRAPIN: A Graphical and PIN-Based Hybrid Authentication Approach for Smart Devices," *Sensors*, vol. 22 , no. 4, pp. 1-17, 2022, doi: 10.3390/s22041349.
- [93] B. Sharma, S. S. Patel, A. Jaiswal, and Y. Arora, "Hybrid Graphical Password Authentication System," no. 02, pp. 113-118, 2021.
- [94] F. Sepideh, "Providing a Secure Hybrid Method for Graphical Password Authentication to Prevent Shoulder Surfing , Smudge and Brute Force Attack," vol. 13 , no. 12 , pp. 624-628, 2019.
- [95] S. Istyaq, A. Nazir, and M. S. Umar, "Hybrid Graphical User Authentication Scheme Using Grid Code," *Int. j. eng. trends technol.*, vol. 69, no. 5, pp. 166176, 2022, doi: 10.14445/22315381/IJETT- V69I5P223.
- [96] M. Elhoseny and A. K. Singh, "Smart Network Inspired Paradigm and Approaches in IoT Applications", 1st ed. Singapore: Singapore: Springer, 2020.
- [97] S. S. Patel, A. Jaiswal, Y. Arora, and B. Sharma, "Survey on Graphical Password Authentication System," pp. 699708, 2021, doi: 10.1007/978-98115-8530-2_55.
- [98] G. C. Yang, "Development status and prospects of graphical password authentication system in Korea," *KSII Transactions on Internet and Information Systems*, vol. 13, no. 11, pp. 5755-5772, 2019, doi: 10.3837/tiis.2019.11.026.
- [99] Y. Zhang, C. Xu, H. Li, K. Yang, N. Cheng, and X. Shen, "PROTECT:

- Efficient Password-Based Threshold Single-Sign-On Authentication for Mobile Users against Perpetual Leakage,” *IEEE Trans Mob Comput*, vol. 20, no. 6, pp. 2297-2312, 2021, doi: 10.1109/TMC.2020.2975792.
- [100] R. H. Khan and J. Miah, "Performance Evaluation of a new one-Time password (OTP) scheme using stochastic petri net (SPN)," 2022 IEEE World AI IOT Congress, Allot 2022, no. August, pp. 407-412, 2022, doi: 10.1109/Allot54504.2022.981723.
- [101] M. A. Hassan, Z. Shukur, and M. K. Hasan, "An Improved Time-Based One Time Password Authentication Framework for Electronic Payments," *International Journal of Advanced Computer Science and Applications*, vol. 11, no. 11, pp. 359-366, 2020, doi: 10.14569/IJACSA.2020.0111146.
- [102] F. M. Farke, L. Lorenz, T. Schnitzler, P. Markert, and M. Dürmuth, "You still use the password after all' - Exploring FIDO2 Security Keys in a Small Company," *Proceedings of the 16th Symposium on Usable Privacy and Security, SOUPS 2020*, pp. 19-36, 2020.
- [103] S. Sudha and S. S. Manikandasaran, "Asynchronous Password-Based Authentication and Service_Provider_ID Module for Secured Cloud Environment," *International Journal of Computer Theory and Engineering*, vol. 12, no. 4, pp. 85-91, 2020, doi: 10.7763/ijcte.2020.v12.1269.
- [104] I. Alsaadi and I. Majeed Alsaadi, "Study On Most Popular Behavioral Biometrics, Advantages, Disadvantages And Recent Applications : A Review," *International Journal of Scientific & Technology Research*, vol. 10, no. January, p. 1, 2021, doi: 10.13140/RG.2.2.28802.09926.
- [105] C. Lipps, J. Herbst, and H. D. Schotten, "How to Dance your Passwords: A Biometric MFA- scheme for Identification and Authentication of Individuals in IIoT Environments," *Proceedings of the 16th International Conference on Cyber Warfare and Security. International Conference on Cyber Warfare and Security (ICWS-2021)*, February 25-26, Cookeville, Tennessee, USA, 2021, doi: 10.34190/IWS.21.016.
- [106] N. A. K. Abiew, M. D. Jnr., and S. O. Banning, "Design and Implementation of Cost Effective Multi-factor Authentication Framework for ATM Systems," *Asian Journal of Research in Computer Science*, no. April, pp. 7-20, 2020, doi: 10.9734/ajrcos/2020/v5i330135.
- [107] M. Akbari, "A Multimodalbiometric Identification System Based on Deep Features to Identify Individuals," 2022.
- [108] D. M. Omarova and I. S. Mutayeva, "BIOMETRICS AS A METHOD OF COMBAT WITH COVID-19," in *Smart Innovation, Systems and Technologies, International scientific conference*, 2020.
- [109] M. Wanuna, "Dynamic knowledge based authentication model for enhancing security of USSD banking transactions," 2020, [Online]. Available: <http://hdl.handle.net/11071/12089> Followthisandadditionalworksat:<http://hdl.handle.net/11071/12089>
- [110] M. Ahsan and Y. Li, "Graphical Password Authentication using Images Sequence," *International Research Journal of Engineering and Technology*, vol. 9001, p. 1824, 2008, [Online]. Available: www.irjet.net
- [111] Pankhuri, A. Sinha, G. Shrivastava, and P. Kumar, "A pattern-based multi-factor authentication system," *Scalable Computing*, vol. 20, no. 1, pp. 101-112, 2019, doi: 10.12694/scpe.v20i1.1460.
- [112] O. N. Toxirjonovich, A. A. Xusnidinovich, and A. U. Y. O'g'li, "Multi-factor Authentication System Based on Template," *JournalNX*, vol. 7, no. 05, pp. 4960, 2021.
- [113] S. Lavanya, N. M. SaravanaKumar, V. Vijayakumar, and S. Thilagam, "Secured Key Management Scheme for Multicast Network Using Graphical Password," *Mobile Networks and Applications*, vol. 24, no. 4, pp. 1152-1159, 2019, doi: 10.1007/s11036-019-01252-4.
- [114] B. Yao, Y. Mu, H. Sun, X. Zhang, H. Wang, and J. Su, "Connection between text-based passwords and topological graphic passwords," *Proceedings of 2018 IEEE 4th Information Technology and Mechatronics Engineering Conference, ITOEC 2018*, no. Itoec, pp. 1090-1096, 2018, doi: 10.1109/ITOEC.2018.8740702.
- [115] B. Rasmussen and D. Zappala, "A Usability Study of FIDO2 Roaming Software Tokens as a Password Replacement," *ProQuest Dissertations and Theses*, p. 36, 2021, [Online]. Available: https://www.proquest.com/dissertations-theses/usability-studyfido2-roaming-software-tokens-as/docview/2600829489/se-2?accountid=202211%0https://media.proquest.com/media/hms/PFT/2/RrxJL?_a=ChgyMDIyMDUyMDA4MjcyNjExND01ODkyMzIsZSBzEzODc5ODEaCk9ORV9TRUFSQ0giD

Super-Resolution of Brain MRI via U-Net Architecture

Aryan Kalluvila

Athinoula Martinos Center, Harvard Medical School, Charleston, MA, Hartford Union High School, Hartford, WI

Abstract—This paper proposes a U-Net-based deep learning architecture for the task of super-resolution of lower resolution brain magnetic resonance images (MRI). The proposed system, called MRI-Net, is designed to learn the mapping between low-resolution and high-resolution MRI images. The system is trained using 50-800 2D MRI scans, depending on the architecture, and is evaluated using peak signal-to-noise ratio (PSNR) metrics on 10 randomly selected images. The proposed U-Net architecture outperforms current state-of-the-art networks in terms of PSNR when evaluated with a 3 x 3 resolution downsampling index. The system's ability to super-resolve MRI scans has the potential to enable physicians to detect pathologies better and perform a wider range of applications. The symmetrical downsampling pipeline used in this study allows for generically representing low-resolution MRI scans to highlight proof of concept for the U-Net-based approach. The system is implemented on PyTorch 1.9.0 with NVIDIA GPU processing to speed up training time. U-Net is a promising tool for medical applications in MRI, which can provide accurate and high-quality images for better diagnoses and treatment plans. The proposed approach has the potential to reduce the costs associated with high-resolution MRI scans by providing a solution for enhancing the image quality of low-resolution scans.

Keywords—MRI; U-Net; Super-Resolution; PyTorch; SRCNN; SR-GAN; Deep Learning; GPU

I. INTRODUCTION

Medical imaging has been an essential tool in the diagnosis and treatment of various diseases. Among the different types of medical imaging, magnetic resonance imaging (MRI) has been widely used because it provides detailed images of the internal structures of the body. However, the resolution of MRI images is limited by several factors, such as the hardware used and the acquisition parameters, which can affect diagnostic accuracy and make it challenging to identify subtle anatomical features.

To address this limitation, researchers have been exploring the use of super-resolution techniques to enhance the resolution of MRI images [1]. Super-resolution is a computational method that enhances the resolution of an image beyond the physical limits of the imaging hardware. The primary objective of this approach is to generate high-resolution images that can provide more detailed information about the anatomy and pathology of the imaged area.

Recent advancements in deep learning-based super-resolution techniques for MRI have shown promising results in generating high-resolution MRI images with improved details and contrast [3]. These techniques use advanced machine learning algorithms to learn the mapping between low-

resolution and high-resolution images. High-resolution MRI images are particularly important in the diagnosis and treatment of neurological disorders, where small changes in the brain's anatomy can have significant implications for patient outcomes. For example, in the diagnosis of brain tumors, high-resolution MRI images can help to accurately identify the location, size, and shape of the tumor, which is critical for surgical planning and treatment.

The use of super-resolution techniques in MRI has the potential to revolutionize the field of medical imaging, leading to significant improvements in medical diagnosis and treatment. With the increasing availability of large datasets and the progress of machine learning algorithms, there is enormous potential for further advancements in this field. However, the effectiveness of super-resolution techniques in enhancing MRI images depends on several factors, including the choice of algorithms and evaluation metrics. In this context, several deep learning-based super-resolution algorithms have been developed and tested to improve the resolution of MRI images. The choice of the appropriate algorithm depends on several factors, including the quality of the input data, the complexity of the target structures, and the available computational resources. Additionally, it is crucial to use appropriate evaluation metrics to assess the effectiveness of these algorithms in improving the resolution of MRI images.

In this paper, we aim to evaluate the effectiveness of super-resolution techniques for enhancing MRI images, with a specific focus on the U-Net algorithm. One of the strengths of our approach is the utilization of the Mean Squared Logarithmic Error (MSLE) as the main loss function, which enables accurate reconstruction of high-resolution MRI images. We compare the performance of the U-Net algorithm against four other commonly used networks in terms of generating high-quality images. To assess the quality of the enhanced images, we employ the widely accepted metric, Peak Signal-to-Noise Ratio (PSNR). Notably, our results demonstrate that the U-Net algorithm surpasses the other networks, yielding higher average PSNR values. These findings have significant implications for the diagnosis and treatment of neurological disorders, as enhanced MRI images obtained through the U-Net algorithm can provide improved insights and precision in medical imaging. The advancements showcased in this research have the potential to make a substantial impact on the field of medical imaging as a whole.

II. LITERATURE REVIEW

Super-resolution of MRI is a critical task in the medical field that involves increasing the resolution of magnetic

resonance images to improve their quality and accuracy. Many researchers have proposed various techniques to achieve super-resolution of MRI, including deep learning, image registration, and image fusion. In this literature review, we will summarize some of the recent research works on super-resolution of MRI.

Li et al. [1] proposed a critic-guided framework for super-resolution of low-resolution MRI scans. In clinical practice, vast quantities of MRI scans are routinely acquired but are of sub-optimal quality for precision medicine, computational diagnostics, and neuroimaging research. To address this limitation, the authors utilized feature-importance and self-attention methods in their model to improve interpretability. Their framework was evaluated on paired low- and high-resolution MRI scans from various manufacturers and was shown to produce qualitatively faithful results to ground-truth scans with high accuracy (PSNR = 35.39; MAE = 3.78E-3; NMSE = 4.32E-10; SSIM = 0.9852).

Ottesen et al. [2] proposed a densely connected cascading deep learning reconstruction framework to improve accelerated MRI reconstruction. The authors modified a cascading deep learning reconstruction framework by incorporating three architectural modifications, namely input-level dense connections, an improved deep learning sub-network, and long-range skip-connections. The proposed framework, called the Densely Interconnected Residual Cascading Network (DIRCN), was evaluated on the NYU fastMRI neuro dataset with an end-to-end scheme at four- and eightfold acceleration. The authors performed an ablation study where they trained five model configurations and evaluated them based on the structural similarity index measure (SSIM), normalized mean square error (NMSE), and peak signal to noise ratio (PSNR). The results showed that the proposed DIRCN with all three modifications achieved an SSIM improvement of 8% and 11%, a NMSE improvement of 14% and 23%, and a PSNR improvement of 2% and 3% for four- and eightfold acceleration, respectively.

Similarly, Qiu, Wang, and Guo [3] proposed a novel deep learning-based approach for super-resolution of MRI, which utilizes a generative adversarial network (GAN) to generate high-resolution MRI images from low-resolution images. Due to limitations in hardware, scan time, and throughput, obtaining high-quality MR images can be a challenging task in clinical settings. Therefore, the authors aimed to use a super-resolution approach to enhance the image quality without requiring any hardware upgrades. In that paper, they proposed an ensemble learning and deep learning framework for MR image super-resolution. To create their framework, the authors first enlarged low resolution images using five commonly used super-resolution algorithms, resulting in differentially enlarged image datasets with complementary priors. Then, they trained a generative adversarial network (GAN) with each dataset to generate super-resolution MR images. Finally, they used a convolutional neural network for ensemble learning, which synergized the outputs of the GANs to produce the final MR super-resolution images.

De Leeuw den Bouter et al. [4] highlighted the potential of low-field MRI scanners to make MRI technology more accessible globally due to their significantly lower cost

compared to high-field counterparts. However, images acquired using low-field MRI scanners tend to be of relatively low resolution, which limits their clinical utility. To address this limitation, the authors presented a deep learning-based approach to transform low-resolution low-field MR images into high-resolution ones. They trained a convolutional neural network to carry out single image super-resolution reconstruction using pairs of noisy low-resolution images and their noise-free high-resolution counterparts obtained from the NYU fastMRI database. The trained network was subsequently applied to noisy images acquired using a low-field MRI scanner, producing sharp super-resolution images with most of the high-frequency components recovered. The authors demonstrated the potential of a deep learning-based approach to increase the resolution of low-field MR images.

Wang et al. [5] proposed a CNN-based multi-scale attention network (MAN) to improve the performance of convolutional super-resolution (SR) networks. While convolutional neural networks can compete with transformer-based methods in many high-level computer vision tasks, transformers with self-attention still dominate the low-level vision, including the super-resolution task. The authors exploit large kernel decomposition and attention mechanisms in their design. The proposed MAN consists of multi-scale large kernel attention (MLKA) and a gated spatial attention unit (GSAU). Within the MLKA, the authors rectify LKA with multi-scale and gate schemes to obtain the abundant attention map at various granularity levels. This approach jointly aggregates global and local information and avoids potential blocking artifacts. In GSAU, a gate mechanism and spatial attention are integrated to remove the unnecessary linear layer and aggregate informative spatial context. The authors evaluate MAN with multiple complexities by simply stacking different numbers of MLKA and GSAU. Experimental results illustrate that their MAN can achieve varied trade-offs between state-of-the-art performance and computations.

Bahrami et al. [6] proposed a novel method for predicting high-resolution 7T-like MR images from low-resolution 3T MR images. The predicted 7T-like MR images demonstrate higher spatial resolution compared to 3T MR images, as well as prediction results obtained using other comparison methods. The authors suggest that such high-quality 7T-like MR images could better facilitate disease diagnosis and intervention. This paper demonstrates proof of concept for reconstruction in even high-resolution MRI dynamics.

Koonjoo et al's paper introduces AUTOMAP, a deep learning method for improving image quality in low-field MRI systems [10]. AUTOMAP outperforms traditional Fourier reconstruction and two contemporary denoising algorithms, reducing noise and artifacts in the reconstructed images. It achieves substantial signal-to-noise ratio gains for both human brain and plant root data, demonstrating the potential of deep learning in enhancing image quality in low-field MRI. This approach contributes to advancing resolution and image quality in low-field MRI applications.

The U-Net architecture outperforms other techniques [9] in medical image super-resolution of brain MRI due to its dedicated design for image segmentation tasks and effective

feature extraction. Its skip connections enable the preservation and utilization of both high-level and low-level features, resulting in enhanced resolution. Unlike other architectures, such as the SRCNN, GAN-based approaches, or multi-scale attention networks, the U-Net consistently achieves superior resolution improvement. Its ability to capture fine details and preserve structural information makes it the preferred choice for medical image super-resolution tasks.

III. METHODOLOGY

A. Downsampling Pipeline

In order to accurately simulate the low-resolution scans typically obtained from lower field strength MRI scanners, we employed a symmetrical down sampling pipeline, as depicted in Fig. 1. This pipeline involved reducing each dimension of the scanner by a factor of three, replicating the effects of decreased resolution. By implementing this downsampling technique, we were able to mimic the conditions of low field strength and lower-quality scanners commonly associated with compromised image resolution and reduced overall image quality. To further ensure the authenticity of the simulated low-resolution scans, we applied bilinear interpolation, a widely adopted interpolation method, to generate the corrupted scans. This approach effectively captures the characteristic imperfections and limitations of lower field strength MRI scanners, providing a reliable basis for evaluating the performance and effectiveness of our super-resolution techniques in enhancing the quality and resolution of these low-resolution MRI images.

In order to enhance the computational efficiency of the U-Net architecture, we employed a technique known as residual learning. Instead of directly generating the complete high-resolution scan, our U-Net model was trained to focus on learning the difference between the high-resolution scan and the bilinear interpolated output. By utilizing this residual learning approach, the model became more adept at capturing the fine details and nuances present in the high-resolution image that may be lost during the bilinear interpolation process.

During the inference stage, the U-Net model would generate the residual, which represented the additional information needed to transform the interpolated scan into a super-resolved MRI scan. This residual was then added to the bilinear interpolated scan, resulting in the creation of a high-resolution image with enhanced details and improved quality. This approach not only improved the computational efficiency of the U-Net architecture but also ensured that the generated super-resolved MRI scan closely resembled the original high-resolution scan by effectively compensating for the limitations of the bilinear interpolation.

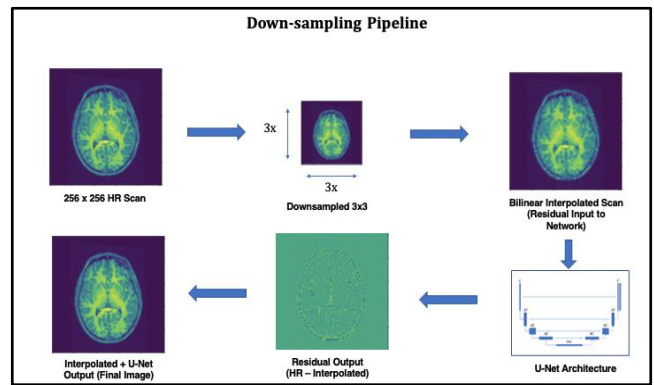


Fig. 1. Downsampling flow chart to create corrupted MRI scans.

B. U-Net Architecture

We used a U-Net architecture as denoted by Fig. 2, as the main super-resolution algorithm to improve the resolution of brain MRI. The U-Net architecture is a type of deep learning neural network that is particularly well-suited for image segmentation tasks, which involve dividing an image into multiple segments to identify specific structures or features within the image.

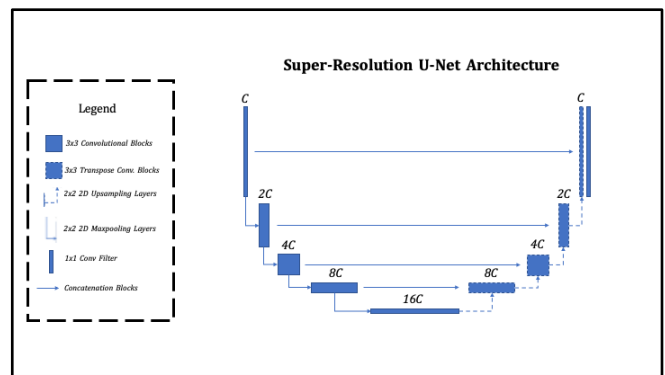


Fig. 2. U-Net architecture for super-resolution task [7].

The U-Net architecture is specifically designed for biomedical image analysis, making it an effective choice for super-resolution of brain MRI. The architecture consists of an encoder, which gradually reduces the resolution of the input image, and a decoder, which gradually increases the resolution of the image to produce the final high-resolution output. The encoder and decoder are connected by a bottleneck layer that contains information about the original image, allowing for precise reconstruction of the high-resolution output.

Compared to other deep learning architectures, such as fully convolutional networks (FCNs) or residual networks (ResNets), U-Net has several advantages for super-resolution of brain MRI. First, the U-Net architecture allows for the preservation of fine details, which is important for identifying subtle anatomical features in MRI images. Second, U-Net is less prone to overfitting, a common problem in deep learning models, as it contains skip connections that enable the model to learn from features at multiple scales. Finally, U-Net is computationally efficient, allowing for faster training and inference times compared to other architectures.

C. Evaluation Metrics

When evaluating the performance of image super-resolution techniques for MRI, several metrics are commonly used, including Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM). While both metrics are useful for evaluating image quality, PSNR is generally considered to be more important than SSIM in the context of super-resolution for MRI. PSNR is a widely used metric that measures the quality of an image by calculating the ratio of the peak signal power to the mean squared error of the image. Higher PSNR values indicate better image quality, with a perfect image having a PSNR of infinity. In the context of MRI super-resolution, PSNR is important because it reflects the ability of the super-resolution technique to accurately reconstruct high-frequency details in the image. This is particularly important in MRI, where small details can have significant clinical implications.

SSIM, on the other hand, is a metric that measures the structural similarity between two images. Specifically, SSIM calculates the similarity of the luminance, contrast, and structure of the images being compared. While SSIM is useful for evaluating overall image similarity, it is less sensitive to high-frequency details, which are important in the context of super-resolution for MRI. Therefore, while SSIM can provide useful information about the overall similarity of two images, it may not be as effective at evaluating the ability of a super-resolution technique to accurately reconstruct high-frequency details.

In our paper, we include only PSNR as a metric for evaluating the performance of our super-resolution technique for brain MRI. However, we primarily focused on the PSNR results as this metric provides a more accurate reflection of the ability of the technique to accurately reconstruct high-frequency details. Our results showed that the use of our super-resolution technique significantly improved the PSNR values compared to the baseline low-resolution images, indicating that our technique was effective at accurately reconstructing high-frequency details.

$$PSNR = 10 \log \frac{255^2}{MSE}$$

D. Loss Function Determination

In our paper, we sought to explore the use of different loss functions to optimize the performance of our super-resolution technique for MRI. While Mean Squared Error (MSE) is a commonly used loss function for image super-resolution, we found that it underperformed during the training process for our specific application. As a result, we decided to experiment with different loss functions to identify the most effective option.

After extensive experimentation, we found that Mean Squared Logarithmic Error (MSLE) performed significantly better than MSE in terms of producing higher resolution metrics. MSLE is particularly useful for image super-resolution applications as it is less sensitive to outliers, which can be a common issue in medical imaging data. MSLE also places a higher weight on errors for lower pixel values, which is

important in the context of MRI super-resolution as lower pixel values typically correspond to high-frequency details.

As a result of our experimentation, we established MSLE as the baseline loss function for our super-resolution technique and used it to test all of the networks. This allowed us to accurately compare the performance of different network architectures and identify the most effective approach for our specific application. By using MSLE as our main loss function, we were able to achieve significant improvements in image resolution and quality, ultimately leading to a more effective super-resolution technique for MRI [8].

$$MSLE = \frac{1}{n} \log(\sum Y_i - Y_j)^2$$

E. Technology and Datasets

In order to ensure that our network is well-equipped to handle a wide range of imaging scenarios, we utilized a large dataset of 50-800 3D MRI scans (depending on the architecture). All of these images came from the ABIDE dataset. These scans were carefully selected to include a variety of imaging parameters, such as field strength, contrast, and resolution, in order to ensure that our network is trained to handle the full range of imaging scenarios that it may encounter in clinical practice.

Each of the 3D scans in our dataset contained 256 slices, from which we selected the 128th slice to train our model. This approach was chosen to ensure that we have a sufficient number of training examples while also avoiding any potential bias that might arise from using only a subset of the available slices. By selecting the middle slice of each 3D scan, we can be confident that our training data is representative of the full range of imaging parameters present in each scan.

To evaluate the performance of our network, we tested it on a set of 10 randomly selected images. We used the peak signal-to-noise ratio (PSNR) as our metric for evaluation. These metrics are widely used in the image processing community and are commonly used to assess the quality of reconstructed images.

All of the experimentation for this study was completed on PyTorch 1.9.0 with NVIDIA GPU processing to speed up training time. The use of GPU processing allowed us to train our network more efficiently, enabling us to complete the necessary experimentation in a timely manner. Additionally, the use of PyTorch provided a powerful and flexible framework for implementing and testing our network, allowing us to easily modify and iterate on our approach as needed.

IV. RESULTS

In our study, we utilized Fig. 3 to present the qualitative observations of our super-resolution technique based on the U-Net architecture. The U-Net algorithm is a sophisticated deep learning model that has gained widespread popularity for its high efficacy in image super-resolution tasks, particularly in the medical imaging domain. One of the key strengths of the U-Net algorithm is its ability to reconstruct fine details from low-resolution inputs, particularly in the deeper regions such as the hippocampal areas. These regions are particularly critical in

detecting neurological conditions such as Alzheimer's and Parkinson's disease.

By effectively improving the resolution of MRI images in these regions, the U-Net algorithm can enhance the accuracy and reliability of disease detection, ultimately leading to improved patient outcomes. Furthermore, our study also compared the U-Net algorithm against four other commonly used networks in terms of average Peak Signal-to-Noise Ratio (PSNR) as denoted by Table I. The results of our study demonstrate that the U-Net algorithm outperformed the other networks in terms of average PSNR. This highlights the superiority of the U-Net algorithm in producing high-quality, super-resolved MRI images, which is of paramount importance in medical diagnosis and treatment.

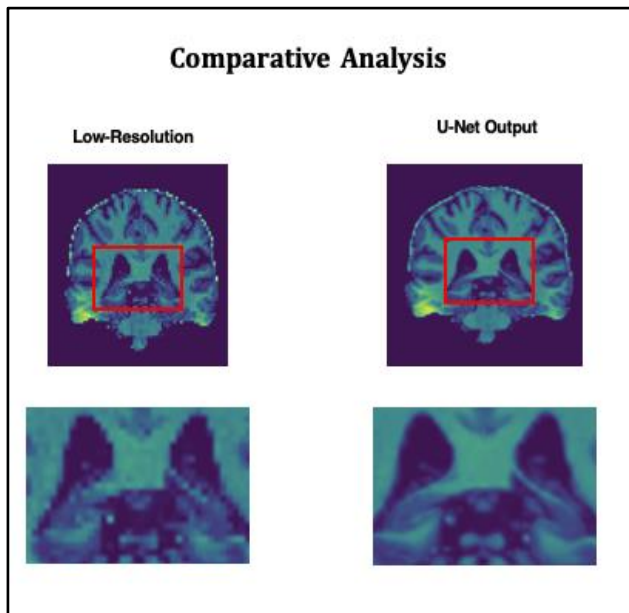


Fig. 3. Qualitative observations from low-resolution (left) to u-net output (right).

TABLE I. PSNR COMPARISON

Dataset I	PSNR
SR DenseNet	29.62458398
VDSR	29.9758636
U-Net	30.40278329
U-Net++	30.18895619
SR CNN	30.13047352

V. DISCUSSION AND CONCLUSION

Our study has delved into the potential of deep learning-based super-resolution techniques to improve the resolution of MRI images in the medical imaging domain. The results of our research are highly promising, demonstrating the effectiveness of the U-Net architecture in reconstructing fine details from low-resolution inputs, specifically in the hippocampal regions that play a crucial role in detecting neurological conditions such as Alzheimer's and Parkinson's disease. Our comparison with four other commonly used networks has highlighted the superiority of the U-Net algorithm in producing high-quality,

super-resolved MRI images. The U-Net performed with an average PSNR of 30.40, outperforming all other algorithms in terms of PSNR.

By improving the accuracy and reliability of medical diagnosis and treatment in the field of neurological disorders, our research could have a significant impact on the lives of patients and their families. However, our study is just the beginning, and there are numerous potential avenues for future research.

For example, we could explore the integration of multiple deep learning models for improved accuracy and efficiency. This could potentially lead to even more precise and comprehensive diagnosis and treatment for neurological disorders.

Another possible direction for future research is to expand the dataset used for training to encompass a broader range of neurological conditions and patient populations. This could help to improve the generalizability of our results and make our super-resolution techniques even more widely applicable in the medical imaging field.

While the U-Net architecture has demonstrated remarkable effectiveness in MRI super-resolution tasks, it is not without limitations. One notable limitation is the potential for overfitting, especially when dealing with limited or imbalanced training datasets. Due to the large number of parameters in the U-Net model, there is a risk of the model memorizing specific features from the training data rather than learning generalizable patterns. This can result in reduced performance when faced with unseen or diverse data during the testing phase. Another limitation is that our U-Net struggled to perform well with regards to the SSIM metric, underperforming current state of the art. Modifying loss function optimized to SSIM could potentially fix this issue.

Additionally, the U-Net architecture may struggle to capture long-range dependencies and complex spatial relationships within the MRI images, which could impact the accurate reconstruction of fine details. Moreover, the U-Net's performance may vary depending on the specific MRI imaging modality or imaging protocols, making it less universally applicable across different types of MRI scans. Addressing these limitations through appropriate regularization techniques, larger and more diverse training datasets, and exploration of alternative architectures could further enhance the performance and generalizability of the U-Net in MRI super-resolution tasks.

Moreover, we could investigate the potential of combining super-resolution techniques with other image processing techniques such as image segmentation and registration. By integrating these techniques, we could potentially achieve even more precise and comprehensive diagnosis and treatment for neurological disorders.

In summary, our study highlights the significant potential of deep learning-based super-resolution techniques for medical imaging, particularly in the detection and treatment of neurological disorders. By enhancing the resolution of MRI images, our research can contribute towards improving patient outcomes and ultimately lead to a better quality of life for

individuals suffering from these conditions. The outcomes of our research could pave the way for further advancements in the field, leading to even more accurate and efficient diagnosis and treatment in the future.

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REFERENCES

- [1] Li BM, Castorina LV, Valdés Hernández MdC, Clancy U, Wiseman SJ, Sakka E, Storkey AJ, Jaime Garcia D, Cheng Y, Doubal F, Thrippleton MT, Stringer M and Wardlaw JM (2022) Deep attention super-resolution of brain magnetic resonance images acquired under clinical protocols. *Front. Comput. Neurosci.* 16:887633. doi: 10.3389/fncom.2022.887633.
- [2] Ottesen, J.A., Caan, M.W.A., Groote, I.R. et al. A densely interconnected network for deep learning accelerated MRI. *Magn Reson Mater Phys* (2022). <https://doi.org/10.1007/s10334-022-01041-3>Zhou Z, Ma A, Feng Q, Wang R, Cheng L, Chen X, Yang X, Liao K, Miao Y, Qiu Y. Super-resolution of brain tumor MRI images based on deep learning. *J Appl Clin Med Phys.* 2022 Nov;23(11):e13758. doi: 10.1002/acm2.13758. Epub 2022 Sep 15. PMID: 36107021; PMCID: PMC9680577.
- [3] Zhou Z, Ma A, Feng Q, Wang R, Cheng L, Chen X, Yang X, Liao K, Miao Y, Qiu Y. Super-resolution of brain tumor MRI images based on deep learning. *J Appl Clin Med Phys.* 2022 Nov;23(11):e13758. doi: 10.1002/acm2.13758. Epub 2022 Sep 15. PMID: 36107021; PMCID: PMC9680577. R. Nicole, "Title of paper with only first word capitalized," *J. Name Stand. Abbrev.*, in press.
- [4] de Leeuw den Bouter, M.L., Ippolito, G., O'Reilly, T.P.A. et al. Deep learning-based single image super-resolution for low-field MR brain images. *Sci Rep* 12, 6362 (2022). <https://doi.org/10.1038/s41598-022-10298-6> M. Young, *The Technical Writer's Handbook*. Mill Valley, CA: University Science, 1989.
- [5] Wang, Li, et al. "Multi-Scale Attention Network for Image Super-Resolution." *Journal of Visual Communication and Image Representation*, vol. 80, 2021, p. 103300., doi:10.1016/j.jvcir.2021.103300.
- [6] Bahrami K, Shi F, Rekiq I, Gao Y, Shen D. 7T-guided super-resolution of 3T MRI. *Med Phys.* 2017 May;44(5):1661-1677. doi: 10.1002/mp.12132. Epub 2017 Apr 22. PMID: 28177548; PMCID: PMC5686784.
- [7] "Image Segmentation with Monte Carlo Dropout UNET and Keras." 42: A Blog on A.I., nchlis.github.io/2019_10_30/page.html.
- [8] "Mean Squared Logarithmic Error Loss." *InsideAIML*, insideaiml.com/blog/MeanSquared-Logarithmic-Error-Loss-1035.
- [9] M. Sharma, S. Chaudhury and B. Lall, "Deep learning based frameworks for image super-resolution and noise-resilient super-resolution," 2017 International Joint Conference on Neural Networks (IJCNN), 2017, pp. 744-751, doi: 10.1109/IJCNN.2017.7965926.
- [10] Koonjoo, N., Zhu, B., Bagnall, G.C. et al. Boosting the signal-to-noise of low-field MRI with deep learning image reconstruction. *Sci Rep* 11, 8248 (2021).

Sentiment Analysis on COVID-19 Vaccine Tweets using Machine Learning and Deep Learning Algorithms

Tarun Jain¹, Vivek Kumar Verma², Akhilesh Kumar Sharma^{3*}, Bhavna Saini⁴, Nishant Purohit⁵, Bhavika⁶,
Hairulnizam Mahdin⁷, Masitah Ahmad^{8*}, Rozanawati Darman^{9*}, Su-Cheng Haw¹⁰, Shazlyn Milleana Shaharudin¹¹,
Mohammad Syafwan Arshad¹²

Manipal University Jaipur, Dehmi Kalan, Off Jaipur-Ajmer Expressway, Jaipur, Rajasthan, 303007 India^{1, 2, 5, 6}
School of Information Technology, Manipal University Jaipur, Jaipur, Rajasthan³

Central University Rajasthan, India⁴

Faculty of Computer Science and Information Technology, Universiti Tun Hussein Onn Malaysia^{7, 9}

Faculty of Computing and Informatics, Multimedia University, Jalan Multimedia, 63100, Cyberjaya, Malaysia⁸

Department of Mathematics, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris, Tanjung Malim, Perak,
Malaysia¹⁰

Department of Statistics, Columbia University, New York, N.Y., USA¹⁰

Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA Shah Alam, Selangor Malaysia¹¹

MZR Global Sdn Bhd, 5A, Jalan Kristal K7/K, Seksyen 7, 40000 Shah Alam, Selangor, Malaysia¹²

Abstract—One of the main functions of NLP (Natural Language Processing) is to analyze a sentiment or opinion of the text considered. In this research the objective is to analyze the sentiment in the form of tweets towards the Covid-19 vaccination. In this study, the collected tweets are in the form of a dataset from Kaggle that have been categorized into positive and negative depending on the polarity of the sentiment in that tweet, to visualize the overall situation. The reviews are translated into vector representations using various techniques, including Bag-Of-Words and TF-IDF to ensure the best result. Machine learning algorithms like Logistic Regression, Naïve Bayes, Support Vector Machine (SVM) and others, and Deep Learning algorithms like LSTM and Bert were used to train the predictive models. The performance metrics used to test the performance of the models show that Support Vector Machine (SVM) achieved the highest accuracy of 88.7989% among the machine learning models. Compared to the related research papers the highest accuracy obtained using LSTM is 90.59 % and our model has predicted with the highest accuracy of 90.42% using BERT techniques.

Keywords—Covid-19 vaccine; sentiment analysis; machine learning; deep learning; natural language processing

I. INTRODUCTION

In the wake of COVID-19, the healthcare sector has received considerable attention. Safety regulations such as wearing masks, keeping a good hygiene by washing hands regularly, and maintaining a safe distance from people are especially important now. Nevertheless, these measures can only decrease the spread of the virus, not eliminate it. In this case, vaccination proved to be the sole solution that had the greatest effectiveness in eradicating the coronavirus. But from the very beginning, the acceptance and public sentiment surrounding the COVID-19 vaccine have been subject to varying opinions and concerns. People have had mixed feelings

about vaccinations; we have even seen the reluctance of our own family members towards it. Since it is very new to the market, people are not ready to trust the invention and are hesitant about it. This hesitancy and skepticism have highlighted the need to delve deeper into understanding the sentiments of individuals towards the vaccine.

Nowadays, the Internet is the best source for any company to learn about public perceptions of their products and services. For its rich knowledge, the business community is tapping into social media content. It has been utilized to carry out marketing and branding initiatives for organizations in the areas of innovation, product design, and stakeholder relations. It is a useful means of communicating and sharing information with the public for government and non-profit organizations. Every day, people use social media platforms such as Facebook, Twitter, and Instagram to voice their opinions and thoughts. These platforms have emerged as powerful sources for expressing opinions and thoughts, making them ideal for capturing and analyzing public sentiments. People began voicing their concerns on the COVID-19 vaccination process as soon as it began. And since COVID 19 has affected so many lives but the vaccine showed up as a ray of hope amidst these extreme conditions, it has been extremely important to analyze the sentiments of people towards the COVID-19 vaccine [1].

Sentiment analysis is one major task of NLP (Natural Language Processing). It is also called Opinion mining. It is done to capture the author's feelings, emotion towards an entity. Sentiment analysis tries to capture this information by analyzing unstructured text data in the form of reviews and comments [2]. By harnessing the potential of sentiment analysis, the aim is to gain valuable insights into the perceptions and emotions of individuals regarding the COVID-19 vaccine. Sentiment analysis particularly is helpful when it comes to negative reviews. It helps discover the exact

shortcomings of the products. This requires the text to be classified into two sentiment polarities that are positive and negative (or neutral). In this research study, various textual and numerical features from tweets are extracted, evaluated on how they correlate, and used to predict sentiment of people related to the COVID-19 vaccine. The goal is to contribute to the existing knowledge on sentiment analysis and its applicability in the context of COVID-19 vaccines, ultimately aiding in the development of informed strategies and interventions for public health initiatives.

Further, the paper is divided into different sections to bring out all parts of the study properly. Section II shows the works of other people on sentiment analysis related to the COVID vaccine and how people have reciprocated to it. Section III gives information about the background of this study, highlighting a contrast between machine learning and deep learning techniques. Next is Section IV that highlights a major part of the study. It starts with the analysis of the data used in the study. Then it talks the complete process followed to carry out the study- the machine learning and deep learning algorithms used, the pre-processing techniques and feature extraction methods for both the type of algorithms, the performance metrics used to analyze the result of the model and lastly a comparison between the way machine learning and deep learning algorithms work [3][4][5][6]. Section V gives a deep analysis of the results obtained on the data with machine learning and deep learning techniques. It shows the results for all the five machine learning algorithms used with different feature extraction methods and then bar plots comparing their accuracy. Then, it shows the results for the two deep learning models used and their plots for accuracy and loss. Section VI highlights the conclusions and key takeaways from the study, along with the discussion of future plans and scope.

II. LITERATURE REVIEW

Sentiment analysis is being used in a large spectrum of fields right now. And a lot of people are increasingly interested in researching it. In the past year there have been much research on the sentiment of people towards the COVID-19 vaccine that came into existence. One such research employing tweets collected between December 21 and July 2, 2021, had information on the most prevalent vaccines that had just become available around the world. It used a tool called VADER to analyze people's sentiment towards certain vaccines. The tool found that 33.96% responses were positive, 17.55% were negative and the left 48.49% were neutral responses. It applied the basic data preprocessing steps and feature extraction algorithms on the tweets in the dataset. Then it finally used a recurrent neural network (RNN) that included LSTM and Bi-LSTM where LSTM secured an accuracy of 90.59% and Bi-LSTM obtained an accuracy of 90.83%. This study contributes to a better knowledge of public opinion on COVID-19 vaccinations and advances the goal of removing the virus worldwide [7]. Another such study used tweets in general and then only from four countries with the most tweets on the COVID-19 vaccine: India, USA, Canada, and England. It consumed two text mining methods that are LDA and VADER to extract the sentiment from those tweets. The overall analysis showed that there were almost twice people that had a positive feeling towards the COVID vaccine than those having a

negative feeling. However, the country-specific analysis showed that the people's sentiment remained consistent for the vaccines that were approved in their country, while most people had some fear towards other vaccines [8]. Another research performing sentiment analysis had tweets that were taken from the 14th to the 18th of January 2021. Covishield and Bharat Biotech's Covaxin were two vaccines employed in this work. The purpose of this study was to examine the sentiments expressed in tweets about these two vaccines in India. It used the Syuzhet package version 1.0.1 to classify tweets based on sentiments into positive and negative as well as eight other emotions (fear, joy, anticipation, anger, disgust, sadness, surprise, trust). It used the NRC Emotion Lexicon to analyze the tweets. The study showed that while most of the population has positive feelings about these vaccines, there are also negative feelings about them, according to the analysis, associated with the sentiments such as fear and anger [9]. Another study introduces a lexicon-based framework for sentiment classification of tweets, categorizing them as positive, negative, or neutral. The results indicate that the proposed system surpasses existing systems in terms of performance and accuracy [10].

This research makes use of a dataset containing tweets about the opinion of people about vaccines like Pfizer/BioNTech, Sinopharm, etc. in the Kaggle data repository. Tweepy, a Python package, was used to capture the data. It synthesizes the dialogue surrounding worldwide immunization attempts and progress using an API called TextBlob and using word cloud visualizations. TextBlob classified roughly half of the tweets in the dataset as neutral, and the other half comprised of 75% positive tweets and 25% tweets depicting a negative sentiment [11]. This study used web scrapping to extract the data from online news and blogs to work on. TextBlob library was used to analyze the sentiments of the public opinion collected. They gave a result that more than 90% of the articles had positive sentiments towards the vaccination drive [12]. From thirteen Reddit communities, data was collected regarding COVID-19 vaccines. LDA topic modelling was done on this data, and it was found that most of the communities had a positive sentiment towards the drive and found no major change in the opinions of people since December 2020 [13]. A RapidMiner software for data science was used for classifying English and Filipino tweets with the help of Naïve Bayes to conduct opinion mining. The results showed that the research had an accuracy of 81.77%. Their conclusion was that majority of people were enthusiastic and supportive of the vaccination drive [14]. This study takes about 1.2 million tweets to perform NLP and sentiment analysis on them to find out useful insights about the approach of people towards the COVID-19 vaccine and the measures to stay safe from the virus. This research used TextBlob and Vader as sentiment analysis tools and performed time series forecasting at a later stage. The result showed that many people have a positive view of the vaccination drive than negative. But more than that, people were highly conscious about maintaining hygiene and social distancing to combat the spread of the virus [15].

A study that was conducted in Indonesia was focused on analyzing the opinion of Indonesian people towards the newly

introduced vaccine. It collected the data from twitter using Rapid miner tool. The results of this study were slightly different. They showed about 39% of positive sentiment and 56% of negative sentiment and 1% of neutral sentiment. The people did not really trust that the vaccine was safe for them to consume [16]. Following this one, another study was conducted to evaluate the opinion of people of Indonesia about the two most prevalent vaccines, Sinovac and Pfizer in the country and understand people's view on both. The best performing model came out to be Support Vector machine and the study concluded that people were more positive for the Pfizer vaccine as compared to Sinovac. While about 77% of the tweets indicated a positive sentiment towards Sinovac, this number shot up to 81% in the case of Pfizer vaccine [17].

In contrast to a country-specific approach, some studies were conducted to analyze the sentiments of people towards the vaccine on a global level, for different countries. This study collected about 820,000 tweets and analyzed the sentiment of those tweets in two stages. In the first stage, the sentiments of people towards the vaccine around the globe was considered and the findings showed which countries had an overall positive attitude and which countries had a negative one. This stage also included gender-based analysis about the sentiments of people to address those issues in a different way. The second phase included the tweets to be organized into word clouds to analyze the most used words and sentiments by people of different countries [18]. This study made use of 928,402 tweets collected from different countries and the six most popular vaccines' tweets were picked from them to perform the analysis. They conducted an aspect-based analysis considering health, policy etc. and used four Bert models. The total accuracy was found out to be 87% and the F1 score lied between 84% to 88% [19]. This study used two different approaches to understand people's hesitancy towards the vaccine. These were machine learning based and lexicon based. It divided the dataset into two cultures English and Arabic and studied them separately. The study analyzed the performance of both the approaches on the datasets and then used the better performing approach for the spatiotemporal analysis [20]. This research collected the English language tweets posted over a course of 3 months and applied the Vader tool to classify the tweets as positive, negative, and neutral. The results revealed that out of the 2,678,372 tweets in consideration, 42.8% were positive, 26.9% were neutral and 30.3% were negative. The important topics from the positive and negative tweets were drawn out using latent Dirichlet allocation analysis, and these topics were then subjected to a geographical and temporal analysis. The study concluded that the highest positive sentiment tweets came from United Arab Emirates and the lowest positive sentiment tweets came from Brazil. Also, the sentiment score increased a good amount at the start, then slowly decreased and finally remained almost the same till the end of the period of the tweets [21].

The works discussed above indicate that previous studies have focused on sentiment analysis using various techniques and datasets. Furthermore, these studies highlight the use of various machine learning and deep learning models for sentiment classification but do not delve deep into comparative studies that evaluate the performance of different models,

feature extraction techniques, and sentiment analysis tools to identify the most effective approaches for sentiment analysis in the context of COVID-19 vaccination. This study employs a comprehensive range of techniques and models, including both machine learning algorithms (Logistic Regression, Naïve Bayes, Support Vector Machine) and deep learning algorithms (LSTM and BERT). It compares the performance of different feature extraction techniques, namely Bag of Words and TF-IDF, to showcase their impact on sentiment analysis accuracy. By utilizing these diverse approaches, it provides a better understanding of the most effective feature extraction methods and evaluation of the performance of different models, highlighting the strengths and weaknesses of each in the context of COVID-19 vaccination sentiment analysis.

III. BACKGROUND

Machine learning and Deep learning both fall under the umbrella of Artificial Intelligence, but they are more efficient in serving different purposes. Deep learning involves the use of something called a neural network which replicates how a human brain works to solve complex problems. But it requires a large amount of data to function with great accuracy, unlike machine learning which can work on lesser amounts of data. Machine learning learns from the data that is provided and makes intelligent predictions on the new data that is fed to it, with some human intervention. Both machine learning and deep learning models have been used on this dataset, but Deep learning has been preferred since the results it gave had better accuracy. Both machine learning and deep learning have a slight difference in how it classifies the data into sentiments.

For machine learning algorithms, firstly input data is fed into the system and pre-processing is performed on it to make it easier for the classification algorithm to classify it. Pre-processing includes converting the whole text into upper or lowercase, removal of extra words such as special characters or words that add no sentiment to the sentence. Then feature extraction is performed onto this data that extracts the important features from the tweet and converts it into vectors for the algorithm to be able to process it. This makes it easier for classification and improves the accuracy of the model in consideration. The next step is the model training which is when the model is trained onto the given data to classify the sentiment of the tweets and then it is tested using the test dataset to give the output or the sentiment of the tweets fed to the model. Here, the sentiment of the tweets can be positive or negative [22].

For deep learning algorithms, the process is slightly different. The input data goes through pre-processing to remove the extra words from the tweets and then it is fed to the deep learning algorithm which takes care of both the feature extraction and model training phase for classifying the sentiment of the data provided. Further the model is tested to check its performance on a test dataset, like how the machine learning algorithms do it [23].

Deep learning solves the problem end-to end whereas machine learning first fragments the problem into smaller statements and then solves it incrementally. In machine learning the data is undergone through feature extraction first and then classification is performed but in deep learning,

feature extraction and classification are performed simultaneously [24]. Deep learning works adequately on large amounts of data by giving higher accuracies. High end systems are required to run deep learning algorithms as it mainly focuses on GPU of the system. Whereas a domain expert is required in Machine learning to spot and reduce the complexity of the data for the traditional algorithms to work. When the amount of data which is fed to the model is less, machine learning performs better than the deep learning models. But as the amount of data increases, the rate with which the performance of a machine learning model was increasing rapidly falls and remains almost the same with further increase in the amount of data. However, for a deep learning model the performance steadily increases with the increase in the amount of data fed to the model. For larger amounts of data, deep learning models perform a lot better than machine learning models. There are two deep learning models used in this study: BERT and LSTM. Both are discussed in detail in the following section.

A. BERT

Bidirectional Encoder Representations from Transformers also known as BERT is a deep learning model which was published by researchers at Google in 2018. It works on the encoder-decoder network where self-attention is used on the encoder side and attention is used on the decoder side. Large text corpus is used to train the Bert model, this gives the model the ability to understand better and grasp variability in data patterns on several NLP tasks. Being bidirectional it gives the model the freedom to learn and understand the context of a word from both the left and the right sides while training the model. This nature of the model helps it to understand the language deeply. Also, for the model to work well, some amount of pre-processing is done on the data. This makes the BERT model suitable for a variety of NLP tasks.

B. LSTM

LSTM also known as Long Short-Term Memory network are a part of a unique kind of RNN that has the potential to learn long-term dependencies. LSTM can remember information for long periods of time without any struggle and reduces the impact of short-term memory. Recurrent neural networks have chain type structure where each module is intertwined several times. LSTMs have a similar structure but instead of caring a single neural network there are four that are connected to each other in a unique way. LSTM networks retain the relevant information from the prior data in the sequence that helps in processing the incoming data points. There are three things that are important to determine the output of LSTM: the cell state, the previous hidden layer, and the input data at the current timestamp. The cell state is like the memory of the network. An LSTM cell has three gates: One is the forget gate, which allows it to forget the irrelevant information from the prior timestamp. The equation for the forget gate is:

$$f_t = \sigma(x_t * U_f + H_{t-1} * W_f) \quad (1)$$

Here, x_t is the input to the current timestamp, U_f is the weight, H_{t-1} is the hidden state of previous timestamp and W_f is the weight matrix of the hidden state.

Next is the input gate, which decides which information must be kept from the current timestamp. The equation for the input gate is:

$$i_t = \sigma(x_t * U_i + H_{t-1} * W_i) \quad (2)$$

Here, x_t is the input to the current timestamp, U_i is the weight matrix of input, H_{t-1} is the hidden state of previous timestamp and W_i is the weight matrix of input corresponding with hidden state.

The last one is the output gate, which determines what the hidden state will be for the next timestamp. The equation for the input gate is:

$$o_t = \sigma(x_t * U_o + H_{t-1} * W_o) \quad (3)$$

Here, x_t is the input to the current timestamp, U_o is the weight matrix of output, H_{t-1} is the hidden state of previous timestamp and W_o is the weight matrix of output corresponding with hidden state [25][26].

IV. METHODOLOGY

A. Data Collection and Analysis

In the initial stages of the research, a dataset comprising 10,000 tweets regarding people's opinions on the COVID-19 vaccine was sourced from Kaggle. However, it was observed that a significant portion of the dataset consisted of neutral tweets. Recognizing the potential impact of these neutral tweets on the data consistency and the subsequent model performance, a decision was made to remove them from the dataset. This cleaning process resulted in a refined dataset of approximately 3,700 tweets. Out of the total tweets, approximately 2,000 exhibited a positive sentiment towards the COVID-19 vaccine, while around 1,700 displayed a negative sentiment. This balanced distribution of positive and negative sentiments provides a suitable foundation for training and evaluating machine learning models.

B. Data Cleaning and Preprocessing

To start with, data pre-processing steps were applied to the given dataset to ensure the data's quality and consistency. These pre-processing steps are crucial in preparing the dataset for accurate model training and reliable outcomes. The dataset was thoroughly cleaned by removing any extraneous data or unnecessary elements that could introduce irregularities. This involved eliminating punctuation, symbols like "#," and Twitter handles such as "@user." Further, this involved removing URLs from the tweet texts, converting the text to lowercase to eliminate case sensitivity, and applying tokenization to break down the text into individual words or tokens. Stopwords, which are commonly used words in a language like "the", "and", "is", were removed from the text. These words are often irrelevant for sentiment analysis and can introduce noise into the data. After that an important step was lemmatization. This was applied to reduce words to their base or root form. This helps in standardizing the text data by converting variations of a word. These pre-processing steps were implemented to ensure the dataset's consistency and to avoid poor model training and inaccurate outcome due to inconsistencies in the dataset [27]. After applying data pre-processing techniques to enhance the quality of the dataset, the

next step involved splitting the dataset into two distinct parts: a training dataset and a testing dataset. The dataset was split in a ratio of 80:20, with 80% of the tweets allocated to the training dataset and the remaining 20% reserved for the testing dataset. This ensures that a substantial portion of the data is utilized for training the model while still leaving a sizable portion for evaluation.

C. Feature Extraction and Model Training

When it comes to the machine learning models, the tweets in the training set undergo a process of vector representation using techniques like Bag of Words and TF-IDF. These techniques filter out irrelevant words and convert the tweets into numerical representations. By utilizing these vectorized representations, the classification algorithms are trained and tested on the given dataset. The results obtained from the testing dataset provide insights into the performance of these models in analyzing the sentiments [28]. The next step involves the classification of the data. In this process, several machine learning algorithms are utilized to train classifiers that can accurately predict the sentiment of the tweets. The following algorithms are applied to the training dataset: Support Vector Machine (SVM), Naïve Bayes, Logistic Regression, Decision Tree Classifier, and Random Forest Classifier. Each algorithm learns from the training data, capturing patterns and relationships between the tweet features and their corresponding sentiments. Once the classifiers are trained, they are evaluated using the testing dataset. By comparing the predicted sentiments with the actual sentiments of the tweets in the testing dataset, various performance metrics such as accuracy, precision, recall, and F1-score are calculated. Finally, the ROC AUC score for each model is compared. It is used to assess the degree of separability between the different classes. A higher ROC AUC score indicates that the model performs well in terms of classification [29]. Thus, these metrics provide insights into how well each classifier can perform in classifying the sentiments of the COVID-19 vaccine-related tweets.

On the other hand, the process for deep learning models differs slightly. In this case, the pre-processed data is directly fed into the deep learning algorithm. The deep learning algorithm itself takes care of both the feature extraction and model training phases. This feature extraction process is performed by the hidden layers of the neural network. It automatically learns and extracts relevant features from the data during the training process, eliminating the need for explicit feature extraction. Deep learning models consist of multiple layers of interconnected artificial neurons. Each neuron receives input signals, applies a mathematical operation, and produces an output signal. The outputs from one layer serve as inputs to the next layer, forming a hierarchical representation of the data. Once the model is trained, it can be tested on a separate test dataset, like how the machine learning algorithms are evaluated. The performance of the deep learning model on the test dataset helps analyze its effectiveness in sentiment classification.

V. RESULTS

The results for the machine learning and deep learning models have been separately illustrated. Deep learning models

perform better than the machine learning models with a maximum accuracy of 90.42%.

A. Machine Learning Models

The results of the proposed models: Support Vector Machine (SVM), Logistic Regression (LR), Naive Bayes (NB), Decision Tree and Random Forest are shown in this section. Different assessment criteria, including Accuracy, Precision, Recall, F-score, Confusion matrix, and ROC curve, were utilized to evaluate the models reviewed here. First, the results for each model using Bag of Words feature extraction algorithm are shown and then using TF-IDF feature extraction techniques are shown. Then, using a unique feature extraction technique that works well, the comparison between the results for each classification model is displayed.

B. Support Vector Machine

Support vector machine model is used for classification, and this algorithm works on the concept of finding a hyperplane that provides the best separability between different classes.

Support Vector Machine model with Bag of Words analyzed and registered 274 positive tweets correctly, 74 positive tweets incorrectly, 362 negative tweets correctly and 31 negative tweets incorrectly as per the confusion matrix. Based on this, Table I shows the major classification metrics precision, recall and f1-score for both the classes individually. Here, 1 is for the positive tweets and 0 is for the negative ones. For the positives, the precision score is 0.83, the f1-score is 0.87 and the recall is 0.92. For the negatives, the precision score is 0.90, the f1-score is 0.84 and the recall is 0.79. The total accuracy of the model comes out to be 0.86.

TABLE I. RESULT OF SUPPORT VECTOR MACHINE USING BAG OF WORDS

	precision	recall	f1-score	support
0	0.90	0.79	0.84	348
1	0.83	0.92	0.87	393
accuracy			0.86	741

Support Vector Machine with TFIDF analyzed and registered 307 positive tweets correctly, 41 positive tweets incorrectly, 351 negative tweets correctly and 42 negative tweets incorrectly as per the confusion matrix. Based on this, Table II shows the major classification metrics precision, recall and f1-score for both the classes individually. Here, 1 is for the positive tweets and 0 is for the negative ones. For the positives, the precision score is 0.90, the f1-score is 0.89 and the recall is 0.89. For the negatives, the precision score is 0.88, the f1-score is 0.88 and the recall is 0.88. The total accuracy of the model comes out to be 0.89.

TABLE II. RESULT OF SUPPORT VECTOR MACHINE USING TF-IDF

	precision	recall	f1-score	support
0	0.88	0.88	0.88	348
1	0.90	0.89	0.89	393
accuracy			0.89	741

C. Naïve Bayes

Naïve Bayes classifier is based on probability. It assumes that each variable input to the classifier is independent but gives good accuracy when applied. It uses conditional probability for obtaining the result. Conditional probability is basically calculating the probability of completing a certain task given a certain condition must always be satisfied.

Naïve Bayes Model with Bag of Words analyzed and registered 281 positive tweets correctly, 67 positive tweets incorrectly, 355 negative tweets correctly and 38 negative tweets incorrectly in the confusion matrix. Based on this, Table III shows the major classification metrics precision, recall and f1-score for both the classes individually. Here, 1 is for the positive tweets and 0 is for the negative ones. For the positives, the precision score is 0.84, the f1-score is 0.87 and the recall is 0.90. For the negatives, the precision score is 0.88, the f1-score is 0.84 and the recall is 0.81. The total accuracy of the model comes out to be 0.86.

TABLE III. RESULT OF NAIVE BAYES USING BAG OF WORDS

	precision	recall	f1-score	support
0	0.88	0.81	0.84	348
1	0.84	0.90	0.87	393
accuracy			0.86	741

Naïve bayes with TFIDF analyzed and registered 271 positive tweets correctly, 77 positive tweets incorrectly, 371 negative tweets correctly and 22 negative tweets incorrectly in the confusion matrix. Based on this, Table IV shows the major classification metrics precision, recall and f1-score for both the classes individually. Here, 1 is for the positive tweets and 0 is for the negative ones. For the positives, the precision score is 0.83, the f1-score is 0.85 and the recall is 0.78. For the negatives, the precision score is 0.83, the f1-score is 0.88 and the recall is 0.94. The total accuracy of the model comes out to be 0.87.

TABLE IV. RESULT OF NAIVE BAYES USING TF-IDF

	precision	recall	f1-score	support
0	0.92	0.78	0.85	348
1	0.83	0.94	0.88	393
accuracy			0.87	741

D. Logistic Regression

Decision tree classifier is used for classification and regression. It forms a tree-like structure and learns simple decision rules to predict the target class value.

Logistic Regression with Bag of Words analyzed and registered 287 positive tweets correctly, 61 positive tweets incorrectly, 358 negative tweets correctly and 35 negative tweets incorrectly in the confusion matrix. Based on this, Table V shows the major classification metrics precision, recall and f1-score for both the classes individually. Here, 1 is for the positive tweets and 0 is for the negative ones. For the positives, the precision score is 0.85, the f1-score is 0.88 and the recall is 0.91. For the negatives, the precision score is 0.89, the f1-score

is 0.86 and the recall is 0.82. The total accuracy of the model comes out to be 0.87.

TABLE V. RESULT OF LOGISTIC REGRESSION USING BAG OF WORDS

	precision	recall	f1-score	support
0	0.89	0.82	0.86	348
1	0.85	0.91	0.88	393
accuracy			0.87	741

Logistic Regression with TFIDF analyzed and registered 295 positive tweets correctly, 53 positive tweets incorrectly, 350 negative tweets correctly and 43 negative tweets incorrectly in the confusion matrix. Based on this, Table VI shows the major classification metrics precision, recall and f1-score for both the classes individually. Here, 1 is for the positive tweets and 0 is for the negative ones. For the positives, the precision score is 0.87, the f1-score is 0.88 and the recall is 0.89. For the negatives, the precision score is 0.87, the f1-score is 0.86 and the recall is 0.85. The total accuracy of the model comes out to be 0.87.

TABLE VI. RESULT OF LOGISTIC REGRESSION USING TF-IDF

	precision	recall	f1-score	support
0	0.87	0.85	0.86	348
1	0.87	0.89	0.88	393
accuracy			0.87	741

E. Decision Tree Classifier

Decision tree classifier is used for classification and regression. It forms a tree-like structure and learns simple decision rules to predict the target class value.

Decision Tree Classifier analyzed and registered 257 positive tweets correctly, 91 positive tweets incorrectly, 347 negative tweets correctly and 46 negative tweets incorrectly in the confusion matrix. Based on this, Table VII shows the major classification metrics precision, recall and f1-score for both the classes individually. Here, 1 is for the positive tweets and 0 is for the negative ones. For the positives, the precision score is 0.79, the f1-score is 0.84 and the recall is 0.88. For the negatives, the precision score is 0.85, the f1-score is 0.79 and the recall is 0.74. The total accuracy of the model comes out to be 0.82.

On plotting its confusion matrix, Decision Tree classifier with TFIDF analyzed and registered 259 positive tweets correctly, 69 positive tweets incorrectly, 322 negative tweets correctly and 72 negative tweets incorrectly in the confusion matrix. Based on this, Table VIII shows the major classification metrics precision, recall and f1-score for both the classes individually. Here, 1 is for the positive tweets and 0 is for the negative ones. For the positives, the precision score is 0.78, the f1-score is 0.80 and the recall is 0.82. For the negatives, the precision score is 0.78, the f1-score is 0.76 and the recall is 0.74. The total accuracy of the model comes out to be 0.78.

TABLE VII. RESULT OF DECISION TREE USING BAG OF WORDS

	precision	recall	f1-score	support
0	0.85	0.74	0.79	348
1	0.79	0.88	0.84	393
accuracy			0.82	741

TABLE VIII. RESULT OF DECISION TREE USING TF-IDF

	precision	recall	f1-score	support
0	0.78	0.74	0.76	348
1	0.78	0.82	0.80	393
accuracy			0.78	741

F. Random Forest Classifier

Random Forest classifier uses many decision trees and finds the average of the results from these trees to obtain improved accuracy for prediction.

Table IX shows the major classification metrics precision, recall and f1-score for both the classes individually. Here, 1 is for the positive tweets and 0 is for the negative ones. For the positives, the precision score is 0.81, the f1-score is 0.86 and the recall is 0.92. For the negatives, the precision score is 0.89, the f1-score is 0.81 and the recall is 0.75. The total accuracy of the model comes out to be 0.84. On plotting its confusion matrix, the random forest model analyzed and registered 258 positive tweets correctly, 90 positive tweets incorrectly, 363 negative tweets correctly and 30 negative tweets incorrectly as shown in Table IX.

TABLE IX. RESULT OF RANDOM FOREST USING BAG OF WORDS

	precision	recall	f1-score	support
0	0.89	0.75	0.81	348
1	0.81	0.92	0.86	393
accuracy			0.84	741

Table X shows the major classification metrics precision, recall and f1-score for both the classes individually. Here, 1 is for the positive tweets and 0 is for the negative ones. For the positives, the precision score is 0.80, the f1-score is 0.87 and the recall is 0.94. For the negatives, the precision score is 0.92, the f1-score is 0.82 and the recall is 0.74. The total accuracy of the model comes out to be 0.85. On plotting its confusion matrix, the random forest classifier with TFIDF analyzed and registered 255 positive tweets correctly, 93 positive tweets incorrectly, 364 negative tweets correctly and 29 negative tweets incorrectly as shown in Table X.

TABLE X. RESULT OF RANDOM FOREST USING TF-IDF

	precision	recall	f1-score	support
0	0.92	0.74	0.82	348
1	0.80	0.94	0.87	393
accuracy			0.85	741

G. Comparing Results

The presented data in Table XI provides a comprehensive overview of the performance metrics evaluated across various

models, specifically focusing on accuracy, precision, recall, and F1-score. These metrics were meticulously analyzed using the Bag of Words technique as the chosen method for feature extraction. By examining these performance indicators, valuable insights are gained into the effectiveness and efficiency of each model in the context of the analyzed dataset.

TABLE XI. COMPARING RESULTS OF ALL THE MODELS USING BAG OF WORDS

Model	Accuracy	Precision	Recall	F1-score
SVM	0.8583	0.8733	0.8303	0.9211
Naive Bayes	0.8583	0.8712	0.8412	0.9033
Logistic Regression	0.8704	0.8818	0.8544	0.8906
Decision Tree	0.7841	0.8010	0.7834	0.8193
Random Forest	0.8556	0.8715	0.8250	0.9236

The following graph in Fig. 1 shows a comparison of accuracy score of different models with Bag of Words as the feature extraction method.

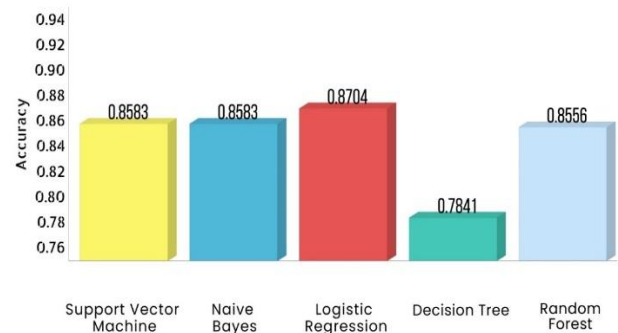


Fig. 1. Accuracy bar plot for machine learning models with bag of words as feature extraction method.

The following graph in Fig. 2 shows a comparison of ROC AUC score of different models with Bag of Words as the feature extraction method.

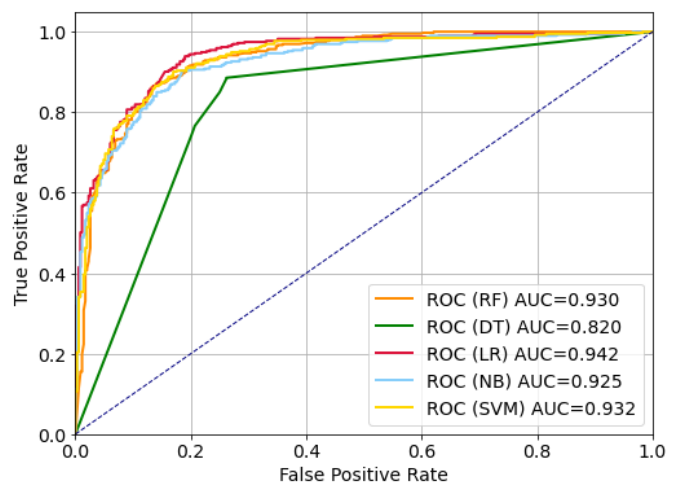


Fig. 2. ROC curve machine learning models with bag of words as feature extraction method.

Here, ‘RF’ is Random Forest, ‘DT’ is Decision Tree, ‘LR’ is Logistic Regression, ‘NB’ is Naïve Bayes and ‘SVM’ is Support Vector Machine.

From the ROC curve and the accuracy bar plot, it can be observed from these plots that most of the classifiers perform decently, and Logistic Regression classifier with Bag of Words feature extraction method performs the best with AUC score of 0.942 and an accuracy of 87.0445%. Close to it is the Support Vector Machine and Naive Bayes classifier with an accuracy of 85.8300%.

The presented data in Table XII provides a comprehensive overview of the performance metrics evaluated across various models that are accuracy, precision, recall, and F1-score. These metrics have been diligently analyzed for all the models, with a specific focus on the utilization of the TF-IDF technique as the chosen approach for feature extraction.

TABLE XII. COMPARING RESULTS OF ALL THE MODELS USING TF-IDF

Model	Accuracy	Precision	Recall	f1-score
SVM	0.8879	0.8943	0.8954	0.8931
Naive Bayes	0.8664	0.8823	0.8281	0.9440
Logistic Regression	0.8704	0.8794	0.8685	0.8906
Decision Tree	0.7841	0.8010	0.7834	0.8193
Random Forest	0.8367	0.8585	0.7944	0.9338

The following graph in Fig. 3 shows a comparison of accuracy scores of different models with TF-IDF as the feature extraction method.

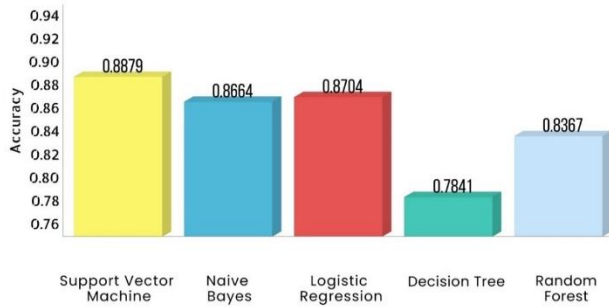


Fig. 3. Accuracy bar plot for machine learning models with TF-IDF as feature extraction method.

The following graph in Fig. 4 shows a comparison of ROC AUC scores of different models with TF-IDF as the feature extraction method. Here, ‘RF’ is Random Forest, ‘DT’ is Decision Tree, ‘LR’ is Logistic Regression, ‘NB’ is Naïve Bayes and ‘SVM’ is Support Vector Machine.

From the ROC curve and the accuracy bar plot, it can be observed from these plots that all the classifiers perform decently, and Support Vector Machine classifier with TF-IDF feature extraction method performs the best with an AUC score of 0.95 and an accuracy of 88.7989%. Close to it is the Logistic Regression and Naive Bayes classifier with an accuracy of 87.0445% and 86.6397% respectively.

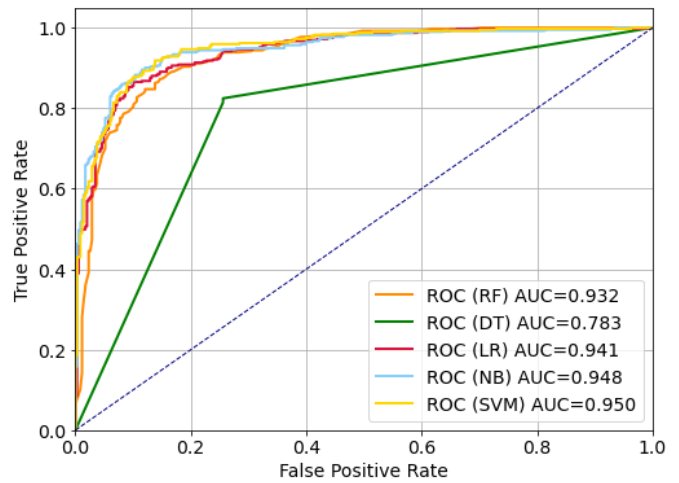


Fig. 4. ROC curve machine learning models with TF-IDF as feature extraction method.

H. Deep Learning Models

1) *BERT*: The deep learning model BERT worked efficiently with the dataset and gave a validation accuracy of 90.42%. The mode ran for three epochs where it gave an accuracy of 89.88% in first epoch, 89.20% in the second epoch and finally 90.42% in the third epoch which was the highest.

The above graph in Fig. 5 shows the relationship between loss and the learning rate. The model experienced the minimum loss when the learning rate was around 10^{-4} .

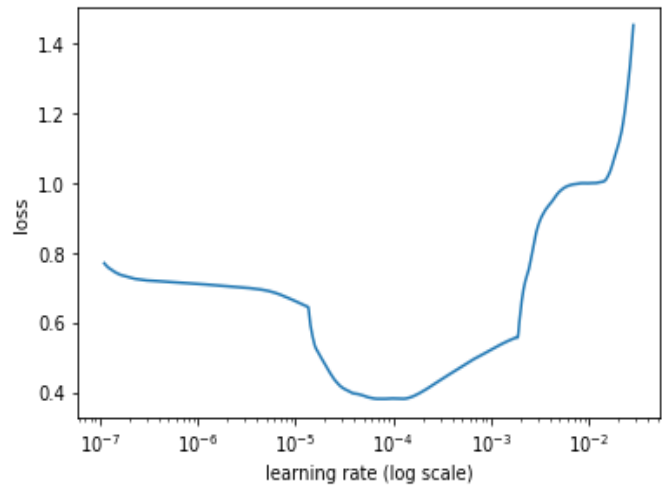


Fig. 5. A plot between learning rate and loss.

2) *LSTM*: The deep learning model LSTM worked decently with the dataset and gave a validation accuracy of 88.26. The mode ran for 5 epochs where it gave an accuracy of 70.04 in first epoch, 86.50 in the second epoch, 87.58 in the third epoch, 87.72 in the fourth and finally 88.26 in the fifth epoch which was the highest. The following graph in Fig. 6 showcases the plot between the accuracy and the number of epochs with the training and the validation set.

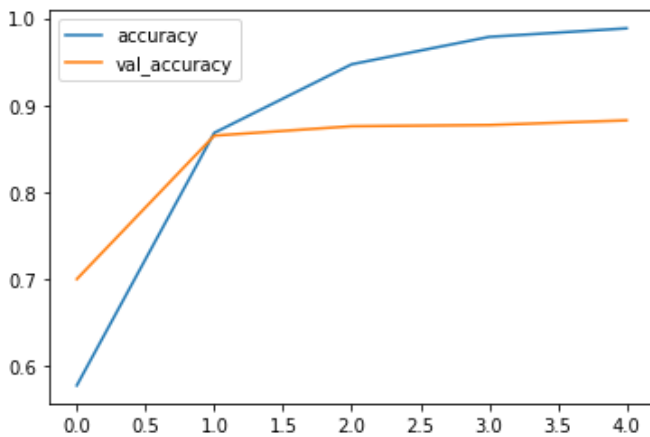


Fig. 6. Accuracy of LSTM model for both training and test set. Here accuracy refers to the training set accuracy and val_accuracy refers to the testing set accuracy.

Here the validation accuracy goes nearly constant after intersecting with accuracy at 0.88 whereas the accuracy plot keeps on increasing and takes over after the intersection.

The following graph in Fig. 7 showcases the plot between the loss and the number of epochs with the training and the validation set.

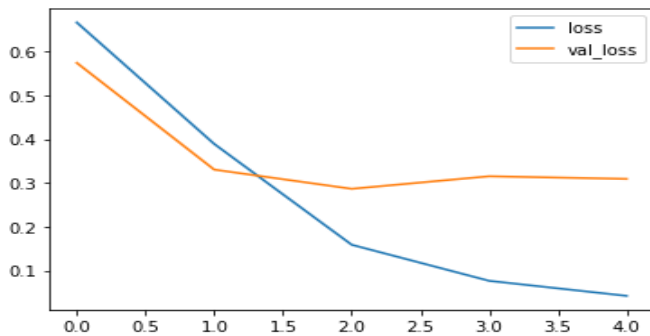


Fig. 7. Loss of LSTM model for both training and test set. Here loss refers to the training set loss and val_loss refers to the testing set loss.

VI. CONCLUSIONS

The aim of this study is to analyze the sentiments of people about the COVID-19 vaccine that has been introduced recently through the social media platform 'Twitter'. To be able to evaluate the opinion of the public, a dataset with the most recent tweets was taken and applied two word embedding techniques to them. Five machine learning algorithms and two deep learning algorithms have been utilized for classification of tweets into positive and negative. Experimental results suggest that out of the machine learning models used, Support vector machine when used with TF-IDF as word embedding technique gives the highest accuracy. However, deep learning models give a higher accuracy. LSTM model when used with some preprocessing gave the accuracy 88.26% after four epochs. They helped in analyzing that most people have a positive outlook for the COVID-19 vaccine, while some part of the population is still hesitant about it. The possible reasons for the same can be that people fear that the vaccine might have side effects, or they might not be open to accept a new vaccine

introduced to the market, or they are not aware enough about the consequences of not taking the COVID vaccine. Compared to the related research papers the highest accuracy obtained using LSTM is 90.59 % and our model has predicted with the highest accuracy of 90.42% using BERT techniques. This study can be of utmost importance to organizations analyzing the sentiment of a large population towards the COVID-19 vaccine in turn acting as a tool to find out ways to cope with the problem. It can help them find what section of society is hesitant and why, so that they can probably change something or improve the quality of services they provide.

However, it should be noted that this study uses only two feature extraction methods, Bag of Words and TF-IDF. Future work might consider utilizing alternative feature extraction methods such as Word2Vec and GloVe to further improve the effectiveness of the models. Another important aspect to consider can be the geographic and cultural context. While this study analyzed sentiments on a global level, further research could focus on sentiment analysis within specific regions or countries. This would allow for a better understanding of the variations in public opinion and can help identify country-specific challenges, such as vaccine hesitancy, misinformation, or unique socio-political factors that influence sentiment.

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REFERENCES

- [1] Khakharia, A.; Shah, V.; Gupta, P. Sentiment Analysis of COVID-19 Vaccine Tweets Using Machine Learning. Rochester, NY June 18, 2021. [Google Scholar]
- [2] Liu, B. Sentiment Analysis and Opinion Mining. Synthesis Lectures on Human Language Technologies 2012, 5, 1–167. [Google S]
- [3] Bhavya Joshi, Akhilesh Kumar Sharma, Narendra Singh Yadav & Shamik Tiwari (2022) DNN based approach to classify Covid'19 using convolutional neural network and transfer learning, International Journal of Computers and Applications, 44:10, 907-919, DOI: 10.1080/1206212X.2021.1983289
- [4] Ramani, P., Pradhan, N., Sharma, A.K. (2020). Classification Algorithms to Predict Heart Diseases—A Survey. In: Gupta, M., Konar, D., Bhattacharyya, S., Biswas, S. (eds) Computer Vision and Machine Intelligence in Medical Image Analysis. Advances in Intelligent Systems and Computing, vol 992. Springer, Singapore.
- [5] A. K. Sharma, K. I. Lakhtaria, A. Panwar and S. Vishwakarma, "An Analytical approach based on self organized maps (SOM) in Indian classical music raga clustering," 2014 Seventh International Conference on Contemporary Computing (IC3), Noida, India, 2014, pp. 449-453, doi: 10.1109/IC3.2014.6897215.
- [6] Shrivastava, D.K., Sharma, A.K., Bhardwaj, S. (2021). Prediction of COVID'19 Outbreak by Using ML-Based Time-Series Forecasting Approach. In: Singh, P.K., Polkowski, Z., Tanwar, S., Pandey, S.K., Matei, G., Pirvu, D. (eds) Innovations in Information and Communication Technologies (IICT-2020). Advances in Science, Technology & Innovation. Springer, Cham
- [7] Alam, K.N.; Khan, M.S.; Dhruva, A.R.; Khan, M.M.; Al-Amri, J.F.; Masud, M.; Rawashdeh, M. Deep Learning-Based Sentiment Analysis of COVID-19 Vaccination Responses from Twitter Data. Computational and Mathematical Methods in Medicine 2021, 2021, 1-4. [Publisher Site] [Google Scholar]
- [8] Yin, H.; Song, X.; Yang, S.; Li, J. Sentiment Analysis and Topic Modeling for COVID-19 Vaccine Discussions. World Wide Web 2022, 25, 1067–1083. [Google Scholar]

- [9] Dubey, A. D. Public Sentiment Analysis of COVID-19 Vaccination Drive in India. Rochester, NY January 24, 2021. [Google Scholar] [CrossRef]
- [10] Asghar, Dr. M.; Kundi, F.; Khan, A.; Ahmad, S. Lexicon-Based Sentiment Analysis in the Social Web. *Journal of basic and applied scientific research* 2014, 4, 238–248. [Google Scholar]
- [11] Dua, S. Sentiment Analysis of COVID-19 Vaccine Tweets. Medium. <https://towardsdatascience.com/sentiment-analysis-of-covid-19-vaccine-tweets-dc6f41a5e1af> (accessed 2023-01-17).
- [12] Bhagat, K. K.; Mishra, S.; Dixit, A.; Chang, C.-Y. Public Opinions about Online Learning during COVID-19: A Sentiment Analysis Approach. *Sustainability* 2021, 13, 3346. [Google Scholar] [CrossRef]
- [13] Melton, C. A.; Olusanya, O. A.; Ammar, N.; Shaban-Nejad, A. Public Sentiment Analysis and Topic Modeling Regarding COVID-19 Vaccines on the Reddit Social Media Platform: A Call to Action for Strengthening Vaccine Confidence. *Journal of Infection and Public Health* 2021, 14, 1505–1512. [Google Scholar] [CrossRef]
- [14] Villavicencio, C.; Macrohon, J. J.; Inbaraj, X. A.; Jeng, J.-H.; Hsieh, J.-G. Twitter Sentiment Analysis towards COVID-19 Vaccines in the Philippines Using Naïve Bayes. *Information* 2021, 12, 204. [Google Scholar] [CrossRef]
- [15] Sattar, N. S.; Arifuzzaman, S. COVID-19 Vaccination Awareness and Aftermath: Public Sentiment Analysis on Twitter Data and Vaccinated Population Prediction in the USA. *Applied Sciences* 2021, 11, 6128. [Google Scholar] [CrossRef]
- [16] Pristiyono; Ritonga, M.; Ihsan, M. A. A.; Anjar, A.; Rambe, F. H. Sentiment Analysis of COVID-19 Vaccine in Indonesia Using Naïve Bayes Algorithm. *IOP Conf. Ser.: Mater. Sci. Eng.* 2021, 1088, 012045. [Google Scholar] [CrossRef]
- [17] Nurdeni, D. A.; Budi, I.; Santoso, A. B. Sentiment Analysis on Covid19 Vaccines in Indonesia: From The Perspective of Sinovac and Pfizer. In 2021 3rd East Indonesia Conference on Computer and Information Technology (EIConCIT); 2021; pp 122–127. [Google Scholar] [CrossRef]
- [18] Ansari, M. T.; Khan, N. Worldwide COVID-19 Vaccines Sentiment Analysis Through Twitter Content. *Electronic Journal of General Medicine* 2021, 18, em329. [Google Scholar] [CrossRef]
- [19] Aygün, İ.; Kaya, B.; Kaya, M. Aspect Based Twitter Sentiment Analysis on Vaccination and Vaccine Types in COVID-19 Pandemic With Deep Learning. *IEEE Journal of Biomedical and Health Informatics* 2022, 26, 2360–2369. [Google Scholar] [CrossRef]
- [20] Alsabban, M. Comparing Two Sentiment Analysis Approaches by Understand the Hesitancy to COVID-19 Vaccine Based on Twitter Data in Two Cultures. In 13th ACM Web Science Conference 2021; WebSci '21; Association for Computing Machinery: New York, NY, USA, 2021; pp 143–144. [Google Scholar] [CrossRef]
- [21] Liu, S.; Liu, J. Public Attitudes toward COVID-19 Vaccines on English-Language Twitter: A Sentiment Analysis. *Vaccine* 2021, 39 (39), 5499–5505. [Google Scholar] [CrossRef]
- [22] Ikonomakis, M.; Kotsiantis, S.; Tampakas, V. Text Classification Using Machine Learning Techniques. *WSEAS TRANSACTIONS on COMPUTERS* 2005, 4, 966-974. [Google Scholar]
- [23] Tang, D.; Wei, F.; Qin, B.; Liu, T.; Zhou, M. Coooolll: A Deep Learning System for Twitter Sentiment Classification. In Proceedings of the 8th International Workshop on Semantic Evaluation (SemEval 2014); Association for Computational Linguistics: Dublin, Ireland, 2014; pp 208–212. [Google Scholar]
- [24] Zulfiker, Md. S.; Kabir, N.; Biswas, A. A.; Zulfiker, S.; Uddin, M. S. Analyzing the Public Sentiment on COVID-19 Vaccination in Social Media: Bangladesh Context. *Array* 2022, 15, 100204. [Google Scholar]
- [25] Nyawa, S.; Tchuente, D.; Fosso-Wamba, S. COVID-19 Vaccine Hesitancy: A Social Media Analysis Using Deep Learning. *Ann Oper Res* 2022. [Google Scholar]
- [26] Nuser, M.; Alsukhni, E.; Saifan, A.; Khasawneh, R.; Ukkaz, D. Sentiment analysis of covid-19 vaccine with deep learning. *Journal of Theoretical and Applied Information Technology* 2022, 100, 1-3. [Google Scholar]
- [27] Didi, Y.; Walha, A.; Ben Halima, M.; Wali, A. COVID-19 Outbreak Forecasting Based on Vaccine Rates and Tweets Classification. *Computational Intelligence and Neuroscience* 2022, 2022, e4535541. [Google Scholar]
- [28] Soni, K. M.; Gupta, A.; Jain, T. Supervised Machine Learning Approaches for Breast Cancer Classification and a High Performance Recurrent Neural Network. In 2021 Third International Conference on Inventive Research in Computing Applications (ICIRCA); 2021; pp 1–7. [Google Scholar]
- [29] Yacouby, R.; Axman, D. Probabilistic Extension of Precision, Recall, and F1 Score for More Thorough Evaluation of Classification Models. In Proceedings of the First Workshop on Evaluation and Comparison of NLP Systems; Association for Computational Linguistics: Online, 2020; 79–91. [Google Scholar]

An Enhanced SVM Model for Implicit Aspect Identification in Sentiment Analysis

Halima Benarafa¹, Mohammed Benkhalifa², Moulay Akhloufi³

Algorithms, Networks, Intelligent Systems and Software Engineering (ANISSE),

Department of Computer Science, Faculty of Sciences, Mohammed V University in Rabat, Morocco^{1,2}

Perception, Robotics, and Intelligent Machines, Research Group (PRIME),

Department of Computer Science, Moncton University, Moncton, NB, Canada³

Abstract—Opinion Mining or Sentiment Analysis (SA) is a key component of E-commerce applications where a vast number of reviews are generated by customers. SA operates on aspect level where the views are expressed on a specific aspect of a product and have a big influence on the customers' choices and businesses' reputation. Aspect Based Sentiment Analysis (ABSA) is the task of categorizing text by aspect and identifying the sentiment attributed to it. Implicit Aspect Identification (IAI) is a subtask of ABSA. This paper aims to empirically investigate how external knowledge (e.g. WordNet) is integrated into SVM model to address some of its intrinsic issues when dealing with classification. To achieve this research goal, we propose an approach to improve Support Vector Machines (SVM) model to deal with IAI. Using WordNet (WN) semantic relations, we suggest an enhancement for the SVM kernel computation. Experiments are conducted on three benchmark datasets of products, laptops, and restaurant reviews. The effects of our approach are examined and analyzed according to three criteria: (i) kernel function used, (ii) different experimental settings, and (iii) SVM behavior towards Overfitting and Underfitting. The research finding of our work is that the integration of external knowledge (e.g. WordNet) is experimentally proved to be significantly helpful to SVM classification for IAI and especially for addressing Overfitting and Underfitting that are considered as two of the main structural SVM issues. The empirical results demonstrate that our approach helps SVM (i) improve its performance for the three considered kernels and under different experimental settings, and (ii) deal better with Overfitting and Underfitting.

Keywords—Implicit aspect-based sentiment analysis; machine learning; supervised approaches; support vector machines; wordnet; lesk algorithm

Abbreviations

ABSA Aspect Based Sentiment Analysis
ACD Aspect Category Detection
ATE Aspect Term Extraction
IAI Implicit Aspect Identification
IAT Implicit Aspect Term
IR Improvement Rate
LDA Latent Dirichlet Allocation
LSTM Long Short Term Memory
NLP Natural Language Processing
POS Part Of Speech
RNN Recurrent Neural Network
SA Sentiment Analysis
SVM Support Vector Machines
WN WordNet
WSD Word Sense Disambiguation

I. INTRODUCTION

Sentiment Analysis (SA), also known as opinion mining, is a research area in the field of Natural Language Processing (NLP) [1] that aims to display emotions and automatically identify the sentiments conveyed in text. SA studies have been conducted at three granularity levels: document level [2], sentence level [3], and aspect level [4]. In Document-level Sentiment Analysis, the entire document is analyzed to determine whether it expresses a positive or negative sentiment. However, in Sentence-level Sentiment Analysis, the opinion of each sentence in the document is analyzed. In Aspect-Based Sentiment Analysis (ABSA), opinions regarding each aspect of the text's existing entities are collected.

The majority of studies are interested in aspect identification task since it is the key task in aspect-level SA. Aspects can be either implicit or explicit. Explicit aspect extraction has attracted a lot of interest, whereas implicit aspects haven't received much attention. Explicit aspects are defined as specific terms that are explicitly stated in the document, they can be expressed using a noun or noun phrase. On the other side, an implicit aspect is not explicitly stated in the text. It takes the form of an adjective, verb, or adverb as shown in [5], [6], and [7]. Implicit aspects are crucial since they can capture the emotions expressed in the text and improve the Opinion Mining Task.

In this study, we propose a method for enriching SVM model by combining its basic kernel function with similarity function inspired from Lesk algorithm [8] when applied to Word Sense Disambiguation (WSD) introduced by Weaver et al. [9]. WSD is the process of automatically assigning a meaning to the ambiguous words in a given context, as defined in [10], [11] and [12]. According to the original Lesk algorithm, a word's appropriate meaning in a particular context is one that has the maximum degree of overlap between its dictionary definition and the given context.

In this paper, we use the fundamental idea of Lesk Algorithm for WSD. However, the originality of our work is established on two different levels: (i) The idea logic: We use WordNet dictionary (WN), developed in [13], to design a similarity function between terms inspired from the Lesk algorithm. We then use this function to create a novel SVM Kernel that assigns higher weights to semantically similar words in terms of the degree of influence they have on classifying new observations. (ii) Model construction: Our similarity function amplifies the similarity score between terms

by first squaring the original score and then adding 1. This new formulation ensures significantly greater similarity scores for terms with similar semantic properties. Nevertheless, it maintains the same basic SVM Kernel value for words with different meanings.

We prepare several experiments in accordance with protocols that are intended to support the goals of our investigation. The key findings of our study are summarized as follows: (i) Our method enhances SVM's performance for the three kernels Gaussian, Anova, and Bessel, for the three considered datasets and under different experimental settings, and (ii) Our approach helps SVM perform better even when dealing with Overfitting and Underfitting which are known to be serious intrinsic issues for SVM classification.

The breakdown of the paper's structure is as follows. Related works on Aspect-based SA are discussed in the second section. Our proposed approach is described in the third section. The experimental setting is provided in section four, which is followed by a section on the results and discussion. The final section concludes this work.

II. RELATED WORKS

There are two major types of techniques used for Aspect Identification. Lexicon based approaches mainly include dictionary-based methods and corpus-based methods, where as machine learning approaches [15] and deep learning-based approaches [14] include supervised, unsupervised, or semi supervised learning methods.

Finding co-occurrence patterns of opinion words with context-specific orientation is the goal of corpus-based approaches. These techniques rely on syntactic patterns and seed opinion words to find additional opinion words and their orientation in domain corpora [16].

Dictionary-based techniques are methods that make use of WordNet or any other dictionary semantic relations. The work in [17], is an earlier dictionary-based method to identify aspects conveyed by adjectives. The authors of [18] perform an implicit aspect identification task for adjectives and verbs using definition and synonym relations extracted from WordNet. In [19], authors propose a new hybrid model for implicit aspect identification that uses semantic relations combined with a frequency-based method and supervised classifiers.

In [20] and [21], two of the most well-known co-occurrence-based approaches are presented. In [20], Schouten et al. predict implicit aspects according to the co-occurrence frequency between explicit aspects and opinion terms. Potential implicit aspects are determined based on a defined threshold value. In [21], the training data are enhanced by the use of WordNet's semantic relations and the co-occurrence score is computed for each extracted implicit aspect and its WordNet synsets. Additional co-occurrence methods are presented in [22] and [23]. The researchers Devi et al. [22] proposed a novel method to detect implicit aspects from opinionated documents using the co-occurrence of aspects with feature indicators and ranking the pair according to how frequently they co-occur. To determine how well a given candidate implicit aspect matches an opinion word, Rana et al. [23] identified implicit aspects using the co-occurrence approach and normalized Google distance.

Traditional machine learning techniques have been frequently used for ABSA. In [24], Sivakumar et al. make use of semantic relatedness between aspect term and opinion sentence to improve some machine learning algorithms for sentiment classification task. Gupta et al. [25], use an ensemble machine learning technique to perform ATE task. They combine the output of different supervised learning algorithms using a majority voting technique. Topic modeling, an unsupervised machine learning technique, has been widely applied to ACD. [26], [27], and [28] all make use of the well-known topic modeling technique Latent Dirichlet Allocation (LDA). García-Pablos et al. [26] suggest an unsupervised system called W2VLDA. To conduct ACD and sentiment classification, the system uses LDA combined with a Maximum Entropy classifier and word embedding. In [27], Poria et al. provide an original LDA technique to group aspect terms into corresponding aspect categories. To enhance the clustering process, semantic similarity between two words is used. Pathik et al. [28] suggest an unsupervised model for ACD using LDA in combination with linguistic rules. To perform ACD, Aspects are first ranked according to their probability distribution values and then clustered into predefined categories using domain knowledge with frequent terms.

Deep learning algorithms have recently begun to be used for ABSA after experiencing great success across a number of application domains. A recent work, [29], provides a hybrid method for detecting implicit aspects that combines a recurrent neural network (RNN) with a similarity function from spaCy and similarity metrics based on WordNet. The authors of [30] suggest a deep learning-based topic-level model for sentiment analysis. They performed ACD and sentiment classification using an LSTM network with a topic-level attention mechanism. Authors in [31] propose a two-step unsupervised model that combines deep learning techniques with language patterns in order to improve the ATE task. First, they extract aspects using a rule-based technique, and then they prune the pertinent aspects using fine-tuned word embedding. The extracted elements from the first phase are used as labeled data in the second phase to train the attention-based deep learning model.

There are numerous challenges and limitations for related works. Some of them conduct evaluations of their proposed models under optimal conditions without considering special situations like Overfitting and Underfitting. Others do not test their models on multiple experimental settings to figure out how they behave in different situations including non-ideal conditions. In addition to the aforementioned general shortcomings, some directly related approaches suffer from particular limitations. It is important to note that every study addresses the same problem, namely "Implicit Aspect Identification". They do, however, operate at various levels. While the techniques proposed in [18] and [19] concentrate on improving training data quality by acting at the data level which is a less challenging level, the approach proposed in [26] and our suggested method operate at the algorithmic level by suggesting modifications or additions. The works in [21], [17], [20] and [28] are hybrid methods that operate at both data level and algorithmic level. The work in [17], treats only aspects implied by adjectives without considering verbs that are very important implicit aspect indicators. In [21], the category is given to a sentence if the greatest conditional probability is greater than the corresponding trained threshold. the main

limitation of this technique is that it needs a sufficient amount of training data to work properly. The amount of training data needed to perform well presents also a limitation for the method proposed in [26] since additional text reviews are needed to compute the topic model and domain-based word embeddings. The technique proposed in [20] suffers from two limitations, the first one is the obvious need for labeled data, and the second one is selecting only one implicit feature for each sentence, since they are working on sentence-level and their datasets contain more than one implicit feature and some implicit aspects can be missed by the algorithm. A common limitation to all these directly related approaches and our technique is that they do not address broad aspects which are often omitted, like the “anecdotes/miscellaneous” aspect on the Restaurant dataset [34]. Unlike [20], [21], and [26], our technique doesn’t require a huge amount of training data to work properly.

Our research concentrates on implicit aspect-level sentiment analysis and its applications, and how to develop more semantic-oriented sentiment analysis. The motivation of our work is to address some of the structural issues of machine learning classification models applied to Implicit Aspect Identification like Overfitting and Underfitting. In this paper, the proposed approach is using semantic relations from WordNet lexical database for enhancing the SVM classification model so that it can better cope with some of its intrinsic issues. To achieve this motivation, we propose our approach which is specifically appropriate thanks to the fact that it captures similarity information between two aspect terms (from WordNet) and uses this similarity to increase the degree of influence on classification between these two aspect terms. Our approach operates at the SVM kernel which controls this degree of influence on classification between two aspect terms and therefore determines how each training term affects the final SVM classification results.

III. PROPOSED APPROACH

In this section, we describe our method, which is illustrated in Fig. 1. Its goal is to integrate relevant external knowledge, namely semantic knowledge obtained from WN lexical database into SVM Kernel calculation. For this purpose, we propose three new semantic kernel functions to SVM.

T_i and T_j are two implicit aspect terms (IAT) in the dataset, and Def_i and Def_j correspond to their respective sets of Wordnet definitions. Def_i and Def_j are defined as follows:

$$Def_i = \{subset_{i1}, \dots, subset_{is}\}, s \in [1, n] \quad (1)$$

$$Def_j = \{subset_{j1}, \dots, subset_{jt}\}, t \in [1, m] \quad (2)$$

Where n and m are respectively the numbers of definitions in Def_i and Def_j , $subset_{is}$ is the set of words representing the s^{th} definition in Def_i , and $subset_{jt}$ is the set of words representing the t^{th} definition in Def_j . The new kernels are computed according to the following formulas:

$$score(Def_i, Def_j) = \max NCW_{ij}(s, t), s \in [1, n], t \in [1, m] \quad (3)$$

$$sim(T_i, T_j) = score^2(Def_i, Def_j) + 1 \quad (4)$$

$$GaussianNew(T_i, T_j) = exp(-\gamma(\|T_i - T_j\|^2 / sim(T_i, T_j))) \quad (5)$$

$$AnovaNew(T_i, T_j) = \sum_{k=1}^n exp(-\sigma((T_{ik} - T_{jk}) / sim(T_i, T_j))^2)^d \quad (6)$$

$$BesselNew(T_i, T_j) = J_0(\sigma\|T_i - T_j\|) * sim(T_i, T_j) \quad (7)$$

Since equivalent word senses are commonly defined by the same terms, the score is determined by comparing word definitions collected from WordNet lexical database [13]. We can make the following assumption: for two terms, the more similar words that their definitions contain the more similar these two terms are. We inspire from Lesk algorithm [8] to create the proposed score. The Lesk algorithm suggests comparing two concepts using the number of common words in their glosses. First, the number of common terms between each subset in Def_i and each subset in Def_j is computed.

Let’s note this number as follows:

$NCW_{ij}(s, t)$ = the number of common terms between $subset_{is} \in Def_i$ and $subset_{jt} \in Def_j$.

As stated in equation (3), the score is then computed as the maximum of all these numbers $NCW_{ij}(s, t)$.

Equation (4) shows how $sim(T_i, T_j)$ is obtained. This latter is calculated by adding 1 to the square of $score(Def_i, Def_j)$.

If T_i and T_j are dissimilar ($score(Def_i, Def_j) = 0$), then the new kernel between them is computed as follows :

- For Gaussian and Anova kernels, the new distance between T_i and T_j is set to the standard distance since $sim(T_i, T_j)$ is equal to 1.
- For Bessel kernel, J_0 (the Bessel function of the first kind) is set to its basic value since $sim(T_i, T_j)$ is equal to 1.

The score is squared to provide higher similarity of terms having a larger number of common words between subsets of their definitions.

In equations (5) and (6), the new SVM kernels ($GaussianNew(T_i, T_j)$ and $AnovaNew(T_i, T_j)$), are calculated by dividing the standard distances used in the original Gaussian and Anova kernel functions by the proposed similarity in equation (4). In each of these new kernels, the division of the distance by the proposed similarity aims to decrease the distance between similar terms and then increase the degree of influence they have on the classification of each others. In other terms, by decreasing the value inside the exponential function, the resulting value of the kernel is amplified for similar terms.

In equation (7), the new Bessel kernel is calculated by multiplying J_0 , which is the Bessel function of the first kind, by

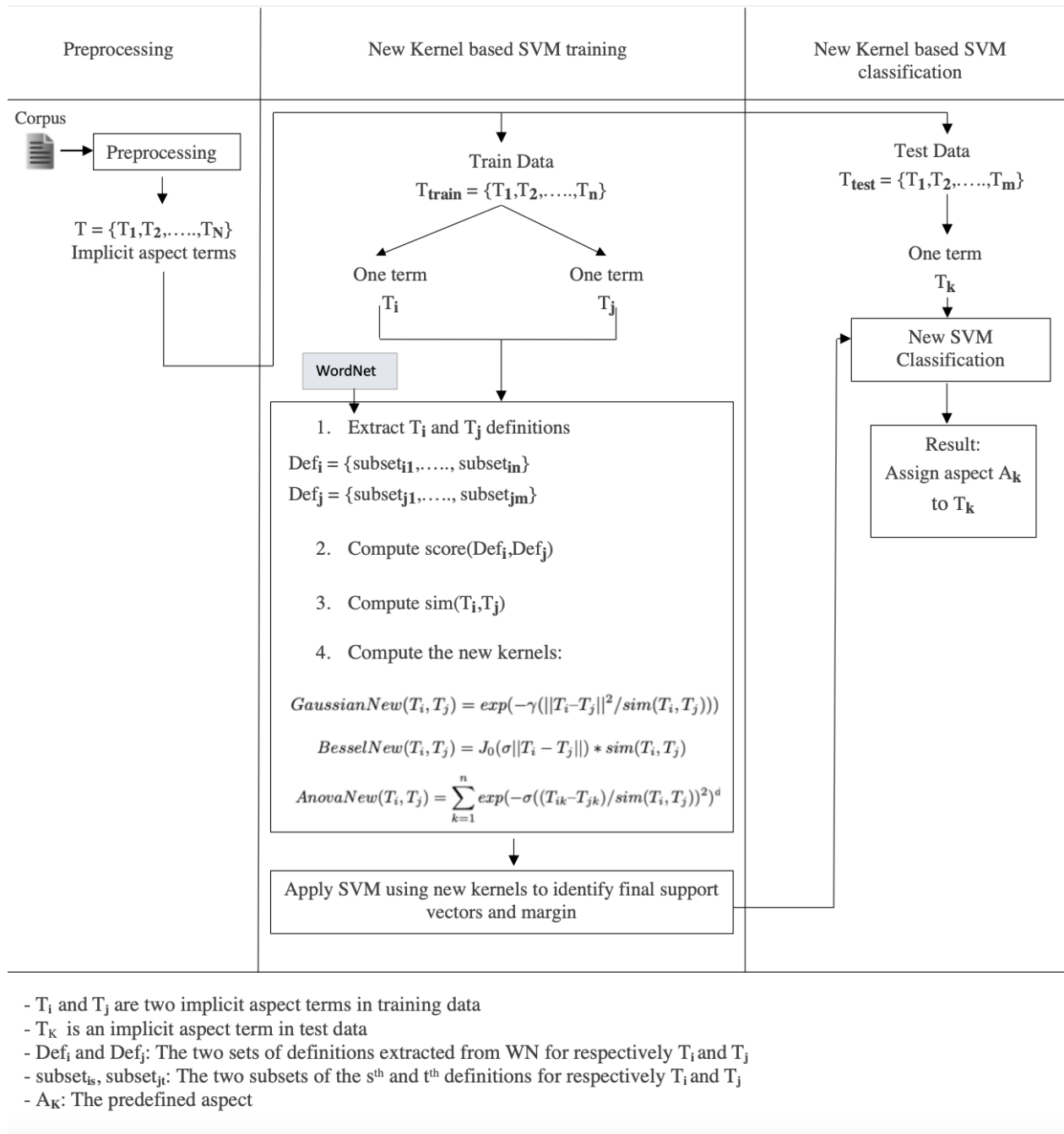


Fig. 1. Summary of our approach.

the proposed similarity in equation (4). The new Bessel kernel value is defined as J_0 multiplied by the proposed similarity function. Consequently, this resulting value is amplified which increases the degree of influence on classification between the nearest terms.

IV. EXPERIMENTS AND RESULTS

This section presents the experiments conducted to assess our proposed method. The pre-processing techniques applied, the classifier used, the utilized datasets, the performance metrics adopted, and the experimental protocols implemented are

all detailed below.

A. Experimental Setup and Protocols

1) *Pre-processing*: Pre-processing begins with corpus parsing to extract a list of adjectives and verbs using Part of Speech Tagger (POS). And then all stop words are removed from the initial list to create the final one.

2) *Classifier used*: Support Vector Machines (SVM) [32] are a group of supervised learning techniques for classification and regression. Putting more emphasis on classification task,

the goal of SVM is to create a hyperplane that divides instances into distinct classes while maximizing the distance (or margin) with the closest data points, known as support vectors.

3) *Datasets*: To evaluate our technique, we used Restaurant, Products and Laptop datasets. Products dataset was created by Cruz-Garcia et al. [33] who manually labeled each IAT. This dataset is based on the customer review corpus described in [36]. It includes five corpora for various electronic products. The primary considered implicit aspects are functionality, performance, appearance, price, quality, weight, and size.

Restaurant dataset is used for SemEval-2014 ABSA task 4 [35]. It contains 3044 English sentences from Ganu et al.'s [34] restaurant reviews with five predetermined implicit aspects: price, food, ambiance, service, and anecdotes/miscellaneous.

Laptop dataset is a modified version of SemEval-2015 ABSA dataset for laptop domain [37]. This corpus is used for SemEval-2016 task 5 for Aspect Based Sentiment Analysis [38]. The primary addressed implicit aspects are operation performance, usability, price, quality, design features, portability, and connectivity.

4) *Evaluation measures*: Accuracy, precision, recall, and F1-score are the most widely utilized evaluation measures for assessing the model's performance. Accuracy is the proportion of correctly predicted samples. Precision, recall, and F1-score are employed instead of accuracy when the dataset is unbalanced since accuracy alone is insufficient. The F1-score is the equally weighted average of precision and recall [39].

$$F1 = \frac{2 \times Precision \times Recall}{Precision + Recall} \quad (8)$$

Where Precision is the percentage of correct predictions over all positive label samples, whereas recall is the percentage of correct predictions across all positive predictions.

5) *Experimental protocols*: Our experimental protocols are prepared in order to evaluate our method according to the following issues:

- SVM behavior depending on kernel functions used,
- SVM behavior under different experimental settings,
- SVM behavior under Overfitting and Underfitting,

To lower the uncertainty of data splitting between testing and training data, 10-fold cross-validation is used in all experiments. The experimental protocols will be detailed in the following four subsections, with an emphasis on each protocol's intended purpose and how each protocol is designed to achieve its goal.

a) *Kernel functions used*: The main function of the kernel is to transform the input data into the required form. There are various types of kernels. In order to evaluate our approach, we used three different kernels.

Gaussian RBF kernel: The Gaussian RBF kernel is one of the most used kernels with SVM. This kernel function is preferred when we do not have any prior knowledge of the data. The equation of Gaussian RBF is presented as follows:

$$K(x, z) = \exp(-\gamma \|x - z\|^2) \quad (9)$$

Where $\|x - z\|$ denotes the Euclidean distance between the two data points x and z , respectively. The parameter γ controls the Gaussian curve's shape and determines how each training sample affects the classification result.

Anova kernel: The ANOVA kernel is a radial basis function that is frequently used in kernel-based techniques, such as SVM. The ANOVA kernel is formulated as:

$$K(x, z) = \sum_{k=1}^n \exp(-\sigma(x_k - z_k)^2)^d \quad (10)$$

Where x and z are two data points, and d denotes the ANOVA kernel's degree. The parameter σ influences both the border of the categorization problem and the shape of the ANOVA kernel.

Bessel kernel: The Bessel kernel is a radial basis function used in kernel-based methods in mathematics, such as SVM. The equation of Bessel kernel is given by:

$$K(x, z) = J_0(\sigma \|x - z\|) \quad (11)$$

Where x and z are two data points, J_0 is the Bessel function of the first kind, and $\|x - z\|$ is the Euclidean distance between them. The parameter σ impacts the boundary of the categorization problem, which also impacts the Bessel kernel's structure.

b) *SVM behavior under different experimental settings*: SVM is a machine learning classification technique whose performance depends not only on kernel function but also on its parameters. The most critical parameters are C , γ , and σ . Parameter C is the error penalty misclassification, It controls the trade-off between maximizing the margin and minimizing the misclassification error. Parameter γ determines the speed of the decrease of the similarity of two points as the distance between them increases. It is in charge of finding the balance between SVM abilities to fitting training data and to generalizing to testing data. Whereas parameter σ decides the boundary uniformity with respect to the quantity of nearby data points considered for Building this boundary. It decides the breath of its corresponding kernel. Thus, both parameters σ and γ determine how far the influence of each training instance reaches.

Protocol 1: Experiments for issues (a) and (b):

For our comparative protocol, we execute BasicSVM and NewSVM using a grid search with respect to combinations $\{C, \gamma\}$ (for Gaussian RBF Kernel) and $\{C, \sigma\}$ (for Anova and Bessel Kernels), where C , γ and σ range within $[2^{-5}, 2^{15}]$ interval, in order to obtain as many as possible significant values for performance ranging from Underfitting values up to Overfitting values.

As the parameter setting changes, the performance of each of NewSVM and BasicSVM models ranges from Minimum to Maximum values that correspond respectively to Underfitting and Overfitting situations. For each model, we identify from its performance range three different pertinent F1 performance values Minimum Value, Median Value, and Maximum Value. The identified Minimum and Maximum performance values

are chosen to be different, if possible, from Underfitting and Overfitting values respectively. This is because Underfitting and Overfitting are treated separately in the next part of this section. Our protocol aims to conduct objective comparisons of F1 performances of both NewSVM and BasicSVM models. In fact, it compares each of the three identified F1 performances of each model to the F1 performance, of the other model, obtained under the same experimental parameter setting leading to the identified performance of the former model.

To deal with issues (a) and (b), we conduct our experiments according to the following protocol:

Protocol 1: kernel functions used and different experimental settings:

For each dataset from {Laptop, Products, Restaurant}:

For each Kernel from {Gaussian RBF, Anova, Bessel}:

If (the best performance is identified for BasicSVM) / (OR the best performance is identified for NewSVM):

Let's denote:

1) BestBasicSVM as the BasicSVM algorithm with the best F1-score performance. (OR BestNewSVM as the NewSVM algorithm with the best F1-score performance.)

2) $NewSVM_{Param-BestBasicSVM}$ as the NewSVM algorithm using the same parameters used by BestBasicSVM. (OR $BasicSVM_{Param-BestNewSVM}$ as the BasicSVM algorithm using the same parameters used by BestNewSVM.)

Compare F1-score average performances of $NewSVM_{Param-BestBasicSVM}$ and BestBasicSVM (OR Compare F1-score average performances of $BasicSVM_{Param-BestNewSVM}$ and BestNewSVM)

If (the median performance is identified for BasicSVM) / (OR the median performance is identified for NewSVM):

Let's denote:

1) MedianBasicSVM as the BasicSVM algorithm with the median F1-score performance. (OR MedianNewSVM as the NewSVM algorithm with the median F1-score performance.)

2) $NewSVM_{Param-MedianBasicSVM}$ as the NewSVM algorithm using the same parameters used by MedianBasicSVM. (OR $BasicSVM_{Param-MedianNewSVM}$ as the BasicSVM algorithm using the same parameters used by MedianNewSVM.)

Compare F1-score average performances of $NewSVM_{Param-MedianBasicSVM}$ and MedianBasicSVM (OR Compare F1-score average performances of $BasicSVM_{Param-MedianNewSVM}$ and MedianNewSVM)

If (the worst performance is identified for BasicSVM) / (OR the worst performance is

identified for NewSVM):

Let's denote:

1) WorstBasicSVM as the BasicSVM algorithm with the worst F1-score performance. (OR WorstNewSVM as the NewSVM algorithm with the worst F1-score performance.)

2) $NewSVM_{Param-WorstBasicSVM}$ as the NewSVM algorithm using the same parameters used by WorstBasicSVM. (OR $BasicSVM_{Param-WorstNewSVM}$ as the BasicSVM algorithm using the same parameters used by WorstNewSVM.)

Compare F1-score average performances of $NewSVM_{Param-WorstBasicSVM}$ and WorstBasicSVM (OR Compare F1-score average performances of $BasicSVM_{Param-WorstNewSVM}$ and WorstNewSVM)

Compute all Improvement Rates (IR) of NewSVM over BasicSVM

Report F1-score averages and IR results

c) SVM behavior under overfitting and underfitting: We design a protocol that is intended to examine and compare the impact of Overfitting and Underfitting on the performance of NewSVM and BasicSVM with three kernels, Gaussian RBF, Anova, and Bessel. To accomplish this aim, our suggested protocol should:

1. Be built under conditions that cause SVM Underfitting and Overfitting. Generally, Overfitting and Underfitting are induced by respectively large values of C , γ and σ , and small values of C , γ and σ . The small and large values of these parameters are experimentally identified using grid search along with cross-validation.

The parameters γ and σ determine the extent of a single training example influence (γ is the hyper-parameter of Gaussian RBF Kernel, and σ is the hyper-parameter of Anova and Bessel kernels). When gamma and sigma are very small the model is too constrained and cannot capture the complexity of the data. Consequently, the region of influence of any selected support vector would include the whole training set. In addition to that, small values of γ and σ consider only nearby points in calculating the separation line. As a result, a low value of γ and σ will loosely fit the training dataset, which causes Underfitting. In contrast to small values, large values of γ and σ consider all the data points in the calculation of the separation line. Consequently, a high value of γ and σ will exactly fit the training dataset, which causes Overfitting.

Parameter C represents the error penalty for misclassification for SVM. The C parameter trades off correct classification of training examples against maximization of the decision function's margin. For larger values of C , a smaller margin will be accepted thus the model will be less tolerant, in other words, the model will be more specific and therefore this leads to Overfitting. A lower C will encourage a larger margin, therefore a simpler decision function at the cost of training accuracy, thus the model will be more tolerant to misclassifications, which causes Underfitting. In other words, C behaves as a regularization parameter in SVM.

2. Provide a measure to analyze the impact of Underfitting and Overfitting on SVM performance, in order to make a comparison between BasicSVM and NewSVM with regard to how they behave under Overfitting and Underfitting situations. In Overfitting, SVM has a good training performance and a bad test performance. In contrast, in Underfitting SVM performs poorly on both testing and training data. For assessing how sensitive both models are to Underfitting and Overfitting, we propose different measures that are presented and described in detail in section B “Results and Discussion”.

Protocol 2: Experiments for issue (c):

We compare the performances of NewSVM and BasicSVM for each of the three kernels (Gaussian RBF, Anova, and Bessel) and for Overfitting and Underfitting conditions. For this comparison, we execute a grid search with respect to $\{C, \gamma\}$ and $\{C, \sigma\}$ combinations, where C, γ and σ range within $[2^{-5}, 2^{15}]$ interval. This range is chosen to be very large (with very small lower bound and very large upper bound) so that grid search results in many combinations of $\{C, \gamma\}$ and $\{C, \sigma\}$ from which we extract relevant values leading to Overfitting and Underfitting that are used to conduct our experimental comparisons of BasicSVM and NewSVM.

In fact, for each situation of Underfitting and Overfitting, grid search identifies several relevant combinations resulting in the same F1-score performance. Thus, for our comparative experiments, we select the combinations of the largest values $\{C_{max}, \gamma_{max}\}$ or $\{C_{max}, \sigma_{max}\}$ and the smallest values $\{C_{min}, \gamma_{min}\}$ or $\{C_{min}, \sigma_{min}\}$ (depending on the kernel used) for respectively Overfitting and Underfitting conditions.

Protocol 2: Overfitting and Underfitting: For each dataset from {Laptop, Products, Restaurant}:

For each Kernel from {Gaussian RBF, Anova, Bessel}:

For each Model from {NewSVM, BasicSVM}:

If Kernel = Gaussian RBF :

If Overfitting :

Select $\{C_{max}, \gamma_{max}\}$ for comparing NewSVM and BasicSVM

Else //Underfitting // :

Select $\{C_{min}, \gamma_{min}\}$ for comparing NewSVM and BasicSVM

If Kernel = Anova or Kernel = Bessel :

If Overfitting :

Select $\{C_{max}, \sigma_{max}\}$ for comparing NewSVM and BasicSVM

Else //Underfitting // :

Select $\{C_{min}, \sigma_{min}\}$ for comparing NewSVM and BasicSVM

Report F1-score average results of Model

- SVM behavior depending on kernel functions used,
- SVM behavior under different experimental settings,
- SVM behavior under Overfitting and Underfitting.

1) SVM behavior depending on kernel functions used and under different experimental settings:: Table I is defined to show the behavior of both BasicSVM and NewSVM models with respect to different experimental settings. It presents, on one hand, the F1-score average performances of BestBasicSVM, MedianBasicSVM, and WorstBasicSVM compared respectively to F1-score average performances of $NewSVM_{Param-BestBasicSVM}$, $NewSVM_{Param-MedianBasicSVM}$ and $NewSVM_{Param-WorstBasicSVM}$, and on the other hand, the F1-score average performance of BestNewSVM, MedianNewSVM, and WorstNewSVM compared respectively to F1-score average performances of $BasicSVM_{Param-BestNewSVM}$, $BasicSVM_{Param-MedianNewSVM}$ and $BasicSVM_{Param-WorstNewSVM}$. It outlines these comparisons for the three considered kernels and the three datasets. Table I reveals that NewSVM outperforms BasicSVM for all kernels and all datasets used (shown by positive IR for all cases). In fact, when we introduce our proposed similarity in SVM kernels this results in tuned kernel values and then enhances the classification performance. These tuned values are obtained by integrating the proposed similarity function in the three considered kernels (Gaussian RBF, Anova, and Bessel), which amplifies kernel values and then increases the level of influence between the nearest terms. As a result, the new kernel functions allow SVM to improve its classification performance.

In addition to global findings marked by positive performance improvement rates of NewSVM over BasicSVM, there are some noteworthy points that clearly show NewSVM's superiority:

- a) We observe that NewSVM outperforms BasicSVM with the lowest, the middle, and the highest average IR over all kernels and datasets respectively for the best, the median, and the worst performances of both models. (IR average values are $\{5, 78\%, 36, 94\%$, $\{34, 48\%, 118, 97\%$, and $\{193, 53\%, 211, 89\%$, for respectively the best, the median, and the worst performances). NewSVM is shown to outperform BasicSVM for all cases but its outperformance rate changes with the level of the performance considered for comparison. Indeed, the best performance, that is chosen for any one of both models, usually corresponds to optimal hyperparameters for both NewSVM and BasicSVM. This fact allows this latter to reach high performances in general, and therefore not to be largely exceeded by NewSVM. Conversely, the worst performance, that is identified for any of both models, leads to the worst hyperparameters mainly for BasicSVM. Hence, this latter achieves its worst performance, which helps NewSVM to highly outperform it.
- b) We notice that NewSVM outperforms BasicSVM with higher average IR over all kernels and datasets when best and median performances

B. Results and Discussion

The results of the experiments are shown and discussed in this part considering the following aspects:

TABLE I. IMPROVEMENT RATES OF NEWSVM OVER BASICSV M UNDER DIFFERENT EXPERIMENTAL SETTINGS FOR THREE DATASETS AND THREE KERNELS

Model	Restaurant			Products			Laptop			Average-IR
	Gaussian	Anova	Bessel	Gaussian	Anova	Bessel	Gaussian	Anova	Bessel	
BestBasicSVM	81.94%	81.94%	81.94%	77.27%	77.02%	77.02%	85.60%	85.60%	85.60%	
NewSVM _{Param-BestBasicSVM}	85.53%	86.56%	87.23%	81.13%	78.76%	80.99%	92.33%	92.47%	92.06%	
IR-BestBasicSVM	4.38%	5.63%	6.45%	5%	1.93%	5.15%	7.86%	8.03%	7.55%	5.78%
BasicSVM _{Param-BestNewSVM}	34.38%	81.94%	81.94%	71.64%	77.02%	58.42%	46.32%	85.60%	85.60%	
BestNewSVM	85.67%	87.29%	87.23%	81.13%	79.57%	81.14%	92.41%	92.73%	92.06%	
IR-BestNewSVM	149.19%	6.53%	6.45%	13.25%	3.31%	38.39%	99.50%	8.33%	7.55%	36.94%
MedianBasicSVM	53.64%	75.89%	49.59%	64.75%	77.02%	58.42%	69.11%	67.29%	64.13%	
NewSVM _{Param-MedianBasicSVM}	85.67%	84.50%	87.23%	79.67%	79.57%	81.14%	87.24%	86.66%	91.90%	
IR-MedianBasicSVM	59.71%	11.35%	75.90%	23.04%	3.31%	38.72%	26.23%	28.79%	43.30%	34.48%
BasicSVM _{Param-MedianNewSVM}	36.16%	75.89%	15.21%	76.31%	77.27%	77.02%	17.66%	85.60%	64.13%	
MedianNewSVM	85.53%	84.50%	86.51%	78.48%	77.90%	80.99%	87.24%	92.29%	91.90%	
IR-MedianNewSVM	136.53%	11.35%	468.77%	2.84%	0.82%	5.14%	394%	7.82%	43.30%	118.97%
WorstBasicSVM	24.95%	49.59%	15.21%	26.27%	58.91%	12.63%	31.63%	67.29%	23.88%	
NewSVM _{Param-WorstBasicSVM}	52.34%	79.35%	86.51%	62.85%	70.46%	80.88%	60.36%	86.66%	91.79%	
IR-WorstBasicSVM	109.78%	60.01%	468.77%	139.25%	19.61%	540.38%	90.83%	28.79%	284.38%	193.53%
BasicSVM _{Param-WorstNewSVM}	24.95%	49.59%	15.21%	26.27%	58.91%	12.63%	16.95%	67.29%	23.88%	
WorstNewSVM	52.34%	79.35%	86.51%	62.85%	70.46%	80.88%	60.36%	86.66%	91.79%	
IR-WorstNewSVM	109.78%	60.01%	468.77%	139.25%	19.61%	540.38%	256.11%	28.79%	284.38%	211.89%

are used for NewSVM than when they are used for BasicSVM (Average-IR(IR-BestNewSVM) ζ Average-IR(IR-BestBasicSVM) and Average-IR(IR-MedianNewSVM) ζ Average-IR(IR-MedianBasicSVM)). In fact, the newly included similarity into SVM kernels helps NewSVM to be much less sensitive to the change of setting, the error misclassification, and the influence of training data instances that are controlled by hyperparameters (C, γ , and σ). Whereas, BasicSVM remains very sensitive as usual to these factors. Therefore, the performances of NewSVM do not significantly change even when we change hyperparameters from values leading to its best, median, and worst performances to values corresponding respectively to the best, median, and worst performances of BasicSVM. At the same time, BasicSVM is generally penalized when its own parameters are changed to NewSVM parameters.

- c) We also note that for the worst performances, NewSVM outperforms BasicSVM with higher average IR over all kernels and datasets (Average-IR(IR-WorstNewSVM) ζ Average-IR(IR-WorstBasicSVM)). However, NewSVM is shown to exceed BasicSVM with the same IR for every kernel and dataset except for the Gaussian kernel on Laptop dataset. This is simply explained by the fact that both models share the same hyperparameter values for their worst performances. In others terms, the values of the parameters that correspond to the worst performance of BasicSVM lead to the worst performance of NewSVM and vice versa.

To better show the behavior of both NewSVM and BasicSVM with respect to kernel functions for all datasets, we create Table II that represents an aggregated view of Table I. Indeed, Table II shows for each kernel function and for each dataset: (i) Average-F1-BasicSVM which is the average of F1-score performances of BestBasicSVM, MedianBasicSVM, and WorstBasicSVM, BasicSVM_{Param-BestNewSVM}, BasicSVM_{Param-MedianNewSVM} and BasicSVM_{Param-WorstNewSVM}, (ii) Average-F1-NewSVM which is the average of F1-score performances of BestNewSVM, MedianNewSVM,

and WorstNewSVM, NewSVM_{Param-BestBasicSVM}, NewSVM_{Param-MedianBasicSVM} and NewSVM_{Param-WorstBasicSVM} and (iii) IR which is the improvement rate of Average-F1-NewSVM over Average-F1-BasicSVM. From Table II, it can be observed that the average improvement rates of NewSVM over BasicSVM reach their highest values with Bessel kernel and their lowest values with Anova kernel for all datasets. This observation may be explained by the low BasicSVM performance with Bessel kernel and the high BasicSVM performance with Anova kernel. This shows that BasicSVM performance is one among other impacting factors of the improvement rate of NewSVM over BasicSVM.

2) SVM behavior under overfitting and underfitting:

- a) *Overfitting*: To analyze the behavior of the new and original model in Overfitting conditions, and as stated previously in our protocol, the comparative experiments are conducted using the combination $\{C_{max}, \gamma_{max}\} = \{32768, 32768\}$ for Gaussian kernel, and $\{C_{max}, \sigma_{max}\} = \{32768, 32768\}$ for Anova and Bessel kernels, corresponding to the largest values of parameters.

Table III shows F1-score averages for NewSVM model and BasicSVM model under Overfitting situations (each average is obtained across multiple folds). In Overfitting, the two models perform well on training data but badly on test data.

We provide three indicators in Table III that are utilized to measure how sensitive BasicSVM and NewSVM are to Overfitting.

Delta-test (Delta-test = F1-test(NewSVM) - F1-test(BasicSVM)) values are positive in all experiments in Table III. This demonstrates that NewSVM outperforms BasicSVM for all kernels and for all datasets, even in Overfitting situation. The fact that NewSVM outperforms BasicSVM on test data is the first indicator of NewSVM's less Overfitting sensitivity in comparison to BasicSVM.

The two other indicators of BasicSVM and NewSVM Overfitting sensitivity are respectively Delta-BasicSVM and Delta-NewSVM (Delta-BasicSVM = F1-Train(BasicSVM) - F1-Test(BasicSVM), Delta-NewSVM = F1-Train(NewSVM) - F1-Test(NewSVM)). These two metrics measure the performance losses that are made respectively by BasicSVM

TABLE II. AVERAGE IMPROVEMENT RATES OF NEW SVM OVER BASIC SVM WITH RESPECT TO KERNELS AND DATASETS

Dataset / Kernel	Gaussian	Anova	Bessel
Average-F1-BasicSVM _{Restaurant}	42.67%	69.14%	43.18%
Average-F1-NewSVM _{Restaurant}	74.51%	83.59%	86.87%
IR _{Restaurant}	74.62%	20.90%	101.18%
Average-F1-BasicSVM _{Products}	57.92%	71.07%	49.36%
Average-F1-NewSVM _{Products}	74.35%	76.12%	81%
IR _{Products}	28.37%	7.10%	64.10%
Average-F1-BasicSVM _{Laptop}	44.54%	76.44%	57.87%
Average-F1-NewSVM _{Laptop}	79.99%	89.58%	91.92%
IR _{Laptop}	79.59%	17.19%	58.84%
Average-IR	60.86%	15.06%	74.71%

and NewSVM between testing and training data. A higher Delta-BasicSVM (Delta-NewSVM) results in a poorer performance on testing data than on training data for BasicSVM (NewSVM). This means that BasicSVM (NewSVM) sensitivity to Overfitting increases. The model that is more sensitive to overfitting is indicated by Delta (Delta = Delta-BasicSVM – Delta-NewSVM). The BasicSVM is more sensitive when Delta is positive; otherwise, the NewSVM is more sensitive. Additionally, BasicSVM becomes more sensitive than NewSVM as Delta increases. Table III shows that for all kernels and for all datasets, all Delta values are positive. This means that the differences between F1-score averages in training data and F1-score averages in test data are smaller for the NewSVM model, and this denotes a lower performance loss between testing and training data, and thus, lower sensitivity to Overfitting.

Therefore, our method aids SVM coping with Overfitting more effectively. Thus, the suggested model is less sensitive than the basic one to Overfitting.

b) Underfitting: To analyze the behavior of the original and new models under Underfitting, and as stated previously in our protocol, the comparative experiments are conducted using the combination $\{C_{min}, \gamma_{min}\} = \{0.03125, 0.03125\}$ for Gaussian kernel, and $\{C_{min}, \sigma_{min}\} = \{0.03125, 0.03125\}$ for Anova and Bessel kernels, corresponding to the lowest values of parameters.

Table IV shows the behavior of BasicSVM and NewSVM under Underfitting when both models show poor performance on both testing and training data.

In order to analyze both models sensitivity to Underfitting, we introduce two indicators in Table IV to measure BasicSVM and NewSVM tolerance to Underfitting.

Delta-test (Delta-test = F1-test(NewSVM) – F1-test(BasicSVM)) values are positive in all experiments in Table IV (except for Gaussian kernel on Restaurant dataset). This shows that NewSVM outperforms BasicSVM for all kernels and for all datasets, even in Underfitting situation. The fact that NewSVM outperforms BasicSVM on test data is the first indicator of NewSVM's less Underfitting sensitivity in comparison to BasicSVM.

Delta-train (which is equal to F1-train(NewSVM) – F1-train(BasicSVM)) is the second indicator. Delta-train values are positive in all experiments in Table IV (except for Gaussian kernel on Restaurant dataset). This implies that NewSVM is more performant than BasicSVM on training data. This indicates that NewSVM is more tolerant to Underfitting than

BasicSVM.

V. COMPARISON WITH OTHER WORKS

In order to evaluate the effectiveness of the proposed approach, it is compared against various existing methods from the literature. Table V shows a comparison between the traditional and deep learning methods and our suggested method for Implicit Aspect Identification. It is crucial to note that all the works use the same datasets. However, they operate at distinct levels. While W2VLDA [26], and our proposed method (using 3 kernels) work at the algorithmic level by proposing adjustments or additions, the rest of the techniques focus on enhancing the quality of training data by operating at the data level. Schouten et al.'s supervised method [21] is a hybrid method that operates at both data level and algorithmic level.

From Table V, we observe that:

- In the case of Restaurant dataset, despite the difficulty of adjusting the core model that is more challenging and sensitive, our proposed technique (with the three kernels) shows a highly competitive performance level when compared to all works even the ones operating on data level which is less challenging and even the deep learning methods of [19] that are generally reputed for high classification performance.
- In the case of the Products dataset, our three proposed approaches, which operate at the algorithm level without modifying the training data structure, are mostly surpassed by all methods of [18] and [19] that make use of data-level techniques. These techniques enhance the training data by incorporating semantic relations from WN, which should help mitigate the issue of high-class imbalance present in the Products dataset. However, Our technique (with three kernels) outperforms KNN [40] with its three versions, which is an algorithmic-level technique.
- In the case of Laptop dataset, our proposed approach with all kernels outperforms LSTM+WN+Frequency [19] and Att-LSTM+WN+Frequency [19] which are not only deep learning methods that are generally reputed for high classification performance, but also operating on less sensitive and less challenging data level.

TABLE III. F1-SCORE AVERAGE PERFORMANCES OF NEWSVM AND BASIC SVM UNDER OVERFITTING FOR ALL DATASETS AND USING THREE KERNELS

Kernel	Gaussian { C_{max}, γ_{max} }			Anova { C_{max}, σ_{max} }			Bessel { C_{max}, σ_{max} }		
	Rest	Prod	Lap	Rest	Prod	Lap	Rest	Prod	Lap
F1-test(BasicSVM)	80.13	76.30	85.45	74.68	77.27	85.50	81.94	77.27	85.60
F1-test(NewSVM)	86.85	78.61	90.48	85.57	77.38	91.91	87.23	80.95	92.06
Delta-test	6.72	2.31	5.03	10.89	0.11	6.41	5.29	3.68	6.46
F1-train(BasicSVM)	100	96.90	99.52	100	96.90	99.52	100	96.90	99.52
F1-train(NewSVM)	100	96.12	98.91	100	96.32	99.38	100	96.90	99.52
Delta-BasicSVM	19.87	20.6	14.07	25.32	19.63	14.02	18.06	19.63	13.92
Delta-NewSVM	13.15	17.51	8.43	14.43	18.94	7.47	12.77	15.95	7.46
Delta	6.72	3.09	5.64	10.89	0.69	6.55	5.29	3.68	6.46

*Rest refers to Restaurant dataset.

*Prod refers to Products dataset.

*Lap refers to Laptop dataset.

TABLE IV. F1-SCORE AVERAGE PERFORMANCES OF NEWSVM AND BASIC SVM UNDER UNDERFITTING FOR ALL DATASETS AND USING THREE KERNELS

Kernel	Gaussian { C_{min}, γ_{min} }			Anova { C_{min}, σ_{min} }			Bessel { C_{min}, σ_{min} }		
	Rest	Prod	Lap	Rest	Prod	Lap	Rest	Prod	Lap
F1-test(BasicSVM)	15.21	5.07	7.50	15.21	14.97	23.96	15.21	5.07	7.50
F1-train(BasicSVM)	15.23	5.07	7.50	15.23	20.76	24.88	15.23	5.07	7.50
F1-test(NewSVM)	15.21	19.15	26.05	16.98	38.63	50.57	83.35	78.30	88.1
F1-train(NewSVM)	15.23	21.82	26.37	17.48	44.11	53.87	98.47	92.35	98.02
Delta-test	0	14.08	18.55	1.77	23.66	26.61	68.14	73.23	80.6
Delta-train	0	16.75	18.87	2.25	23.35	28.99	83.24	87.28	90.52

*Rest refers to Restaurant dataset.

*Prod refers to Products dataset.

*Lap refers to Laptop dataset.

TABLE V. PERFORMANCES OF SELECTED TRADITIONAL AND DEEP LEARNING TECHNIQUES AND OUR PROPOSED TECHNIQUES FOR IAI ON RESTAURANT, PRODUCTS AND LAPTOP DATASETS

Method	Type	F1-score (Restaurant)	F1-score (Products)	F1-score (Laptop)
W2VLDA [26]	traditional	72.00%	-	-
Schouten et al. Supervised [21]	traditional	83.80%	-	-
MNB+WN [18]	traditional	77.40%	90.00%	-
BNB+WN [18]	traditional	78.40%	93.30%	-
SVM+WN+frequency [19]	traditional	85.30%	91.80%	-
KNN+WN+frequency [19]	traditional	85.30%	91.80%	-
MNB+WN+frequency [19]	traditional	87.55%	91.80%	-
LSTM+WN+frequency [19]	deep learning	85.20%	89.09%	86.71%
Att-LSTM+WN+frequency [19]	deep learning	87.83%	94.36%	88.26%
KNN with Cosine dist. [40]	traditional	87.80%	74.60%	-
KNN with Jaccard dist. [40]	traditional	84.40%	74.00%	-
KNN with Euclidian dist. [40]	traditional	77.60%	72.60%	-
Proposed SVM with Gaussian	traditional	88.83%	80.21%	89.35%
Proposed SVM with Anova	traditional	88.54%	79%	92.84%
Proposed SVM with Bessel	traditional	89.81%	80.89%	93.42%

VI. CONCLUSION

In this work, we suggest a method to enhance SVM algorithm to address Implicit Aspect Identification. We provide an improvement for SVM kernel computation to support the IAI task through the use of WordNet semantic relations. For empirical evaluation, experiments are conducted on three datasets of laptop reviews, electronic product reviews, and restaurant reviews, and the effects of our approach on SVM performance are examined and analyzed according to three criteria: (i) kernel function used, (ii) different experimental settings, and (iii) SVM behavior under Overfitting and Underfitting.

The key conclusions of our research can be summarized as follows:

- a) Our technique helps SVM improve its performance under different experimental settings and for the three considered kernels and datasets.
- b) Our method helps SVM deal with Overfitting and Underfitting more effectively by minimizing their effects on SVM and thereby enhancing its performance.

Even though our approach helps SVM classifier better deal with some of its main issues, it has some limitations at different levels:

- Machine learning model: it only uses one popular eager machine learning model. It would be more interesting to test other types of machine learning models such as lazy or deep learning techniques.
- WordNet semantic relations: it uses only one semantic relation which is "definition relation". It would be also more interesting to explore other semantic relations offered by WordNet like synonyms, antonyms, and their combinations. These relations seem to have significant linguistic importance that may help improve machine learning models to address their critical issues when applied to IAI.
- Datasets used: it uses three datasets that are medium-sized and noise-free that better suit the SVM classification model. We plan to use other less suitable datasets like noisy and large data which present many challenges to the SVM model.

Future work will investigate the use of our method to improve SVM model with non-distance-based kernels and evaluate it under different aspects like dataset size, curse of dimensionality, and noise tolerance. It will also look into considering our approach to address the above-mentioned limitations of our work.

REFERENCES

- [1] Chowdhary, K.R. (2020). Natural Language Processing. In: Fundamentals of Artificial Intelligence. Springer, New Delhi. https://doi.org/10.1007/978-81-322-3972-7_19
- [2] A. Tripathy, A. Anand, and S.K. Rath, "Document-level Sentiment Classification using Hybrid Machine Learning Approach," Knowledge Information Systems, vol. 53, no. 3, pp. 805831, 2017.
- [3] B. Liu, "Sentiment Analysis and Subjectivity," Handbook of Natural Language Processing, pp. 627-666, 2010.
- [4] K. Schouten and F. Frasinca, "Survey on Aspect-Level Sentiment Analysis," IEEE Trans. Knowledge and Data Eng., vol. 28, no. 3, pp. 813-830, 2016.
- [5] B. Liu, Mingqing Hu, and Junsheng Cheng. Opinion observer: analyzing and comparing opinions on the web. In WWW '05, 2005.
- [6] Li Sun, Sheng Li, Jiyun Li, and JuTao Lv. A novel context-based implicit feature extracting method. 2014 International Conference on Data Science and Advanced Analytics (DSAA), pages 420–424, 2014.
- [7] Geli Fei, B. Liu, Meichun Hsu, Malú Castellanos, and Riddhiman Ghosh. A dictionary-based approach to identifying aspects implied by adjectives for opinion mining. In COLING, 2012.
- [8] Michael E. Lesk. Automatic sense disambiguation using machine readable dictionaries: how to tell a pine cone from an ice cream cone. In SIGDOC '86, 1986.
- [9] Weaver, Warren. 1955. Translation. In William N. Locke and A. Donald Booth, editors, Machine Translation of Languages. John Wiley & Sons, New York, pages 15-23. (Reprint of mimeographed version, 1949.)
- [10] Ide, Nancy & Véronis, Jean (1998). Word sense disambiguation: The state of the art. Computational Linguistics. 24. 1-41.
- [11] Marco Maru, Simone Conia, Michele Bevilacqua, and Roberto Navigli. 2022. Nibbling at the Hard Core of Word Sense Disambiguation. In Proceedings of the 60th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers), pages 4724–4737, Dublin, Ireland. Association for Computational Linguistics.
- [12] Simone Conia and Roberto Navigli. 2021. Framing word sense disambiguation as a multi-label problem for model-agnostic knowledge integration. In Proceedings of the 16th Conference of the European Chapter of the Association for Computational Linguistics: Main Volume, pages 3269–3275, Online. Association for Computational Linguistics.
- [13] George A. Miller. Wordnet: A lexical database for english. Communications of the ACM, 38:39–41, 1992.
- [14] Zhou, J, JX Huang, Q Chen, QV Hu, T Wang and L He (2019). Deep learning for aspect-level sentiment classification: Survey, vision, and challenges. IEEE Access, 7, 78454–78483.
- [15] Tubishat, M, N Idris and MAM Abushariah (2018). Implicit aspect extraction in sentiment analysis: Review, taxonomy, opportunities, and open challenges. Information Processing & Management, 54(4), 545–563.
- [16] Agarwal, B and N Mittal (2016). Semantic orientation-based approach for sentiment analysis. In Prominent Feature Extraction for Sentiment Analysis, B Agarwal and N Mittal (eds.), pp. 77–88. Springer International Publishing.
- [17] Geli Fei, B. Liu, Meichun Hsu, Malú Castellanos, and Riddhiman Ghosh. A dictionary-based approach to identifying aspects implied by adjectives for opinion mining. In COLING, 2012.
- [18] Hajar El Hannach and M. Benkhalifa. Using synonym and definition wordnet semantic relations for implicit aspect identification in sentiment analysis. In NISS19, 2019.
- [19] Hajar El Hannach and M. Benkhalifa. A new semantic relations-based hybrid approach for implicit aspect identification in sentiment analysis. Journal of Information and Knowledge Management, 19:2050019:1–2050019:37, 2020.
- [20] Kim Schouten and Flavius Frasinca. Finding implicit features in consumer reviews for sentiment analysis. In ICWE, 2014.
- [21] Kim Schouten, Onne van der Weijde, Flavius Frasinca, and Rommert Dekker. Supervised and unsupervised aspect category detection for sentiment analysis with co-occurrence data. IEEE Transactions on Cybernetics, 48:1263–1275, 2018.
- [22] Devi Sri Nandhini, M., Pradeep, G. A Hybrid Co-occurrence and Ranking-based Approach for Detection of Implicit Aspects in Aspect-Based Sentiment Analysis. SN COMPUT. SCI. 1, 128 (2020). <https://doi.org/10.1007/s42979-020-00138-7>
- [23] Rana TA, Cheah YN. Hybrid rule-based approach for aspect extraction and categorization from customer reviews. In: IT in Asia (CITA), 2015 9th international conference on IEEE, p. 1–5, 2015.
- [24] M. Sivakumar and U. S. Reddy, "Aspect based sentiment analysis of students opinion using machine learning techniques," 2017 International Conference on Inventive Computing and Informatics (ICICI), 2017, pp. 726-731, doi: 10.1109/ICICI.2017.8365231.
- [25] Gupta, Deepak & Ekbal, Asif. (2014). IITP: Supervised Machine Learning for Aspect based Sentiment Analysis. 319-323. 10.3115/v1/S14-2053.
- [26] Aitor García-Pablos, Montse Cuadros, and German Rigau. W2vlda: Almost unsupervised system for aspect based sentiment analysis. Expert Systems with Applications, 91:127–137, 2018.

- [27] Soujanya Poria, Iti Chaturvedi, E. Cambria, and Federica Bisio. Sentic LDA: Improving on LDA with semantic similarity for aspect-based sentiment analysis. 2016 International Joint Conference on Neural Networks (IJCNN), pages 4465–4473, 2016.
- [28] Pathik, N.; Shukla, P. Aspect Based Sentiment Analysis of Unlabeled Reviews Using Linguistic Rule Based LDA. *Journal of Cases on Information Technology (JCIT)* 2022, 24, 1–9.
- [29] Soni, P. K., Rambola, R. (2021). Deep Learning, WordNet, and spaCy based Hybrid Method for Detection of Implicit Aspects for Sentiment Analysis. 1–6. <https://doi.org/10.1109/conit51480.2021.9498372>
- [30] Ajeet Ram Pathak, Manjusha Pandey, Siddharth Rautaray, Topic-level sentiment analysis of social media data using deep learning, *Applied Soft Computing*, Volume 108, 2021, 107440, ISSN 1568-4946, <https://doi.org/10.1016/j.asoc.2021.107440>.
- [31] Ganpat Singh Chauhan, Yogesh Kumar Meena, Dinesh Gopalani, Ravi Nahta, A two-step hybrid unsupervised model with attention mechanism for aspect extraction, *Expert Systems with Applications*, Volume 161, 2020, 113673, ISSN 0957-4174, <https://doi.org/10.1016/j.eswa.2020.113673>.
- [32] Vapnik VN (1995) *The nature of statistical learning theory*. Springer Verlag, New York.
- [33] Ivan Cruz, Alexander Gelbukh, and Grigori Sidorov. Implicit aspect indicator extraction for aspect-based opinion mining. *International Journal of Computational Linguistics and Applications*, 5:135–152, 2014.
- [34] Gayatree Ganu, Noémie Elhadad, and Amélie Marian. Beyond the stars: Improving rating predictions using review text content. In *WebDB*, 2009.
- [35] Maria Pontiki, Dimitris Galanis, John Pavlopoulos, Harris Papageorgiou, Ion Androutsopoulos, and Suresh Manandhar. SemEval-2014 task 4: Aspect based sentiment analysis. In *Proceedings of the 8th International Workshop on Semantic Evaluation (SemEval 2014)*, pages 27–35, Dublin, Ireland, August 2014. Association for Computational Linguistics.
- [36] Mingqing Hu and Bing Liu. Mining and summarizing customer reviews. *Proceedings of the tenth ACM SIGKDD international conference on Knowledge discovery and data mining*, 2004.
- [37] Maria Pontiki, Dimitrios Galanis, Harris Papageorgiou, Suresh Manandhar, and Ion Androutsopoulos. 2015. SemEval-2015 Task 12: Aspect Based Sentiment Analysis. In *Proceedings of the 9th International Workshop on Semantic Evaluation*, Denver, Colorado.
- [38] Pontiki, Maria & Galanis, Dimitris & Papageorgiou, Haris & Androutsopoulos, Ion & Manandhar, Suresh & AL-Smadi, Mohammad & Al-Ayyoub, Mahmoud & Zhao, Yanyan & Qin, Bing & de clerq, Orphee & Hoste, Véronique & Apidianaki, Marianna & Tannier, Xavier & Loukachevitch, Natalia & Kotelnikov, Evgeny & Bel, Nuria & Zafra, Salud María & Eryigit, Gülşen. (2016). SemEval-2016 Task 5: Aspect Based Sentiment Analysis. 19-30. 10.18653/v1/S16-1002.
- [39] B.C. Vickery. *Reviews : van rijsbergen, c. j. information retrieval*. 2nd edn. london, butterworths,1978. 208pp. *Journal of librarianship*, 11(3):237–237, 1979.
- [40] Benarafa Halima, Benkhalifa Mohammed & Akhloufi Moulay, WordNet Semantic Relations Based Enhancement of KNN Model for Implicit Aspect Identification in Sentiment Analysis. *Int J Comput Intell Syst* 16, 3 (2023). <https://doi.org/10.1007/s44196-022-00164-8>

Ethereum Cryptocurrency Entry Point and Trend Prediction using Bitcoin Correlation and Multiple Data Combination

Abdellah EL ZAAR¹, Nabil BENAYA², Hicham EL MOUBTAHIJ³,
Toufik BAKIR⁴, Amine MANSOURI⁵, Abderrahim EL ALLATI⁶
Laboratory of R and D in Engineering Sciences, FST Al-Hoceima,
Abdelmalek Essaadi University, Tetouan, Morocco^{1,2,6}
Higher School of Technology, University Ibn Zohr, Agadir, Morocco³
IMVIA Laboratory, University of Burgundy, Dijon, France^{4,5}

Abstract—Deep learning methods have achieved significant success in various applications, including trend signal prediction in financial markets. However, most existing approaches only utilize price action data. In this paper, we propose a novel system that incorporates multiple data sources and market correlations to predict the trend signal of Ethereum cryptocurrency. We conduct experiments to investigate the relationship between price action, candlestick patterns, and Ethereum-Bitcoin correlation, aiming to achieve highly accurate trend signal predictions. We evaluate and compare two different training strategies for Convolutional Neural Networks (CNNs), one based on transfer learning and the other on training from scratch. Our proposed 1-Dimensional CNN (1DCNN) model can also identify inflection points in price trends during specific periods through the analysis of statistical indicators. We demonstrate that our model produces more reliable predictions when utilizing multiple data representations. Our experiments show that by combining different types of data, it is possible to accurately identify both inflection points and trend signals with an accuracy of 98%.

Keywords—Deep learning; cryptocurrency; bitcoin trend prediction; price action; convolutional neural network; transfer learning

I. INTRODUCTION

Trading refers to buying and selling operations carried out on the financial markets. These operations are executed by traders from the trading room of a financial organization or the stock market institution, or from the Internet in the case of independent traders. The operations in financial markets are made in a secure and controlled environment which brings together hundreds of thousands of market participants who wish to buy and sell shares. The buying and selling activities operate electronically on well known platforms for trading. These platforms contain all information and tools that the trader needs to analyse the different markets. Hence, a strong knowledge about the market psychology is essential to trade in the live market. In trading, market movement can be observed and analyzed through various types of trading charts. These charts often contain technical indicators that assist traders in accurately predicting market trends and trading signals. Examples of popular trading charts include bar charts, line charts, point and figure charts, market profile charts, and candlestick charts. In this article, we will specifically focus on candlestick charts, which are widely used in financial markets

for their visual representation of price movements and patterns (see Fig. 1).



Fig. 1. Candlesticks chart : Ethereum vs US Dollar in daily time frame.

Candlestick charts offer unique visual indicators that differentiate them from other types of trading charts. The shapes and patterns of candlesticks on these charts can provide valuable insights into price action. Candlesticks come in various sizes, and understanding the psychology behind the different body sizes is crucial in trading. Each candlestick is formed using the open, high, low, and close prices of the chosen time frame, and analyzing these components can provide valuable information for traders (see Fig. 2). The graph chart contains several types of candles which are decisional and have a strong effect on market trend. The most powerful candlestick patterns are: bearish engulfing bar, bullish engulfing bar, Doji, morning star, evening star, Hammer, shooting star, Harami and the Tweezers tops and bottoms [1], [2], [3].

In this research paper, we have implemented a deep learning algorithm based on Convolutional Neural Networks (CNNs) to predict the trend of Ethereum cryptocurrency. The main objective of this work is to develop an intelligent trading system that can assist traders in automating their trades, predicting market trends, and mitigating high volatility. The proposed system is designed to identify high probability setups and maximize profits. To achieve accurate predictions, we have utilized different data representations. We have found that combining multiple data representations significantly improves the efficiency of the algorithms during the training process, enabling them to learn data dependencies with high accuracy.

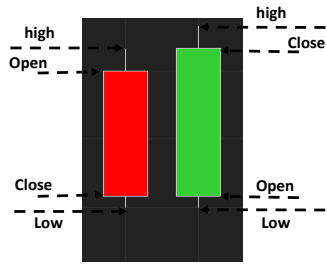


Fig. 2. Candlestick price levels.

In addition to incorporating candlestick pattern data and statistical indicators, we have also considered the Ethereum-Bitcoin correlation to precisely identify Ethereum price action.

When using such structured data, a Convolutional Neural Network (CNN) is superior for learning features dependencies in wide datasets. In addition to that, CNN can also provide satisfactory performance with 1-dimensional data [4], [5], [6], [7], [8]. When working with time series data, Long Short-Term Memory (LSTM) algorithm can also learn easily temporal patterns and dependencies using memory cells and gates [9], [10], [11], [12], [13]. To find the most effective architecture, two different 1-Dimensional Convolutional Neural Network training strategies are evaluated and tested : training from scratch strategy and transfer learning strategy.

The current state-of-the-art research in the field of financial time series forecasting using deep learning has primarily overlooked the relationship between predicted market movements and the optimal trading entry point [14], [15], [16]. Financial time series data often contain significant noise, posing challenges for accurate analysis and predictions. Notably, Ethereum cryptocurrency exhibits a price action pattern that closely resembles Bitcoin. However, Ethereum demonstrates comparatively less noise in its price action chart. The presence of fake breakouts and high volatility are considered major hurdles in employing deep learning for financial time series prediction. To address the issue of noise in financial time series data, particularly in the case of cryptocurrency markets like Ethereum, we employed 1D Convolutional Neural Networks (1DCNN) using various strategies. Utilizing 1D Convolutional Neural Networks (1DCNN) is a robust approach for analyzing financial time series data. These networks have demonstrated significant potential in capturing meaningful patterns and dependencies in sequential data. When applied to financial time series, 1DCNNs can effectively learn and extract relevant features such as price fluctuations, trends, and patterns from the input data. The inherent capability of 1DCNNs to capture both local and global dependencies makes them highly suitable for modeling complex relationships in financial time series. By leveraging their multi-layered architecture and convolutional operations, 1DCNNs can uncover valuable insights, enhance prediction accuracy, and assist in decision-making processes related to trading and investment strategies. In order to ensure precise trading entry points, we meticulously collected the data and performed comprehensive feature engineering. We trained and tested three learning strategies based on 1DCNN to compare their performance and determine the most effective strategy. 1DCNN have proven to be highly proficient in identi-

fying short trends and establishing optimal trading entry points. Leveraging their specialized architecture and convolutional operations, 1DCNNs excel at capturing local dependencies and extracting relevant features from sequential financial data. By analyzing price fluctuations and other pertinent information, 1DCNNs can effectively detect and interpret short-term trends, providing valuable insights to traders. These networks possess the capability to uncover subtle patterns that might elude human analysts, leading to enhanced prediction accuracy and informed decision-making for trading strategies. With their robust ability to learn complex relationships within financial time series data, 1DCNNs have emerged as a powerful tool in the field of financial analysis, contributing significantly to successful trading strategies. To the best of our knowledge, this is the first work that uses market correlation combined with price action and moving average data to predict the Ethereum trend signal. Market correlation helps to understand the behaviour of price action and avoid volatility. In our case study, we based on Ethereum and Bitcoin correlation (Fig. 3). These two markets have strong relationship and have almost same price action.



Fig. 3. ETH-BTC correlation.

It can be seen from Fig. 3 that Ethereum and Bitcoin have the same price movement, the thing that facilitates Ethereum trend prediction. This price correlation data combined with the other data representation that we used, can ameliorate the accuracy of our model. A detailed study is presented in Section IV. The rest of the paper is organised as follows: In Section II, we give a brief overview of some significant and recent contributions to market trend prediction using deep learning approaches and Section III describes the proposed approach.

II. RELATED WORK

The majority of works done in the field of market trend prediction using deep learning refer to the data issued from technical analysis of the market. This data is used to train machine learning models. Technical analysis aims to study market behaviour throughout price action data, statistical indicators and news. In the chart of the market, candlestick patterns Fig. 2 are considered as an important visual indicator that can help to analyse the price movement. These patterns are also used to predict the trend of the market. For example, in [17], J.Hao Chen and Y.Cheng Tsai proposed a two-step approach based on a GAF-CNN algorithm to recognize candlestick patterns automatically. They were able to identify eight types of candlestick patterns with 90.7%. In [18], the authors introduced a deep learning-based approach to forecast

trend signals and determine trading entry points. Their method combines LSTM, 1DCNN, and the XGBoost algorithm. The experimental results demonstrate that their approach achieves a high level of accuracy in both predicting market movements and identifying optimal trading entry points. PL Seabe et al. [19], proposed three types of Recurrent Neural Networks (RNNs): Long Short-Term Memory (LSTM), Gated Recurrent Unit (GRU), and Bi-Directional LSTM (Bi-LSTM) for predicting exchange rates of three prominent cryptocurrencies: Bitcoin (BTC), Ethereum (ETH), and Litecoin (LTC), based on their market capitalization. The proposed methodology demonstrates high performance, with Bi-LSTM exhibiting the most accurate predictions compared to GRU and LSTM. The Mean Absolute Percentage Error (MAPE) values for BTC, LTC, and ETH are reported as 0.036, 0.041, and 0.124, respectively, indicating the superior predictive capabilities of Bi-LSTM in this context. RMI.Kusuma et al. [20] used the Convolutional Neural Network to perform candlestick analysis, their method provides a satisfactory result with a recognition score of 92%. A. Andriyanto, A. Wibowo and NZ.Abidin [21] presented a CNN approach to identify the strength of a trend pattern in the movement of the stock market, the proposed approach produces an accuracy of 99% with a remarkable noise during the training process, this problem generally is behind the noisy dataset and a non suitable CNN strategy during the training process. In [22], JH.Chen et al. provide an approach based on the local search adversarial attacks algorithm to predict the patterns of candlesticks. The applied strategy gives good results with an attack ratio of 64.36%. J.Chen et al. [23] propose modeling strategies based on machine learning (ML) techniques. They introduce a vector autoregression (VAR)-based rolling prediction model for forecasting stock prices and a Gaussian feed-forward neural networks (GFNN)-based graphical signal identification method to recognize different types of stock price signals. The experimental results demonstrate improved performance; however, the method encounters challenges when dealing with high volatility signals. These difficulties can significantly impact trading strategies and long-term cumulative profits. In case of Bitcoin trend prediction, S.cavalli and M.Amoretti [24], proposed a methodology for building useful datasets that take into account social media data, the full blockchain transaction history, and a number of financial indicators. The data was trained and tested using CNN model with an accuracy of 74.2%. M Poongodi et al. [25] combined the Latent Dirichlet Allocation (LDA) and Neural Network to predict the Bitcoin trend using data issued from social media and forums. S Alonso-Monsalve et al. [26], implemented and compared various Long Short-Term Memory (LSTM) and Convolutional Neural Network (CNN) architectures for predicting the trend of several cryptocurrencies, including Bitcoin, Dash, Ether, Litecoin, Monero, and Ripple. The proposed approaches demonstrated promising results, particularly for Bitcoin, Ether, and Litecoin cryptocurrencies. In [27], M Poongodi et al. implemented two machine learning techniques to Predict the price of Ethereum blockchain cryptocurrency in an industrial finance system. When using their proposed model, the SVM method has a higher accuracy (96.06%) than the LR method (85.46%). This can be explained by the SVM ability to classify 1-Dimensional data. T. Shintate and L. Pichl [28] provided a trend prediction classification framework named the random sampling method (RSM) for cryptocurrency time series that are

non-stationary. Their proposed approach shows strong results and outperformed those based on LSTM.

III. PROPOSED APPROACH

The proposed approach for Ethereum entry point and signal prediction is illustrated in Fig. 4. The historical data of Ethereum and Bitcoin is extracted from the Exchange broker via the trading platform using python packages. The dataset is then used to train the Convolutional Neural Network (CNN) using two different strategies: 1-dimensional transfer learning and training from scratch strategy. The first block of the system extracts the Bitcoin OHLC dataset and the trend signal, then, it is combined with the price action of Ethereum and the data issued from the moving averages to predict the Ethereum trend. In the following we describe every Block in detail.

A. Dataset and Processing

The Bitcoin and Ethereum cryptocurrencies historical data is extracted from the Exchange via the Broker. The data is characterized by the Open, High, Low and Close of prices during a time interval. OHLC data is used to analyse the price movement and calculate the statistical indicators. The collected dataset contains the OHLC prices of 4 (four) hour timeframe during one year from 11/2021 to 11/2022 as indicated in the Fig. 5. Two important Moving averages are used to determine the entry point and the signal trend: Simple Moving Average (SMA) and Hull Moving Average (HMA).

The Table I shows the used dataset to train our proposed approach. The dataset contains OHLC prices and the calculated Moving averages in addition to the bitcoin trend (1 for uptrend and 0 for downtrend):

B. Ethereum and Bitcoin Correlation

As illustrated in Fig. 3, it can be seen that Bitcoin (BTC) and Ethereum (ETH) have almost the same price action. According to the correlation analysis, Bitcoin (BTC) and Ethereum (ETH) have a strong positive relationship from the period of 2019 to 2022. Notably, data from Coin Metrics (Fig. 6) highlighted that ETH-BTC correlation coefficient was nearing all-time high values, sitting at 0.90. For that reason we used BTC price action data to predict the movement and the signal trend of Ethereum cryptocurrency. The diversity and the quality of the data is very important to determine with high accuracy the trend signal of cryptocurrency markets. Therefore, we combined the price action data and the statistical indicators with the data provided by Bitcoin (BTC) price action to spot with high accuracy the trading entry point and price movement.

C. Ethereum and Moving Averages

Concerning the statistical indicators, we choose to work with both SMA (Simple Moving Average) and HMA (hull moving average). SMA indicator calculates the average of recent prices by the number of periods within this range of prices. SMA can be described by the following formula:

$$SMA = \frac{\sum_1^n P_n}{N} \quad (1)$$

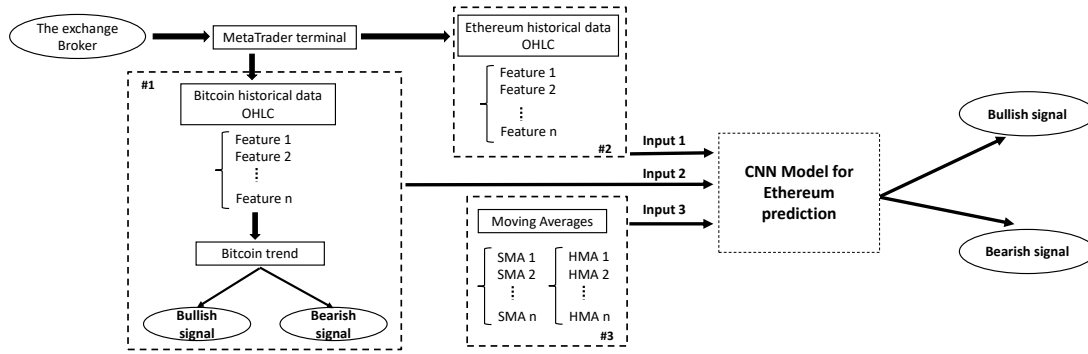


Fig. 4. System overview.

TABLE I. OHLC DATASET COMBINED WITH HMA, SMA INDICATORS AND BITCOIN TREND SIGNAL

	open	high	low	close	close_HMA_361	Close_SMA_19	BTC trend	Ethereum Trend
378	1733.25	1813.23	1729.69	1807.71	1705.174187	1805.202105	1	01
379	1807.71	1818.01	1763.28	1790.32	1705.906096	1808.170526	1	01
380	1790.32	1840.95	1782.22	1837.21	1706.676816	1813.645263	1	01
381	1839.34	1841.54	1790.68	1806.32	1707.426536	1814.555263	1	01
382	1806.32	1822.66	1792.01	1807.52	1708.156744	1812.817895	1	01
...
1359	3158.43	3167.58	3062.28	3102.27	3445.458519	3242.601579	0	00
1360	3102.27	3130.62	3052.56	3099.67	3448.097849	3230.160526	0	00
1361	3100.33	3149.47	3075.14	3112.04	3450.442989	3218.079474	0	00
3825	1307.58	1323.95	1307.09	1318.33	1233.700725	1295.621053	1	01
3826	1318.36	1336.41	1317.89	1328.69	1234.024134	1295.136842	1	01



(a) BTC close prices.



(b) ETH close prices.

Fig. 5. Bitcoin and Ethereum close prices from 11/2021 to 11/2022.

P_n represents the closing price at specific period n , and N is the number of total periods. In this work we chose period (19) which reacts perfectly with the price.

HMA indicator can be calculated using two WMAs (Weighted Moving Average): one with the specified number of periods and one with half the specified number of periods.

$$WMA_1 = WMA(n/2) \tag{2}$$

$$WMA_2 = WMA(n) \tag{3}$$

Then, we calculate the non-smoothed Hull Moving Average:

$$HMA_{nonsth} = (2 \times WMA_1) - WMA_2 \tag{4}$$

The final smooth HMA is calculated with periods of non-smoothed HMA with the following formula:

$$HMA_{sth} = WMA(\sqrt{n}) \tag{5}$$

n represents periods of non smoothed HMA

In addition to their capacity to show the price movement, moving averages are also used to spot trend reversals and the inflection point of the market. It can be seen from the Fig. 7 that SMA(19) is more responsive to the price action and turns quickly than the HMA(361).

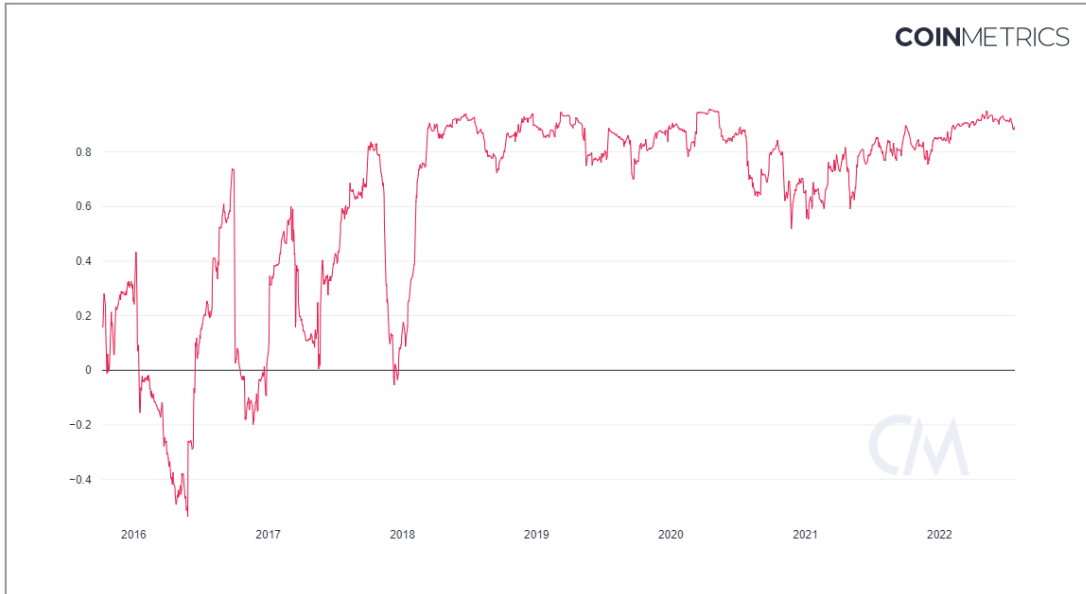


Fig. 6. Ehterium and Bitcoin (ETH-BTC) correlation chart based on coin metrics from 2016 to 2022.

The computation for the technical indicators relies on a number of n periods, that was set to 19 candlestick bars (4 hours time frame) for the Simple Moving Average (SMA) indicator, and 361 candlestick bars for Hull Moving Average (HMA) indicator. This parameter was defined at the start and it is optimized. The cross between the two moving averages using the optimised periods provide an excellent trading entry point. In addition to that it provides the start of the price movement.



Fig. 7. Hull moving average(HMA) period 19 and simple moving average(SMA) period 361 crossover.

A crossover occurs when two different moving average lines cross over one another. As indicated in Fig. 7 above, the red entry point marks the beginning of the signal trend and we have a bearish crossover. This takes place when a fast moving average (SMA 19) crosses down through a slow moving average (HMA 361). This implies that the trend is falling or becoming bearish.

At the green entry point, the trend changes again and this produces a bullish crossover. The fast moving average (SMA 19) is the first to react. It crosses up through the slow line (HMA 361). After the crossing, the two lines then follow the same path as the trend continues upwards.

D. CNN Architectures

To determine the entry point and the trend of the Ethereum crypto-currency we implemented the Convolutional Neural Network. CNN algorithm is used to train our collected 1-Dimensional Data. Convolution and pooling layers are configured to learn 1D features using two different strategies: CNN learned from scratch and 1D transfer learning (see Fig. 8).

The two strategies are built using the convolutional neural network architecture indicated in Fig. 9. The output dimensions after every layer is presented in the Table II.

TABLE II. MODEL SUMMARY

Layer (type)	Output Shape	Param #
conv1d_1 (Conv1D)	(None, 7, 64)	192
conv1d_2 (Conv1D)	(None, 6, 64)	8256
max_pooling1d_1 (MaxPooling1D)	(None, 3, 64)	0
conv1d_3 (Conv1D)	(None, 2, 128)	16512
conv1d_4 (Conv1D)	(None, 2, 128)	16512
max_pooling1d_2 (MaxPooling1D)	(None, 2, 128)	0
flatten_1 (Flatten)	(None, 256)	0
dense_1 (Dense)	(None, 256)	65792
dropout_1 (Dropout)	(None, 256)	0
dense (Dense)	(None, 2)	514
Total params: 107,778		
Trainable params: 107,778		
Non-trainable params: 0		

The Table I indicates the data fed to convolutional neural network. The data contains seven (7) features: The Open, High, Low and Close (OHLC) features of Ethereum (ETH), the moving averages (SMA 19) and (HMA 361) of Ethereum (ETH) and Bitcoin (BTC) Trend. For the training from scratch strategy, the data is fed from the input to the output of the model, the output. In other side, the proposed 1-Dimensional transfer learning strategy consists on transferring the knowledge from a pretrained model using different dataset to a tar-

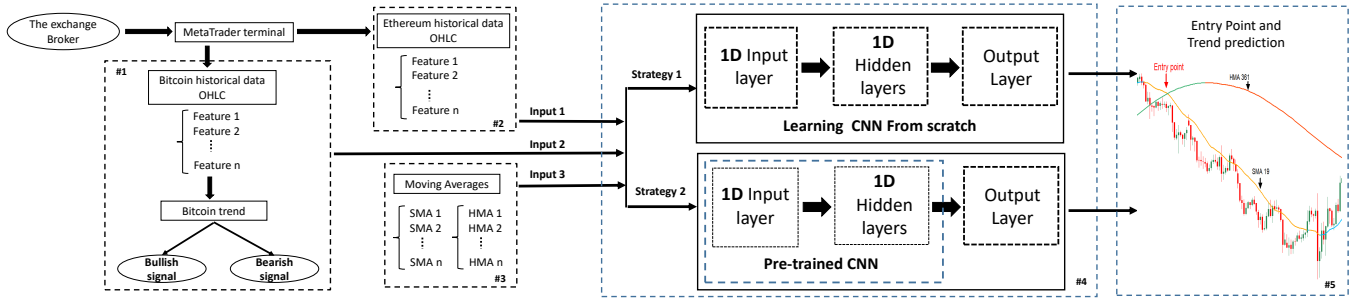


Fig. 8. CNN strategies.

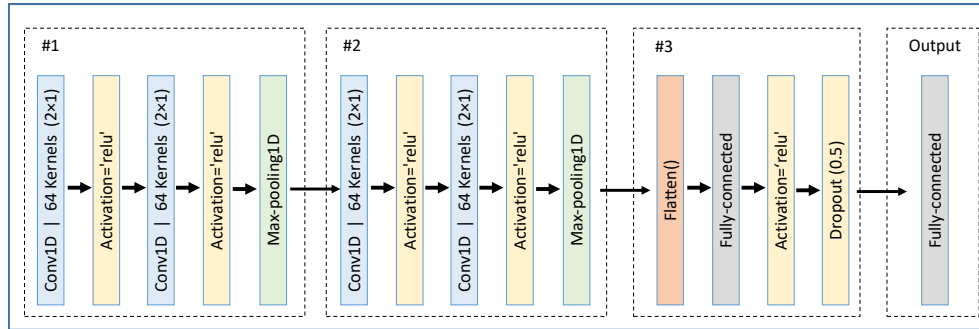


Fig. 9. CNN model architecture.

geted model (see Fig. 8). The pretrained model is trained using BTC OHLC dataset and used to perform the transfer learning strategy. The implementation of pre-trained models offers several benefits in analyzing the Ethereum cryptocurrency market. These models facilitate the extraction of pertinent features and the recognition of common patterns and interdependencies, thereby enhancing the accuracy of forecasts and enabling better decision-making. The potential implications of employing one-dimensional transfer learning in finance are promising, as they have the potential to yield excellent results.

IV. EXPERIMENTS AND RESULTS

A. Experiments and Parameterization

In this section we present the model behaviour and results using the approaches identified in Section III. The two approaches are evaluated in term of Training accuracy, training loss, testing accuracy and testing loss. The experiments were conducted using a system running on a six (06) core processor equipped with 56Go of RAM. The algorithms were implemented using the Python language and processed a multivariate dataset with 10747 samples. The experimental procedure starts with preparing the dataset. After the step of data collection and organisation mentioned in Section III-A, the data were saved in the CSV format for preprocessing convenience. As illustrated in Fig. 7, the entry point occurs when the two moving averages crossover is happening. Therefore, the trader can choose to buy if it is a bullish crossover or sell if it is a bearish crossover. In our case the entry point and also the trend signal are predicted by the proposed algorithms using the collected dataset attributes and parameters (Section III). The training accuracy according to the learning rate, the number of

fully connected layers and Epochs of both learning strategies is indicated in Tables III, IV, VI, VII, V and VIII.

TABLE III. ACCURACY OF CONVOLUTIONAL NEURAL NETWORK TRAINED FROM SRATCH ON TRAINING DATA

Model: 1D CNN		Epochs		
FC layers	Learning rate	100	150	200
1	0.1	0.5020	0.5031	0.5046
	0.01	0.5172	0.5215	0.5211
	0.001	0.9984	0.9998	1.000
	0.0001	0.9891	0.9943	0.9959
2	0.1	0.5212	0.5215	0.5180
	0.01	0.5277	0.5278	0.5125
	0.001	0.9934	0.9979	0.9998
	0.0001	0.9884	0.9876	1.0000
3	0.1	0.5023	0.5040	0.5048
	0.01	0.5171	0.5215	0.5217
	0.001	0.9751	0.9980	0.9999
	0.0001	0.9952	1.000	1.0000

B. Results and Discussion

In the study, the multi-layer perceptron was used as baseline. The sensitivity of the multi-layer perceptron was studied using different learning rates and a variety of the number of the fully connected layers (see Tables V and VIII). The accuracy metrics are calculated to compare the effectiveness of the proposed approaches using Training and validation data sets. In general both 1DCNN trained from scratch and 1D transfer learning using CNN provides high accuracy during the training and validation. When analysing the 1DCNN training from scratch accuracy (see Tables III VI), it can be seen that the learning strategy provides high accuracy only for Learning rate (LR) is superior or equal to

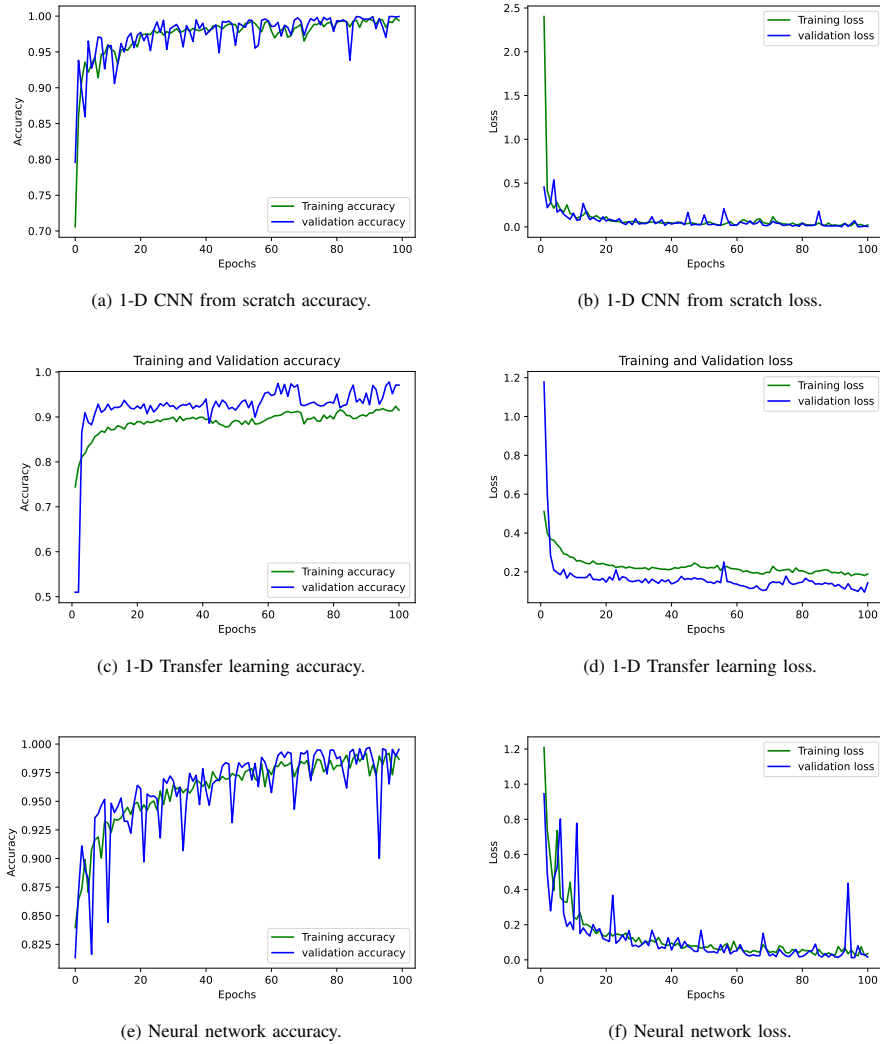


Fig. 10. Proposed approaches behaviour during the training and validation steps.

TABLE IV. ACCURACY OF CONVOLUTIONAL NEURAL NETWORK USING 1-D TRANSFER LEARNING STRATEGY ON TRAINING DATA

Model: 1D CNN		Epochs		
FC layers	Learning rate	100	150	200
1	0.1	0.4974	0.5047	0.5145
	0.01	0.8037	0.8362	0.8586
	0.001	0.9074	0.9337	0.9405
	0.0001	0.8822	0.9180	0.9391
2	0.1	0.5009	0.5131	0.5079
	0.01	0.8192	0.8589	0.8845
	0.001	0.9072	0.9130	0.9394
	0.0001	0.8815	0.9203	0.9318
3	0.1	0.5125	0.5093	0.5102
	0.01	0.7475	0.7487	0.7484
	0.001	0.9245	0.9142	0.9104
	0.0001	0.8768	0.9220	0.9271

TABLE V. ACCURACY OF NEURAL NETWORK ON TRAINING DATA

Model: NN		Epochs		
FC layers	Learning rate	100	150	200
1	0.1	0.5119	0.5055	0.5137
	0.01	0.5215	0.5215	0.5215
	0.001	0.9754	0.9860	0.9875
	0.0001	0.8026	0.8786	0.9063
2	0.1	0.5064	0.5169	0.5073
	0.01	0.5215	0.5215	0.5215
	0.001	0.9948	0.9997	1.0000
	0.0001	0.9729	0.9767	0.9721
3	0.1	0.5111	0.5084	0.5093
	0.01	0.5195	0.5215	0.5215
	0.001	0.9789	0.9846	0.9968
	0.0001	0.9500	0.9660	0.9805

0.001 for both Training and validation data and regardless of the number of the Fully connected layers. In case of 1D transfer learning strategy, it can be seen from Tables IV

and VII that the model shows high accuracy for learning rate equal or superior to 0.01. Deep neural networks are very sensitive to the learning rate value. A large value of LR may result an unstable training process as is the case when using both strategies with a LR=0.1, whereas a value

TABLE VI. ACCURACY OF CONVOLUTIONAL NEURAL NETWORK TRAINED FROM SCRATCH ON VALIDATION DATA

Model: 1D CNN				
FC layers	Learning rate	Epochs		
		100	150	200
1	0.1	0.5099	0.5099	0.5099
	0.01	0.5099	0.5099	0.5099
	0.001	1.0000	1.0000	1.0000
	0.0001	0.9971	0.9988	0.9994
2	0.1	0.5099	0.5099	0.5099
	0.01	0.5099	0.5099	0.5000
	0.001	1.0000	1.0000	1.0000
	0.0001	0.9983	0.9936	1.0000
3	0.1	0.5099	0.4901	0.5099
	0.01	0.5099	0.5099	0.5099
	0.001	0.9762	0.9843	1.0000
	0.0001	0.9988	1.0000	1.0000

TABLE VII. ACCURACY OF CONVOLUTIONAL NEURAL NETWORK USING 1-D TRANSFER LEARNING STRATEGY ON VALIDATION DATA

Model: 1D CNN				
FC layers	Learning rate	Epochs		
		100	150	200
1	0.1	0.5099	0.5099	0.5099
	0.01	0.8558	0.8698	0.9198
	0.001	0.9215	0.9733	0.9843
	0.0001	0.9657	0.9866	0.9953
2	0.1	0.5099	0.5099	0.5099
	0.01	0.8552	0.8599	0.8622
	0.001	0.9320	0.9797	0.9785
	0.0001	0.9651	0.9913	0.9907
3	0.1	0.5099	0.5099	0.5099
	0.01	0.9209	0.9820	0.8762
	0.001	0.9651	0.9750	0.9895
	0.0001	0.9692	0.9878	0.9913

too small may cause a long training process but effective. Learning rate refers to the step size that the weights are updated during training. It is a configurable hyper-parameter often in the range between 0.01 and 1.0. When analysing the model behaviour during the training process, it can be seen from Fig. 10 that the multilayer perceptron is unstable compared with the 1DCNN using learning from scratch and transfer learning strategies. This can be explained by the ability of CNN to learn perfectly data dependencies using the convolution and pooling functions. It can be analyzed also that the accuracy of 1DCNN attained 98.6% without overfitting and perturbations during the training process. The 1DCNN trained from scratch exhibits superior performance compared to the transfer learning strategy and the Multilayer Perceptron. Although the transfer learning strategy and the Multilayer Perceptron achieve high accuracy, the training process lacks stability. This observation can be attributed to the remarkable ability of the 1DCNN trained from scratch to accurately capture dependencies, particularly when analyzing Ethereum close price data. To evaluate and test our model architectures, we used a test data which was not used for training and validation. Fig. 11a, 11b and 11c show the confusion matrices of the proposed approaches. The x-axis is the prediction and the y-axis is the true label. We observe that the three methods work perfectly on test data

It can be seen from the Tables IX, X, XI and XII that all the used methods perform perfectly with the unseen test data.

TABLE VIII. ACCURACY OF NEURAL NETWORK ON VALIDATION DATA

Model: NN				
FC layers	Learning rate	Epochs		
		100	150	200
1	0.1	0.5099	0.5099	0.5099
	0.01	0.5099	0.5099	0.5099
	0.001	0.9872	0.9988	0.9983
	0.0001	0.8238	0.8715	0.8953
2	0.1	0.5099	0.5099	0.5099
	0.01	0.5099	0.5099	0.5099
	0.001	0.9988	0.9994	1.0000
	0.0001	0.9500	0.9448	0.9483
3	0.1	0.5099	0.5099	0.5099
	0.01	0.5099	0.5099	0.5099
	0.001	0.9913	0.9930	0.9953
	0.0001	0.9715	0.9866	0.9901

TABLE IX. CLASSIFICATION REPORT USING CNN FROM SCRATCH

Class	Precision	Recall	F-score	Support
0	1.00	1.00	1.00	1003
1	1.00	1.00	1.00	1146
micro avg	1.00	1.00	1.00	2149
macro avg	1.00	1.00	1.00	2149
avg	1.00	1.00	1.00	2149

TABLE X. CLASSIFICATION REPORT CNN USING TRANSFER LEARNING STRATEGY

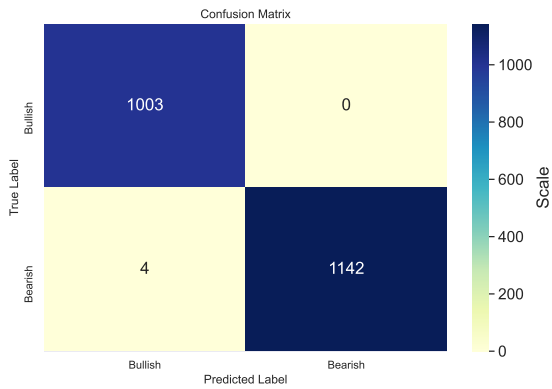
Class	Precision	Recall	F-score	Support
0	0.98	0.98	0.98	1003
1	0.98	0.98	0.98	1146
micro avg	0.98	0.98	0.98	2149
macro avg	0.98	0.98	0.98	2149
avg	0.98	0.98	0.98	2149

TABLE XI. CLASSIFICATION REPORT MLP

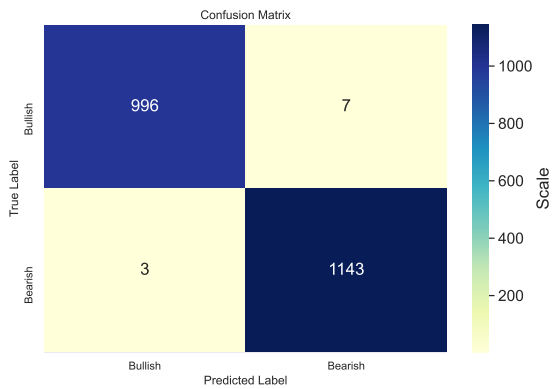
Class	Precision	Recall	F-score	Support
0	1.00	0.99	1.00	1003
1	0.99	1.00	1.00	1146
micro avg	1.00	1.00	1.00	2149
macro avg	1.00	1.00	1.00	2149
avg	1.00	1.00	1.00	2149

TABLE XII. PROPOSED MODEL STRATEGIES EVALUATION ON ACCURACY, PRECISION, RECALL AND F1 SCORE. WE USED A TEST DATA WHICH IS NOT USED IN TRAINING AND VALIDATION PROCESSES

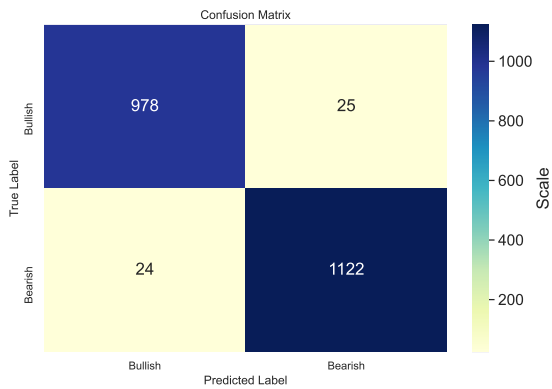
	Accuracy	Precision	Recall	F1 Score
Multi-layer perceptron	0.995	0.996	0.993	0.994
1D CNN trained from scratch	0.998	0.996	1.000	0.997
1D CNN and transfer learning	0.977	0.976	0.975	0.975



(a) 1-D CNN from scratch confusion matrix.



(b) Multilayer perceptron confusion matrix.



(c) 1-D Transfer learning confusion matrix.

Fig. 11. Confusion matrices.

Note that the 1 dimensional Convolutional Neural Network trained from scratch obtained the highest accuracy, recall, precision and F1 score. This can be explained by the ability of the CNN to learn perfectly dependencies on providing historical data.

C. Profitability

In this section we will provide profit results based on our 1-DCNN learned from scratch entry point and trend prediction. As mentioned in Section III, our model predicts the entry

point based on Simple Moving Average (SMA), Hull Moving Average (HMA) crossover and Bitcoin-Ethereum correlation. The proposed approach can predict with high accuracy the entry point and avoids the fake breakout.



Fig. 12. Profits based on 1D CNN from scratch entry point prediction.



Fig. 13. Predicted positions using 1D CNN from scratch close.



Fig. 14. Profits based on MLP entry point prediction.

It can be seen from the Fig. 12 That the proposed method based on 1D CNN trained from scratch can reach a profit of 7K dollars in 6 months (from the period of 6 June 2022 to 21 December 2022). Based on predicted entry points (see Fig. 13) which is 14% of the initial Balance (50K Dollars). For the multilayer perceptron (see Fig. 14), the profit is 4.9K dollars with 9.8% of the initial balance based on predicted positions (see Fig. 15). In other side, the predictions based on transfer learning strategy (see Fig. 16) give 7% of the initial balance with a profit of



Fig. 15. Predicted positions using MLP close.

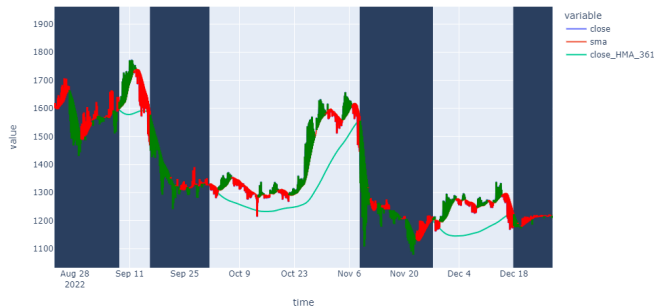


Fig. 16. Predicted positions using transfer learning close.



Fig. 17. Profits based on 1D CNN transfer learning entry point prediction.

TABLE XIII. PROFITABILITY BASED ON ENTRY POINTS PREDICTED BY THE PROPOSED APPROACHES FOR AN ACCOUNT OF 50K DOLLARS

Proposed approach	Profits (USD)	Ppercentage (%)
1D CNN transfer learning	3500	7%
Multilayer Perceptron	4900	9.8%
1D CNN trained from scratch	7000	14%

3.5K Dollars (see Fig. 17). The Table XIII summarizes the profitability percentage using each of the proposed algorithms.

V. CONCLUSION

Market movement and entry point prediction using Deep learning algorithms can help traders to automate their trades and make more profits. The most important thing in trading is controlling the emotions. Indeed, fear, doubt and impulsiveness are the most common causes of capital loss. However, the solution is to employ Deep learning algorithms and a strong strategy. In our case we combined the BTC-ETH correlation with two key moving averages periods HMA(361) and SMA(19). The proposed methods yielded highly accurate results. Therefore, the trained models can be deployed and implemented in real time. Compared with the transfer learning strategy, and the MLP algorithm, the training from scratch provides a higher accuracy (99.8%). The 1D transfer learning strategy can provide better results when working with very large datasets. The difference in accuracy between the transfer learning strategy and learning from scratch is about 2%. In term of profitability using unseen data, the entry points and positions predicted by the 1DCNN from scratch can reach a profit of 14% of the initial balance compared with 7% for the transfer learning strategy and 9.8% for the multilayer perceptron. As a perspective, the proposed approach can be developed to find the relationship between several cryptocurrencies to predict the most profitable position during specific time interval. Moreover, the proposed algorithms will help to avoid fake breakouts during trading and identify the real trends.

VI. DECLARATION OF COMPETING INTEREST

I declare that I have no Conflict of Interest.

REFERENCES

- [1] A. Heinz, M. Jamalooden, A. Saxena, and L. Pollacia, "Bullish and bearish engulfing japanese candlestick patterns: A statistical analysis on the s&p 500 index," *The Quarterly Review of Economics and Finance*, vol. 79, pp. 221–244, 2021.
- [2] R. Naranjo and M. Santos, "A fuzzy decision system for money investment in stock markets based on fuzzy candlesticks pattern recognition," *Expert Systems with Applications*, vol. 133, pp. 34–48, 2019.
- [3] A. Noertjahyana, Z. A. Abas, and Z. I. M. Yusoh, "Combination of candlestick pattern and stochastic to detect trend reversal in forex market," in *2019 4th Technology Innovation Management and Engineering Science International Conference (TIMES-iCON)*. IEEE, 2019, pp. 1–4.
- [4] S. Kiranyaz, O. Avci, O. Abdeljaber, T. Ince, M. Gabbouj, and D. J. Inman, "1d convolutional neural networks and applications: A survey," *Mechanical systems and signal processing*, vol. 151, p. 107398, 2021.
- [5] W. Tang, G. Long, L. Liu, T. Zhou, M. Blumenstein, and J. Jiang, "Omni-scale cnns: a simple and effective kernel size configuration for time series classification," in *International Conference on Learning Representations*, 2021.
- [6] R. Assaf and A. Schumann, "Explainable deep neural networks for multivariate time series predictions," in *IJCAI*, 2019, pp. 6488–6490.
- [7] T. Q. Feng, M. Choy, and M. N. Laik, "Predicting book sales trend using deep learning framework," *International Journal of Advanced Computer Science and Applications*, vol. 11, no. 2, pp. 28–39, 2020.
- [8] H. Lamtougui, H. El Moubtahij, H. Fouadi, A. Yahyaouy, and K. Satori, "Offline arabic handwriting recognition using deep learning: Comparative study," in *2020 International conference on intelligent systems and computer vision (ISCV)*. IEEE, 2020, pp. 1–8.

- [9] Y. Yu, X. Si, C. Hu, and J. Zhang, "A review of recurrent neural networks: Lstm cells and network architectures," *Neural computation*, vol. 31, no. 7, pp. 1235–1270, 2019.
- [10] A. Sherstinsky, "Fundamentals of recurrent neural network (rnn) and long short-term memory (lstm) network," *Physica D: Nonlinear Phenomena*, vol. 404, p. 132306, 2020.
- [11] G. Choudakkanavar and J. A. Mangai, "A hybrid 1d-cnn-bi-lstm based model with spatial dropout for multiple fault diagnosis of roller bearing," *International Journal of Advanced Computer Science and Applications*, vol. 13, no. 8, 2022.
- [12] K. Albeladi, B. Zafar, and A. Mueen, "Time series forecasting using lstm and arima," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 1, 2023.
- [13] H. Fouadi, H. El Moubtahij, H. Lamtougui, K. SATORI, and A. Yahyaouy, "Applications of deep learning in arabic sentiment analysis: Research perspective," in *2020 1st International Conference on Innovative Research in Applied Science, Engineering and Technology (IRASET)*. IEEE, 2020, pp. 1–6.
- [14] R. P. Masini, M. C. Medeiros, and E. F. Mendes, "Machine learning advances for time series forecasting," *Journal of economic surveys*, vol. 37, no. 1, pp. 76–111, 2023.
- [15] L. M. Bennett and W. Hu, "Filtration enlargement-based time series forecast in view of insider trading," *Journal of Economic Surveys*, 2023.
- [16] Z. Hajirahimi and M. Khashei, "Hybridization of hybrid structures for time series forecasting: A review," *Artificial Intelligence Review*, vol. 56, no. 2, pp. 1201–1261, 2023.
- [17] J.-H. Chen and Y.-C. Tsai, "Encoding candlesticks as images for pattern classification using convolutional neural networks," *Financial Innovation*, vol. 6, pp. 1–19, 2020.
- [18] A. EL ZAAR, N. BENAYA, T. BAKIR, A. MANSOURI, and A. EL ALLATI, "Prediction of us 30-years-treasury-bonds movement and trading entry point using robust 1dcnn-bilstm-xgboost algorithm," 2023.
- [19] P. L. Seabe, C. R. B. Moutsinga, and E. Pindza, "Forecasting cryptocurrency prices using lstm, gru, and bi-directional lstm: A deep learning approach," *Fractal and Fractional*, vol. 7, no. 2, p. 203, 2023.
- [20] R. M. I. Kusuma, T.-T. Ho, W.-C. Kao, Y.-Y. Ou, and K.-L. Hua, "Using deep learning neural networks and candlestick chart representation to predict stock market," *arXiv preprint arXiv:1903.12258*, 2019.
- [21] A. Andriyanto, A. Wibowo, and N. Z. Abidin, "Sectoral stock prediction using convolutional neural networks with candlestick patterns as input images," *International Journal*, vol. 8, no. 6, 2020.
- [22] J.-H. Chen, S. Y.-C. Chen, Y.-C. Tsai, and C.-S. Shur, "Explainable deep convolutional candlestick learner," *arXiv preprint arXiv:2001.02767*, 2020.
- [23] J. Chen, Y. Wen, Y. Nanekaran, M. Suzaiddola, W. Chen, and D. Zhang, "Machine learning techniques for stock price prediction and graphic signal recognition," *Engineering Applications of Artificial Intelligence*, vol. 121, p. 106038, 2023.
- [24] S. Cavalli and M. Amoretti, "Cnn-based multivariate data analysis for bitcoin trend prediction," *Applied Soft Computing*, vol. 101, p. 107065, 2021.
- [25] M. Poongodi, T. N. Nguyen, M. Hamdi, and K. Cengiz, "Global cryptocurrency trend prediction using social media," *Information Processing & Management*, vol. 58, no. 6, p. 102708, 2021.
- [26] S. Alonso-Monsalve, A. L. Suárez-Cetrulo, A. Cervantes, and D. Quintana, "Convolution on neural networks for high-frequency trend prediction of cryptocurrency exchange rates using technical indicators," *Expert Systems with Applications*, vol. 149, p. 113250, 2020.
- [27] M. Poongodi, A. Sharma, V. Vijayakumar, V. Bhardwaj, A. P. Sharma, R. Iqbal, and R. Kumar, "Prediction of the price of ethereum blockchain cryptocurrency in an industrial finance system," *Computers & Electrical Engineering*, vol. 81, p. 106527, 2020.
- [28] T. Shintate and L. Pichl, "Trend prediction classification for high frequency bitcoin time series with deep learning," *Journal of Risk and Financial Management*, vol. 12, no. 1, p. 17, 2019.

Security in the IoT: State-of-the-Art, Issues, Solutions, and Challenges

Ahmed SRHIR¹, Tomader MAZRI², Mohammed, BENBRAHIM³

Department of Electrical Engineering-Networks and Telecommunication Systems-National School of Applied Sciences,
Ibn Tofail University, Kenitra, Morocco

Abstract—Now-a-days, the Internet of Things (IoT) has enormous potential and growth impact due to the technological revolution and the spread and appearance of events. It has received considerable attention from researchers and is considered the future of the Internet; however, according to Cisco Inc. reports, the IoT will be crucial in transforming our standards of living, as well as our corporate and commercial models. By 2023, the number of devices connected to IP networks will reach more than three times the population of the entire world. In addition, there will be 5.3 billion Internet users worldwide, representing 66% of the world's population, up from 3.9 billion in 2018. IoT enables billions of devices and services to connect to each other and exchange information; however, most of these IoT devices can be easily compromised and are subject to various security attacks. In this article, we present and discuss the main IoT security issues, categorizing them according to the IoT layer architecture and the protocols used for networking. In the following, we describe the security requirements as well as the current attacks and methods with adequate solutions and architecture for avoiding these issues and security breaches.

Keywords—Internet of things (IoT); IoT security; IoT protocols; security issues in IoT; network security; data security

I. INTRODUCTION

Due to the continuous fast development of smart environments and broadband networks, the Internet of Things is now widely accepted and popular, earning its designation as the main standard for low-loss networks (LLN) with limited resources. It refers to a network where "objects" or devices that are integrated with sensors are interlinked through a network that may either be private or public [1, 2]. The sharing of information between the different devices is done through the network using standard communication protocols. The intelligent connected devices, or "objects," range from basic accessories to larger devices that each includes chips and detection sensors. For example, smart shoes contain chips that track and analyze fitness data [3]. Likewise, electric devices that may be operated remotely through the IoT, as well as any security cameras that are installed for surveillance of a place can be controlled remotely from anywhere. In addition to personal use, IoT also meets community needs. Several intelligent devices perform various functions such as surgical operation monitoring in hospitals, detection of weather conditions, automobile tracking, and connectivity. Due to its use in daily life, the IoT's potential size is obvious. It keeps expanding quickly as a result of the development of hardware techniques like bandwidth augmentation using networks based on cognitive radio to solve the underutilization of frequency

spectrum resources [4,5]. Limited resources are one of the major challenges to IoT security, given that small devices or objects with sensors have limited computing and processing power and memory, making it easy for attackers to exploit these devices. On the other hand, the main challenge is ensuring consistency and adaptation between solutions with these limited architectures. For this reason, the global deployment architecture should be secured and reinforced against attacks that could impact the services offered by the IoT. In the last few years, considerable work has been done to solve security in the IoT ecosystem paradigm. While some methodologies focus on addressing security concerns at a particular layer, others strive to offer comprehensive end-to-end security for the entire Internet of Things (IoT) layer.

Security issues are categorized according to application, architecture, communication, and data in research by Alaba et al. [6]. The traditional layered design differs from the suggested topology for IoT security. After that, hardware, network, and application component threats are analyzed. Another study by Granjal et al. [7] examines and addresses security risks with IoT protocol definitions. The security studies detailed in [8–9] analyze and contrast various cryptographic algorithms and key management systems. Similar goals are shared by the authors of [10–11], who want to compare and evaluate intrusion detection technologies. IoT privacy, security, access control, and confidentiality contributions, as well as cross-software security, are examined in a review by Sicari et al. [12]. Additionally, Oleshchuk [13] presents an overview of IoT privacy preservation strategies. The author outlines secure multi-party computations that can be used to maintain user privacy, and attribute-based access control mechanisms are outlined as an efficient solution to ensure privacy in the Internet of Things. Numerous security risks for cloud-based IoT are covered by Zhou et al. [14], along with potential preventative measures. They discuss IoT employing clouds for key management, node compromise, layer removal or addition, identity and location privacy, and node compromise. In their article [15], Zhang et al. highlight the fundamental issues with IoT security including the requirement for lightweight cryptographic processes, privacy, unique object identification, authentication and authorization, malware, and software susceptibility.

Our primary contributions and methods are enumerated below in comparison to survey studies that have been published in the literature:

- A parametric examination of security risks and how well they fit with potential IoT solutions.

- IoT security challenges classification and categorization in relation to the various tiers, as well as the solutions employed.
- Future views providing workable answers to security issues with the Internet of Things.

The remaining sections of the paper are structured as follows: The IoT architecture is explained in Section II, as well as the security challenges encountered at every level of the IoT protocol stack. In Section III, the major security challenges and issues are categorized, while Section IV examines and provides a map of potential solutions, and finally, Section V concludes the paper.

II. IOT ARCHITECTURE AND SECURITY REQUIREMENTS

The integration of the Internet of Things is a fundamental element in the development of an intelligent ecosystem, connecting physical objects to the internet. It lets sensors, controllers, machines, people, and objects work together in a new way so that they can be intelligently identified, located, tracked, and monitored. While the Internet of Things is still in its development, many applications and standards must be adopted, including home automation, traffic control, smart cars, smart grids, etc. [16]. Fig. 1 illustrates how an IoT deployment typically consists of a number of heterogeneous devices with embedded sensors connected to one another through a network. These devices are all individually recognizable and typically have low power consumption, little memory, and limited computational power. In order to remotely transmit data and services to IoT consumers, gateways are used to link IoT devices to the public domain.

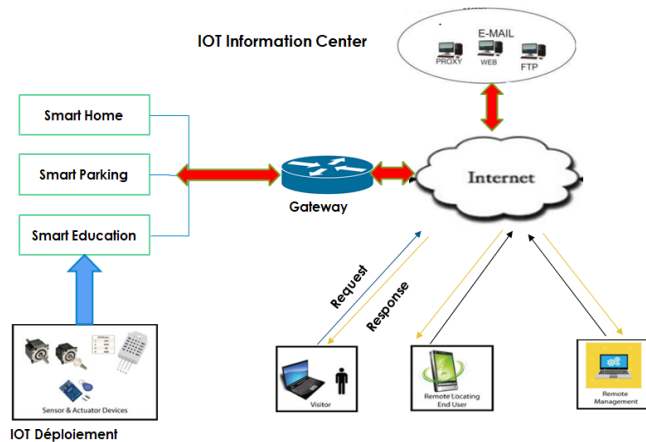


Fig. 1. Overview of IoT components.

A. IoT Architecture

Protocols are a group of instructions that allow data to be sent and received between electronic devices while respecting the agreements made in advance regarding the structure of the data. Accordingly, IoT protocols are standards that allow data to be exchanged and transmitted across the internet and between devices. Different IoT architectures are proposed by different authors, such as middleware-based architectures, Service-oriented architecture (SOA), architectures with six layers and three layers [17], In our case, and to address the fundamental communication issue, we will focus on the

fundamental three-layer IoT architecture depicted in Fig. 2, which provides a general list of the most widely used protocols and standards for powering IoT devices, applications, and systems. As stated below, these three levels consist of a "perception layer," a "network layer," and an "application layer":

- The perception layer consists of physical and communication devices composed of captors and controllers that collect, desensitize, and treat information before transmitting it to the network layer. It includes the physical devices like cameras, Radio Frequency Identification (RFID),
- The network and transport layer represents a communication tier that uses gateways, switches, and routers to transmit and route data aggregated at the perception layer and delivered to the application layer.
- The application layer is a communication layer that contains the application in charge of the interaction with the users.

Every IoT layer employs a distinct set of protocols and standards, as shown in Fig. 2, protocols used by physical devices and communication technology include Zigbee Wi-Fi, 4G/5G, NB-IoT, and LoRaWAN. Different protocols are used by the network and the transport, including IPv6, 6LoWPAN, RPL, TCP/UDP TLS, and DTLS. The message and application protocols include XML, HTTP, MQTT, and CoAP. Additionally, many protocols, including OAuth 2.0, OpenID, and PKI, are used for key management and authentication [17, 18]. Fig. 2 also illustrates a structured architecture based on the most prevalent IoT protocols for applications, emailing, authentication, key management, routing and transfer, and those for physical devices. The physical layer and the MAC (Media Access Control) layer are two low-level layers specified by the IEEE 802.15.4 standard. The physical layer specification relates to data rates and frequency bands for wireless channels used for communication. The channel access techniques and synchronization are covered by the MAC layer specification. Routing Protocol for Low Power and Lossy Networks (RPL) [19] is used to provide IPv6 across low-power wireless personal area network (6LoWPAN) environments, enabling connection and exchange between numerous points and a single point; this standard also permits point-to-point traffic. Due to the limited payload, User Datagram Protocol (UDP) [20] is used in the IoT application architecture for communication. The UDP protocol is considered more efficient and simpler than the TCP protocol. Additionally, UDP header compression guarantees that the restricted payload space is used more effectively [21]. CoAP (Constrained Application Protocol) [22] presents a model for low-power loss networks working in confined spaces based on demand response. Additionally, it permits asynchronous message transmission and has the ability to connect to IoT resources using HTTP mapping, LPWAN enables long-range connections of IoT "objects." It provides low-power and low-bit-rate connectivity compared to a wireless WAN that demands more energy to operate at a high bit rate. LPWAN provides connectivity between gateways and end devices to manage changing data rates.

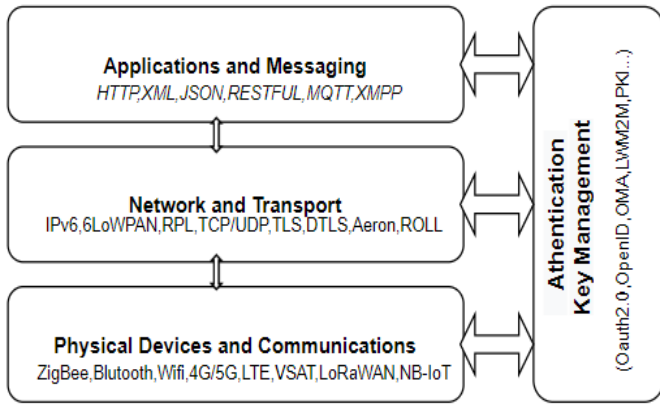


Fig. 2. The protocols and standards of IoT.

B. Security Requirements

Several research initiatives have been proposed in recent years to identify various methods for securing the connection between an end device and its components. The primary objectives of the Internet of Things are the configuration of a smart environment and autonomous devices, such as smart living, smart objects, smart health, and smart cities, among others domains [23]. Ensuring security in smart systems poses a major challenge, due to the diversity and complexity of the end device and its components [24,25]. Fig. 3 illustrates the considerations that must be made to ensure the reliability and security of IoT implementation.

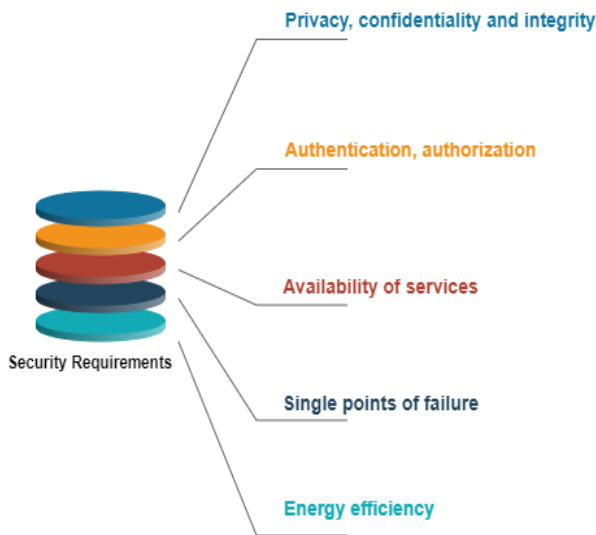


Fig. 3. Security requirements for IoT.

- Privacy, confidentiality, and integrity

Given that IoT data moves over several network hops, an appropriate encryption technique is needed in order to assure

the privacy of the data. And this, because of the diversity of services and microservices integration, means that the vast majority of the information saved and kept on any device is exposed to invasions of privacy, and assaults can allow a malicious user to gain data integrity by changing the saved data for illegal uses.

- Authentication and authorization

In order to ensure secured IoT communication between different devices, authentication is paramount between the different parties who are communicating. the multiplicity of IoT device architectures and different underlying ecosystems are primarily responsible for the IoT devices' wide range of authentication procedures. Creating an associated standard protocol for authentication in the IoT will be extremely difficult in these situations. Similar to that, authorization methods make sure that only authorized people are allowed access to systems or information. Additionally, keeping track of how resources are used and making sure they are used correctly through audits and reports is a reliable and effective way to manage network security.

- Availability of services

Traditional denial-of-service attacks against IoT devices could obstruct the delivery of services. Different tactics, such as replay assaults, sinkhole attacks, and jammer advertisements, employ IoT components at various stages to reduce the quality of service (QoS) offered to IoT users.

- Single points of failure

IoT-based infrastructure's continuous reliance on heterogeneous networks has the potential to expose numerous single points of failure, which could harm the IoT's intended services. As a result, it's necessary to create a safe environment in order to accommodate a greater number of Internet of Things devices and to propose other techniques to build a fault-tolerant system.

- Energy management

IoT devices frequently have a small battery life and a weak storage capacity. Attacks on IoT systems can lead to increased power usage by saturating the network and draining device resources with repetitive and false service queries.

III. SECURITY ISSUES CLASSIFICATION

Nowadays, several reports and research findings indicate that the IoT is susceptible to various forms of attack, such as active and passive attacks, which have the potential to disrupt the operation of the device as well as affect its functionality and remove the benefits of its services. A taxonomy of security issues related to the Internet of Things has been developed and presented in Fig. 4 based on the IoT deployment architecture, as mentioned below:

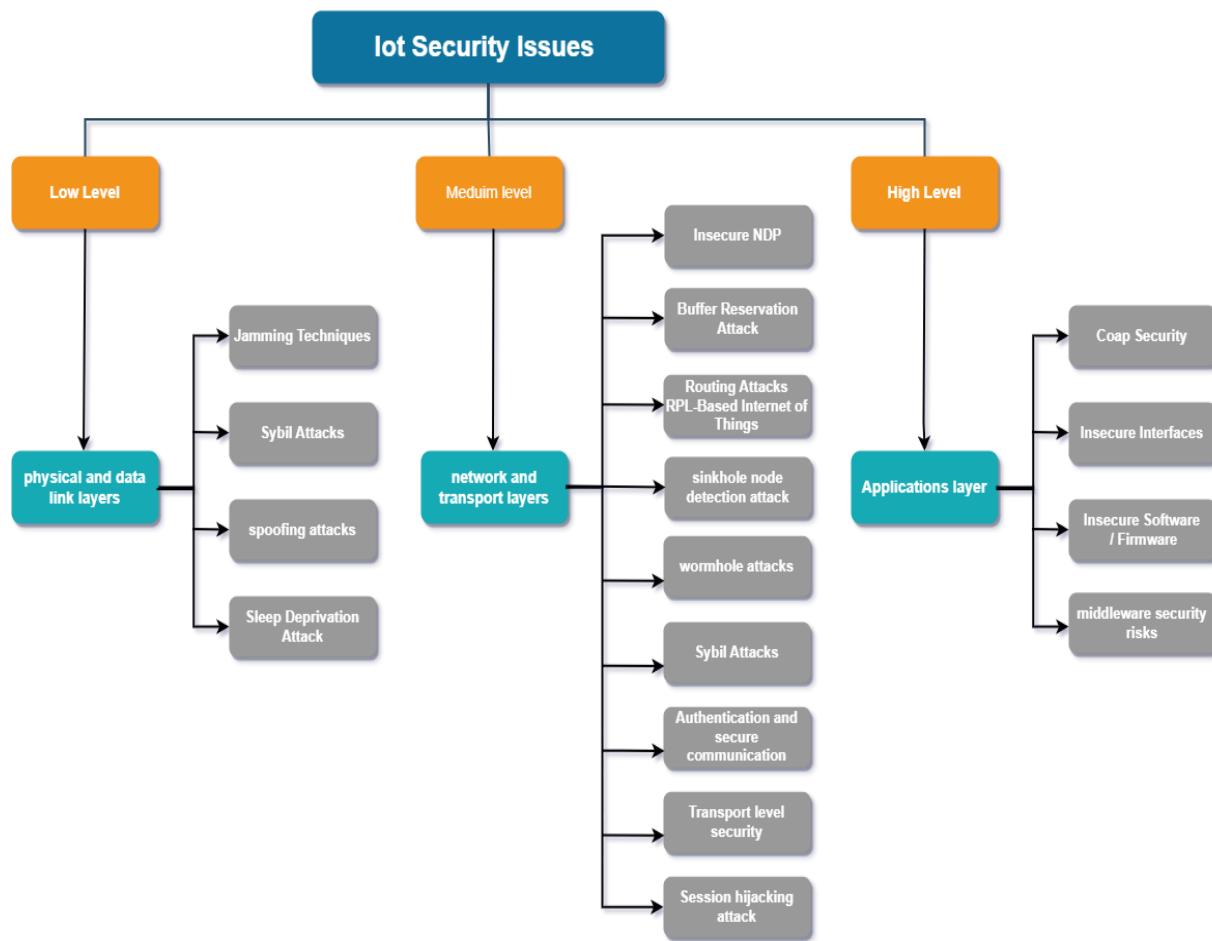


Fig. 4. Classification of security issues.

A. Low Security Issues

It relates to security vulnerabilities at the hardware level as well as the physical and data link levels of communication, as described below:

- Jamming attacks

Jamming is an attack method that disrupts the radio signals utilized by nodes in a network. It's characterized as the intentional use of electromagnetic radiation to disrupt or disable a communication system. These attacks aim to degrade networks by transmitting Radio frequency (RF) signals without having to adhere to a specified protocol [26, 27]. Radio interference has a significant impact on how a network operates because it interferes with authorized nodes' ability to send and receive data, which makes the system unstable or dysfunctional.

- Low-level Sybil attacks:

Malicious Sybil nodes utilize false identities to carry out Sybil attacks on wireless networks and impair IoT capabilities. A Sybil node may employ random, fabricated MAC values on the physical layer to pretend to be another device in order to drain network resources [28]. This could prevent the authorized nodes from getting access to resources.

- Spoofing attacks

Spoofing attacks are simple to launch on an access IoT network. An attacker can pretend to be another approved IoT device by claiming the real user's MAC or IP (internet protocol) address. The attacker can perform attacks on the IoT network after gaining illegal access.

- Sleep deprivation attack

The target of this attack is battery-operated computational hardware, like a sensor node, which is trying to conserve power by entering a low-power sleep state for as long as feasible without disrupting the node's activities [29].

By keeping the sensor nodes awake, "sleep deprivation" attacks can take advantage of energy-constrained IoT devices [30]. The battery is drained when too many tasks are scheduled to run in 6LoWPAN.

B. Medium-Level Security Issues

The security concerns at the intermediate level primarily pertain to the communication, routing, and session management that occur at the network and transport layers of IoT, as outlined below:

- Insecure NDP

Every device must have a unique network identifier in order to comply with the IoT deployment architecture. Secure

communication transmission is required for security purposes. To ensure that all information sent to a device across a continuous connection reaches its intended destination, the phase of neighbor discovery performs a number of operations prior to data transfer, including router detection and resolving addresses [31]. Utilizing neighbor discovery packets without conducting adequate verification could have serious consequences, including distributed denial of service (DDoS) attacks.

- Buffer reservation attack.

An attacker may take advantage of this by delivering incomplete packets to a receiving node must allocate slots for the reassembling of received packets [32]. Due to the attacker's unfinished packets taking up space and causing other fragment packets to be deleted, this attack causes denial-of-service.

- Routing Attacks RPL-Based

The IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL) is susceptible to numerous attacks that are launched by infected network nodes [33]. This attack might cause resource exhaustion and eavesdropping.

- Sinkhole Node detection attacks

The attacker uses falsified routing information to lure nearby nodes, after which it performs selective forwarding or modifies the data traveling through them as illustrated in Fig. 5. The attacking node asserts that it is providing a very alluring link. As a result, this node is skipped by a lot of traffic. The sinkhole attack can be combined with other attacks besides straightforward traffic analysis, such as selective forwarding or denial of service.

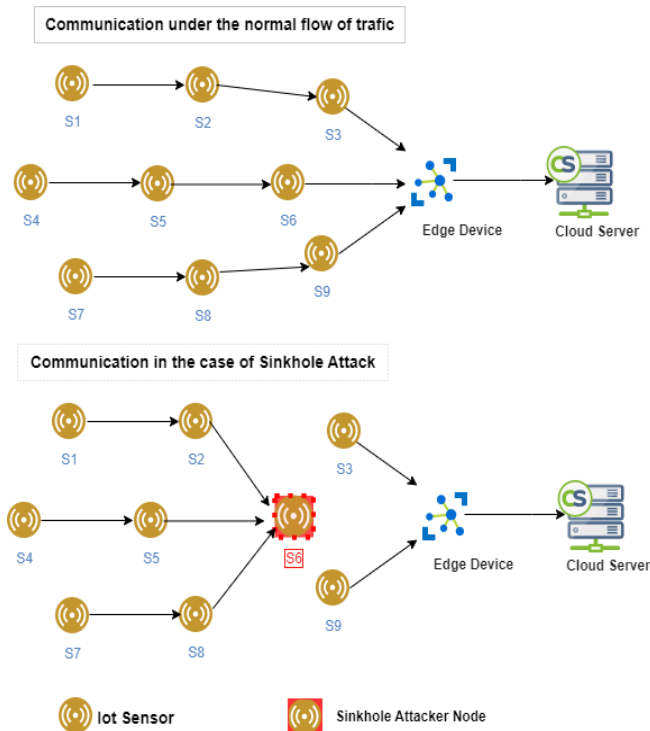


Fig. 5. Sinkhole attack in Internet of Things communication.

- wormhole attacks

During a wormhole attack, as illustrated in Fig. 6 the data is delivered across many channels, or the malicious node makes use of the incoming data in various ways. Due to these attacks, which form a tunnel connecting two nodes to ensure that the packets coming from one node immediately reach the other node, 6LoWPAN operations can be further hampered by network attacks [34].

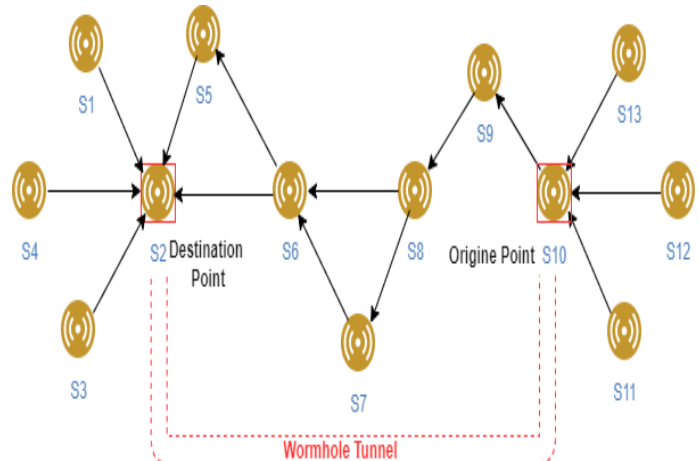


Fig. 6. Wormhole attack in internet of things.

- Sybil Attacks

The deployment of Sybil nodes can affect network performance and breach data privacy. In a network, Sybil nodes communicating under false identities run the risk of sending spam, spreading malicious software, or conducting phishing attacks [35].

In Fig. 7, the lowest layer contains one Sybil node and four regular nodes. However, due to the fact that the Sybil node carries several identities in the overlay network, there are three Sybil nodes in the top layer. In this situation, the Sybil node has the ability to seize network control. For instance, the Sybil node has the ability to transmit malicious software to conduct a DDoS attack or fake computation results to disrupt the nodes that are not malicious.

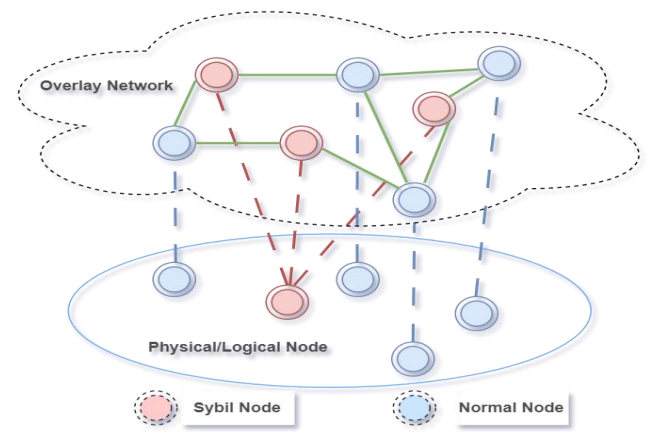


Fig. 7. illustration of Sybil nodes and the Sybil attack.

- Authentication and secure communication

Device identification is done through authentication, and permissions are given through authorization. IoT devices employ these procedures to perform role-based access control and make sure that only the access and permissions necessary for their tasks are granted to devices. The use of applications and other devices requires authorization. Cloud accounts, gateways, and key management systems are required for the IoT to authenticate people and devices. Any security flaw at the network layer or significant cost associated with communication security may expose the network to several vulnerabilities [36–38]. Due to limited resources, for example, Datagram Transport Level Security (DTLS) overhead must be kept to a minimum, and the cryptographic algorithms enabling secure data flow in the Internet of Things require consideration of the lack of other resources and performance [39].

- Transport level security

The goal of end-to-end security at the transport level is to provide secure mechanisms which ensure that the sending node's data is reliably received by the target destination node [37]. It required extensive authentication processes that offer encrypted secure message transfer while maintaining privacy and run with the least amount of overhead possible [40,41].

- Session hijacking attack

Denial-of-service may be caused via the hijacking of a session on the transport layer using falsified messages [42]. An attacker node might prolong the session between the two nodes by acting as though it is the victim node by faking its identity. By changing the sequence numbers, the communicating nodes may even need to resend messages.

C. High Level Security Issues

Most high-level security problems affect IoT apps that run at the application and communications layers, as will be discussed below:

- CoAP security

A CoAP (Constrained Application Protocol) is an IETF standard, and RFC 7252 defines the basic protocol. Additional extensions are defined in several RFCs. It works well for nodes that communicate over LPWAN, such as 6LoWPAN, and are powered by basic microcontrollers with little ROM and RAM. UDP is used as the underlying transport protocol, and it operates at the application layer of the TCP/IP stack. RFC 8323, a new standard that covers CoAP over TCP, TLS, and WebSockets, was published in 2018. Attacks can potentially target the high-level layer, which houses the application layer [43–44]. In order to guarantee end-to-end security, the Limited Application Protocol (CoAP) combines DTLS bindings with a variety of security options. The CoAP messages must be encrypted for safe communication and adhere to a certain format specified in RFC-7252 [22]. Similar to this, suitable key management and authentication techniques are needed for CoAP's multicast capability.

- Insecure Ecosystem interfaces

The user interfaces for IoT services on the web, mobile, and cloud are vulnerable to a number of risks that pose a major risk to data privacy [45].

- Insecure Software / Firmware

Insecure software/firmware is one source of numerous IoT vulnerabilities [45]. Carefully testing the code that uses languages like JSON, XML, SQLi, and XSS is necessary. Similar to this, firmware and software upgrades should be made properly.

- Middleware security

The Internet of Things middleware must be sufficiently secure to enable service delivery among the diverse elements of the Internet of Things paradigm [61,62]. To offer reliable and safe communication, several middleware-based interfaces and environments must be used.

IV. SECURITY SOLUTIONS FOR IOT

IoT security threats take advantage of flaws in a variety of components, including applications and interfaces, network components, and different levels of software, firmware, and physical devices. In the IoT paradigm, users communicate with these components using protocols that might not be secure. We've broken out the security risks for each IoT layer level in this area, along with their relevance and the suggested appropriate solutions for each of the cases listed in Section III.

This section examines the key security solutions that have been put forth. Table I presents a comparative analysis of security threats and potential countermeasures for the lowest level, the middle level, which includes the transit layer, and the highest level, respectively. All of the threat parameters, their effects, and comparative analyses are taken into consideration.

A. Low-Level Security Solutions

Jamming attacks on Wireless Sensor Networks (WSN) involve interference that causes message collisions or channel floods. Young et al. [48] present a method for detecting jamming attacks by determining the signal quality, which will be used to extract noisy signals; attacks can be detected in this manner. Then, for attack detection, these statistics are compared to preset threshold levels. False MAC values could be used by a malicious Sybil node to impersonate another device. It may lead to resource exhaustion and the denial of access to authorized network devices. Demirbas et al. [49] provide a method for identifying Sybil attacks using signal strength measures. In order to determine the sender position during message communication, their method deploys detector nodes. When a different message communication has the same sender location but a different sender identity, a Sybil attack is suspected. MAC address signal strength measurements are used to spot spoofing attempts. The study [30] outlines a methodology for preventing sleep deprivation attacks in WSNs. The suggested architecture uses a cluster-oriented model, in which each cluster is further broken down across various areas. Avoiding long-distance communication lowers energy use. A wireless sensor network architecture with five layers is used by the framework to perform intrusion detection.

TABLE I. COMPARATIVE ANALYSIS OF SECURITY THREATS AT THE IoT LEVEL, IMPLICATIONS, AND POTENTIAL COUNTERMEASURES

IoT levels	Security issue	Implications	layers	Suggested Solution
Low	Jamming Technique	Destabilization and Denial of service (DoS)	Physical	Changing frequencies and locations, encoding packets, and measuring the packet delivery ratio.
	Sybil attacks	Network disruption, DoS	Physical	Measurements of the signal strength and channel estimation
	Spoofing attacks	Network disruption, DDoS	Physical	Measurements of the signal intensity and channel estimation
	Sleep deprivation attack	Energy consumption	Link	Intrusion detection system with multiple layers
Medium	Insecure NDP	IP Spoofing	Network	Using SEND's signature algorithm agility and multiple-key CGA to secure NDP messages Signature authentication using Elliptic Curve Cryptography (ECC)
	wormhole attacks	DoS	Network	Rank verification through hashing chain function Anomaly detection through IDS rank verification via the hash chain function
	Buffer reservation attack	Closing reassembly buffer	6LoWPAN adaptation, Network	Address space layout randomization (ASLR) Split buffer approach
	Authentication and secure communication	Privacy violation	6LoWPAN adaptation, Transport Network	OTP, Digital Signature, and Mutual Authentication Using ECDSA for signing and verification and ECDH for encryption Public Key Cryptography TPM employing RSA, hybrid authentication, compression and software-based AES IACAC using the Elliptic Curve Cryptography
	Routing Attacks RPL-Based	Eavesdropping, man-in-the-middle attacks	Network	Monitoring node behavior and authentication Using hashing and signatures Placement of an IDS or IPS in the IoT Eliminating malicious nodes from RPL by using a whitelist or a blacklist Nodes
	Sinkhole Node detection attacks	DoS	Network	Signal intensity measurement, Graph Traversal Analysis, IDS anomaly detection, cryptographic key management, communication behavior analysis, rank verification via hash chain function
	Sybil Attacks	Privacy violation, spamming	Network	verification of identities observing user behavior and keeping a list of trusted and untrusted users
	Transport level security	Privacy violation eavesdropping	Transport, Network	Using the 6LoWPAN Border Router (6LBR) as a conduit between nodes and the inter-net IKEv2 employing compressed UDP, compressed IPSEC, and DTLS header compression.
Session hijacking attack	DoS	Transport	Encrypting all data transmitted Session Management Session Key	
High	CoAP security	Network bottleneck, DoS	Application, Network	protection by Datagram Transport Layer Security (DTLS) TLS-tunnel Filtering messages using 6LBR
	Insecure interfaces	DoS, invasion of privacy, and network disruption	Application	Use of https and firewalls; prevention of the use of weak passwords by enforcing expiration policies and forcing compliance with password complexity requirements; assessment of the interface against software tool vulnerabilities (SQLi and XSS).
	Insecure Software / Firmware	DoS, invasion of privacy, and network failure	Application, Transport	updating software and firmware securely on a regular basis, using file signatures, and encrypting data with validation
	Middleware security	DoS, invasion of privacy, and network failure	Application, Transport, Network	The safeguarding of communication is achieved through the implementation of authentication protocols, security policies, key management mechanisms between devices, gateways, and M2M components, as well as transparent middleware.

B. Mediate-Level Security Solutions

Riaz et al. [31] suggest a security system that includes modules for secure neighbor finding, authentication, key generation, and data encryption. Elliptic Curve Cryptography (ECC) [50] is utilized for secure neighbor finding. In the neighbor discovery phase, nodes are identified using ECC public key signatures. Depending on the needs of the application, both symmetric and asymmetric key management solutions are recommended for deployment. Then, in order to guarantee node-to-node security, the encrypted data is transmitted.

A node's reassembly buffer could be prevented by a buffer reservation attack. This attack is lessened by the split buffer technique [32], which raises the cost of launching the attack by necessitating the transmission of full fragmented packets in brief bursts. Each node must calculate the completion rate of the packet and monitor the behavior of sending pieces. When under load, the node may reject packets that have low fragment percentages or a high fragment sending pattern fluctuation.

The Directed Acyclic Graph (DAG) is created by the RPL protocol with root at any of the gateways. RPL utilizes ranks to describe the quality of the path to the last sink node. To link to the root for eavesdropping, a node's rank value may be reduced. Version Number and Rank Authentication (VeRA), a proposed security technique, authenticates version numbers and rankings using the hash function (SHA), MAC function (HMAC), and digital signature (RSA) [51,52].

Weekly et al. propose a strategy that involves failover and authentication techniques to counter sinkhole attacks. [53], Pirzada et al. [54] provide another approach to thwart sinkhole attacks by utilizing various trust levels. Their method makes use of a variety of Dynamic Source Routing (DSR) protocol features to identify and prevent wormhole and sinkhole attacks in wireless networks.

Pseudo-identities, also known as Sybil nodes, are used in Sybil attacks on the network layer to impersonate numerous distinct identities. Peer-to-peer (P2P) and distributed systems, such as the Internet of Things, are seriously at risk from these attacks. A trust connection is added to social networks to prevent the establishment of Sybil identities [55]. By moving across the graph randomly or utilizing community detection methods, legitimate nodes can use the countermeasures employing social graphs to identify Sybil nodes. [42,56–57] Similar to this, users' behavior in relation to network activity is examined; users who consistently follow the same pattern are automatically labeled as sybils. [35]. Mahalle et al. have proposed a method that can protect the Internet of Things against attacks involving a man-in-the-middle as well as denial-of-service (DoS) attacks.

In a networked environment, man-in-the-middle attacks resulting from secret keys exposed as a result of eavesdropping may lead to identity theft. Additionally, the credentials or identity information might be replayed by attackers to influence network traffic. The Elliptic Curve Cryptography-based Diffie Hellman algorithm is used to mutually authenticate devices for communication and access via encryption and secret keys. With capability-based access, two

devices' capacity to communicate is first confirmed. Additionally, before performing the actual operation, the device's capacity to carry out the specified functionality is verified. To create secret keys in the proposed method is known as Identity Authentication and Capability-based Access Control (IACAC). Kothmayr et al. [59, 60] detail a strategy for achieving end-to-end security by employing public key cryptography in conjunction with two-way authentication. For the purpose of storing the network's publishers' access privileges, a reliable access control server is built, and the publisher's website must store both the publisher's and the Authority's certificates. Authentication can be done with RSA or DTLS preshared keys by the Trusted Platform Module (TPM) processors [61], whereas TPMs are utilized to transmit RSA certificates in X.509 format.

Alghamdi et al. [62] recommend using Transport Layer Security pre-shared key ciphersuites (TLS-PSK) to ensure security during the entire transaction, allowing communication to occur between HTTP and CoAP. This necessitates a conversion message on the DTLS layer. Similar to this, a DTLS extension including pre-shared key (PSK) is recommended to provide processing of session keys for multicast message security. The 6LoWPAN Border Router (6LBR) is proposed as a dedicated authentication approach for transport-level security [37]. The 6LBR is able to intercept packets, compute for public key authentication, and then forward them. For the implementation of transport-level security, elliptic curve cryptography (ECC) is used. Also, end-to-end security at the transport level has been proposed using a variety of header compression approaches. Raza et al. [63] offer a method for reducing the size of the maximum transmission unit (MTU) of 6LoWPAN packets by compressing DTLS Record and Handshake headers and other Handshake data. An additional technique for encryption that employs hash functions for devices with limited resources has been suggested. The efficiency of the system is attributed to its minimal computational overhead. A proposed approach for achieving mutual authentication in fog computing environments that involve devices with limited resources is presented in research [58].

Park et al. [42] provide a mutual authentication strategy for safe session management with symmetric key-based encryption techniques. The suggested method first chooses a random number, encrypts it, and creates a session key that is then used to encrypt another random number. The encrypted number serves as an authentication key. Another hash-based encryption technique is also suggested for devices with limited resources that implement hash functions. As a result of the minimal computational overhead, it operates effectively.

C. High-Level Security Solutions

A method using TLS and DTLS is suggested by Brachmann et al. [43] to secure CoAP-based Low-power and Lossy Networks (LLN) connected to the internet. The suggested method is effective in situations where a 6LoWPAN Border Router (6LBR) connects the LLN to the internet so that devices can be accessed remotely. The CoAP and HTTP clients are serviced by the LLN nodes. It is suggested to map TLS and DTLS to provide end-to-end security that shields LLNs against internet-based threats.

Granjal et al. [64] present a different method of protecting messages for applications connecting across the internet utilizing various CoAP security parameters. SecurityOn, SecurityToken, and SecurityEncap are the new security settings for CoAP.

The SecurityOn option is important for the security of CoAP messages at the application level. Through identity and permission, the SecurityToken option at the application level makes it easier to access CoAP resources. The SecurityEncap option performs [65] and proposes a security paradigm that uses 6LBR for message filtration to guarantee end-to-end security for IoT. The TLS-DTLS tunnel can be formed. Similar to this, it is advised that message verification or replay detection be carried out at the CoAP device when two hosts share the same key. Sethi et al. [44] present an energy-efficient security paradigm for IoT-based CoAP based on public key cryptography. The proposed security architecture, which is a model, employs a mirror proxy (MP) and resource directory to service demands throughout the server's sleep process and to supply a catalog of the endpoint's resources.

The OWASP project [45] offers suggestions for IoT security countermeasures to deal with vulnerable high-level interfaces, including setups that prevent the use of weak passwords and evaluate the interface for common software tool weaknesses (SQLi and XSS), and utilize firewalls and secure HTTPS connections. Additionally, through a secure transfer method, the device's software or firmware should be frequently updated. The updated files need to be signed and correctly validated before installation, and they should be downloaded from a secure site.

Conzon et al. [46] have proposed the utilization of VIRTUS middleware to provide authentication and encryption for safeguarding distributed applications that operate within an IoT ecosystem.

IoT middleware solutions are heavily used in contexts with limited resources, such as memory, computational power, and the network. Because of this, middleware system components must cope with lightweight security techniques. However, it is seen as difficult to deploy new security strategies in accordance with the demands of certain Internet of Things applications. Liu et al. [47] propose a middleware server that provides data filtering during communication among heterogeneous IoT environments. The suggested middleware offers effective methods for addressing, naming, and profiling in a variety of settings. A key hierarchy comprising keys for the root, applications, and services is used to achieve the common authentication, authorization, and accounting (AAA) functionalities. A web-based portal is used to register for services, limiting access to those services to approved users. A common architecture with various security layers is suggested for machine-to-machine (M2M) communications in the IoT environment [66].

The resource contents should be encrypted for M2M service layer security, and securing message transmission using TLS or DTLS sessions is recommended. The study [67] suggests a security architecture for IoT middleware that makes use of accepted encryption techniques like AES to ensure data confidentiality. The proposed architecture-based approach has

the ability to secure the communications of IoT entities, such as users, devices, and services.

V. CONCLUSION

Today's Internet of Things devices are unsafe and vulnerable, and they are not able to provide any security to protect themselves. This is due to the resource limitations in IoT devices as well as the lack of developed standards and weakly implemented security measures in hardware and software.

This paper presents an analysis of IoT security issues. The components of IoT technology are defined, and the areas of its application are considered. An analysis of the security of the Internet of Things has been carried out; looking at assets and technologies, and a classification of these issues has been compiled into three groups according to the standard IoT layers: high, medium, and low. We briefly go over the literature-proposed approaches for utilizing IoT security at various tiers; requirement for security, including privacy, authenticity, and integrity, is discussed; in addition, we present a parametric evaluation of IoT possible attacks and countermeasures. We analyze the effects of the attack and connect them to countermeasures that have been presented in the literature. The ultimate goal of addressing IoT security and protection issues is to ensure that all assets are prioritized, maintain the required level of privacy, and achieve and maintain a high level of attack resistance, thereby ensuring comprehensive security.

REFERENCES

- [1] L. Atzori, A. Iera, G. Morabito, The internet of things: A survey, *Comput. Netw.* 54 (15) (2010) pp.2787–2805. doi.org/10.1016/j.comnet.2010.05.010.
- [2] D. Giusto, A. Iera, G. Morabito, L. Atzori, *The Internet of Things: 20th Tyrrhenian Workshop on Digital Communications*. Springer Publishing Company, Incorporated, 2014.
- [3] Stolojescu-Crisan, C., Crisan, C., & Butunoi, B.-P. (2021). Access Control and Surveillance in a Smart Home. *High-Confidence Computing*, 100036. doi: 10.1016/j.hcc.2021.100036
- [4] Khan, A. A., Rehmani, M. H., & Rachedi, A. (2017). Cognitive-Radio-Based Internet of Things: Applications, Architectures, Spectrum Related Functionalities, and Future Research Directions. *IEEE Wireless Communications*, 24(3), 17–25. doi:10.1109/mwc.2017.1600404
- [5] Akhtar, F., Rehmani, M. H., & Reisslein, M. (2016). White space: Definitional perspectives and their role in exploiting spectrum opportunities. *Telecommunications Policy*, 40(4), 319–331. doi: 10.1016/j.telpol.2016.01.003
- [6] M.Sadeeq, M. A., Zeebaree, S. R. M., Qashi, R., Ahmed, S. H., & Jacksi, K. (2018). Internet of Things Security: A Survey. 2018 International Conference on Advanced Science and Engineering (ICOASE). doi:10.1109/icoase.2018.8548785.
- [7] Granjal, J., Monteiro, E., & Sa Silva, J. (2015). Security for the Internet of Things: A Survey of Existing Protocols and Open Research Issues. *IEEE Communications Surveys & Tutorials*, 17(3), 1294–1312. doi:10.1109/comst.2015.2388550.
- [8] Granjal, J., Monteiro, E., & Sa Silva, J. (2015). Security for the Internet of Things: A Survey of Existing Protocols and Open Research Issues. *IEEE Communications Surveys & Tutorials*, 17(3), 1294–1312. doi:10.1109/comst.2015.2388550.
- [9] Cirani, S., Ferrari, G., & Veltri, L. (2013). Enforcing Security Mechanisms in the IP-Based Internet of Things: An Algorithmic Overview. *Algorithms*, 6(2), 197–226. doi:10.3390/a6020197.
- [10] utun, I., Morgera, S. D., & Sankar, R. (2014). A Survey of Intrusion Detection Systems in Wireless Sensor Networks. *IEEE Communications*

- Surveys & Tutorials, 16(1), 266–282. doi:10.1109/surv.2013.050113.00191.
- [11] Mitchell, R., & Chen, I.-R. (2014). A survey of intrusion detection in wireless network applications. *Computer Communications*, 42, 1–23. doi: 10.1016/j.comcom.2014.01.012.
- [12] Sicari, S., Rizzardi, A., Grieco, L. A., & Coen-Porisini, A. (2015). Security, privacy and trust in Internet of Things: The road ahead. *Computer Networks*, 76, 146–164. doi:10.1016/j.comnet.2014.11.008.
- [13] Oleshchuk, V. (2009). Internet of things and privacy preserving technologies. 2009 1st International Conference on Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology. doi:10.1109/wirelessvitae.2009.51.
- [14] Zhou, J., Cao, Z., Dong, X., & Vasilakos, A. V. (2017). Security and Privacy for Cloud-Based IoT: Challenges. *IEEE Communications Magazine*, 55(1), 26–33. doi:10.1109/mcom.2017.1600363.
- [15] Zhang, Z.-K., Cho, M. C. Y., Wang, C.-W., Hsu, C.-W., Chen, C.-K., & Shieh, S. (2014). IoT Security: Ongoing Challenges and Research Opportunities. 2014 IEEE 7th International Conference on Service-Oriented Computing and Applications. doi:10.1109/soca.2014.58.
- [16] Alghamdi, A., Mohammed, T., Alsulami, (2019). Toward a Smart Campus Using IoT: Framework for Safety and Security System on a University Campus. doi: 10.25046/aj040512.
- [17] Sethi, P., & Sarangi, S. R. (2017). Internet of Things: Architectures, Protocols, and Applications. *Journal of Electrical and Computer Engineering*, 2017, 1–25. doi:10.1155/2017/9324035.
- [18] Wang, Y., Uehara, T., & Sasaki, R. (2015). Fog Computing: Issues and Challenges in Security and Forensics. 2015 IEEE 39th Annual Computer Software and Applications Conference. doi:10.1109/compsac.2015.173.
- [19] Mercy Amrita C., & Pravin Renold A. (2014). Routing protocol for low power lossy networks. 2014 IEEE International Conference on Advanced Communications, Control and Computing Technologies. doi:10.1109/icaccct.2014.7019343.
- [20] J. Postel, User datagram protocol, 1980. URL <https://tools.ietf.org/html/rfc768>.
- [21] J.W. Hui, P. Thubert, Compression format for IPv6 datagrams over IEEE 802.15.4-based networks, 2011. URL <https://tools.ietf.org/html/rfc6282>.
- [22] Z. Shelby, K. Hartke, C. Bormann, The constrained application protocol (CoAP), 2014. URL <https://tools.ietf.org/html/rfc7252>
- [23] Abomhara, M., Ien, G.M.K., 2015. Cyber Security and the Internet of Things: Vulnerabilities, Threats, Intruders and Attacks. *Journal of Cyber Security and Mobility* 4, 60–90.
- [24] Hager, M., Schellenberg, S., Seitz, J., Mann, S., & Schorcht, G. (2012). Secure and QoS-aware communications for smart home services. 2012 35th International Conference on Telecommunications and Signal Processing (TSP). doi:10.1109/tsp.2012.6256188.
- [25] G. Mantas, D. Lymberopoulos and N. Komninos, Security in smart home environment, *Wireless Technologies for Ambient Assisted Living and Healthcare: Systems and Applications* (Medical Information Science, Hershey, PA, 2010), pp. 170–191.
- [26] Xu, W., Trappe, W., Zhang, Y., & Wood, T. (2005). The feasibility of launching and detecting jamming attacks in wireless networks. Proceedings of the 6th ACM International Symposium on Mobile Ad Hoc Networking and Computing - MobiHoc '05. doi:10.1145/1062689.1062697.
- [27] Noubir, G., & Lin, G. (2003). Low-power DoS attacks in data wireless LANs and countermeasures. *ACM SIGMOBILE Mobile Computing and Communications Review*, 7(3), 29. doi:10.1145/961268.961277.
- [28] Chen, Y., Trappe, W., & Martin, R. P. (2007). Detecting and Localizing Wireless Spoofing Attacks. 2007 4th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks. doi:10.1109/sahcn.2007.4292831.
- [29] Pirretti, M., Zhu, S., Vijaykrishnan, N., McDaniel, P., Kandemir, M., & Brooks, R. (2006). The Sleep Deprivation Attack in Sensor Networks: Analysis and Methods of Defense. *International Journal of Distributed Sensor Networks*, 2(3), 267–287. doi:10.1080/15501320600642718.
- [30] Bhattasali, T., & Chaki, R. (2011). A Survey of Recent Intrusion Detection Systems for Wireless Sensor Network. *Communications in Computer and Information Science*, 268–280. doi:10.1007/978-3-642-22540-6_27.
- [31] Riaz, R., Kim, K.-H., & Ahmed, H. F. (2009). Security analysis survey and framework design for IP connected LoWPANs. 2009 International Symposium on Autonomous Decentralized Systems. doi:10.1109/isads.2009.5207373.
- [32] Hummen, R., Hiller, J., Wirtz, H., Henze, M., Shafagh, H., & Wehrle, K. (2013). 6LoWPAN fragmentation attacks and mitigation mechanisms. Proceedings of the Sixth ACM Conference on Security and Privacy in Wireless and Mobile Networks - WiSec '13. doi:10.1145/2462096.2462107.
- [33] Dvir, A., Holczer, T., & Buttyan, L. (2011). VeRA - Version Number and Rank Authentication in RPL. 2011 IEEE Eighth International Conference on Mobile Ad-Hoc and Sensor Systems. doi:10.1109/mass.2011.76.
- [34] Wazid, M., Das, A. K., Kumari, S., & Khan, M. K. (2016). Design of sinkhole node detection mechanism for hierarchical wireless sensor networks. *Security and Communication Networks*, 9(17), 4596–4614. doi:10.1002/sec.1652.
- [35] Zhang, K., Liang, X., Lu, R., & Shen, X. (2014). Sybil Attacks and Their Defenses in the Internet of Things. *IEEE Internet of Things Journal*, 1(5), 372–383. doi:10.1109/jiot.2014.2344013.
- [36] Granjal, J., Monteiro, E., & Silva, J. S. (2012). Network-layer security for the Internet of Things using TinyOS and BLIP. *International Journal of Communication Systems*, 27(10), 1938–1963. doi:10.1002/dac.2444.
- [37] J. Granjal, E. Monteiro, J.S. Silva, End-to-end transport-layer security for internet-integrated sensing applications with mutual and delegated ecc public-key authentication, in: 2013 IFIP Networking Conference, 2013, pp.1–9.
- [38] Granjal, J., Monteiro, E., & Silva, J. S. (2010). Enabling Network-Layer Security on IPv6 Wireless Sensor Networks. 2010 IEEE Global Telecommunications Conference GLOBECOM 2010. doi:10.1109/glocom.2010.5684293.
- [39] D.U. Sinthan, M.-S. Balamurugan, Identity authentication and capability-based access control (IACAC) for the Internet of Things, *J. Cyber Secur. Mob.* 1 (4) (2013) 309–348.
- [40] Peretti, G., Lakkundi, V., & Zorzi, M. (2015). BlinkToSCoAP: An end-to-end security framework for the Internet of Things. 2015 7th International Conference on Communication Systems and Networks (COMSNETS). doi:10.1109/comsnets.2015.7098708.
- [41] S. Raza, T. Voigt, V. Jutvik, Lightweight IKEv2: a key management solution for both the compressed IPsec and the IEEE 802.15. 4 security, in: Proceedings of the IETF Workshop on Smart Object Security, vol. 23, 2012.
- [42] Park, N., & Kang, N. (2015). Mutual Authentication Scheme in Secure Internet of Things Technology for Comfortable Lifestyle. *Sensors*, 16(1), 20. doi:10.3390/s16010020.
- [43] Brachmann, M., Keoh, S. L., Morchon, O. G., & Kumar, S. S. (2012). End-to-End Transport Security in the IP-Based Internet of Things. 2012 21st International Conference on Computer Communications and Networks (ICCCN). doi:10.1109/icccn.2012.6289292.
- [44] Sethi, M., Arkko, J., & Keranen, A. (2012). End-to-end security for sleepy smart object networks. 37th Annual IEEE Conference on Local Computer Networks - Workshops. doi:10.1109/lcnw.2012.6424089.
- [45] OWASP, Top IoT Vulnerabilities, 2019. URL <https://owasp.org/www-chapter-toronto/assets/slides/2019-12-11-OWASP-IoT-Top-10---Introduction-and-Root-Causes.pdf>.
- [46] Conzon, D., Bolognesi, T., Brizzi, P., Lotito, A., Tomasi, R., & Spirito, M. A. (2012). The VIRTUS Middleware: An XMPP Based Architecture for Secure IoT Communications. 2012 21st International Conference on Computer Communications and Networks (ICCCN). doi:10.1109/icccn.2012.6289309.
- [47] Liu, C. H., Yang, B., & Liu, T. (2014). Efficient naming, addressing and profile services in Internet-of-Things sensory environments. *Ad Hoc Networks*, 18, 85–101. doi:10.1016/j.adhoc.2013.02.008.
- [48] Young, M., & Boutaba, R. (2011). Overcoming Adversaries in Sensor Networks: A Survey of Theoretical Models and Algorithmic Approaches

- for Tolerating Malicious Interference. *IEEE Communications Surveys & Tutorials*, 13(4), 617–641. doi:10.1109/surv.2011.041311.0015.
- [49] Demirbas, M., & Youngwhan Song. (n.d.). An RSSI-based Scheme for Sybil Attack Detection in Wireless Sensor Networks. 2006 International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM'06). doi:10.1109/wowmom.2006.27 .
- [50] R. Harkanson, Y. Kim, Applications of elliptic curve cryptography: A light introduction to elliptic curves and a survey of their applications, in: Proceedings of the 12th Annual Conference on Cyber and Information Security Research, CISRC '17, ACM, New York, NY, USA, 2017, pp. 6:1–6:7.
- [51] D. Eastlake, P.E. Jones, RFC 3174 - US Secure Hash Algorithm 1 (SHA1), 2001. URL <https://tools.ietf.org/html/rfc3174>.
- [52] H. Krawczyk, M. Bellare, R. Canetti, HMAC: keyed-hashing for message authentication, 1997. URL <https://tools.ietf.org/rfc/rfc2104.txt>.
- [53] Weekly, K., & Pister, K. (2012). Evaluating sinkhole defense techniques in RPL networks. 2012 20th IEEE International Conference on Network Protocols (ICNP). doi:10.1109/icnp.2012.6459948.
- [54] A.A. Pirzada, C. McDonald, Circumventing sinkholes and wormholes in wireless sensor networks, in: International Workshop on Wireless Ad-Hoc Networks, 2005.
- [55] Alvisi, L., Clement, A., Epasto, A., Lattanzi, S., & Panconesi, A. (2013). SoK: The Evolution of Sybil Defense via Social Networks. 2013 IEEE Symposium on Security and Privacy. doi:10.1109/sp.2013.33 .
- [56] Mohaisen, A., Hopper, N., & Kim, Y. (2011). Keep your friends close: Incorporating trust into social network-based Sybil defenses. 2011 Proceedings IEEE INFOCOM. doi:10.1109/infcom.2011.5934998.
- [57] Kim, H. (2008). Protection Against Packet Fragmentation Attacks at 6LoWPAN Adaptation Layer. 2008 International Conference on Convergence and Hybrid Information Technology. doi:10.1109/ichit.2008.261.
- [58] M.H. Ibrahim, Octopus: An edge-fog mutual authentication scheme, *International Journal of Network Security*, 18, 6, 2016 PP.1089-1101, Nov.
- [59] Kothmayr, T., Schmitt, C., Hu, W., Brunig, M., & Carle, G. (2012). A DTLS based end-to-end security architecture for the Internet of Things with two-way authentication. 37th Annual IEEE Conference on Local Computer Networks -- Workshops. doi:10.1109/lcnw.2012.6424088.
- [60] Kothmayr, T., Schmitt, C., Hu, W., Brünig, M., & Carle, G. (2013). DTLS based security and two-way authentication for the Internet of Things. *Ad Hoc Networks*, 11(8), 2710–2723. doi:10.1016/j.adhoc.2013.05.003.
- [61] S.L. Kinney, *Trusted Platform Module Basics: Using TPM in Embedded Systems*, Newnes, Newton, MA, USA, 2006.
- [62] Alghamdi, T. A., Lasebae, A., & Aiash, M. (2013). Security analysis of the constrained application protocol in the Internet of Things. Second International Conference on Future Generation Communication Technologies (FGCT 2013). doi:10.1109/fgct.2013.6767217.
- [63] Raza, S., Trabalza, D., & Voigt, T. (2012). 6LoWPAN Compressed DTLS for CoAP. 2012 IEEE 8th International Conference on Distributed Computing in Sensor Systems. doi:10.1109/dcoss.2012.55.
- [64] Granjal, J., Monteiro, E., & Silva, J. S. (2013). Application-Layer Security for the WoT: Extending CoAP to Support End-to-End Message Security for Internet-Integrated Sensing Applications. *Lecture Notes in Computer Science*, 140–153. doi:10.1007/978-3-642-38401-1.
- [65] M. Brachmann, O. Garcia-Morchon, S.-L. Keoh, S.S. Kumar, Security considerations around end-to-end security in the IP-based Internet of Things, *Workshop on Smart Object Security, in Conjunction with IETF83*, 2012.
- [66] OneM2M, Security solutions –OneM2M Technical Specification, 2019. URL https://www.onem2m.org/images/files/deliverables/Release3/TS-0003_Security_Solutions-v3_10_2.pdf.
- [67] Ferreira, H. G. C., de Sousa, R. T., de Deus, F. E. G., & Canedo, E. D. (2014). Proposal of a secure, deployable and transparent middleware for Internet of Things. 2014 9th Iberian Conference on Information Systems and Technologies (CISTI). doi:10.1109/cisti.2014.6877069.

A Mobile App for the Identification of Flowers Using Deep Learning

Gandhinee Rajkomar, Sameerchand Pudaruth
ICT Department, FoICDT, University of Mauritius, Mauritius

Abstract—Flowers are admired and used by people all around the world for their fragrance, religious significance, and medicinal capabilities. The accurate taxonomy of these flower species is critical for biodiversity conservation and research. Non-experts typically need to spend a lot of time examining botanical guides in order to accurately identify a flower, which can be challenging and time-consuming. In this study, an innovative mobile application named FloralCam has been developed for the identification of flower species that are commonly found in Mauritius. Our dataset, named FlowerNet, was collected using a smartphone in a natural environment setting and consists of 11660 images, with 110 images for each of the 106 flower species. Seventy percent of the data was used for training, twenty percent for validation and the remaining ten percent for testing. Using the approach of transfer learning, pre-trained convolutional neural networks (CNNs) such as the InceptionV3, MobileNetV2 and ResNet50V2 were fine tuned on the custom dataset created. The best performance was achieved with the fine tuned MobileNetV2 model with accuracy 99.74% and prediction time 0.09 seconds. The best model was then converted to TensorFlow Lite format and integrated in a mobile application which was built using Flutter. Furthermore, the models were also tested on the benchmark Oxford 102 dataset and MobileNetV2 obtained the highest classification accuracy of 95.90%. The mobile application, the dataset and the deep learning models developed can be used to support future research in the field of flower recognition.

Keywords—Flowers; deep learning; mobile application; Mauritius

I. INTRODUCTION

Flowers have long been appreciated as a significant phenomenon in the history of mankind [1]. They are adored and used by humans around the globe to embellish their environment as well as for fragrance, religion, and medicine [2]. Flowering plants, commonly known as angiosperms (Merriam-Webster, 2021), have been the most dominant plant biodiversity in our terrestrial ecosystem for over 60 million years [3]. The dominance of these living organisms over more primitive angiosperms, such as pines and palms, was even described as an “abominable mystery” by Charles Darwin [4]. According to [5], there are about 400,000 species of plants on Earth. Over the last few decades, the world’s biomass have undergone a change of more than 10% owing to the various effects of climate change and land use. In addition, the increasing invasion of alien plant species has shown a negative impact on native plants, destroying our natural ecosystem. The accurate identification of invasive non-native plant species can therefore aid in the development of awareness and educational programs contributing to the mitigation of their impacts [5].

According to [6], accurate identification of species is

critical for ecological monitoring. Therefore, proper plant and flower identification can help stakeholders with a variety of activities, such as investigating the biodiversity richness of an area and monitoring the population of endangered species while species misidentification can lead to erroneous conservation strategies [7]. As can be deduced, accurate species classification is essential for biodiversity conservation and research. Furthermore, accurate flower classification is a non-tedious task for skilled taxonomists and for people with expertise in anthology and botany [8]. Non-experts and novices typically find it complex and time-consuming to properly identify a flower. They usually must spend a significant amount of time examining botanical guides [9]. Automatic recognition technologies, such as machine learning (ML) and artificial intelligence (AI), can thus be utilised for the automatic identification of flowers, overcoming this taxonomic gap.

Several studies have been conducted on flower detection and recognition systems by employing different flower images and methods. Flower shape and colour, as well as the stamen region, can be used to identify different flowers [10]. Deep learning techniques such as the convolutional neural networks (CNN) are effective in distinguishing between numerous flower species [11]. Also, a mobile application for the automatic recognition of plants from their leaves was developed by [12]. However, no such application for flower recognition has yet been developed in Mauritius. The purpose of this paper is therefore to create such an application to facilitate the identification of flowers among common people with little or no botany knowledge through pictures taken using a smartphone. Moreover, information on the flower, such as its scientific name, common name, and a brief description will be displayed.

Today, it is still challenging to differentiate flowers in image processing systems. This is because many flower species exhibit similar shapes and colours. In addition, there are several difficulties when images are captured in natural outdoor scenes. For example, lighting is largely dependent on the weather conditions and the time of day. Furthermore, due to illumination considerations, specular highlights can affect the appearance of flowers, for example flowers may appear brighter or whiter than usual. Moreover, differences in occlusions, viewpoints, and scales in flower images, as well as uncertainty across different flower species with similar characteristics such as colour and form, contribute to the difficulties of automatic flower recognition. Another challenge is that the flower in the image must be segmented properly and with as few errors as possible [13].

Thus, a mobile application that can automatically identify and categorise flowers found in Mauritius will be developed.

The system will be created using AI and deep learning approaches and will make use of a new dataset of flowers, which are available in the Republic of Mauritius. This paper proceeds as follows. In section II, we provide an overview of all the related works that have been done on the automatic recognition of flowers. The datasets and the deep learning models used are described in section III. Section III discusses the results for each experiment, together with a comparison with existing works. Section V concludes the paper. A list of all the flowers using in this work are provided in the appendix.

II. RELATED WORKS

Artificial intelligence along with machine learning and deep learning, has been used for the development of software involving image recognition. Numerous models, approaches, and methodologies have been adopted in the classification of flower species. This section includes some pertinent research on various flower recognition studies.

One of the first flower recognition studies was conducted by [14] using an approach that indexes flower images based on their colours and spatial domains. Their research focus was mainly based on developing efficient methods for querying a database by colour for identification of flowers. An iterative segmentation algorithm with the aim of reducing unnecessary processing, was used to extract flower regions from their background using the flower's domain knowledge. This allowed for the indexing of flower images based solely on the colours present in the flower rather than the complete image. The database could then be queried by a specific colour or by supplying a sample flower image. This colour-based algorithm, however, makes it difficult to classify flowers primarily based on their colour, without considering their shape and other features.

An approach with the aim of classifying wildflowers based on more than one attribute (shape and colour) was implemented in [15]. Their method involved the use of a three-layered network along with a back propagation learning algorithm. A dataset consisting of 20 sets of images from 16 flower species was used, with each set containing two images of a plant: a leaf and a flower's frontal image captured using a digital camera. The proposed model was trained using 19 sets of images, with the remaining one was used for testing. They obtained an accuracy of 96% by using four features from the leaf and two from the flower. Their study also demonstrated that having too many features from the input images can have an impact on the recognition performance. Images were taken under controlled environments by positioning a black cloth behind the flower and leaf to enable easier segmentation.

Saitoh et al. enhanced their previous work by conducting further research to automatically recognise blooming flowers [16]. The innovation in their research was a new way of extracting the flowers from their background, as opposed to their earlier work, which used K-means clustering. This new method, called "Intelligent Scissors", was proposed by [17]. In this innovative approach, images were taken such that the flowers appeared in the centre of the photo with a defocused background. A total of 600 pictures, comprising 20 images per flower for 30 different species, were taken for this experiment. Of these, 19 images from each flower species were used for

training and the rest for testing. They achieved a classification accuracy of 90% by using 10 colour and shape features.

Traditional flower recognition studies usually implicate constraints such as variations in flower positions as well as having multiple flowers in an image, resulting in poor recognition performance. Kim et al. therefore proposed using the Difference Image Entropy (DIE) and contour features retrieved from images comprising of multi-flower objects in their mobile system [18]. Their application works by using two images. Firstly, the user draws a contour line around the flower region on the original congregated flower image to retrieve the first image. Next, contour features such as Zero-Crossing Rate (ZCR), minimum distance, and length of the contour line are extracted from the first image. These features are then used to reduce the number of flower candidates in the entire identification process. Following that, pixel subtraction is used to calculate the difference between the second image (the sub image containing the flower from the original image), and the normalized average of the reduced images obtained from the previous step. Their system used a dataset consisting of 20 images per flower species, for a total of 10 species. Ten images per flower for all species were used in training, and the other 10 images were used for testing the model. The recognition accuracy was 95%.

Automatically extracting flower boundaries from flower images is a key part of the recognition process. Given the difficulties of extracting flowers from its background, Aydin and Ugur presented the IPSOAntK-Means algorithm [19]. Their proposed solution combines the K-means algorithm with particle swarm optimisation and an ant colony algorithm to improve the flower boundary extraction process. Their approach was evaluated by using two different datasets, namely the CAVIAR and Oxford 17 datasets. The first dataset contained 1078 flowers from 113 distinct species, while the second one had flowers from 17 different species. Based on images from the CAVIAR dataset, their investigation revealed that the IPSOAntK-means method performed better than the K-means algorithm, with a segmentation accuracy of 96.4%. However, since only colour was used for the extraction process, the proposed method has decreased extraction performance on flowers with similar colours to that of their background.

Flowers come in a variety of colours and contours, and it is difficult to distinguish between them based only on their contours. In their mobile application, Hong and Choi used both colour and contour aspects, as well as K-means clustering and history matching, to increase the recognition accuracy [20]. A dataset consisting of 500 images was built, with 400 images used for training and the remaining 100 images used for testing their model. Their study demonstrated that they could improve contour detection quality by using colour-based contour detection and edge-based contour detection. They also observed that light and camera angle can lead to recognition failures by wrongly detecting the contours of the flowers. Therefore, they applied image recovery and partial recognition to mitigate this issue. With all these measures, their application obtained an accuracy of 94.8%.

Tiay et al. also attempted to recognise flowers based on their colour and edge properties by using the K-nearest neighbour (KNN) algorithm [21]. Their system displayed the top three similar flowers by using seven edge and forty colour

characteristics. Their proposed system consisted of 10 flower species with 50 images per species for testing and 100 images for training. Their study showed that having flowers with overlapping edge and colour properties can impact the classification accuracy. Their method resulted in a classification accuracy of more than 80%.

CNN-based recognition method was used by [22] for apple blossom identification. Dias et al. used a pre-trained CNN model with Support Vector Machines (SVM). Their detection rate was 90%. Another closely related approach was the hybrid method proposed by [23] Their method used CNN models along with feature selection methods. Their dataset had 4242 photos, non-uniformly distributed by species: each flower had a different number of images. Adding to that, their dataset was partitioned into 80% for training and the remaining 20% for testing. For feature extraction, the GoogleNet, AlexNet, ResNet-50, and VGG-16 CNN models were used and trained using the transfer learning method. The features extracted were then combined, and only the efficient ones were finalised using the f-regression and multiple inclusion criterion (MIC) methods yielding two sets of features. The 2-feature sets obtained were then compared and only the intersecting features in both sets (stable features) were extracted and classified using the SVM method. Their research indicated that the stable features obtained by the feature selection methods contributed to their high classification accuracy of 98.91%. However, their study was conducted using only 5 different flower species.

Liao and Zhang also used the feature selection method in their system along with a classification method based on SVM and a DenseNet architecture called DN-F-SVM [24]. DenseNet was utilised to extract several features from the flower images. Furthermore the Fast Correlation-Based Filter (FCBF), was employed to select the most effective features. The proposed model was trained on the Oxford 17 and Oxford 102 datasets. A classification accuracy of 99.12% and 98.90% was obtained, respectively for each dataset.

Researchers have also adopted the CNN ensemble approach to achieve optimum recognition accuracy in real-world applications. Such an approach was proposed by Wang et al. and it consisted of 3 steps [25]. The first phase, known as feature extraction, was achieved by pretraining the MobileNet models on the ILSVRC-2012-CLS image dataset. Following that, the retrieved features were used to train different classifiers. In addition, a re-sampling strategy was used to improve the diversity of the individual models used. Finally, an ensemble model was implemented using the weighted average technique. They tested the effectiveness of their system on two flower datasets consisting of 3670 and 1660 images from 5 flower species. The first dataset consisted of a training set with 3320 images and a test set with 350 images while the second dataset was used entirely for testing. Their findings demonstrated that the ensemble technique outperformed single classifiers. Adding to that, they also noted that the ensemble method can achieve better performance with a larger dataset.

A hybrid approach integrating the Viola-Jones algorithm and multi-template matching for effective and accurate identification of Anthurium flower cultivars was done in [26]. Their system had a computation time of less than 0.5s and a classification accuracy of more than 99%. Their results indicated that the technique had acceptable performance in detecting

the spadix region and very good performance in classifying the flower cultivars. Based on the VGG-16 CNN method, Lv et al. designed a flower classification model using the saliency detection algorithm [27]. They also used the stochastic gradient descent algorithm to adjust network weights. The dropout and the transfer learning methods were also used in optimising the model to reduce overfitting. They utilised the Oxford-102 dataset, which included 102 flower species and around 40-258 images per species for a total of 8189 images. The categorisation accuracy was 91.9%.

III. METHODOLOGY

This section describes the different steps followed to build the flower recognition system. The datasets and the deep learning models are used are described in detail.

A. Datasets

1) *FlowerNet*: The first and most critical step in implementation of the system is data acquisition. As a result of the non-availability of a large image dataset of flowers found in Mauritius at the beginning of the study, a new dataset had to be created to undertake the research. To achieve the primary objective of building a huge dataset, flower images were captured in various locations, including plant nurseries, neighbourhoods, gardens, and parks from the period of November 2021 to April 2022. For this research, the Huawei Y9 2019 smartphone with a resolution of 13 megapixels was utilised to collect data samples for 106 flower species. The dataset was constructed either by capturing close-up flower pictures continuously or extracting frames from recorded flower videos. The images and recorded videos were captured in a natural environment, such as in sunny and rainy weather conditions with variations in viewpoints, illumination and rotation. This new dataset was named as FlowerNet. It consists of 106 classes of flower species with a total of 11660 images. Each class has 110 different flower images. The dataset can be obtained by contacting the authors.

2) *Other datasets*: For a fair consideration, we will compare the performance of our implemented models with the Oxford 102 flower dataset. This dataset contains 40 to 258 images for 102 flower species commonly found in the UK with a total of 8189 images. The dataset contains images that vary in terms of scaling, lighting and poses.

Additionally, three different variations of these two datasets were also created:

- (i) A merged dataset consisting of flower categories from both the Oxford 102 and the FlowerNet but excluding the overlapping flowers from the Oxford 102 dataset,
- (ii) A flower dataset consisting of overlapping flowers from the Oxford 102 dataset only, and
- (iii) A flower dataset consisting of overlapping flowers from the FlowerNet dataset only.

3) *Overlapping flowerNet and oxford 102 datasets*: Table I shows the corresponding overlapping flowers in FlowerNet and Oxford 102 datasets. The flowers in the first column are used to create the overlapping flower dataset for the Oxford 102 dataset while the flowers in the second column are used to create the overlapping flower dataset for the FlowerNet dataset.

Also, flowers of different colours were considered as different flower categories in the FlowerNet dataset. However, for the creation of the overlapping flower dataset for the FlowerNet dataset, the different colours were merged as a single flower category as shown in Table II.

TABLE I. OVERLAPPING FLOWERS IN FLOWERNET AND OXFORD 102 DATASETS

#	Oxford 102 Dataset	FlowerNet Dataset
1	anthurium	Flamingo Lily (Pale Pink) Flamingo Lily (Dark Red)
2	blackberry lily	Leopard Flower
3	bougainvillea	Paper Flower (Fuchsia) Paper Flower (White) Paper Flower (Sundown Orange)
4	barbeton daisy	Gerbera (Dark Pink) Gerbera Daisy (Dark Orange) Gerbera Daisy (Fuchsia) Gerbera Daisy (Pale Orange) Gerbera Daisy (Pale Pink) Gerbera Daisy (Red) Gerbera Daisy (White) Gerbera Daisy (White_Pink) Gerbera Daisy (Yellow)
5	canna lily	Canna Lily
6	desert-rose	Desert Rose (Pink) Desert Rose (Dark Red)
7	frangipani	Frangipani (Yellow) Frangipani (Pink)
8	geranium	Geranium (Pink) Geranium (Red)
9	hibiscus	Hibiscus (Red) Hibiscus (Pale Pink) Hibiscus (Pale Orange)
10	mexican petunia	Mexican Petunia
11	oxeye daisy	Daisy (White)
12	red ginger	Ostrich Plume
13	rose	Rose (Cream) Rose (Pink) Rose (Dark Red)

TABLE II. OVERLAPPING FLOWER DATASET FOR FLOWERNET

#	Flower Category	No of Flowers
1	Canna lily	110
2	Daisy (White)	110
3	Desert Rose	220
4	Flamingo Lily	220
5	Frangipani	220
6	Geranium	220
7	Gerbera	990
8	Hibiscus	330
9	Leopard Flower	110
10	Mexican Petunia	110
11	Ostrich Plume	110
12	Paper Flower	330
13	Rose	330

B. Balancing the Imbalanced Datasets

Table III shows the different datasets: Oxford 102, Merged, Overlapping Oxford 102 and Overlapping FlowerNet. A hybrid sampling strategy combining both data augmentation and under sampling is adopted to balance the imbalanced datasets. Data augmentation is the process of artificially generating new data images using available images by utilising a variety of transformation techniques such as rotation, flipping, zooming, image blurring and adjustment of brightness and contrast. Under sampling, on the other hand refers to a technique whereby samples from the majority classes are randomly removed to balance the dataset.

TABLE III. DATASET SUMMARY

Dataset	# Images per Flower Category
Oxford 102	40 - 258
FlowerNet	110
Merged	40 - 258
Overlapping Oxford 102	42 - 171
Overlapping FlowerNet	110 - 990

C. Classification System

Different CNN models were trained on the FlowerNet dataset using the transfer learning approach. Transfer learning, as the term implies, is the application of knowledge gained from one problem to solve other distinct but related problems. In deep learning, the knowledge of a neural network previously trained to tackle one problem can be leveraged as a starting point to address another classification challenge. AlexNet, GoogleNet, MobileNet, ResNet, and VGG19 are a few examples of CNN models trained on the huge ImageNet dataset which encompasses 1.4 million images with 1000 classes. These pre-trained models can be repurposed for another target domain by using the fixed feature extraction and fine-tuning methods. During this study, several models were implemented, and the optimal model is chosen through a series of experiments and converted into TensorFlow Lite for integration into a mobile application. Fig. 1 illustrates the processes in the flower recognition system.

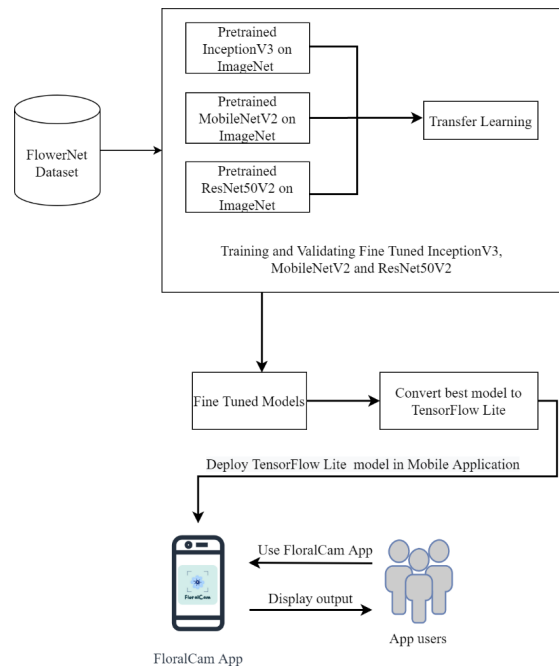


Fig. 1. The flow of processes in the flower recognition system.

D. Fine Tuning Pre-trained CNNs

The InceptionV3, MobileNetV2 and ResNet50V2 models were fine-tuned for the flower classification problem. The fully connected layers of the pretrained networks were removed while the remaining network, consisting of a sequence of convolution and pooling layers, were retained for fixed feature extractor. New classification layers were incorporated to

perform classification on the different flower classes. In our study, a global average pooling layer, dropout layer along with two dense layers with ReLu and a dense layer with SoftMax classifier were added as classification layers as shown in Fig. 2.

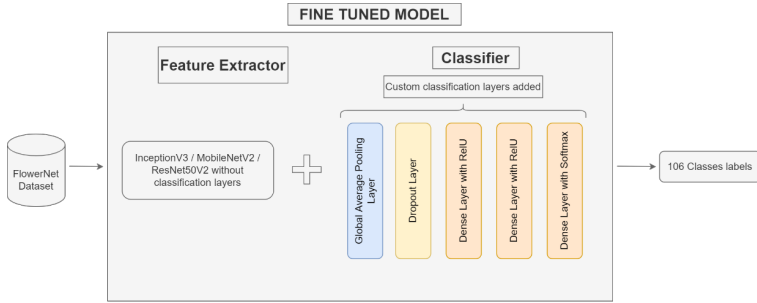


Fig. 2. Proposed architecture of fine-tuned InceptionV3, ResNet50V2 and MobileNetV2.

E. Summary of Models Implemented

Table IV summarises the different models that were implemented in this study.

TABLE IV. SUMMARY OF MODELS

Pre-Trained CNN	Trainable Layer	Classifier
MobileNetV2	True	SoftMax
	False	SoftMax
ResNet50V2	True	SoftMax
	False	SoftMax
InceptionV3	True	SoftMax
	False	SoftMax

F. Summary of Datasets Used

Table V summarises the different datasets that have been used in this study.

TABLE V. SUMMARY OF DATASETS

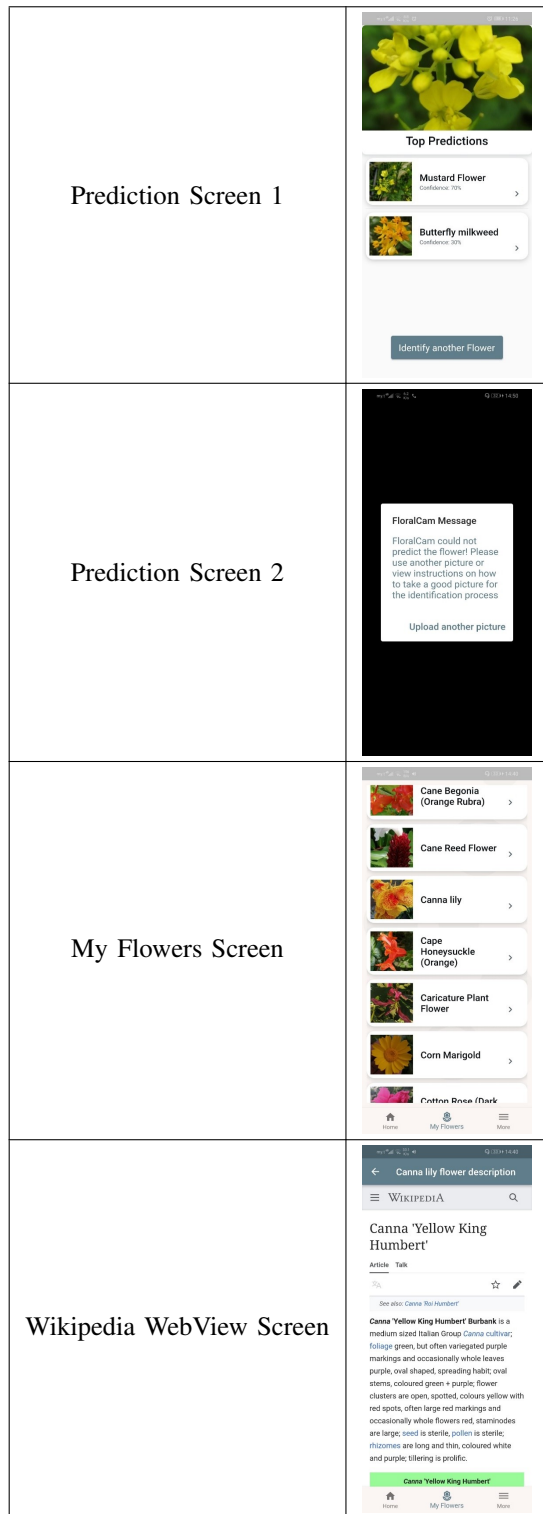
Dataset	Flower Classes	Images per Flower Class	Total Images	Training (70%)	Validation (20%)	Testing (10%)
FlowerNet	106	110	11660	8162	2332	1166
Oxford 102	102	110	11220	7854	2244	1122
Merged	195	110	21450	15015	4290	2145
Overlapping Oxford	13	110	1430	1001	286	143
Overlapping FlowerNet	13	110	1430	1001	286	143

G. Mobile Application

Flutter is chosen as the framework for developing the mobile application since it can be utilised to develop user-friendly interfaces with the help of well-structured documentation. Additionally, Flutter is cross-platform allowing it to run on different mobile operating systems. Table VI shows the different screens developed for the mobile application.

TABLE VI. SCREENS IN MOBILE APPLICATION

Screen	Screen Image
Splash Screen	
Home Page	
Choosing Image Upload Option	
Cropping Screen	
Loading Screen	



IV. RESULTS AND DISCUSSION

The results obtained by the implemented models on the different datasets are described in this section. The performance of each model is assessed using the classification accuracy and F1 scores. The FlowerNet dataset consists of 11660 images, 106 flowers each having 110 images. The dataset was divided into three sets before training the models: 70% for training, 20% for validation, and remaining 10% for testing.

A. FlowerNet Dataset

Table VII displays the accuracy values achieved after evaluating all the models with the FlowerNet dataset. The MobileNetV2 and InceptionV3 models achieved the highest accuracy scores of 99.74% and 99.31%, respectively. These highest accuracy scores were obtained when the feature extraction layers were set to trainable. When trainable layers are set to true, this implies that all the weights of the neural network are updated during training. When feature extraction layers were not trained, the maximum accuracy score was 98.97%.

TABLE VII. FLOWERNET DATASET RESULTS

Model	#	Trainable Layers	Accuracy	F1 Macro	F1 Weighted
MobileNetV2	1	TRUE	99.74%	0.9974	0.9974
	2	FALSE	98.97%	0.9897	0.9897
ResNet50V2	3	TRUE	98.97%	0.9897	0.9897
	4	FALSE	98.97%	0.9897	0.9897
InceptionV3	5	TRUE	99.31%	0.9931	0.9931
	6	FALSE	98.80%	0.9881	0.9881

B. Oxford 102 Dataset

Table VIII displays the accuracy values achieved after evaluating all the models with the Oxford 102 dataset. The MobileNetV2 and InceptionV3 models achieved the highest accuracy scores of 95.90% and 95.28%, respectively. These highest accuracy scores were obtained when the feature extraction layers were set to trainable. When the layers in the InceptionV3 model are set to non-trainable, the accuracy drops to 91%.

TABLE VIII. OXFORD 102 DATASET RESULTS

Model	#	Trainable Layers	Accuracy	F1 Macro	F1 Weighted
MobileNetV2	1	TRUE	95.90%	0.9594	0.9594
	2	FALSE	92.87%	0.9278	0.9278
ResNet50V2	3	TRUE	92.25%	0.9217	0.9217
	4	FALSE	91.18%	0.9111	0.9111
InceptionV3	5	TRUE	95.28%	0.9530	0.9530
	6	FALSE	91.00%	0.9089	0.9089

When trainable layers are set to true, the feature extraction layers of the pretrained CNNs are re-trained, and their weights are updated according to the FlowerNet dataset. This explains why the best results are obtained when the trainable layers are set to true. However, when trainable layers are set to false, this implies that the feature extraction layers of the CNNs are using the original weights and features of the ImageNet dataset, and this resulted in poor prediction, as compared to re-training all layers in the pretrained CNNs for the FlowerNet and Oxford 102 dataset. The ImageNet dataset, Oxford 102 and the FlowerNet datasets have distinct characteristics. Therefore, training the feature extraction layers from scratch using the FlowerNet/ Oxford 102 dataset resulted in better accuracies.

C. Merged Dataset

Table IX displays the accuracy values achieved after evaluating all the models with the merged dataset. The InceptionV3 and MobileNetV2 models achieved the highest accuracy scores of 97.30% and 97.11%, respectively. These highest accuracy scores were obtained when the feature extraction layers were set to trainable. When the layers in the InceptionV3 model are set to non-trainable, the accuracy drops to 94.22%.

TABLE IX. MERGED DATASET RESULTS

Model	#	Trainable Layers	Accuracy	F1 Macro	F1 Weighted
MobileNetV2	1	TRUE	97.11%	0.9711	0.9711
	2	FALSE	96.13%	0.9603	0.9603
ResNet50V2	3	TRUE	95.15%	0.9513	0.9513
	4	FALSE	94.87%	0.9474	0.9474
InceptionV3	5	TRUE	97.30%	0.9728	0.9728
	6	FALSE	94.22%	0.9414	0.9414

The models which were trained on the merged dataset have obtained a lower accuracy as compared to the original FlowerNet dataset. As the number of classes in a computer vision task increases, the identification process becomes complex. When the number of classes is increased from 106 (FlowerNet) to 195 (Merged), the complexity of the model increases, which makes the model more prone to errors.

D. Overlapping Flowers Datasets

For the FlowerNet dataset, the images were captured as close-up flower pictures. Oxford 102, on the other hand, consists of a variety of images taken in different positions and orientations. In this study, the effect of training a model with close-up pictures is also analysed with flowers found in both the FlowerNet and the Oxford 102 datasets.

Table X displays the accuracy values achieved after evaluating all the models with the overlapping FlowerNet dataset. A general observation is that all models have obtained an accuracy of above 99%. For the MobileNetV2 and ResNet50V2 models, the accuracies and F1 macro and weighted scores are all 100%. For the InceptionV3 model, the accuracy and F1 macro and weighted scores dropped by 0.7% when trainable layers are set to false.

TABLE X. OVERLAPPING FLOWERNET DATASET RESULTS

Model	#	Trainable Layers	Accuracy	F1 Macro	F1 Weighted
MobileNetV2	1	TRUE	100%	1.0000	1.0000
	2	FALSE	100%	1.0000	1.0000
ResNet50V2	3	TRUE	100%	1.0000	1.0000
	4	FALSE	100%	1.0000	1.0000
InceptionV3	5	TRUE	100%	1.0000	1.0000
	6	FALSE	99.30%	0.9930	0.9930

Table XI displays the accuracy values achieved after evaluating all the models with the overlapping Oxford 102 dataset. When trainable layers are set to true, the InceptionV3 model achieved the best accuracy of 99.30% followed by an accuracy of 96.50% by the MobileNetV2 and ResNet50V2 models. When the layers in the InceptionV3 model are set to non-trainable, the accuracy drops to 97.90%.

TABLE XI. OVERLAPPING OXFORD 102 DATASET RESULTS

Model	#	Trainable Layers	Accuracy	F1 Macro	F1 Weighted
MobileNetV2	1	TRUE	99.30%	0.9930	0.9930
	2	FALSE	97.90%	0.9793	0.9793
ResNet50V2	3	TRUE	96.50%	0.9641	0.9641
	4	FALSE	97.20%	0.9719	0.9719
InceptionV3	5	TRUE	96.50%	0.9646	0.9646
	6	FALSE	95.80%	0.9582	0.9582

Models trained on the overlapping FlowerNet flowers have performed relatively better than models trained on the overlapping Oxford 102 dataset. The overlapping FlowerNet dataset

classes consist of mostly close-up images of flowers with minimal background while the overlapping Oxford 102 dataset consists of flower images with a lot of background. This result suggests that the proportion of background in the images has influenced the identification process, hence the difference in accuracy.

E. Model Prediction Time

A good model is not dependent solely on classification accuracy. The prediction time of the model should also be considered. As a result, an experiment is carried out to test the prediction time with models that have trainable layers set to true. To calculate the inference time of the models, the prediction time was recorded for the test images. The experiment was then repeated seven times to obtain an average prediction time for a more realistic inference time. The prediction time per image was then computed and the results are tabulated as shown in Table XII.

From Table XII, it can be deduced that MobileNetV2 has a lower prediction time (0.09 seconds) followed by the ResNet50V2 (0.12 seconds). InceptionV3 has the highest inference time of 0.22 seconds per image. In terms of model size, MobileNetV2 has the smallest size followed by InceptionV3 and ResNet50V2.

MobileNetV2 obtained the least prediction time as compared to ResNet50V2 and InceptionV3. This is because the network size and parameter count affect the inference time and MobileNetV2 (3.1 million) has a lower parameter count as compared to InceptionV3 (23.0 million) and ResNet50V2 (24.8 million). Adding to that, the trained MobileNetV2 model has the lowest size compared to the others. This is another reason influencing the prediction time.

F. Comparison with Existing Works

Wang et al. performed classification on five different flower categories using an initial dataset consisting of a training set to train their model and a test set to evaluate it [25]. Additionally, another dataset set was used to test their models. They used the ensemble method, whereby the predictions of seven MobileNet models were combined. They achieved the best accuracy of 94.63% and 91.14% on their first and second datasets, respectively. Compared to the result in this paper, an accuracy of 99.7% was achieved when the MobileNetV2 model was used. Even with a much more significant number of categories of flowers (106 classes), our models produced better accuracy. The dataset used by [25] was not publicly available to perform additional testing.

Lv et al. used the VGG16 CNN model to perform flower classification [27]. They were able to achieve an accuracy of 91.9% when the model was trained on the Oxford 102 dataset. The Oxford 102 dataset was also used to compare the implemented models with that of [27]. The best accuracy obtained when trained on the Oxford 102 dataset was 95.90% when the MobileNetV2 model was used. Thus, our work outperformed the VGG16 model used in [27].

V. CONCLUSIONS

The classification of flower species is a challenging process. Flower images captured in varying viewpoints, lightings

TABLE XII. MODELS PREDICTION TIME

Model	No of test images	Total Prediction Time for 7 iterations /sec	Average Prediction Time /sec	Prediction time per image /sec	Model Size/ MB
MobileNetV2	1166	730	104	0.09	35.8
ResNet50V2		1010	144	0.12	284.1
InceptionV3		1836	262	0.22	264.4

and occlusion by leaves and other debris make it difficult to classify flower species. Deep learning has recently surfaced as one of the preferred approaches for achieving promising results in such classification problems. A new dataset, named FlowerNet, consisting of 106 flower species was created and deep learning models such as InceptionV3, MobileNetV2, ResNet50V2 were used for the classification. The best performing model, MobileNetV2, achieved an accuracy of 99.74% with the smallest prediction time of 0.09 seconds. Moreover, this model was deployed in a mobile application named FloralCam. In the real environment, FloralCam achieves a good level of accuracy when high-quality close-up flower images are used, but it may result in poor prediction in cases when blurry and low-quality images with a high proportion of background are used. Further experiments may be carried out to fine tune the best model's performance in the real world by utilising a larger and a more diverse dataset.







REFERENCES





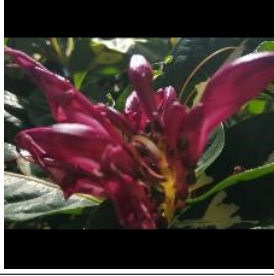
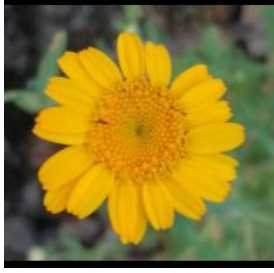
- [1] A. S. Chanderbali, B. A. Berger, D. G. Howarth, P. S. Soltis, and D. E. Soltis, "Evolving ideas on the origin and evolution of flowers: New perspectives in the genomic era," *Genetics*, vol. 202, no. 4, pp. 1255–1265, Mar. 2016. [Online]. Available: <https://doi.org/10.1534/genetics.115.182964>
- [2] R. S. Kumar, "Cultivation and marketing of flowers in india - an empirical study," *International Journal of Research in Social Sciences*, vol. 7, no. 7, pp. 244–271, 2017.
- [3] P. Kenrick, "Fossil Plants | angiosperms," in *Encyclopedia of Geology*. Elsevier, 2005, pp. 418–427. [Online]. Available: <https://doi.org/10.1016/b0-12-369396-9/00018-6>
- [4] J. O'Donoghue, "What the first flower on earth might have looked like." 2017. [Online]. Available: <https://www.newscientist.com/article/2142372-what-the-first-flower-on-earth-might-have-looked-like/>
- [5] "About the world flora online project," 2023. [Online]. Available: <https://about.worldfloraonline.org/>
- [6] G. E. Austen, M. Bindemann, R. A. Griffiths, and D. L. Roberts, "Species identification by experts and non-experts: comparing images from field guides," *Scientific Reports*, vol. 6, no. 1, Sep. 2016. [Online]. Available: <https://doi.org/10.1038/srep33634>
- [7] J. Wäldchen and P. Mäder, "Plant species identification using computer vision techniques: A systematic literature review," *Archives of Computational Methods in Engineering*, vol. 25, no. 2, pp. 507–543, Jan. 2017. [Online]. Available: <https://doi.org/10.1007/s11831-016-9206-z>
- [8] T. Islam, N. Absar, A. Z. Adamov, and M. U. Khandaker, "A machine learning driven android based mobile application for flower identification," in *Applied Intelligence and Informatics*. Springer International Publishing, 2021, pp. 163–175. [Online]. Available: https://doi.org/10.1007/978-3-030-82269-9_13
- [9] J. Wäldchen and P. Mäder, "Machine learning for image based species identification," *Methods in Ecology and Evolution*, vol. 9, no. 11, pp. 2216–2225, Sep. 2018. [Online]. Available: <https://doi.org/10.1111/2041-210x.13075>
- [10] T.-H. Hsu, C.-H. Lee, and L.-H. Chen, "An interactive flower image recognition system," *Multimedia Tools and Applications*, vol. 53, no. 1, pp. 53–73, 2011.
- [11] Y. Liu, F. Tang, D. Zhou, Y. Meng, and W. Dong, "Flower classification via convolutional neural network," in *2016 IEEE International Conference on Functional-Structural Plant Growth Modeling, Simulation, Visualization and Applications (FSPMA)*. IEEE, Nov. 2016. [Online]. Available: <https://doi.org/10.1109/fspma.2016.7818296>
- [12] T. Munisami, M. Ramsurn, S. Kishnah, and S. Pudaruth, "Plant leaf recognition using shape features and colour histogram with k-nearest neighbour classifiers," *Procedia Computer Science*, vol. 58, pp. 740–747, 2015. [Online]. Available: <https://doi.org/10.1016/j.procs.2015.08.095>
- [13] D. Guru, Y. S. Kumar, and S. Manjunath, "Textural features in flower classification," *Mathematical and Computer Modelling*, vol. 54, no. 3-4, pp. 1030–1036, Aug. 2011. [Online]. Available: <https://doi.org/10.1016/j.mcm.2010.11.032>
- [14] M. Das, R. Manmatha, and E. Riseman, "Indexing flower patent images using domain knowledge," *IEEE Intelligent Systems*, vol. 14, no. 5, pp. 24–33, Sep. 1999. [Online]. Available: <https://doi.org/10.1109/5254.796084>
- [15] T. Saitoh and T. Kaneko, "Automatic recognition of wild flowers," in *Proceedings of the 15th International Conference on Pattern Recognition (ICPR-2000)*. IEEE Computer Society. [Online]. Available: <https://doi.org/10.1109/icpr.2000.906123>
- [16] T. Saitoh, K. Aoki, and T. Kaneko, "Automatic recognition of blooming flowers," in *Proceedings of the 17th International Conference on Pattern Recognition (ICPR-2004)*. IEEE. [Online]. Available: <https://doi.org/10.1109/icpr.2004.1333997>
- [17] E. N. Mortensen and W. A. Barrett, "Intelligent scissors for image composition," in *Proceedings of the 22nd annual conference on Computer graphics and interactive techniques - SIGGRAPH '95*. ACM Press, 1995. [Online]. Available: <https://doi.org/10.1145/218380.218442>
- [18] J.-H. Kim, R.-G. Huang, S.-H. Jin, and K.-S. Hong, "Mobile-based flower recognition system," in *2009 Third International Symposium on Intelligent Information Technology Application*. IEEE, 2009. [Online]. Available: <https://doi.org/10.1109/iita.2009.407>
- [19] D. Aydin and A. Uğur, "Automatic flower boundary extraction using ipsoantk-means algorithm," *Cybernetics and Systems*, vol. 41, no. 6, pp. 416–434, Aug. 2010. [Online]. Available: <https://doi.org/10.1080/01969722.2010.500799>
- [20] S.-W. Hong and L. Choi, "Automatic recognition of flowers through color and edge based contour detection," in *2012 3rd International Conference on Image Processing Theory, Tools and Applications (IPTA)*. IEEE. [Online]. Available: <https://doi.org/10.1109/ipta.2012.6469535>
- [21] T. Tiay, P. Benyaphaichit, and P. Riyamongkol, "Flower recognition system based on image processing," in *2014 Third ICT International Student Project Conference (ICT-ISPC)*. IEEE, 2014, pp. 99–102.
- [22] P. A. Dias, A. Tabb, and H. Medeiros, "Apple flower detection using deep convolutional networks," *Computers in Industry*, vol. 99, pp. 17–28, Aug. 2018. [Online]. Available: <https://doi.org/10.1016/j.compind.2018.03.010>







- [23] M. Toğaçar, B. Ergen, and Z. Cömert, "Classification of flower species by using features extracted from the intersection of feature selection methods in convolutional neural network models," *Measurement*, vol. 158, p. 107703, Jul. 2020. [Online]. Available: <https://doi.org/10.1016/j.measurement.2020.107703>
- [24] L. Liao and S. Zhang, "A flower classification method combining DenseNet architecture with SVM," in *2020 16th International Conference on Computational Intelligence and Security (CIS)*. IEEE. [Online]. Available: <https://doi.org/10.1109/cis52066.2020.00014>
- [25] Z. Wang, K. Wang, X. Wang, and S. Pan, "A convolutional neural network ensemble for flower image classification," in *Proceedings of the 2020 9th International Conference on Computing and Pattern Recognition*. ACM. [Online]. Available: <https://doi.org/10.1145/3436369.3437427>
- [26] A. Soleimanipour and G. Chegini, "A vision-based hybrid approach for identification of anthurium flower cultivars," *Computers and Electronics in Agriculture*, vol. 174, p. 105460, Jul. 2020. [Online]. Available: <https://doi.org/10.1016/j.compag.2020.105460>
- [27] R. Lv, Z. Li, J. Zuo, and J. Liu, "Flower classification and recognition based on significance test and transfer learning," in *2021 IEEE International Conference on Consumer Electronics and Computer Engineering (ICCECE)*. [Online]. Available: <https://doi.org/10.1109/iccece51280.2021.9342468>







APPENDIX

TABLE XIII. FLOWER SPECIES IN FLOWERNET DATASET







#	Common Name	Scientific Name	
1	Purple Allamanda	Allamanda Blanchetii	
2	Yellow Allamanda	Allamanda Cathartica	
3	Angel Wing Begonia (Pink)	Begonia coccinea	
4	Angel Wing Begonia (White)	Begonia coccinea	
5	Billygoat weed	Ageratum conyzoides	
6	Butterfly milkweed	Asclepias tuberosa	







7	Cane Begonia (Orange Rubra)	Begonia coccinea 'Orange'	
8	Cane Reed Flower	Cheilocostus speciosus	
9	Canna lily	Canna 'Yellow King Humbert'	
10	Cape Honeysuckle (Orange)	Tecoma capensis	
11	Caricature Plant Flower	Graptophyllum pictum	
12	Corn Marigold	Glebionis segetum	


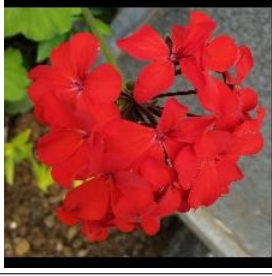




13	Cotton Morning Glory	<i>Ipomoea cordatotriloba</i>	
14	Cotton Rose (Dark Pink)	<i>Hibiscus mutabilis</i>	
15	Cotton Rose (Pale Pink)	<i>Hibiscus mutabilis</i>	
16	Cotton Rose (Red)	<i>Hibiscus mutabilis</i>	
17	Daisy (White)	<i>Bellis perennis</i>	
18	Daylily (Orange)	<i>Hemerocallis fulva</i>	




19	Desert Rose (Pink)	Adenium obesum	
20	Dessert Rose (Dark Red)	Adenium obesum	
21	Double Dahlia (Pale Yellow)	Dahlia	
22	Double Dahlia (White)	Dahlia	
23	Dwarf Marigold (Orange)	Tagetes erecta	
24	Dwarf Marigold (Pale Yellow)	Tagetes erecta	







25	Dwarf Marigold (Yellow)	Tagetes erecta	
26	Easter Lily (Red)	Lilium longiflorum	
27	Easter Lily (White)	Lilium longiflorum	
28	Egyptian Starcluster (Pale Purple)	Pentas lanceolata	
29	Egyptian Starcluster (White)	Pentas lanceolata	
30	Madagascar jewel	Euphorbia Leuconeura	







31	Fairy Lily (Pink)	Zephyranthes candida	
32	Fairy Lily (White)	Zephyranthes candida	
33	False sunflower	Heliopsis helianthoides	
34	Firecracker Flower	Crossandra infundibuliformis	
35	Flamevine	Pyrostegia venusta	
36	Flamingo Lily (Pale Pink)	Anthurium andraeanum	







37	Flamingo Lily (Pink)	Anthurium andraeanum	
38	Frangipani (Pink)	Plumeria rubra	
39	Frangipani (White)	Plumeria pudica	
40	Frangipani (Yellow)	Plumeria rubra	
41	French Marigold	Tagetes patula	
42	Garlic Vine	Mansoa alliacea	







43	Geranium (Pink)	Pelargonium × hortorum	
44	Geranium (Red)	Pelargonium × hortorum	
45	Gerbera (Dark Pink)	Gerbera	
46	Gerbera Daisy (Dark Orange)	Gerbera	
47	Gerbera Daisy (Fuchsia)	Gerbera	
48	Gerbera Daisy (Pale Orange)	Gerbera	







49	Gerbera Daisy (Pale Pink)	Gerbera	
50	Gerbera Daisy (Red)	Gerbera	
51	Gerbera Daisy (White)	Gerbera	
52	Gerbera Daisy (White_Pink)	Gerbera	
53	Gerbera Daisy (Yellow)	Gerbera	
54	Ground Orchid (White)	Spathoglottis plicata	







55	Hibiscus (Light pink)	Hibiscus rosa-sinensis	
56	Hibiscus (Pale Orange)	Hibiscus rosa-sinensis	
57	Hibiscus (Red)	Hibiscus rosa-sinensis	
58	Hummingbird Fuchsia	Fuchsia magellanica	
59	Hydrangea	Hydrangea macrophylla	
60	Pink Orchid Balsam	Impatiens flaccida	

61	Indian chrysanthemum	Chrysanthemum indicum	
62	Ixora (orange)	Ixora coccinea	
63	Japanese Hawkweed	Youngia japonica	
64	Lantana (White)	Lantana camara	
65	Lantana (Yellow)	Lantana camara	
66	Leopard Flower	Iris domestica	







67	Madamfate	Hippobroma	
68	Showy Medinilla	Medinilla magnifica	
69	Mexican Flame Vine	Pseudogynoxys chenopodioides	
70	Mexican Heather	Cuphea hyssopifolia	
71	Mexican Petunia	Ruellia simplex	
72	Moss Flower (Orange_Yellow)	Portulaca grandiflora	





73	Moss Flower (Pale Pink)	Portulaca grandiflora	
74	Mustard Flower	Brassica nigra	
75	Nora Grant (Red)	Ixora coccinea	
76	Ostrich Plume	Alpinia purpurata	
77	Paper Flower (Fuchsia)	Bougainvillea glabra	
78	Paper Flower (Sundown Orange)	Bougainvillea glabra	

79	Paper Flower (White)	Bougainvillea glabra	
80	Parakeet Flower (Red_Orange)	Heliconia psittacorum	
81	Parakeet Flower (Yellow)	Heliconia psittacorum	
82	Peregrina	Jatropha integerrima	
83	Periwinkle (Pink)	Catharanthus roseus	
84	Periwinkle (Red)	Catharanthus roseus	

85	Periwinkle (White with Pink centre)	Catharanthus roseus	
86	Periwinkle (White)	Catharanthus roseus	
87	Princess Flower	Pleroma urvilleanum	
88	Rose (Cream)	Rosa	
89	Rose (Dark Red)	Rosa	
90	Rose (Pink)	Rosa	

91	Rose Balsam (Lavender)	Impatiens balsamina	
92	Rose Balsam (Red)	Impatiens balsamina	
93	Rose Balsam (White_Pink)	Impatiens balsamina	
94	Rose Balsam(Fuchsia)	Impatiens balsamina	
95	Shower Orchid	Congea tomentosa	
96	Silver Cockscomb (Fuchsia)	Celosia argentea	

97	Single Dahlia (Yellow)	Dahlia	
98	Singapore daisy	Sphagneticola trilobata	
99	Spiny sowthistle	Sonchus asper	
100	Stargazer Lily	Lilium Stargazer	
101	Tagar Flower	Tabernaemontana divaricata	
102	Thai Eggplant Flower	Solanum melongena	

103	Thornless Crown of Thorns	Euphorbia geroldii	
104	Turmeric Flower	Curcuma longa	
105	Wax Begonia	Begonia cucullata	
106	Yesterday Today and Tomorrow	Brunfelsia latifolia	

A Study of Prediction of Airline Stock Price through Oil Price with Long Short-Term Memory Model

Jae Won Choi¹, Youngkeun Choi^{2*}

Department of Computer Science, University of Texas at Dallas, Richardson, TX, USA¹
Division of Business Administration, Sangmyung University, Seoul, Korea²

Abstract—This study aims to present a model that predicts the stock price of an airline by setting the economic and technical information of oil as features and taking advantage of the LSTM method. In this study, oil price data for about seven years from January 4, 2016, to April 14, 2023, were collected through FinanceDataReader. The collected data is a total of 1,833 days of AA stock price data. The price data consists of six categories: Date, Open, High, Low, Close, Volume, and Change (price is based on dollars). Data is stored every 24 hours, so it was judged to be most suitable for short-term price prediction (24 hours later) to be conducted in this study. In this paper, normalized closing price data was trained for 50 epochs. As a result of learning, the loss value converged close to 0. The MSE measured by the accuracy of the model shows a result of 0.00049. The significance of this study is as follows. First, it is meaningful in that it can present indicators such as more sophisticated predictions and risk management to airline companies. Oil price as our selected feature can compensate for the poor performance of a simple model and its limitations on overfitting.

Keywords—Stock price prediction; airline; oil; long short-term memory

I. INTRODUCTION

For a considerable period, scholars have been interested in forecasting future stock price movements [1]. While proponents of the efficient market hypothesis argue that accurate stock price prediction is unattainable, empirical evidence suggests that by employing appropriate variables and suitable models, it is feasible to predict future stock prices and detect patterns of stock price movements with a relatively high level of precision. LSTM (Long Short-Term Memory) is a powerful technique for predicting stock prices due for several compelling reasons [2]. Firstly, stock prices exhibit sequential patterns, and LSTMs are designed to capture long-term dependencies in time-series data. They can effectively model the sequential relationships in historical stock price data, enabling them to capture relevant trends, patterns, and seasonality for accurate future price forecasting. Secondly, LSTMs incorporate a memory cell that selectively retains or forgets information over time. This memory cell helps in preserving important historical information while filtering out irrelevant noise, making LSTMs robust in handling noisy and volatile stock price data where multiple factors may affect price movements. Thirdly, stock prices are influenced by a wide range of factors with non-linear relationships, and LSTMs are capable of modeling such non-linearity. With non-linear activation functions and multiple gates, LSTMs can capture complex patterns in the data, allowing them to capture intricate

relationships in stock price data that linear models may miss. Fourthly, LSTMs can automatically learn relevant features from raw data without relying on manual feature engineering. This is particularly advantageous for stock price prediction as relevant features may change over time and may be difficult to identify manually. LSTMs can learn to represent important features from historical data, enhancing the accuracy of predictions. Lastly, LSTMs are adaptable and can be trained on different time scales, such as daily, weekly, or monthly data, depending on the prediction task requirements. They can also be trained on various stock markets or different stocks, making them flexible for different prediction scenarios. Finally, LSTMs can undergo training using extensive historical stock price data, which is often accessible for multiple stocks. This enables them to capture prolonged patterns and trends, rendering them suitable for predicting stock prices over extended timeframes. Consequently, the ability of LSTMs to handle sequential data, capture long-term dependencies, model non-linear relationships, learn relevant features, adapt to different time scales, and scale to large datasets makes them a formidable tool for stock price prediction.

Selecting crucial factors for predicting stock prices using LSTM is imperative to capture relevant information that can impact stock prices [3]. Economic indicators, financial statements, market sentiment, and news are significant factors that can significantly affect stock prices. Incorporating these relevant factors into the LSTM model enables it to capture the complex relationships and patterns in the data, resulting in more accurate stock price predictions. The careful selection of these factors ensures that the LSTM model is trained on meaningful inputs, enhancing its ability to forecast stock prices and potentially assisting in making informed investment decisions.

The stock market is influenced by crude oil prices, which reflect economic conditions. Existing studies present mixed findings, with some reporting positive associations and others indicating negative associations. Park and Ratti [4] discovered a negative influence on composite stock market returns but a positive influence on energy stock market returns. Filis and Chatziantoniou [5] found a negative influence on the stock markets of importing countries but a positive influence on the stock markets of exporting countries. Narayan and Sharma [6] identified that the influence depends on the scale of the enterprise. Bjornland [7] observed a positive influence on crude oil production stock prices and a negative influence on transportation stock prices. Lu and Chen [8] investigated the influence of WTI crude oil prices on stock prices of

*Corresponding Author.

transportation companies across eight countries and found that sea transportation is less affected due to increased crude oil transportation volume. Mohanty et al. [9] revealed a negative impact on US airlines during the financial crisis, while Shaeri et al. [10] identified a stronger impact on airlines. Although there is limited literature on the effect of crude oil prices on aviation stocks, Kristjanpoller and Concha [11] reported a negative relationship between oil prices and aviation stocks. The researchers utilized statistical analysis techniques to examine the impact of oil on stock prices in their academic paper. They employed various datasets and models, such as three-factor and two-factor asset pricing models, GARCH model, the standard market model, the event study methodology, and CAPM with GARCH models. However, no prior research has employed LSTM (Long Short-Term Memory) based on crude oil prices to predict airline stock prices. Predicting airline stock prices using LSTM based on crude oil prices hold significant value due to the influence of oil prices on airline operational costs, industry dynamics, risk management, investor confidence, and operational optimization. Accurate predictions can assist airlines in planning and budgeting for fuel costs, making informed strategic decisions, managing risk exposure, attracting investors, and optimizing operations, potentially impacting profitability and stock prices.

As a result, this study focuses on oil prices while considering the characteristics of airlines. From this perspective, there is a need to identify an accurate method for predicting airline stock prices using machine learning algorithms. Since stock prices do not exhibit seasonality, machine learning models are applicable and beneficial. Therefore, the study has implemented a long short-term memory (LSTM) model, which is one of the popular machine learning algorithms used in previous studies. However, previous studies simply input data into the model without considering data frequency or sample size. Data with different frequencies possess distinct structures, and employing simplistic machine learning algorithms may result in errors such as overfitting due to their complex methods. Thus, in this study, we investigate whether the information concealed in the economic and technological determinants of oil can accurately predict airline stock prices.

II. RELATED WORK

Crude oil is a significant resource, and its price change is closely linked to the stock market, which serves as an indicator of economic development [12][13][14]. While some studies suggest a positive correlation between oil and stocks, other studies also report a negative correlation. Firstly, Park and Ratti [4] emphasize that although the crude oil price hurts the overall stock market returns, it has a positive impact on the energy stock market returns. Filis and Chatziantoniou [5] also conclude that an increase in crude oil prices negatively affects the stock market of crude oil-importing countries, but positively affects the stock market of crude oil-exporting countries. Secondly, Narayan and Sharma [15] analyze the stock market prices of 560 companies across 14 industries listed on the New York Stock Exchange (NYSE), and find that the impact of oil prices on different companies depends on their scale. Bjornland [7] concludes that an increase in crude

oil prices positively affects the stock prices of crude oil production companies, but negatively affects the stock prices of transportation companies.

In particular, Lu and Chen [8] conducted a study on the effects of WTI crude oil prices on the stock prices of 160 transportation companies in eight countries. The findings revealed that sea transportation companies were able to mitigate the negative impact of rising crude oil prices by increasing their crude oil transportation volume, while air transportation companies were more vulnerable to crude oil price volatility. Mohanty et al. [9] examined the impact of WTI crude oil prices on six industries in the US, including airlines, gambling, hotels, recreational services, restaurants & bars, and travel & tourism. They discovered that crude oil prices had a significant negative effect on the stock price returns of airlines, with a stronger impact observed during the 2008-2009 financial crisis. Similarly, Shaeri et al. [10] found that the impact of crude oil price risk on airlines was more pronounced compared to other industries. Despite limited research on the relationship between crude oil prices and aviation stocks, Kristjanpoller and Concha [11] demonstrated a negative association between oil prices and aviation stocks. Specifically, they analyzed the impact of fuel price fluctuations on aviation stocks associated with the International Air Transport Association (IATA) and found a positive influence of oil prices on aviation stocks.

Researchers conducted a statistical analysis methodology to investigate the impact of oil on stock prices. Mohanty and Nandha (2011) utilized a three-factor asset pricing model to analyze monthly data from July 1992 to December 2008. Mohanty et al. [9] employed a two-factor model to analyze industry returns from September 1983 to August 2011. Narayan and Sharma [15] used the GARCH Model to analyze data from January 2000 to December 2008 for 560 US firms listed on the New York Stock Exchange. Nandha and Brooks [16] analyzed the Transport Indices of thirty-eight countries and WTI Crude Oil, as well as all companies in the S&P Transportation industry index from January 1986 to July 2008, using the Standard Market Model and Event Study Methodology. Kristjanpoller and Concha [11] analyzed data from 56 airlines for the period of 2008–1 to 2013–10, employing the CAPM and GARCH Models.

However, utilizing LSTM (Long Short-Term Memory) to predict airline stock prices based on crude oil prices can minimize similarity in academic papers when considering the following points. Firstly, crude oil prices significantly impact airline operational costs, as jet fuel constitutes a significant portion of expenses. Accurate prediction of crude oil prices can enable airlines to plan and budget their fuel costs more effectively, ultimately affecting profitability and stock prices. Secondly, the airline industry is highly competitive and sensitive to external factors, including changes in crude oil prices. Reliable predictions of crude oil prices can provide airlines with valuable insights into industry dynamics, facilitating informed strategic decision-making and operational adjustments, which in turn can impact stock prices as investors closely monitor industry trends. Thirdly, fluctuating crude oil prices introduce risks to airlines' financial performance and stock prices. LSTM-based predictions of crude oil prices can

aid airlines in managing risk exposure by developing risk mitigation strategies such as hedging or adjusting pricing strategies, to minimize the impact of volatile oil prices on stock prices. Fourthly, accurate predictions of airline stock prices based on crude oil prices can enhance investor confidence. Factors such as fuel costs and industry dynamics are often considered by investors when making investment decisions in the airline sector. Reliable predictions of stock prices can attract and retain investors, leading to increased market demand for airline stocks and potentially driving up stock prices. Lastly, timely and accurate predictions of crude oil prices can help airlines optimize their operations for better efficiency. To mitigate the potential impact of rising oil prices, airlines can implement proactive strategies such as optimizing flight routes, adjusting ticket prices, and negotiating fuel contracts. By employing LSTM to predict airline stock prices using crude oil prices, valuable insights can be gained into fuel costs, industry dynamics, risk management, investor confidence, and operational efficiency. These insights can inform decision-making, optimize airline operations, and potentially influence stock prices, making it a valuable tool for financial forecasting in the airline industry.

III. METHODOLOGY

A. Data Collection

This study utilized oil and American Airlines (AA) stock price data from FinanceDataReader. The stock of American Airlines represents the airline industry stock price for the following reasons: Industry leader: American Airlines is one of the prominent airlines in the United States, with a wide network of routes including international air transportation connecting the U.S. and other countries. Moreover, it has a strong competitive position in the U.S. air transportation market, making it a representative indicator of the trend in airline stock prices. Market size: The aviation industry is a significant part of the global economy, closely tied to economic activities in countries around the world. Therefore, airline stock prices can serve as a representative indicator of the market size concerning global economic conditions and expectations for economic growth. Industry trends: The aviation industry is highly sensitive to fluctuations in the economy and various factors such as oil prices, exchange rate fluctuations, government regulations, and international geopolitical situations can impact airline stock prices. The stock of American Airlines reflects these industry trends, representing the movements in airline stock prices. Investor interest: Airline stocks garner significant attention from investors due to the industry's unique characteristics, competitive landscape, technological advancements, and profitability prospects, all of which influence investors' decisions. Therefore, the stock of American Airlines can serve as a representative indicator of the overall trends in the aviation industry and economic conditions, reflecting the factors that represent airline stock prices.

In this study, oil price data for about seven years from January 4, 2016, to April 14, 2023, were collected through FinanceDataReader. The collected data is a total of 1,833 days of AA stock price data. The price data consists of six categories: Date, Open, High, Low, Close, Volume, and

Change (price is based on dollars). Data is stored every 24 hours, so it was judged to be most suitable for short-term price prediction (24 hours later) to be conducted in this study. Fig. 1 shows the change in oil prices over time of the data. Fig. 2 shows the change in the stock price of AA over time of the data.

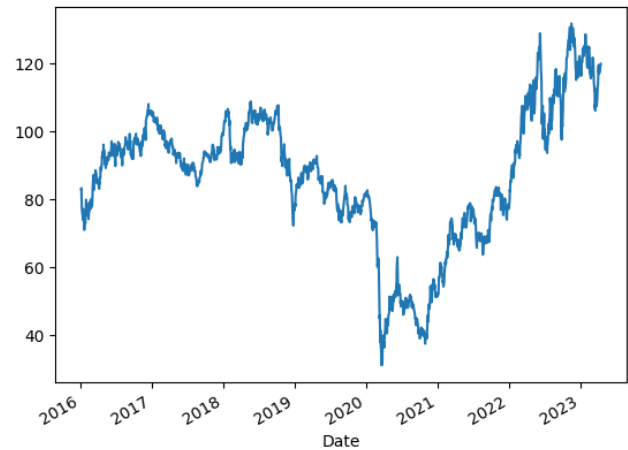


Fig. 1. Oil price distribution.

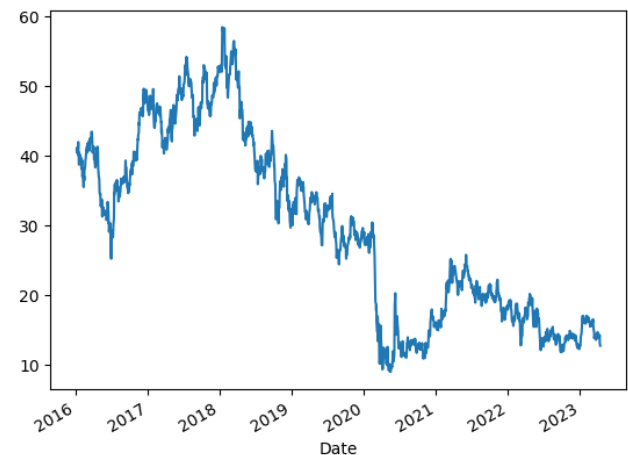


Fig. 2. AA stock price distribution.

B. Data Preprocessing

In this study, data pre-processing was performed using Python as follows. Pre-processing is a total of 4 steps, 1) converting raw data into a data frame, 2) data refinement, 3) data normalization, and 4) data division. First, the sequence length of data consisting of daily was set to 30, and it was reconstructed into a data frame matrix in units of 30 days. Second, in the data refinement process, null values or data marked as 0 among the data were replaced with the mean value to handle missing values. Third, all input values were converted into values between 0 and 1 through the data normalization process. Finally, data segmentation was performed. The entire collected Ethereum data was divided in a ratio of 7:3, and 7 parts of data (training data) were used for model learning, and 3 parts of data (test data) were used for testing. However, since the data is composed of time series, considering the order, the test data was selected as the most recent data. In addition, the hyper-parameters were divided into

training and verification parts at a ratio of 8:2 to the 7 parts of the training data split for optimization.

C. Price Prediction with LSTM Model

Recurrent neural network (RNN) can reflect the sequence-related characteristics of financial time-series data, but it has the problem of gradient disappearance or gradient explosion. Also, its mining of historical information for financial time-series data is very limited. LSTM is a special RNN that can well handle the long-term dependencies of time-series data [17]. Therefore, the LSTM model is an improved RNN model, to some extent.

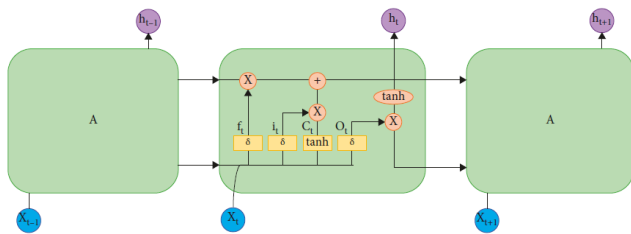


Fig. 3. LSTM network structure.

Fig. 3 shows the network structure of the LSTM. The basic unit of the LSTM model is a memory block, which includes a memory cell and three gate structures that control the state of the memory cell, forget gate, input gate, and output gate. To be specific, the forget gate decides to forget the useless historical information from the memory cell state, the input gate decides the influence of the current input data on the memory cell state, and the output gate decides the output information.

Firstly, the data that must be erased from the cell is identified based on the forget gate (f_t) of the (1) as outlined below:

$$f_t = \sigma(bf + Wf x_t + Uf h_t - 1) \quad (1)$$

The sigmoid activation function σ is used to determine the amount of information retained. The x_t refers to the current input vector, while h_t represents the hidden layer vector. b_f , x_t , and h_t are the bias, input weight, and loop weight of the forget gate, respectively, in the neural network architecture.

Subsequently, the information state is updated within the cell. The external input gate (i_t) is regulated by a sigmoid activation function as described in (2):

$$i_t = \sigma(bi + Wi x_t + Ui h_t - 1) \quad (2)$$

Meanwhile, the update of the cell state (C_t) is carried out by equation (3), which utilizes C_{t-1} as the input.

$$C_t = f_t * C_{t-1} + i_t * \tanh(bc + Wc x_t + Uch_t - 1) \quad (3)$$

The state of the memory cell at time t is represented by C_t .

Lastly, the output gate (O_t) of (4) regulates the information output in the following manner:

$$h_t = (O_t) \tanh(C_t) \quad (4)$$

$$O_t = \sigma(bo + Wo x_t + Uo h_t - 1) \quad (5)$$

The model's accuracy was assessed using Mean Squared Error (MSE), which is a common loss function for regression tasks in neural network models. MSE calculates the average of the squared differences between the predicted values and the actual values. This study chose to use MSE for several reasons. Firstly, MSE is a differentiable function, which makes it suitable for updating the model's weights using the backpropagation algorithm. Secondly, MSE accounts for the magnitude of the error, as larger errors are squared, emphasizing their impact and aiding in reducing prediction errors during model training. Thirdly, MSE is robust to outliers, making it suitable for evaluating model performance even in the presence of data outliers. The calculation of MSE was performed as shown in Equation (6), where y_k represents the predicted value and t_k represents the actual value.

$$MSE = \frac{1}{n} \sum_k (y_k - t_k)^2 \quad (6)$$

where the variable "n" denotes the data size.

D. Train and Test the Model

In this study, after constructing the model, the hyperparameter optimization process of the LSTM model was performed to optimize performance. The primary process explored the number of neurons and the number of times of learning (Epoch). The two layers inside the LSTM model consist of n number of neurons. In this study, we experimented by changing the number of neurons to 16, 32, 64, 128, and 200. In addition, the number of times of learning was experimented by changing to 10, 30, 50, and 100. If the number of training is too small, the model does not train well, and if the number of training is too large, overfitting problems occur. In conclusion, when the number of neurons is 32 and the number of learning is 50, the verification data prediction results are the best.

As a secondary process, the optimal window size and activation function were optimized. The second process was carried out with the number of neurons and the number of learning selected in the first fixed at 32 and 50, respectively. The window size refers to the size of the previous data set used by the model in the process of learning, and the analysis was conducted while reducing it in the order of 10, 7, 5, and 3. An activation function means a function that converts an input value into an output value in the two hidden layers inside the LSTM. Recurrent activation is a commonly used time.

The sigmoid function was used as it is, and the gate function was compared and analyzed with four functions, tanh, relu, linear, and softmax. As a result of the secondary analysis, when the window size was 7 and the gate function was composed of a combination of the tanh function, the verification data prediction result was the best. Additional hyperparameter selection work was carried out through the first and second optimization processes. The dropout ratio means the ratio of randomly disconnecting some of all the lines connected between neurons to prevent overfitting and was designated as 0.25 in this study. Batch size refers to the amount that is passed to the next network after learning by dividing the entire data. The larger the size, the more computer memory is used, so 2 was designated in this study. The sequence length and output dimension were configured in units of 30 days. And

the optimizer used Adam, and the loss function used MSE (Mean Squared Error).

IV. RESULTS

In this paper, normalized closing price data was trained for 50 epochs. As a result of learning, the loss value converged close to 0 as shown in Fig. 4.

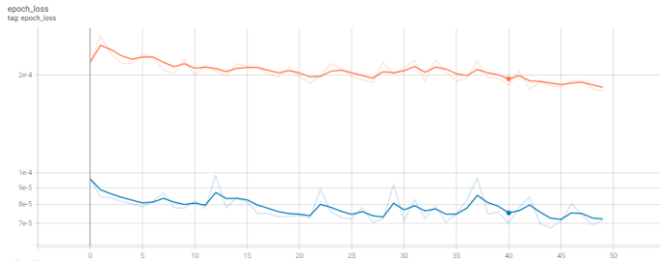


Fig. 4. Learning loss value.

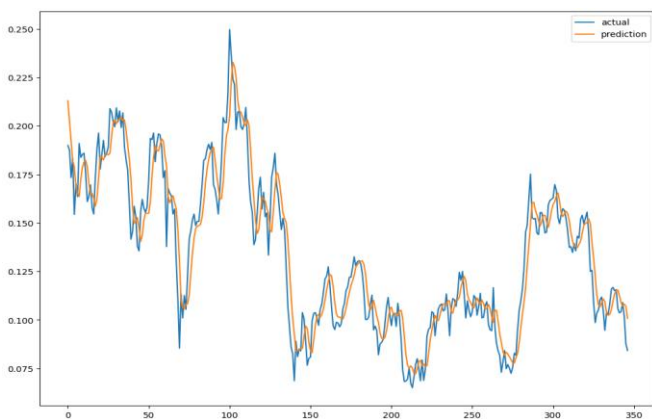


Fig. 5. Prediction results.

There was a case where the validation-set loss soared temporarily due to a sudden rise or fall in the stock price, but it generally converged to 0. The results of testing with test data using the trained model are shown in Fig. 5. Inverse normalization was performed on the test results before output. The MSE measured by the accuracy of the model shows a result of 0.0004. As a result of testing with the trained model, it was confirmed that the trend of the actual value was followed with high accuracy, as shown in Fig. 5.

V. CONCLUSION

The selection of influential factors for stock price prediction using LSTM is crucial as it allows for capturing relevant information that can impact stock prices. Economic indicators, financial statements, market sentiment, and news are significant factors that can affect stock prices. Including these relevant factors in the LSTM model enhances its ability to capture complex relationships and patterns in the data, leading to more accurate stock price predictions. Crude oil prices have been found to affect stock markets, but studies show mixed associations with some reporting positive and others negative effects. Previous studies have used statistical analysis methods to study the impact of oil prices on stock prices, but there is a gap in research predicting airline stock prices using LSTM based on crude oil prices. Accurate

predictions can help airlines plan and budget fuel costs, make strategic decisions, manage risk exposure, and optimize operations. Therefore, this study focuses on accurately predicting airline stock prices using machine learning algorithms, particularly LSTM, considering the impact of oil prices on airline operations and industry dynamics. Different frequencies of data have different structures, and simple copy machine learning algorithms may have errors such as overfitting. Hence, this study investigates whether the information hidden in the economic and technological determinants of oil can accurately predict airline stock prices using LSTM. Based on the necessity of this study, this study developed an LSTM model that predicts the price of airline stock prices through oil prices. As a result of learning, the loss value converged close to zero. The MSE value for AA stock closing price predictions resulted in 0.00049.

The significance of this study is as follows. First, it is meaningful in that it can present indicators such as more sophisticated predictions and risk management to airline companies. In addition, many researchers are attempting to develop new algorithms for predicting airline stock prices, and studies have been conducted with various types of statistical models. However, in this study, we developed a model with improved performance by constructing optimal hyperparameters based on LSTM, an existing algorithm. Oil price as our selected feature can compensate for the poor performance of a simple model and its limitations on overfitting. This result is meaningful in that the prediction accuracy of this study is superior to the results of previous studies that attempted to predict airline stock prices based on a simple machine-learning model.

REFERENCES

- [1] J. Kaur, and K. Dharni, "Data mining-based stock price prediction using hybridization of technical and fundamental analysis", *Data Technologies and Applications*, Vol. ahead-of-print No. ahead-of-print., 2023, <https://doi.org/10.1108/DTA-04-2022-0142>.
- [2] Q. Jia, Y. Zhu, R. Xu, Y. Zhang, and Y. Zhao, "Making the hospital smart: using a deep long short-term memory model to predict hospital performance metrics", *Industrial Management & Data Systems*, vol. 122 no. 10, 2022, pp. 2151-2174.
- [3] J. Wang, Q. Cheng, and Y. Dong, "An XGBoost-based multivariate deep learning framework for stock index futures price forecasting", *Kybernetes*, Vol. ahead-of-print No. ahead-of-print.,2022, <https://doi.org/10.1108/K-12-2021-1289>.
- [4] J. W. Park, and R. A. Ratti, "Oil price shocks and stock markets in the U.S. and 13 European countries," *Energy Economics* vol. 30, no. 5, 2008, pp. 2587-2608.
- [5] G. Filis, and I. Chatziantoniou, "Financial and monetary policy responses to oil price shocks: evidence from oil-importing and oil-exporting countries," *Review of Quantitative Finance and Accounting*, vol. 42, no. 4, 2014, pp. 709-729.
- [6] P. K. Narayan, and S. S. Sharma, "New evidence on oil price and firm returns," *Journal of Banking and Finance*, vol. 35, no. 12, 2011, pp. 3253-3262.
- [7] C. H. Bjornland, "Oil price shocks and stock market booms in an oil exporting country," *Scottish Journal of Political Economy*, vol. 2, no. 5, 2009, pp. 232-254.
- [8] J. R. Lu, and C. C. Chen, "Effect of oil price risk on systematic risk from transportation services industry evidence," *The Service Industries Journal*, vol. 30, no. 11, 2010, pp. 1853-1870.

- [9] S. Mohanty, M. Nandha, E. Habis, and E. Juhabi, "Oil price risk exposure: the case of the U.S.," *Travel and Leisure Industry, Energy Economy*, vol. 41, 2014, pp. 117–124.
- [10] K. Shaeri, C. Adaoglu, and S. T. Katircioglu, "Oil price risk exposure: a comparison of financial and non-financial subsectors," *Energy*, vol. 109, 2016, 712–723.
- [11] D. W. Kristjanpoller, and D. Concha, "Impact of fuel price fluctuations on airline stock returns," *Applied Energy*, vol. 178, 2016, pp. 496–504.
- [12] B. N. Huang, M. J. Hwang, and H. P. Peng, "The asymmetry of the impact of oil price shocks on economic activities: an application of the multivariate threshold model," *Energy Economics*, vol. 27, no. 3, 2005, pp. 455–476.
- [13] S. A. Basher, and P. Sadorsky, "Oil price risk and emerging stock markets," *Global Finance Journal*, vol. 17, no. 2, 2006, pp. 224–251.
- [14] J. I. Miller, and R. A. Ratti, "Crude oil and shock markets: stability, instability, and bubbles," *Energy Economics*, vol. 31, no. 4, 2009, pp. 559–568.
- [15] P. K. Narayan, and S. S. Sharma, "Firm return volatility and economic gains: the role of oil prices," *Economic Modelling*, vol. 38, 2014, pp. 142–151.
- [16] M. Nandha, and R. Brooks, "Oil prices and transport sector returns: an international analysis," *Quant. Finance Account*, vol. 33, no. 4, 2009, pp. 393–409.
- [17] H. Ouyang, K. Huang, and H. Yan, "Prediction of financial time series based on LSTM neural network," *Chinese Journal of Management Science*, vol. 28, no. 4, 2020, pp. 27–35.

Method for Ad-hoc Blockchain of Wireless Mesh Networking with Agent and Initiate Nodes

Kohei Arai

Information Science Department, Saga University
Saga City, Japan

Abstract—Method for Ad-Hoc blockchain of wireless mesh networking with agent and initiate nodes is proposed. Minimizing the number of hops and maintaining connectivity of mobile terminals are concerns. Through simulation studies, it is found that increasing number of initiator nodes caused nodes to route a large number of messages. Thus, these nodes will die out quickly, causing the energy required to get the remaining messages to increase and more nodes to die. This will create a cascading effect that will shorten system lifetime. Multi-hop routing, however, imply high packet overhead, (more nodes in the network means more hops will be available). The packet overhead of the multi-hop routing is extremely high compared to single path routing since many nodes near the shortest path participate in packet forwarding. This additional overhead caused by moving node can cause congestion in the network.

Keywords—Blockchain; Ad-hoc network; agent and initiate nodes; the number of hops; connectivity; routing protocol; multi-hop routing; packet forwarding

I. INTRODUCTION

Blockchain was born in 2008 when an individual or group of unknown nationality named Satoshi Nakamoto published a paper on Bitcoin. There are two types of blockchains, Public and Private. Public blockchains allow an unspecified number of participants to participate in block generation, but on the other hand, there is a problem that processing speed and safety are impaired due to this. On the other hand, with private blockchains, the authority to generate blocks is given only to a limited number of participants, making it difficult to differentiate from conventional databases and making it impossible to demonstrate the inherent strengths of blockchains.

In this study, ad-hoc blockchain of wireless mesh networking is proposed for private blockchains for mobility services. Connected cars are called as smartphones with mobility services. Mobile devices, mobility service sharing, sometimes, needs ad-hoc blockchain functions such as payment confirmation, etc. In such cases, ad-hoc wireless mesh networking is needed. One of the problems of the ad-hoc wireless networking is continuous connectivity among the moving targets of mobile objects, cars, mobile devices, etc.

Wireless mesh network technology, which connects access points by wireless communication, is being considered as an access network [1], [2], [3], [4]. A wireless mesh network consists of access points with interconnection functions called mesh STAs. In a wireless mesh network, route control is necessary for multi-hop communication between mesh STAs.

Each meshSTA exchanges information used for routing on the network. Since this information exchange is also performed by wireless communication, there is a possibility that the opportunity of data packet delivery may be deprived due to the collision caused by the communication.

On the other hand, in wireless mesh networks, there are studies to improve packet transfer efficiency by adjusting the transfer rate of each path [5], [6]. There is also a method of leaving routes that can achieve high throughput by deleting unnecessary routes from multiple routes [7]. In addition to these, there is a method of constructing detours using signaling messages included in standard specifications [8], and research that utilizes the characteristics of hash functions when searching for moving user terminals in mesh networks [9]. Also, there is a method [10] that exchanges position information with adjacent mesh STAs on the Euclidean plane, constructs a Delaunay overlay network, and builds detour routes with neighboring mesh STAs that are not directly adjacent physically. Furthermore, we proposed a basic method for route design and route control using the estimated adjacency relations between mesh STAs [11], and applied it to IPv6 networks [12]. Moreover, there is Ad-hoc On-Demand Distance Vector (AODV) Routing [13]. There are some related research works to the Ad-Hoc wireless network [14]-[24]. There is such related research work to Ad-Hoc wireless blockchain networking at all.

The method proposed here is based on the ad-hoc networking protocol for a block chain of peer-to-peer (P2P) networks with mobile devices. In particular, nodes of mobile devices move from one coverage area to the other coverage areas. The locations of the mobile devices are known with GPS. Therefore, only thing it has to do is to establish ad-hoc network in the moved network area. An agent node is assumed to be an initiate node for establishment of the network. Thus, a blockchain can be created in Ad Hoc manner. This would be useful for “Web3.0” because “Web 3.0” is a decentralized Internet realized by blockchain technology. The decentralized Internet has the advantage that data and information can be decentralized and managed by individuals without depending on specific companies or administrators. This is the basic idea of the proposed method.

In the following section, research background is described followed by the proposed method. Then, some of simulation studies are described followed by conclusion with some discussions.

II. RESEARCH BACKGROUND

A. Blockchain

A block that stores information = a hash function (which replaces some data with a certain other random string: this replacement makes it impossible to read the original data from the string, acting as a cipher) where a hash function is a function that calculates input data in a fixed procedure and outputs a character string of a fixed length regardless of the length of the data of the input value. This research assumes SHA-3: Secure Hash Algorithm 3 as the hash function. This is because there is no regularity between the input data and the output hash value, and if the input data is even slightly different, a completely different hash value is output. In addition, it is difficult to guess input data that gives a specific hash value (weak collision resistance), and it is not easy to find other input data with the same hash value (strong collision resistance). In addition, it is a method of connecting blocks of data that are equally connected without management in the center of the block and that have been replaced with hash values. The basis of the networking method is the P2P method, which manages data.

When it is wanted to mine to add a new block, encrypt the transaction with a hash function and check the consistency with the previous block before adding. Mining is the issuance of a new block, and this issuance must be confirmed by the computer calculations involved in the blockchain to be consistent. Confirming consistency requires astronomical calculations, and all nodes participating in the blockchain participate in the calculations to confirm consistency.

One of the characteristics of blockchain is that it is resistant to attacks because there is no central administrator. In addition, a huge number of computers are involved in the procedures carried out on the blockchain, and they are also encrypted. If the information is tampered with, the hash value will be replaced, and it will be known that all the nodes in the world have been tampered with. Since the information is distributed and managed, there is no need to centralize it, and the more people who participate, the cheaper the operation becomes.

Governance is also an issue for blockchain. This is the problem of how to design and make decisions that affect the design to securely and stably record and process transactions on the blockchain. There is also the issue of scalability. A public blockchain is a distributed ledger with an unspecified number of participants, so the throughput (processing speed) is slow. In addition, there is the issue of privacy. Since the ledger of information traded on the blockchain is public, anyone who participates in the network can see the transaction information. Therefore, in order for blockchain to be implemented in society and spread widely, it is necessary to ensure the confidentiality of sensitive transaction information.

Tapyrus is one of the publicly available blockchain tools. Anyone can freely participate in this blockchain network and can create and view transactions. On the other hand, since the authority to generate blocks and add functions belongs to the administrator network, the governance problems of conventional public blockchains can be resolved.

Tapyrus clarifies the domain to which the blockchain is applied, and multiple federations (coordinators) can be configured by the stakeholders of the domain. In addition, the consensus algorithm used for block generation can be multi-signed by federation instead of Proof of Work (PoW) adopted by Bitcoin and Ethereum. This ensures consistent and stable approval of transactions. Furthermore, since anyone can participate in node operation and the ledger information is open to the public, the reliability of the public blockchain can be guaranteed. Next, a block verification method will be described. It is necessary to clarify the domain to which blockchain is applied. Select multiple federations (coordinators) from domain stakeholders. Construct a signature network that realizes block generation by "multisignature" by 2/3 of the federation (parameter adjustable). The signing network blocks transactions transferred to the Tapyrus network and broadcasts the created blocks to the Tapyrus network. Network participants will then verify the validity of the blocks created by the transaction and signature network.

Colored Coins were developed as part of the Bitcoin 2.0 project (handling Bitcoin as financial assets such as securities and bonds, assets such as commodities and real estate, and expressing this asset information in colors). Besides the underlying cryptocurrency that maintains the Tapyrus chain, it can support the operation of issuing, canceling, and transferring arbitrary tokens designed with unique value by network participants. This includes support for data provision by Oracle, and Tapyrus will support data provision by a trusted third party (Oracle) to enable the execution of smart contracts conditional on real-world data.

Two important features are introduced here. Atomic Swap and Extension Chain. The former is a technology that enables peer-to-peer exchanges between two cryptocurrency tokens on different blockchain networks, and Tapyrus can support coin/token exchanges between chains with features based on atomic swaps. . In addition, by making the unique functions of various blockchains mutually usable, participants can implement the necessary functions at any time. Also, Extension Chain is a mechanism that adds specific functions to the blockchain without changing the first layer, and only the participants who need the functions bear the additional overhead. This avoids the centralization of the network and the burden of data not directly related to transactions by network participants, which could have been caused by implementing the first layer to handle all needs in the past.

A feature of transactions using blockchain is that all transaction histories are recorded in a block (ledger). When dealing with, huge storage and throughput are required. In addition, with a proprietary protocol that uses an accumulator, a large amount of transaction data is compressed and recorded in each block, thereby solving storage and throughput problems, which was difficult until now without compromising security. Enables massive data transactions.

"Paradium" is a blockchain traceability application. "Paradium" is an application that can manage the movement of large amounts of goods (massive transaction volume) by solving problems of storage and throughput by installing Tracking Protocol using Accumulator developed by

“Chaintope”. It is possible to implement the traceability function of blockchain not only on private chains that are managed independently, but also on public chains that do not have a central administrator. It is possible to safely manage the movement of goods using blockchain technology not only for one company but also between companies or across industries.

Tapyrus version 0.5.0 is now available for download¹. Tapyrus v0.5.0 is supported on three platforms: Linux, MacOS and Windows (WSL). Introduce new opcode `OP_COLOR` (0xbc) to allow issuing/sending/destroying arbitrary tokens in Tapyrus. `OP_COLOR` is based on `OP_GROUP`, which was previously considered for introduction in BCH, with some improvements, and has the following functions.

- Token issuance.
- Issuing reissue able tokens.
- Issuance of non-reissue able tokens.
- Issuing NFTs.
- Sending token.
- Incineration of tokens.

B. Web3.0

Blockchain has affinity with Web3.0 and decentralized applications. Web3.0 (Web3) was proposed by Gavin Wood, co-founder of Ethereum in 2014. It consists of a web system built in a distributed manner instead of the conventional centralized one. It refers to an ecosystem where Blockchain is the underlying technology. Gavin Wood proposed the notation Web3. Initially, Web 3.0 was the Semantic Web advocated by Tim Berners-Lee of W3C, that is, the Web that allows computers to collect information and make decisions autonomously, but this concept has spread to the general public. Web 3.0 and Web3 have come to be equated because they were not.

There is “Infrastructure mode” which is one of the operation modes that can be performed with a wireless LAN. To use the wireless LAN environment, install a router that serves as an access point. Installing an access point enables Internet communication via wireless LAN. Wireless LAN is not limited to Internet communication. In a wireless LAN environment, communication between terminals using the same LAN is possible. The function to communicate between terminals using the same LAN is called infrastructure mode.

On the other hand, “Ad hoc mode” is also one of the operation modes of wireless LAN, but it is a paired function with infrastructure mode. In ad-hoc mode, terminals communicate with each other without using an access point. In ad-hoc mode, communication is encrypted using the WEP method, but because the security standard is older, the risk of being deciphered is higher than in infrastructure mode, where communication is encrypted in a more complicated format. In infrastructure mode, files can be shared faster than in ad-hoc mode. Infrastructure mode is also superior in terms of ease of

setup, so there aren't many benefits to using ad-hoc mode from now on.

When communicating between terminals in ad-hoc mode, the Internet cannot be used while files are being shared. In infrastructure mode, the Internet can be used even while terminals are communicating with each other. Ad-hoc mode allows only one-to-one communication, but infrastructure mode allows one-to-many communication. A single computer can communicate with multiple devices at the same time.

There are no major disadvantages to infrastructure mode, but the following three points should be noted.

- Need to prepare an access point.
- A compatible router is required.
- Peripheral devices must support wireless LAN.

To use infrastructure mode, installation of a wireless LAN router that will act as an access point is needed. Note that one-to-many communication is not possible without a wireless router. In addition, any wireless LAN router is not sufficient, and a model that supports infrastructure mode is required.

In the ad-hoc networking, terminals that can communicate using infrastructure mode are not limited to PCs but can also be used with various peripheral devices.

III. PROPOSED METHOD

The network architecture is based on IEEE 802.11s. Wireless ad-hoc mode is a method for wireless devices to directly communicate with each other. Operating in ad-hoc mode allows all wireless devices within range of each other to discover and communicate in peer-to-peer fashion without involving central access points.

On the other hand, blockchain technology is a type of database that directly connects terminals on an information communication network and processes and records transaction records in a distributed manner using cryptographic technology. Blockchain has a mechanism that can easily detect falsification of data by using encryption technology such as “hash” and “electronic signature”. Blockchain has a mechanism that can easily detect falsification of data by using encryption technology such as “hash” and “electronic signature”. In addition, although an unspecified number of participants conduct transactions in blockchain, many participants (not necessarily all participants) record copies of everyone's transaction history, so some computers may go down. However, the entire system does not go down, as many of the remaining participants continue to keep records. Since the copy of this transaction history cannot be deleted, the transaction record once recorded remains as evidence without disappearing. A system in which data is distributed among many participants is called a distributed system.

Many distributed systems to date have had a central administrator for the system. However, in blockchain, all participants continue to copy transaction history autonomously. This is called an autonomous decentralized system and can be said to be one of the major features of blockchain. The characteristics of this autonomous decentralized system, which

¹ <https://github.com/chaintope/tapyrus-core/releases/tag/v0.5.0>

does not allow fraud or tampering and stably records the history of fair transactions, has been indispensable for transactions that require high credibility, such as cryptocurrencies.

Essentially, networking for the block chain, therefore peer-to-peer based networks. The proposed method is applicable to the block chain networking even for the network nodes are moving devices. Furthermore, the mobile devices can be moved from one to the others. Even so, the network connectivity can be maintained. Therefore, the method works well for block chain networking.

The network situation is illustrated in Fig. 1 where MPP: mesh portals, MP: mesh point, AP: access point, MAP: mesh access point, STA: pure client station.

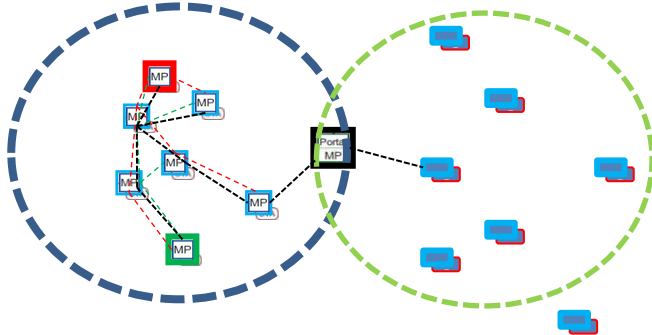


Fig. 1. Network situation.

The followings are situations,

- 1) Each Node has direction, speed, move with distance.
- 2) Each Node will sense path to others (same area) for send DATA.
- 3) Each node will keep path to Agent for send DATA (to other area).
- 4) Agent is special Node (unlimited Energy).
- 5) Agents become relay to other area.

Research focused on three bottom layers of the OSI model. In the physical layer was air (wireless medium) and the followings are set-up in the Data Link layer (Interface),

- 1) Node addressing.
- 2) Packet transmission / re-transmission,
- 3) Buffer receives / transmit,

The followings are also set-up in the Interface with Link,

- 1) Network layer (Data Handler),
- 2) Route calculation *weight criteria,
- 3) Path determination,
- 4) Packet examination,
- 5) Fragmentation / de-fragmentation,
- 6) Packet re-formation,

When nodes do communicate with others, they will use other node as relay (if destination located far away). The number of relays will determine hops. Relay will receive,

process, and transmit packet. Relay will calculate the best route to next relay / node. Transmission will follow sequential process (from node to node until destination). Source and destination (*also agents) will maintain end-to-end communication (TCP communication type) as shown in Fig. 2.

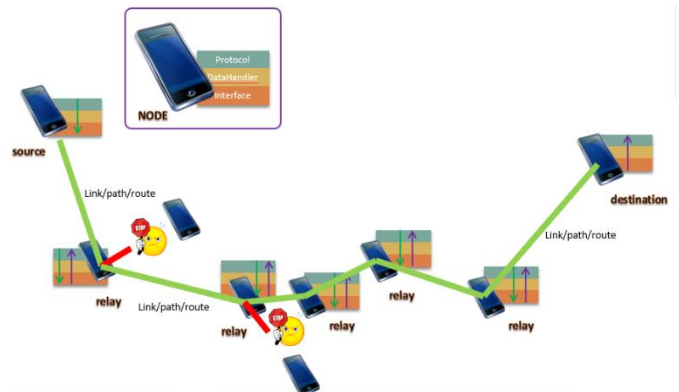


Fig. 2. Communications among the nodes.

Node to node communication is done in accordance with the following steps,

- 1) Broadcast to get neighbor's knowledge,
- 2) Broadcast to send packet to next node,
- 3) Receive messages (packet, reply/Hello, etc.) from the other node, examine it, and process it,
- 4) During data transmission, each node must follow point to point communication type.

a) In this situation, error transmission through wireless medium is considered. Bit error happen when source sent bit 'b' and receiver doesn't receive 'bit' b. Bit error rate (BER) shows the probability of bit got error. Typical value of BER for electric link was 10⁻⁹, and for optical link was 10⁻¹². Source of error: EM interferences, loss signal, hardware failure and memories error during the path route, etc. In this simulation, BER was set to zero. Also, there is no detection and correction scheme.

Duplex link is assumed as shown in Fig. 3. Packet here imitated IPPacket. On each packet, there were:

- HEADER*.
- Source and destination.
- Flags (to mark packet with certain purpose).
- TTL (time to live).
- Type of protocol used*.
- Detection error CRC*.
- Source hop and destination hop.
- DATA (real transmission goal).

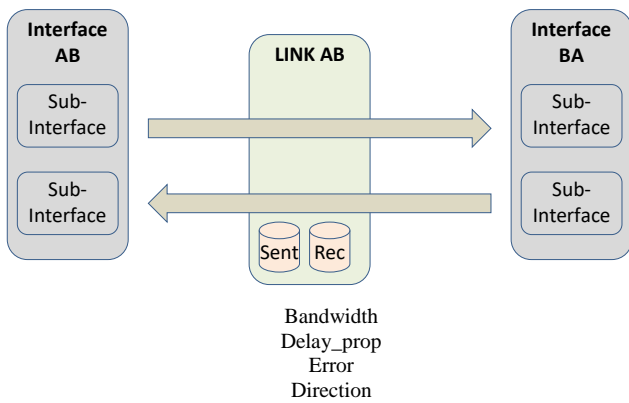


Fig. 3. Assumed duplex link in the simulation model.

There are assumptions made in IPPacket creation. Packets are treated as follows,

- IPPacket formation (executed in Protocol layer).
- IPPacket encapsulation/de-encapsulation.
- IPPacket queue.
- IPPacket transmission (unload/reload source hop and destination hop).
- IPPacket fragmentation / de-fragmentation.
- IPPacket re-formation.

Furthermore, packet formation is as follows,

DATA in BYTES (which intended to be sent).

Header information.

Protocol TCP.

Source and Destination.

Length.

ID.

TTL (time to live).

Source HOP and Destination HOP.

Flags.

Encapsulate DATA within IPPacket.

Packets are transmitted as follows,

Sender Station A:

When IF, send it out; Start Tout timer for this IF,

Wait for Tout (Time-out value) for ACK,

If (ACK) Then clear timer; proceed to next transmission,

Else backoff for a random number of Tout intervals; retransmit; If no ACK after repeated transmissions, give up.

Receiver Station B:

If (CRC(IF) OK && DA(IF) == address(B), send ACK,

If may be damaged by noise or by another station transmitting at the same time (collision).

Any overlap of frames causes collision.

Packet Framing is done as follows,

Responsible for: reliable transmission of frame through Link.

Determine complete packet receiving.

Error detection: CRC check.

Error recovery: retransmission of packets.

Live time of packet exceeded.

Selective ARQ (Automatic Repeat Request).

Boundaries of frame:

Character oriented framing.

Length counts – fix length.

Bit oriented protocols (flags) *used.

Also, Bit Oriented Framing: BOF (Flag) is assumed as follows,

Flag is (actually sequence of bits) that used to indicate the beginning and end of completed packet.

Together with fragment_offset, sequence of fractioned packet can be determined.

Standard protocol used bit sequence of 8 01111110 as ONE flag.

INVENTED ~ 1970 by IBM for SDLC (synchronous data link protocol).

Packet fragmentation means break up the data into smaller pieces. This is necessary when the maximum transmission unit (MTU) is smaller than the packet size. For example, the maximum size of an IP packet is 65,535 bytes while the typical MTU for Ethernet is 1,500 bytes. Since the IP header consumes 20 bytes (without options) of the 1,500 bytes, 1,480 bytes are left for IP data per Ethernet frame (this leads to an MTU for IP of 1,480 bytes). Therefore, a 65,535-byte data payload (including 20 bytes of header information) would require 45 packets $(65535-20)/1480 = 44.27$, rounded up to 45 as shown in Fig. 4. On the other hand, Fig. 5 and 6 show packet transmission in send and receive, respectively.

Meanwhile, as shown in Fig. 7, route / path calculation can be done as follows,

Stated as Table_routing.

Used 3 criteria: buffer on next hop, distance (*RTT), and direction of next hop (getting closer or away).

Buffer and distance made throughput weight on the link.

Route decision is executed in DataHandler layer.

Table_Routing is shown in Table 1. In the table, the followings are detailed assumptions,

Node_address: address of Interface in next hop.

Interface: set Interface must be used to reach next hop.

RTT: round trip time.

Throughput: throughput calculation for link.

Direction: + (getting closer), - (getting away).

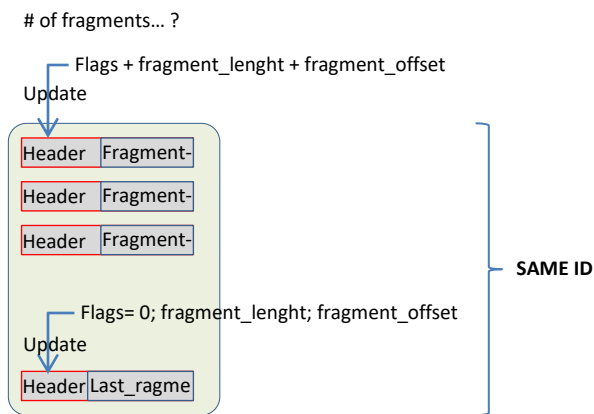


Fig. 4. Packet fragmentation.

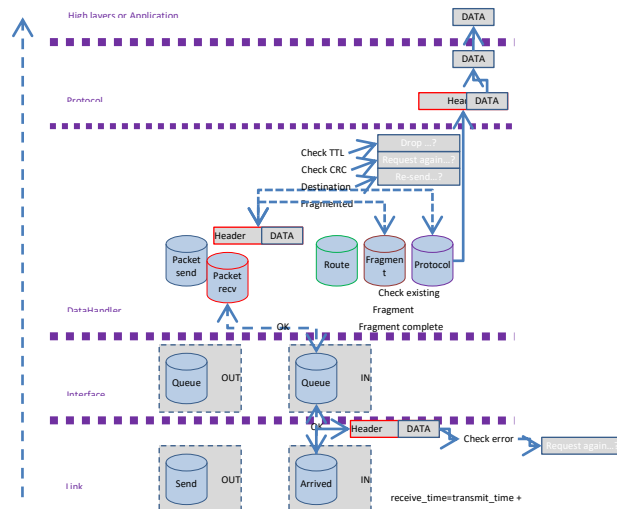


Fig. 6. Packet transmission (receive).

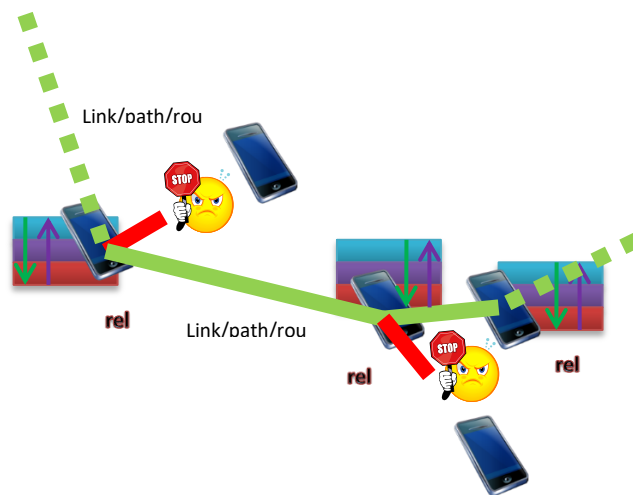


Fig. 7. Route / path calculation.

TABLE I. ROUTING TABLE

Node_address	Interface	RTT	Throughput	Direction
192.168.0.2	ABIface	b ms	1000 Bytes/ms	+
192.168.0.20	ATIface	t ms	8000 Bytes/ms	-
...				

Energy can be calculated as follows,

- 1) Node dissipates $E_{elec} = 50$ nJ/bit to run the transmitter or receiver and $\epsilon_{amp} = 100$ pJ/bit/m² for the transmit amplifier.
- 2) To transmit a k-bit message a distance d, the Node expends:
- 3) To receive the message, the Node expends:
- 4) The communication range of the nodes is a perfect symmetric unit disk. If $dx,y \leq r_x \rightarrow$ then Node-x and Node-y can see each other.

Fig. 5. Packet transmission (send).

IV. SIMULATION STUDIES

Node Deployment is shown in Fig. 8 and is assumed as follows,

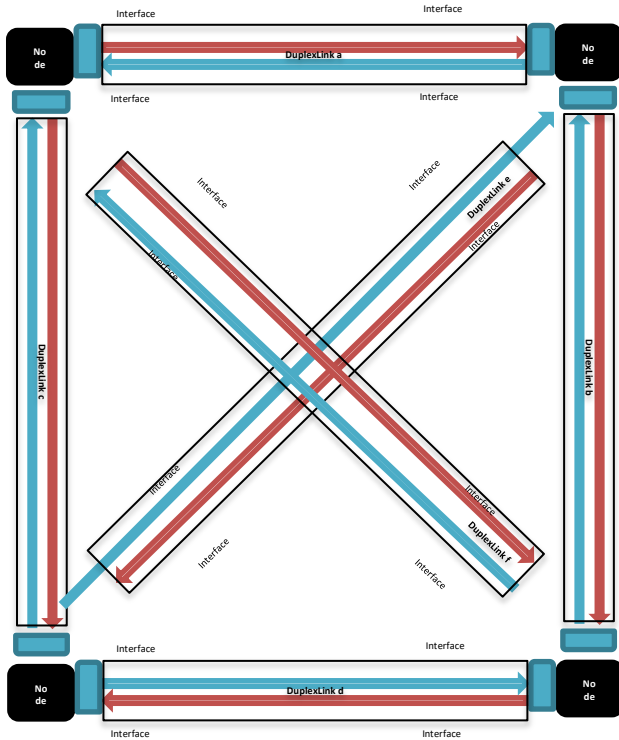


Fig. 8. Node deployment.

- 1) Each node examines itself and senses its neighbors.
- 2) Nodes create object Interface (with #Interface equals to #neighbors).
- 3) Ex. Node A has Interface AB, AC, and AD.
- 4) Interface AB is read as Interface at Node A that can reach Node B. Interfaces at a Node have same address.
- 5) Every Interface (in Node) is related with object Link (#Link equals to #neighbors).
- 6) Ex. Node A connected with Link "a", Link "f", and Link "c". Link "a" was used by Interface AB; Link "f" was used by Interface AC; Link "c" was used by Interface AD.
- 7) Nodes calculate buffer, RTT, and throughput through each owned Link.

With these, Node forms a routing table.

- route 1:192.168.0.2; Interface_AB; RTT; throughput; 0.
- route 2:192.168.0.3; Interface_AC; RTT; throughput; 0.
- route 3:192.168.0.4; Interface_AD; RTT; throughput; 0.

In the simulation study, the following 25 nodes and 4 initiators are considered as shown in Fig. 9.

Initiator node is node that initiates transmission of packet. Like other nodes, initiator is always moving with random direction, speed, and distance as shown in Fig. 10.

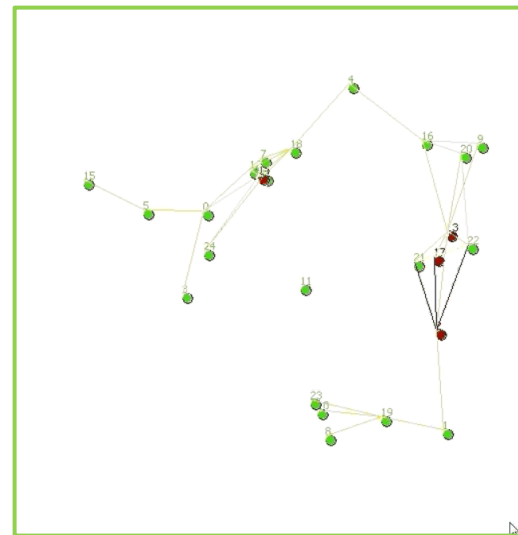


Fig. 9. Network configuration.

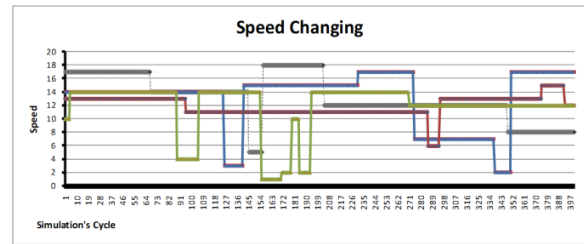


Fig. 10. Packet transmission speed.

V. CONCLUSION

Method for Ad-Hoc blockchain of wireless mesh networking with agent and initiate nodes is proposed. Minimizing the number of hops and maintaining connectivity of mobile terminals are concerns. Through simulation studies, it is found that increasing number of initiator nodes caused nodes to route a large number of messages. Thus, these nodes will die out quickly, causing the energy required to get the remaining messages to increase and more nodes to die.

This will create a cascading effect that will shorten system lifetime. Multi-hop routing, however, imply high packet overhead, (more nodes in the network means more hops will be available). The packet overhead of the multi-hop routing is extremely high compared to single path routing since many nodes near the shortest path participate in packet forwarding. This additional overhead caused by moving node can cause congestion in the network.

The idea of a "decentralized network", which is the greatest feature of Web 3.0, may change the existing corporate form. That is the birth of the decentralized autonomous organization "DAO". A DAO is an organizational form without a centralized administrator. Because it is an organization operated by a program on the blockchain, it has the advantage of being extremely transparent. In addition, since there is no top, it is managed democratically, such as by voting when deciding something, and the direction is decided by the party that wins the majority. The proposal method that can build this block chain ad-hoc can contribute to promote Web3.0.

VI. FUTURE RESEARCH WORKS

Further investigation needs to be conducted on dynamic routing advantages and factors which affect routing mode, e.g., flow type, delay, and etc. The throughput/delay/reliability tradeoff between wireless network areas that deploy agents and without agents is also investigated.

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REFERENCES

- [1] IEEE Standards Association: IEEE Standard for Information Technology — Telecommunications and information exchange between systems — Local and metropolitan area networks — Specific requirements — Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, IEEE Standard 802.11, 2011.
- [2] Akyildiz, I.F., Wang, X. and Wang, W.: Wireless mesh networks: A survey, *Computer Networks*, Vol.47, pp.445–487, 2005.
- [3] Shiro Sakata, Hidenori Aoki, Kenichi Mase: Ad Hoc Networks network and wireless LAN mesh network, *The Institute of Electronics, Information and Communication Engineers Journal B*, Vol.J89-B, No.6, pp.811–823, 2006.
- [4] Kenichi Mase, Shiro Sakata: Ad Hoc Mesh Network C. Toward the realization of a ubiquitous network society, *Nasha*, Tokyo, 2007.
- [5] Takahiko Sakamoto, Kenichi Mase: In Wireless Mesh Networks Link Quality Measurement Control Method for Optimal Rate Estimation, *Transactions of the Institute of Electronics, Information and Communication Engineers*, Vol.J95-B, No.7, pp.819–826, 2012.
- [6] Kei Okada, Hirotsuka Kitahara, Kenichi Mase: Wireless Mesh Network node-by-node transmission rate selection method in *IEICE Transactions*, Vol.J94-B, No.12, pp.1556–1565, 2011.
- [7] Yoshihiko Takahashi, Yoichiro Kaneko, Kenichi Mase: Wireless Mesh Network Experimental Verification of High-Throughput Route Selection in Networks, *Transactions of the Institute of Electronics, Information and Communication Engineers*, Vol.J90-B, No.3, pp.311–314, 2007.
- [8] Kotaro Nishizawa, Naoki Yamamoto: Wireless mesh network Detour route construction linked with traffic congestion control signaling Algorithm, *Transactions of the Institute of Electronics, Information and Communication Engineers B*, Vol.J92-B, No.9, pp.1500–1512, 2009.
- [9] Reiji Momma, Takuya Yamada, Naoki Yamamoto: Large-Scale Wireless Mesh STA Rank Using Hash Function in Network Characteristic Evaluation of Registration and Search Methods, *Transactions of the Institute of Electronics, Information and Communication Engineers*, Vol.J93-B, No.7, pp.1025–1030, 2010.
- [10] Ohnishi, M., Inoue, M. and Harai, H.: Incremental Distributed Construction Method of Delaunay Overlay Network on Detour Overlay Paths, *Journal of Information Processing*, Vol.21, No.2, pp.216–224, 2013.
- [11] Ueda, K. and Baba, K.: Proposal of Initial Route Establishment Method in Wireless Mesh Network, *Proc. The Sixth Workshop for Ubiquitous Networking and Enablers to Context-Aware Services*, pp.173–176, 2009.
- [12] Maruoka, Y. and Ueda, K.: A method for establishing routes and IPv6 addressing based on the estimated distance from neighboring nodes in wireless mesh networks, *Proc. 27th International Conference on Advanced Information Networking and Applications Workshops*, pp.21–26, 2013.
- [13] Perkins, C.E., Belding-Royer, E.M. and Das, S.R.: Ad hoc On-Demand Distance Vector (AODV) Routing, *IETF RFC 3561*, 2003.
- [14] Kohei Arai, Lipur Sugiyanta, Approach of improved topology development protocol in Ad Hoc network minimizing the number of hops and maintaining connectivity of mobile terminals which move from one to the others, *Anthony V. Stavros Edt., Advances in Communication and Media Research*, Vol.8, ISBN 978-1-61324-794-5, 2011.
- [15] Chen Liming, Kapoor Supriya, Bhatia Rahul, Edt, Kohei Arai, Rescue System with Sensor Network for Vital Sign Monitoring and Rescue Simulations by Taking into Account Triage with Measured Vital Signs, *Emerging Trends and Advanced Technologies for Computational Intelligence*, 647, Springer, 2016.
- [16] Kohei Arai, The Data Network System for Advanced Earth Observation Satellite System, *Journal of International GEOCATO*, Vol.3, No.2, pp.21-26, Jul.1988.
- [17] Kohei Arai, Lipur Sugiyanta, Approach of improved topology development protocol in ad-hoc network minimizing the number of hops and maintaining connectivity of mobile terminals which moves from one to the others, *Journal of Communication and Networks*, 2, 6, 190-204, 2011.
- [18] Kohei Arai and Lipur Sugiyanta, Energy Behavior in Ad Hoc Network Minimizing the Number of Hops and Maintaining Connectivity of Mobile Terminals Which Move from One to the Others, *International Journal of Computer Networks (IJCN)*, 2, 6, 190-204, 2011.
- [19] Kohei Arai, Lipur Sugiyanta, Successful Transmission Rate of Mobile Terminals with Agents in Segmented Ad Hoc Network, *International Journal of Advanced Computer Science and Applications(IJACSA)*, 2, 6, 1-12, 2011.
- [20] Kohei Arai, Lipur Sugiyanta, Energy behavior in Ad Hoc network minimizing the number of hops and maintaining connectivity of mobile terminals which moves from one to the others, *International Journal of Computer Science and Security*, 2, 5, 2011.
- [21] Kohei Arai and Lipur Sugiyanta, Energy consumption in ad hoc network with agents minimizing the number of hops and maintaining connectivity of mobile terminals which move from one to the others, *International Journal of Computer and Network*, 3, 2, 71-86, 2011.
- [22] Kohei Arai, Wireless sensor network for tea estate monitoring in complementally usage with Earth observation satellite imagery data based on Geographic Information System(GIS), *International Journal of Ubiquitous Computing*, 1, 2, 12-21, 2011.
- [23] Kohei Arai and Lipur Sugiyanta, Transmission behavior in ad hoc network minimizing the number of hops and maintaining connectivity of mobile terminals which move from one to the others, *Advances in Communications and Media Research*, Vol.9, 2011.
- [24] Kohei Arai, Lipur Sugiyanta, Energy consumption in Ad Hoc network with agents minimizing the number of hops and maintaining connectivity of mobile terminals which move from one to the others, *International Journal of Computer Networking*, 3, 2, 71-86, 2011.

AUTHOR'S PROFILE

Kohei Arai, He received BS, MS and PhD degrees in 1972, 1974 and 1982, respectively. He was with The Institute for Industrial Science and Technology of the University of Tokyo from April 1974 to December 1978 also was with National Space Development Agency of Japan from January, 1979 to March, 1990. During from 1985 to 1987, he was with Canada Centre for Remote Sensing as a Post Doctoral Fellow of National Science and Engineering Research Council of Canada. He moved to Saga University as a Professor in Department of Information Science on April 1990. He was a councilor for the Aeronautics and Space related to the Technology Committee of the Ministry of Science and Technology during from 1998 to 2000. He was a councilor of Saga University for 2002 and 2003. He also was an executive councilor for the Remote Sensing Society of Japan for 2003 to 2005. He is a Science Council of Japan Special Member since 2012. He is an Adjunct Professor of University of Arizona, USA since 1998. He also is Vice Chairman of the Science Commission "A" of ICSU/COSPAR since 2008 then he is now award committee member of ICSU/COSPAR. He wrote 77 books and published 670 journal papers as well as 500 conference papers. He received 66 of awards including ICSU/COSPAR Vikram Sarabhai Medal in 2016, and Science award of Ministry of Mister of Education of Japan in 2015. He is now Editor-in-Chief of IJACSA and IJISA. <http://teagis.ip.is.saga-u.ac.jp/index.html>.

Recommendation System on Travel Destination based on Geotagged Data

Clarice Wong Sheau Harn, Mafas Raheem

School of Computing,

Asia Pacific University of Technology and Innovation, Technology Park, Kuala Lumpur, 57000, Malaysia

Abstract—Tourism research has benefitted from the worldwide spread and development of social networking services. People nowadays are more likely to rely on internet resources to plan their vacations. Thus, travel recommendation systems are designed to sift through the mammoth amount of data and identify the ideal travel destinations for the users. Moreover, it is shown that the increasing availability and popularity of geotagged data significantly impacts the destination decision. However, most current research concentrates on reviews and textual information to develop the recommendation model. Therefore, the proposed travel recommendation model examines the collective behaviour and connections between users based on geotagged data to provide personalized suggestions for individuals. The model was developed using the user-based collaborative filtering technique. The matrix factorization model was selected as the collaborative filtering technique to compute user similarities due to its adaptability in dealing with sparse rating matrices. The recommendation model generates prediction values to recommend the most appropriate locations. Finally, the model performance of the proposed model was assessed against the popularity and random models using the test design established using Mean Average Precision (MAP), Root Mean Square Error (RMSE), and Mean Absolute Error (MAE). The findings indicated that the proposed matrix factorization model has an average MAP of 0.83, with RMSE and MAE values being 1.36 and 1.24, respectively. The proposed model got significantly higher MAP values and the lowest RMSE and MAE values compared to the two baseline models. The comparison shows that the proposed model is effective in providing personalized suggestions to users based on their past visits.

Keywords—Geotagged data; travel recommendation system; travel recommender; collaborative filtering; matrix factorization

I. INTRODUCTION

A. Background

The World Travel and Tourism Council reported that the tourism industry contributed around 11% to the global economy in 2019 before the pandemic outbreak [1]. This illustrates that the tourism industry has been one of the most influential and profitable industries and has been a major contributor to the global economy. It is also one of the most promising sectors. The travel industry has evolved dramatically over time, and the introduction of big data analytics has profoundly impacted people's travel. Travelers used to rely on newspapers, magazines, and radio to get to know about places and plan their trips with help of the travel agencies. However, in modern society, travelers have numerous options to plan their trips.

The rise of big data and the evolution of technology have significantly impacted people's travel [2], [3]. Today, many people book their trips online using platforms such as TripAdvisor and Expedia. The increasing amount of data collected and accessible by travel providers has facilitated the creation of sophisticated analytics and forecasting algorithms. The rise of social media has also greatly impacted how people communicate allowing users to exchange content, such as pictures and videos, and has greatly aided in human interaction. The report by Wyman [4] further illustrates that travelers have expanded their social media usage by 44% since the pandemic, and 92% of users find useful information online about places to visit.

The impact of social media on travel destinations was investigated in several studies in the past. Various social media platforms, blogs and online communities are becoming more prevalent in the travel industry as they allow users to connect and share their experiences [5-7]. Social media platforms such as Twitter, Flickr, and Facebook have enabled travelers to share information and express their travel experiences online, which has helped boost the reputation of a city as a desirable travel destination. The study also noted that Generation Z and Millennials are more likely to utilize social media to plan their vacations because they value online experiences more than commercials. The study [8] elaborated that having a strong online presence is very important for a destination to gain a positive reputation, and social media significantly impacts how customers choose travel destinations.

The travel industry is one of the most data-driven industries in the world due to the exponentially increasing amount of data. It is often difficult for individuals to select the ideal holiday destination due to a lack of understanding of the various attractions and the complexity of the planning process. Consequently, several research works were conducted on travel recommendations that consider the different elements to deliver personalized recommendations based on the preferences and behaviours of users [9-11].

A geotagging service is a type of geographic identification service that may be used to identify the location of a media file or social media post. The data typically includes a latitude and longitude coordinate that may be used to locate the captured place on a map, as well as the date and time the picture or post was filmed [12]. According to the study, the growth of location-based social networks has enabled individuals to construct their social networks based on interpersonal contacts. Studies explained that the expansion in publicly available geotagged social media data may be attributed to the adoption

of social media platforms such as Facebook, Instagram, and Flickr [13-15]. In addition, geotagged data is rich in information about the users' interests and may be utilized to discover new regions of interest. The statement is reinforced and demonstrated that the analysis of geotagged data may assist the government in promoting tourist places [16]. Therefore, using geotagged social media data to identify tourist hotspots is advantageous for developing a trip recommendation model.

A major portion of establishing successful travel recommendation systems has focused on examining the reviews from Google Maps and TripAdvisor. Although the models are accurate, oriented towards a few famous landmarks and do not utilize geotagged data to make personalized recommendations depending on the user's preferences.

B. Problem Statement

Numerous studies indicate that the prevalence of social media networks that supply geotagged data is increasing the influence of this data type on users' destination selections [5], [7], [17]. Due to the rising popularity of geotagged social media as a source of travel destinations, the existing travel recommendation system lacks the efficiency to fully leverage the information gathered from geotagged data to construct a travel recommendation model that can study users' preferences.

C. Aim

The research aims to determine the role of geotagged data in shaping the selection of attractions using clustering techniques and develop a travel recommendation model as well as compare it to the models with different approaches.

D. Significance and Scope

Extensive studies have attempted to develop a personalized travel recommendation model to assist people in filtering data to attractions that match their preferences [10], [18], [19-20]. The proposed travel recommendation system allows travelers to discover possible destinations based on their interests. Additionally, the tourist sector may utilize the potential information gathered from the research to establish successful marketing plans in the tourism sector and increase operational efficiency. The dataset for this research was acquired from Kaggle which contains 20,000 geotagged data points in London between 2014 and 2019 [21]. London is recognized for its various attractions, including stunning architecture and historical buildings. Given that the coronavirus pandemic in 2020 may impede travel mobility, the final year of 2019 in the dataset is ideal [22]. Given that the data obtained for this research was collected at random and across time, the recommendation model will focus on location recommendations rather than route suggestions.

II. RELATED WORKS

A brief history of the recommendation system describes various forms of recommendation systems including the current state-of-the-art techniques for the travel recommendation system. Past studies conducted using geotagged data were reviewed and summarized at the end of this section.

A. Recommendation System

During the 1990s, research in the field of recommendation models started focusing on developing systems that can predict product ratings [23-24]. The recommendation model suggests the best suitable goods and services to its consumers through the information gathered [25]. The most notable examples include Amazon's personalized shopping system, YouTube's suggestions for videos relevant to the viewers' interests, and Facebook's system allows users to interact with more people. The rise of information technology made users and organizations more dependent on recommendation systems to sift through the vast amount of data collected in this century.

B. Types of Recommendation Systems

The recommendation systems can be categorized into four different categories such as content-based, collaborative-based, hybrid-based, and knowledge-based [25-30]. The content-based method connects user traits with items most likely to satisfy their demands. The collaborative filtering technique, on the other hand, believes that individuals with similar interests and historical behaviours would act similarly in the future. The disadvantage of implementing a content-based system is that it heavily relies on the knowledge base to provide recommendations while implementing collaborative filtering can be very challenging when the users are relatively new to the platform. A knowledge-based system can be very useful in helping users find the best products and services that are seldom acquired, such as luxury goods and real estate. As the calculation is based on the similarity between the item descriptions and the user's needs, it is essential to outline the knowledge base needed to generate recommendations [31]. However, the process can be very time-consuming and costly. Besides, a hybrid recommendation system uses the best elements from various techniques to overcome these shortcomings. The research [29] proposed the hybrid system integrated the characteristics of content-based and collaborative filtering to have the right predictions.

To date, numerous pieces of literature have studied the recommendation system in a broad range of industries. For instance, [30] proposed a matrix factorization-based recommender system that can recommend books based on the similarities and ratings of users. In contrast, a movie recommendation system was developed by applying the content filtering technique to exploit the movie's genre characteristics and requested the users to answer a few questions while building up their profiles to enrich the users' data [32]. Moreover, [33] used the content-based approach to suggest music to users based on the musical features utilizing the convolutional recurrent neural network (CRNN) method. As online learning sites grew in popularity, a knowledge-based recommendation system was proposed, which serves as an agent to assist users in recommending appropriate courses and materials based on their preferences and requirements [34].

C. Algorithms used in Travel Recommendation System

Multiple studies on recommender systems in the tourism industry were undertaken over the years to assist individuals with their trip decisions. The authors in [35] analyzed the essential information and interests of the users on social media platforms to suggest travel-related activities in Tunisia. The

proposed system created user profiles using the content-based filtering algorithm based on the content they posted on social media sites such as Facebook, TripAdvisor, and Twitter. Furthermore, [11] conducted a study that analyzed the opinions of Korean undergraduates on various destinations. The study used a collaborative method to analyze the similarities and differences between the users. It also considered the various restrictions and demands to provide personalized suggestions. However, since the data for the study was only collected from a single university, the results might be biased.

The study [10] collected users' reviews from TripAdvisor and developed a collaborative system to deliver suggestions to their users. The researchers used a combination of text processing and semantic clustering to analyze the data and extract their preferences for recommendations. However, the research only acquired 100 reviews from the site on specific locations, which may have led to skewed findings and the neglect of other less-visited attractions. Likewise, [20] sought to discover the ideal tour route for international visitors in South Korea by examining TripAdvisor ratings. Text mining and network analysis were used to perform a comprehensive analysis of user preferences. However, the study overlooked the lesser-known attractions since the model only collected reviews from top attractions in the country.

The research [18] proposed a travel recommendation model to analyze the reviews collected from Google Maps and identify the most relevant locations for travellers based on the similarities and differences between the users' reviews. The Jaccard Similarity and Cosine Similarity were used to calculate the similarity scores. The algorithm ranked the most popular locations using a neural network and associated the users' preferences through the similarities of their reviews. On the other hand, [9] used Twitter data and built a system using a collaborative filtering framework with users' profile matrix and their interests. The travel-related tweets were mined for sentiment analysis, and a follow-up step was performed to determine the social media activity of their friends. The algorithm will generate travel recommendations and suggest various destinations based on relevant tweets. Unlike previous systems, the model was time-sensitive, allowing it to collect the users' most recent interests.

Moreover, [36] proposed a deep learning-based recommendation model to analyze the data from blogs, Google Maps and TripAdvisor to recommend travel activities in the country. Latent Dirichlet Allocation (LDA) was employed by the researchers for topic modelling in tourist blogs. These topics were used to extract the sentiments from Google and TripAdvisor reviews. The user history was extracted based on the information and a collaborative filtering technique was used to predict the most likely visited locations based on the users' preferences.

D. Analyzing Geotagged Data

The development of geotagging services and Web technologies have boosted the amount of geotagged data accessible. Through social media platforms like Foursquare, Facebook, and Flickr, individuals can now easily share their locations with others. Consequently, a growing corpus of

research explored the use of geotagged data in personalized travel destination suggestions [37-39].

The authors in [38] presented a travel recommendation system that combines geotagged data with users' textual information. The multiclass SVM classifier was used to identify candidates from the user's travel history. The data was analyzed using a gradient-boosting regression model, which ranked the candidates based on their interests. Moreover, [19] proposed a weighted multi-information criteria matrix factorization model for recommending travel locations based on geotagged photos from Flickr. The model was built to examine the various aspects of a user's visit sequence, as well as the textual and visual information to recommend travel locations. The textual information in the photos was processed using Latent Dirichlet Allocation (LDA) to profile the attractions, and the model was tested on a sample of six Chinese cities.

The researchers in [37] combined the sequential and temporal information from the geotagged photos to build personalized itineraries based on the travel patterns of individual users. The model was developed using a collaborative filtering strategy to analyze the visit sequences and preferences of other users. In addition, [39] established a framework for determining the interests of Hong Kong tourists based on geotagged data. The study combined image processing, text processing, and clustering algorithms to evaluate geotagged data in three geographical locations, enabling the government to comprehend better and promote popular vacation spots.

Numerous studies have identified landmarks and tourist attractions based on geotagged data acquired using clustering algorithms [36-37], [39-40]. The geotagged data was clustered using several techniques, including K-means clustering, mean shift clustering, and density-based clustering to build a location database containing the travel records of users to different destinations.

E. Summary

According to the existing travel recommendation models, the most common technique used in developing travel recommendation models is the collaborative filtering approach, which involves analyzing the users' interactions or similarities. However, most studies have focused on leveraging reviews from travel websites or textual information for topic modelling from geotagged data. This demonstrates a deficiency in using the implicit information from the geotagged data, which does not require extra information. Additionally, clustering techniques are often used to group geotagged data to build a location database. Therefore, the proposed model would employ a clustering algorithm to identify locations from the geotagged data, and the collaborative approach will be utilized to compute user similarities. The model will then deliver personalized recommendations to the users based on their travel histories.

III. MATERIALS AND METHOD

The research process was structured as a sequence of stages designed to achieve the study's goals. The steps include data selection, data pre-processing, data transformation, model

building, and evaluation. A flowchart is also provided to visualize the whole process as shown in Fig. 1.

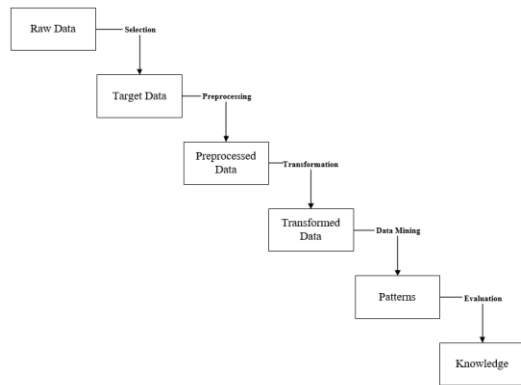


Fig. 1. KDD process.

A wide variety of data mining approaches are available for detecting patterns and interpreting data to develop a model. Knowledge Discovery in Databases (KDD) was chosen as the data mining methodology to develop the travel recommendation model. It is a process of studying data to uncover patterns that can be utilized to identify meaningful information [41]. Fig. 2 illustrates the entire process of developing the travel recommendation model.

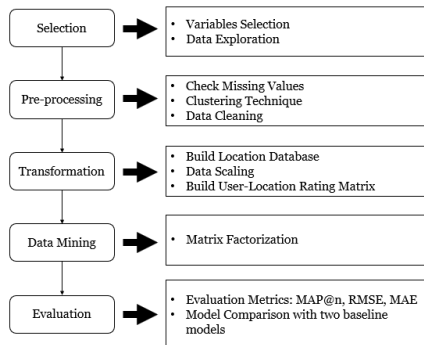


Fig. 2. Project workflow.

F. Selection

The literature review and research objectives provided a clear understanding to create the model. The selection procedure defined the target dataset for model building. The variables that could be used to construct the travel recommendation model were chosen at this stage.

1) *Variables selection*: As specified in the research scope, the dataset used for this study was obtained from Kaggle with 20,000 records and 13 attributes [21]. The attributes that contain the geographical information, the owner and the time were used to develop the recommendation model.

2) *Dataset exploration*: Data exploration is the process of examining data to comprehend better the data and reduces the likelihood of incorrect decisions [41]. The data properties were examined, and the geotagged data were visually analyzed. In addition, the missing values were also inspected.

G. Pre-Processing

Data pre-processing is typically performed to prepare the data before data modelling. The geotagged data were clustered, and redundant data was removed to improve the efficiency of the analysis.

1) *Data cleaning*: Data is the foundation of every data mining project. However, as data comes in a variety of formats and sizes, it must be thoroughly analyzed to ensure no discrepancies or outliers. Therefore, data cleaning was performed to identify missing values, outliers, and inconsistencies. The two most important attributes used in developing the travel recommendation model were the geotagged data, which includes latitude and longitude information. As a result, individuals with incomplete information for these two attributes were removed from the dataset, as the imputation of geographic location may disrupt the dataset's balance.

2) *Clustering technique*: The initial step in the development of the travel recommendations model was to identify the locations from the geotagged data. This process was carried out through the clustering technique, which was used to group the collected data into clusters. Three main types of clustering techniques were commonly used in this process: hierarchical clustering, partitional clustering, and density-based clustering [42].

Several studies have been conducted on identifying landmarks and hotspots from the geotagged data. A classical method used in discovering tourist attractions is the Density-based spatial clustering of applications with a noise clustering algorithm (DBSCAN) [37], [40], [43-45]. DBSCAN is effective in clustering geotagged data since it requires less knowledge to detect arbitrary shape clusters with varying densities. This method seems to be more effective when analyzing spatial data concerning latitude-longitude coordinates. The clustering process shall result in a dataset that resembles Table I.

TABLE I. DATASET AFTER DBSCAN

photo_id
user_id
lat
lon
Taken (time stamp)
location_id (cluster label)
cent_lat (cluster lat)
cent_lon (cluster lon)

3) *Location database*: A location database is built by applying the appropriate clustering technique which helped to label the geotagged data. The resulting database was found with the sorted locations visited according to the timestamp included. According to the study by [19], if the user concurrently uploads two geotagged posts during the same visit, the two posts should be regarded as one. This is to reduce the number of repeat visits by the same users and improve the quality of the location database. The duplicate records would be deleted if the time interval between two

successive postings is less than three hours and assumed to have originated from the same visit.

Individuals with less than three geotagged posts were excluded from the dataset since the model was constructed using the collaborative approach. As illustrated in Table II, the final location database containing user travel histories shall have five variables: location id (cluster label), user id, lat, lon, and time taken (timestamp).

TABLE II. LOCATION DATABASE

location_id	user_id	lat	lon	time_taken
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H. Transformation

The data transformation process involves arranging the data into a suitable form for modelling. In this stage, the user-location rating matrix was built using the pre-processed geotagged data.

1) User-location rating matrix: Using their historical travel records, individuals' preferences for a place may be inferred by the frequency of their visits to a travel destination. Inspired by the research of [19], the user-location rating table estimates the frequency of a user's visits to a travel location as ratings. Therefore, the number of times a user has visited a specific location is used to construct a new variable, ratings. As illustrated in Table III, three variables: user id, location id, and ratings depending on the frequency of visits were transformed into a matrix as shown in Table IV. The ratings were standardized using the min-max approach to ensure that the forecast is not skewed towards popular attractions.

TABLE III. USER-LOCATION RATING TABLE

location_id (cluster label)	User_id	Ratings
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TABLE IV. USER-LOCATION RATING MATRIX

User_id	location_id			
	A	B	C	D
1	rating	rating	rating	rating
2	rating	rating	rating	rating
3	rating	rating	rating	rating

I. Data Mining

Data mining is the process of examining data to uncover hidden insights and patterns. This process aims to develop a personalized travel recommendation model that can provide the best possible Matrix Factorization Model.

Multiple techniques are used in the construction of the recommendation model. According to the literature review, there are four main techniques such as content-based, collaborative-based, knowledge-based, and hybrid-based. This study used a collaborative approach based on user similarities since many prior studies relied on collaborative techniques to investigate user interactions and provide recommendations. For instance, [11] investigated destination reviews and user similarities to recommend vacation places, while [37] presented an itinerary planner by assessing different travel

patterns from other users and matching the suggestions to the users' preferences.

TABLE V. USER-USER SIMILARITY MATRIX

User_id	User_id		
	1	2	3
1	similarity	similarity	similarity
2	similarity	similarity	similarity
3	similarity	similarity	similarity

Similarity value is one of the most crucial aspects when building a recommendation system using a collaborative method. The user-location rating matrix was used to generate the user-user similarity matrix (Table V) to construct the recommendation model. The cosine similarity algorithm was selected as the metric to determine the similarities between various users since it is one of the most extensively used and well-known similarity measures [18-19], [40], [46-50].

The recommendation model was built to predict the ratings to generate recommendations based on the user profiles from the user-user similarity matrix with a sparse rating matrix. Despite the popularity of the K-Nearest Neighbor (KNN) model as a collaborative-based technique, the KNN model required users to select the number of nearest neighbours, making the prediction unstable [51]. The study found that the non-negative matrix factorization model outperformed the k-nearest neighbour model in terms of accuracy and error metrics while constructing the movie rating recommendation system. Besides, [52] noted that the matrix factorization model was able to provide more precise pairwise preference scores and ranking predictions. Therefore, using the value generated from the cosine similarity algorithm, the matrix factorization model, which was extensively used in recommender systems in a variety of domains, was used to provide personalized recommendations to the target users [47], [53-55]. The system would be able to identify latent factors in the data and recommend the most appropriate destination according to their preferences without requiring additional features.

The matrix factorization can be equation as:

$$P \times Q^T \approx R \quad (1)$$

The main idea of a matrix factorization technique is to fit the rating matrix with a low-ranking approximation that considers the latent features. For instance, the matrix P in the equation represents the association between the user and its features. The matrix Q represents the association between the item and its features. The prediction of the rating is the dot product of the latent factors. The model is fueled by the ratings provided by the user-location rating matrix. The prediction values will be used to rank the top-n suggestions. This aligns with the project's goal of providing personalized suggestions ranked according to the prediction values.

J. Evaluation

Model evaluation is an integral part of the data mining process for measuring the performance of models using a variety of evaluation metrics. Multiple studies indicate that Mean Average Precision (MAP), Root Mean Square Error (RMSE), and Mean Absolute Error (MAE) are the common

assessment metrics for measuring the performance of a recommendation model [19], [30], [38], [47], [53], [55-57].

1) Mean average precision@n (MAP@n) [38]

The formula:

$$Precision = \frac{True\ Positive}{Total\ Positive\ Results} \quad (2)$$

$$MAP@n = \frac{1}{N} \sum_{i=1}^{N_q} AP_i, AP_i = \frac{1}{r} \quad (3)$$

2) Mean absolute error (MAE)

The formula:

$$MAE = \frac{1}{N} \sum |Predicted\ Ratings - Actual\ Ratings| \quad (4)$$

3) Root mean square error (RMSE)

The formula:

$$RMSE = \sqrt{\frac{\sum (Predicted\ Ratings - Actual\ Ratings)^2}{N}} \quad (5)$$

4) Comparison with two baseline methods: The performance of the proposed travel recommendation model was compared with two baseline models. The random selection technique and the popularity-based strategy were chosen for comparative studies [37], [47], [58]. The popularity-based technique recommends the most popular vacation destination based on an overall popularity score. The random selection strategy, on the other hand, generates travel destinations at random from the location database, ignoring similarities between users.

The data was split into training (80%) and testing (20%). The recommendations were made based on the users' past travel experiences, and the recommended locations were ranked based on the projected values. The top-n recommendations to the target users were compared with the actual ratings.

IV. IMPLEMENTATION

A. Data Pre-Processing

The data pre-processing is crucial to building the model since it allows the dataset to be prepared for modelling purposes.

The data was obtained from Kaggle with over 20,000 records and 13 attributes as described in Table VI.

1) Variables selection: The project's objective was to recommend travel destinations to users based on geotagged information collected. As shown in Table VII, the study employed only five variables for building the model such as picture id, user id, geographical information, including the latitude and longitude of the images, and the time at which the photos were taken.

TABLE VI. DATASET DESCRIPTION BEFORE VARIABLES SELECTION

No	Attributes	Description
1	photo_id	photo id
2	owner	user id related to the owner of the photo
3	gender	owner's gender
4	occupation	occupation of owner
5	title	title of photo
6	description	description of photo
7	tags	photo tag
8	faves	photo's favorite rate
9	lat	photo's latitude
10	lon	photo's longitude
11	u_city	owner's city
12	u_country	owner's country
13	taken	the time of the photo taken

2) Data exploration: The data type of the dataset was inspected after eliminating unnecessary attributes. Suitable type conversions were done to the variables such as date, latitude, and longitude to prevent slower operations during data transformation and model construction. The dataset was examined for missing values and confirmed with no imputation or removal of data required.

3) Clustering algorithm: The initial step in developing the travel recommendation model involved identifying the locations of the geotagged data. The study [59] highlighted that it is often challenging to process spatial data due to the existence of redundant points. By transforming the number of latitude-longitude coordinates into the corresponding values generated by the clustering technique, DBSCAN can reduce the size of a geographical data set to a small collection of representative points. The data were grouped into clusters to serve as a location for recommendations. The latitude and longitude data were extracted as dbscan_data as the first step.

The two main parameters for the DBSCAN algorithm are the epsilon (eps) and the minimum points (MinPts). The epsilon specifies the radius of a neighbourhood around the center point of the clusters, and it is important to determine the optimal number of clusters. If the eps value is too low, a significant amount of the data will be omitted from the cluster. This is because the value is insufficient to produce a dense region. Conversely, if the value is very high, many objects will be merged into a cluster, making the clustering meaningless. Besides, the parameter MinPts specifies the minimum number of points necessary to create a cluster. The estimation of the various parameters used is often a challenge during the development of an algorithm. Therefore, different combinations of eps and MinPts values were examined to discover the optimal values.

Research [59] stated the haversine metric was used as the metric of the DBSCAN algorithm to minimize the noise generated by the random selection process by computing the great-circle distances between the various points in the data set. Given their respective latitudes and longitudes, the haversine formula relates the great-circle distance of a sphere to two locations on a specified plane. The parameter and coordinates were then converted to radians to ensure the algorithm to perform precise calculations.

Fig. 3 shows the number of clusters generated by various parameter combinations. The optimal value for eps and MinPts was determined using the elbow approach, which is a basic procedure used in cluster analysis [60]. As a result, the eps and minimum points selected were 0.15 and 10, respectively.

The geographical coordinates were converted from 20,000 data points to 181 clusters using the given parameters. With cluster_num = 0 as the noises in the data, 180 clusters were found as the representative points of the travel locations for recommendations. The coordinates of the geotagged data that were formed as part of the cluster were labelled by its cluster labels using the points closest to the cluster's centroid. It was accomplished by taking a set of points and returning to the centermost point of the cluster.

Fig. 4 illustrates the original data set which was reduced to a cluster-representative collection of points where different colours correspond to each cluster formed by the DBSCAN algorithm. The grey dots represent the outliers of the geotagged data points, often known as the dataset's noise.

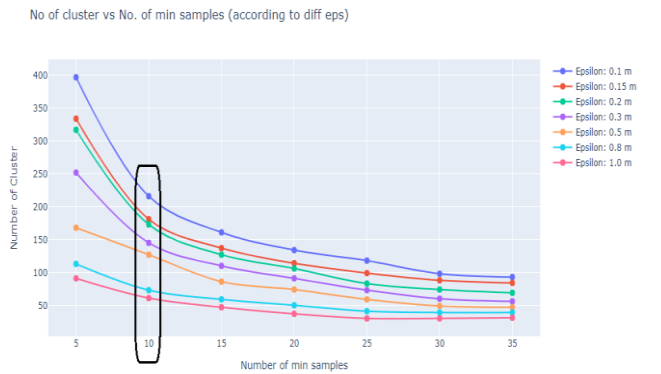
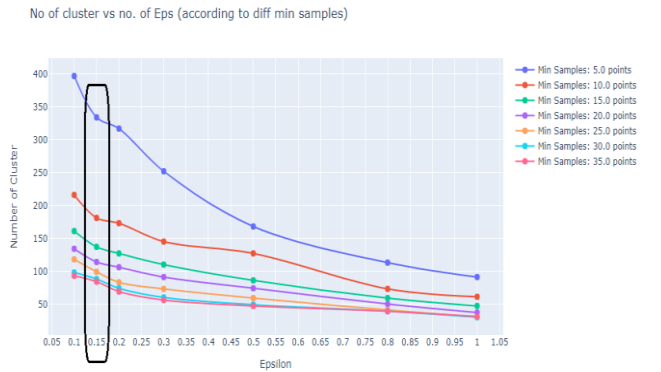


Fig. 3. Selecting DBSCAN parameters.

TABLE VII. DATASET DESCRIPTION AFTER VARIABLES SELECTION

No	Attributes	Description
1	photo_id	photo id
2	owner	user id related to the owner of the photo
3	lat	photo's latitude
4	lon	photo's longitude
5	taken	the time of the photo taken

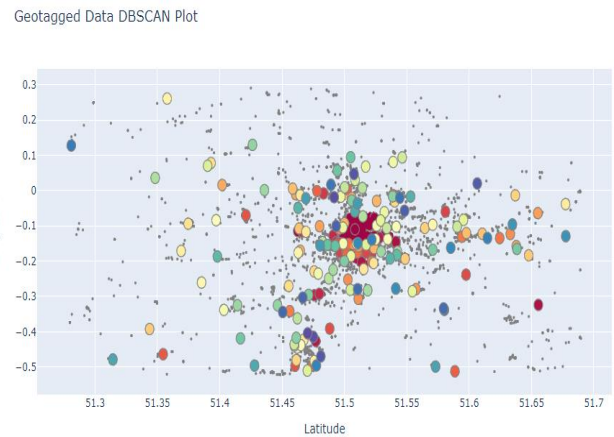


Fig. 4. DBSCAN result.

4) *Remove outliers*: The outliers were eliminated as found as noise in the dataset and not beneficial for the recommendation process after constructing the cluster labels for each geotagged data set.

5) *Remove duplicate data*: It is important to note that users may take multiple photos of the same location while visiting a venue. Therefore, if the timestamps between two photos taken at the same location are less than three hours, the visit must be treated as a single visit. The most recent timestamps of the images taken at the same place are then used to determine the time. The elimination of duplicate data was done by merging users with visits within three hours. In addition, for consistency, a random number between 100 and 999 was generated in place of the cluster labels 0 to 180.

6) *Remove users with less than three visits*: Users who have visited less than three distinct places were eliminated as the model was developed using a collaborative filtering approach.

B. Data Transformation

The rating matrix to construct the recommendation model was formed by calculating the number of times a user visited a certain location as a rating. The ratings were scaled to a range between 1 and 5 using the min-max scale function to eliminate bias in the training phase and enhance the efficiency of the data mining process. After the data scaling process was completed, the user-location rating matrix was generated using the pivot_table function to develop a travel location recommendation model and provide users with ideal suggestions based on their previous visits.

The final dataset was split into two: training (80%) and testing (20%) to assess the recommendation model.

C. Data Mining

This section discusses the matrix factorization model, a widely used technique in the collaborative filtering approach to construct the travel location recommendation model.

1) *Matrix factorization model*: The rating matrix is sparse by nature. The goal of the modelling process was to forecast the ratings of the areas that have not been visited by the target

user through user similarities. Therefore, the user-user similarity matrix is crucial for determining the possibility that they will visit other travel destinations. According to [61], the sparsity in the rating matrix is a major factor that affects the performance of collaborative filtering systems, and the matrix factorization model is effective in addressing the insufficiency of ratings. Therefore, the modelling process utilized the matrix factorization model to factorize the various similarities between different pairs of users. The main objective of this process was to predict the missing values of the user-user similarity matrix. The cosine similarity was selected as the metric to predict the similarities between the users. The matrix factorization model decomposed the original matrix of user preferences into two smaller matrix elements, known as latent factors. The model discovered the hidden features of the interactions between different users and analysed the various factors that affect the users' behaviour to recommend the most appropriate destination according to their preferences. The approach was inspired by the study by [57], who revealed that the matrix factorization performed well with sparse data using movie ratings.

After determining various similarities between every pair of users, a weighted average of the ratings from the users like the target user was then used to calculate the ratings to a location for the current user. The projected rating of a specific location was the weighted sum of the ratings given to a certain location by the number of users like the target user. The predicted rating was the expected value that the target users will be assigned to the specific location.

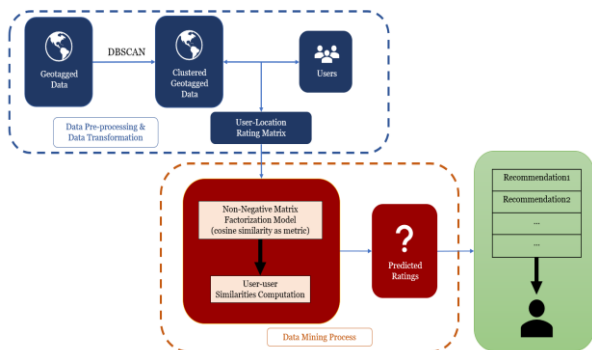


Fig. 5. Data mining process.

Fig. 5 provides a summary of the model implementation. Multiple approaches were used to prepare and transform the data, and the data mining process enables the model to learn and predict ratings for the target user to a certain location.

V. RESULTS AND DISCUSSION

This Section provides a comprehensive analysis of the performance of the developed model. Several evaluation metrics were used to test the model's performance. The results of the study were analyzed through a comparative analysis with two baseline models.

A. Results

The testing datasets were used to construct the test rating matrix for evaluating the proposed model. In the testing dataset, the ratings were also scaled to a range of 1 to 5. Using the proposed model, the predict function was defined to forecast the ratings of locations for a user. Fig. 6 shows the top five suggestions for the representative target user, 41087279@N00. The ratings are displayed side by side with the predictions.

	true	pred
location_id		
137	5.000000	3.261260
511	1.363636	2.655470
115	0.000000	2.650794
152	0.000000	2.650794
155	0.000000	2.650794

Fig. 6. Prediction result.

The proposed model was evaluated against two different baseline approaches selected from past studies, and the assessment was conducted using the same dataset [37], [47], [58]. One of these is the popularity-based method, which used a general popularity score as the basis for its recommendations. It considered the number of unique visits to these locations. On the other hand, the random model generated random travel destinations for the target users regardless of their similarities or popularity scores.

B. Model Comparison

1) *Mean average precision@n (MAP@n)*: The mean average precision (MAP) is a measure that takes into the list of recommendations and compares it with the true set. The n represents the number of recommendations generated to the users. Using n = 5, 10, 15, the MAP for each model was calculated and tabulated for comparison. Based on Fig. 7 and Table VIII, the results show that the proposed matrix factorization model got an average precision value of 0.83, which is higher than the popularity and random models.



Fig. 7. MAP@n.

TABLE VIII. MAP@N

MAP@n	Popularity Model	Random Model	Matrix Factorization Model
5	0.746	0.744	0.829
10	0.749	0.744	0.829
15	0.753	0.745	0.831

2) *Root mean square error (RMSE)*: The Root Mean Square Error (RMSE) is a statistical tool used to assess the accuracy of rating predictions. It measures the square root of the difference between predicted and actual values. As shown in Fig. 8 and Table IX, the matrix factorization model got an RMSE value of 1.36, which is the lowest compared to the two baseline models.

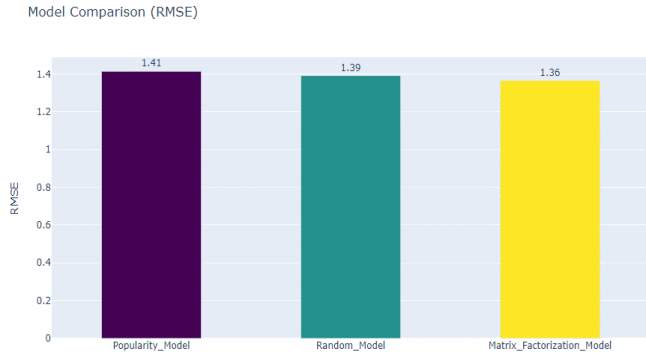


Fig. 8. RMSE.

TABLE IX. RMSE

Models	RMSE
Popularity Model	1.41
Random Model	1.39
Matrix Factorization Model	1.36

3) *Mean absolute error (MAE)*: The Mean Absolute Error (MAE) represents the deviations between the model's predictions and the actual results. Fig. 9 and Table X reveal that the proposed matrix factorization model got the lowest MAE of 1.24 value among the three models. In contrast, the MAE value for the popularity and random models is 1.27 and 1.28, respectively.

The Mean Average Precision@n (MAP@n), Mean Absolute Error (MAE), and Root Mean Square Error (RMSE) of the three models are summarized in Table XI. The results demonstrate that the proposed model has the lowest RMSE and MAE values and the highest MAP@n regardless of the number of recommendations. This proves that the user-based collaborative filtering technique, which computes user-user similarities using a matrix factorization model, effectively identifies the ideal destination for the target users based on their previous visits.

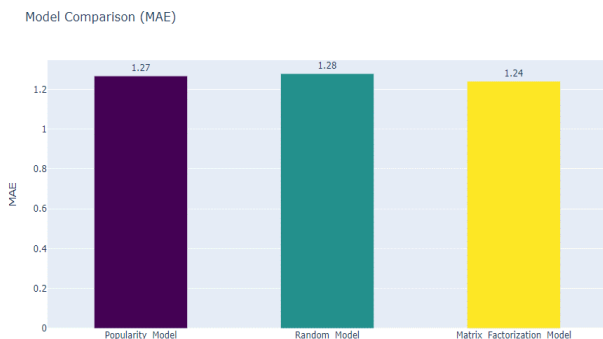


Fig. 9. MAE.

TABLE X. MAE

Models	MAE
Popularity Model	1.27
Random Model	1.28
Matrix Factorization Model	1.24

TABLE XI. MODEL COMPARISON

Models	MAP@n			RMSE	MAE
	5	10	15		
Popularity Model	0.74 6	0.74 9	0.75 3	1.4 1	1.2 7
Random Model	0.74 4	0.74 4	0.74 5	1.3 9	1.2 8
Matrix Factorization Model (Proposed Model)	0.82 9	0.82 9	0.83 1	1.3 6	1.2 4

VI. CONCLUSION

This Section summarizes the findings and the study's contribution to the research field. Limitations and future recommendations are additionally highlighted to improve the algorithm's performance and enhance its usability for the general population.

A. Conclusion

The rapid development and growth of the tourism industry has led to the need for more effective tools and methods to help travellers make informed decisions when planning their trips. Numerous studies have been conducted on the development of effective travel recommendation systems, but most of them have been reliant on reviews and descriptions of the attractions.

The study develops a recommendation system for travellers using geotagged data to provide personalized location recommendations based on user interactions. The evaluation metrics used, such as MAP@n, RMSE and MAE, revealed that the proposed model outperforms the two baseline models chosen by exhibiting recommendations with the highest MAP values and the lowest RMSE and MAE values. As per the findings, the proposed model obtained the highest MAP value using the different number of recommendations generated, with an average value of 0.83. Further, compared to the two baseline models, the proposed model got the lowest RMSE and MAE, with values of 1.36 and 1.24, respectively. This proves that the matrix factorization model effectively generates personalized location recommendations based on users' past visits and interactions with other users.

The study has significant implications for the tourism industry, as the proposed system can help travellers make informed decisions when planning their trips. The use of geotagged data provides a more comprehensive and unbiased view of travel destinations, as it considers both popular and less popular spots. Additionally, the results of this study also contribute to the existing literature on travel recommendation systems by showcasing the efficacy of utilizing geotagged data to generate personalized recommendations.

B. Contributions and Importance of the Study

Overall, the study has accomplished its aim of analyzing the impact of geotagged data in selecting attractions and proposing a travel recommendation model based on geotagged data. The proposed travel recommendation model can analyze the collective behaviour of tourists and identify regions that are ideal for them. It also introduces serendipity by enabling users to discover new interests in different areas depending on the interests indicated by other similar users based on the data collected.

In conclusion, the proposed model has the potential to be a valuable tool for users who have uploaded geotagged social media posts to get travel destination ideas from other places. This can ultimately reduce the time spent browsing through different websites to find the ideal destination to travel to. Additionally, the tourism sector may incorporate this model into their applications to promote tourism in their respective countries to create revenue and contribute to their Gross Domestic Product (GDP). With further implementation in the future, this can provide significant benefits to both users and the tourism industry.

C. Limitations and Future Recommendations

The collaborative filtering technique does not require domain knowledge since embeddings are automatically learnt, and the matrix factorization can solve the sparsity problem. However, the proposed model suffers from the cold-start problem, which occurs for users that are relatively new due to insufficient connection with other users. To address this issue, users with less than three visits were excluded from the recommendation process. It is recommended to incorporate other algorithms such as content-based filtering to build a hybrid recommender to eliminate the cold-start issue. Content-based filtering can be used to construct user profiles by collecting user information based on their social media postings or through a questionnaire.

It is also recommended to build a mobile application or a graphical user interface (GUI) using the developed recommendation model to provide personalized recommendations. The application should have an interactive interface that allows the users to select their previous visits and display the various locations that it recommends. In addition to providing locations as recommendations, the proposed model should also add side features collected from sites like Google Maps to enhance the location profiles. For example, it can provide the type of activities and opening hours in the area to allow users to understand more about the recommended locations.

REFERENCES

- [1] World Travel & Tourism Council, "Economic Impact Reports," 2020. <https://wtcc.org/Research/Economic-Impact> (accessed Oct. 19, 2021).
- [2] V. Kazandzhieva and H. Santana, "E-tourism: Definition, development and conceptual framework," *Tourism: An International Interdisciplinary Journal*, vol. 67, no. 4, pp. 332–350, 2019.
- [3] S. Singh and A. Bashar, "A bibliometric review on the development in e-tourism research," *International Hospitality Review*, vol. ahead-of-print, no. ahead-of-print, Jan. 2021, doi: 10.1108/IHR-03-2021-0015.
- [4] O. Wyman, "To Recovery & Beyond | Future of Travel & Tourism | World Travel & Tourism Council (WTTC)," 2020. Accessed: Oct. 10, 2021. [Online]. Available: <https://wtcc.org/Initiatives/To-Recovery-Beyond>
- [5] X. Liu, F. Mehraliyev, C. Liu, and M. Schuckert, "The roles of social media in tourists' choices of travel components," *Tour Stud*, vol. 20, no. 1, pp. 27–48, Apr. 2019, doi: 10.1177/1468797619873107.
- [6] B. Hysa, A. Karasek, and I. Zdonek, "Social Media Usage by Different Generations as a Tool for Sustainable Tourism Marketing in Society 5.0 Idea," *Sustainability*, vol. 13, no. 3, 2021, doi: 10.3390/su13031018.
- [7] B. T. Khoa, N. M. Ly, V. T. T. Uyen, N. T. T. Oanh, and B. T. Long, "The impact of Social Media Marketing on the Travel Intention of Z Travelers," in 2021 IEEE International IOT, Electronics and Mechatronics Conference (IEMTRONICS), 2021, pp. 1–6. doi: 10.1109/IEMTRONICS52119.2021.9422610.
- [8] S. W. Litvin, R. E. Goldsmith, and B. Pan, "A retrospective view of electronic word-of-mouth in hospitality and tourism management," *International Journal of Contemporary Hospitality Management*, vol. 30, no. 1, pp. 313–325, Jan. 2018, doi: 10.1108/IJCHM-08-2016-0461.
- [9] P. Nitu, J. Coelho, and P. Madiraju, "Improving personalized travel recommendation system with recency effects," *Big Data Mining and Analytics*, vol. 4, no. 3, pp. 139–154, 2021, doi: 10.26599/BDMA.2020.9020026.
- [10] Z. Abbasi-Moud, H. Vahdat-Nejad, and J. Sadri, "Tourism recommendation system based on semantic clustering and sentiment analysis," *Expert Syst Appl*, vol. 167, p. 114324, Apr. 2021, doi: 10.1016/J.ESWA.2020.114324.
- [11] I. Y. Choi, Y. U. Ryu, and J. K. Kim, "A recommender system based on personal constraints for smart tourism city," *Asia Pacific Journal of Tourism Research*, vol. 26, no. 4, pp. 440–453, Apr. 2021, doi: 10.1080/10941665.2019.1592765.
- [12] J.-S. Kim et al., "Location-Based Social Network Data Generation Based on Patterns of Life," in 2020 21st IEEE International Conference on Mobile Data Management (MDM), 2020, pp. 158–167. doi: 10.1109/MDM48529.2020.00038.
- [13] X. Wei, Y. Qian, C. Sun, J. Sun, and Y. Liu, "A survey of location-based social networks: problems, methods, and future research directions," *Geoinformatica*, 2021, doi: 10.1007/s10707-021-00450-1.
- [14] A. Hardy, "Tracking via Geotagged Social Media Data," in *Tracking Tourists*, Goodfellow Publishers, 2020. doi: 10.23912/9781911635383-4575.
- [15] C. Barros, J. Gutiérrez, and J. García-Palomares, "Geotagged data from social media in visitor monitoring of protected areas; a scoping review," *Current Issues in Tourism*, pp. 1–17, May 2021, doi: 10.1080/13683500.2021.1931053.
- [16] V. Taecharunroj and B. Mathayomchan, "Traveller-generated destination image: Analysing Flickr photos of 193 countries worldwide," *International Journal of Tourism Research*, vol. 23, no. 3, pp. 417–441, Apr. 2021, doi: 10.1002/JTR.2415.
- [17] M.-I. Ana and L.-G. Istudor, "The Role of Social Media and User-Generated-Content in Millennials' Travel Behavior," *Management Dynamics in the Knowledge Economy*, vol. 7, no. 1, pp. 87–104, 2019, doi: <http://dx.doi.org/10.25019/MDKE/7.1.05>.
- [18] S. Bairavel and M. Krishnamurthy, "User preference and reviews analysis with neural networks for travel recommender systems," *International Journal of Engineering Research and Technology*, vol. 13, no. 8, pp. 1896–1900, 2020, doi: 10.37624/IJERT/13.8.2020.1896-1900.
- [19] D. Lyu, L. Chen, Z. Xu, and S. Yu, "Weighted multi-information constrained matrix factorization for personalized travel location recommendation based on geo-tagged photos," *Applied Intelligence*, vol. 50, no. 3, pp. 924–938, 2020, doi: 10.1007/s10489-019-01566-6.
- [20] S.-T. Park and C. Liu, "A study on topic models using LDA and Word2Vec in travel route recommendation: focus on convergence travel and tours reviews," *Pers Ubiquitous Comput*, 2020, doi: 10.1007/s00779-020-01476-2.
- [21] A. Sariaslani, "Flickr (London City)," 2020. https://www.kaggle.com/datasets/amiralisa/flickr_london (accessed Apr. 04, 2022).
- [22] WHO, "WHO Director-General's opening remarks at the media briefing on COVID-19 - 11 March 2020," World Health Organization, 2020. <https://www.who.int/director-general/speeches/detail/who-director->

- general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020 (accessed Dec. 05, 2021).
- [23] C. Basu, H. Hirsh, and W. Cohen, "Recommendation as classification: Using social and content-based information in recommendation," in *AAAI*, 1998, pp. 714–720.
- [24] A. Ansari, S. Essegaier, and R. Kohli, "Internet Recommendation Systems," *Journal of Marketing Research*, vol. 37, no. 3, pp. 363–375, 2000, doi: 10.1509/jmkr.37.3.363.18779.
- [25] C. C. Aggarwal, "An Introduction to Recommender Systems," *Recommender Systems: The Textbook*. Springer International Publishing, pp. 1–28, 2016. doi: 10.1007/978-3-319-29659-3_1.
- [26] Z.-P. Zhang, Y. Kudo, T. Murai, and Y.-G. Ren, "Enhancing Recommendation Accuracy of Item-Based Collaborative Filtering via Item-Variance Weighting," *Applied Sciences*, vol. 9, no. 9, 2019, doi: 10.3390/app9091928.
- [27] D. Jannach, M. Zanker, A. Felfernig, and G. Friedrich, *Recommender systems: an introduction*. Cambridge University Press, 2010.
- [28] J. Lu, D. Wu, M. Mao, W. Wang, and G. Zhang, "Recommender system application developments: A survey," *Decis Support Syst*, vol. 74, pp. 12–32, 2015, doi: <https://doi.org/10.1016/j.dss.2015.03.008>.
- [29] B. Walek and V. Fojtik, "A hybrid recommender system for recommending relevant movies using an expert system," *Expert Syst Appl*, vol. 158, p. 113452, 2020, doi: <https://doi.org/10.1016/j.eswa.2020.113452>.
- [30] S. Khalifeh and A. A. Al-Mousa, "A Book Recommender System Using Collaborative Filtering Method," *International Conference on Data Science, E-Learning and Information Systems 2021*, pp. 131–135, 2021, doi: 10.1145/3460620.3460744.
- [31] J. K. Tarus, Z. Niu, and G. Mustafa, "Knowledge-based recommendation: a review of ontology-based recommender systems for e-learning," *Artif Intell Rev*, vol. 50, no. 1, pp. 21–48, 2018, doi: 10.1007/s10462-017-9539-5.
- [32] Y. Deldjoo, M. Schedl, and M. Elahi, "Movie Genome Recommender: A Novel Recommender System Based on Multimedia Content," in *2019 International Conference on Content-Based Multimedia Indexing (CBMI)*, 2019, pp. 1–4. doi: 10.1109/CBMI.2019.8877452.
- [33] Adiyansjah, A. A. S. Gunawan, and D. Suhartono, "Music Recommender System Based on Genre using Convolutional Recurrent Neural Networks," *Procedia Comput Sci*, vol. 157, pp. 99–109, 2019, doi: <https://doi.org/10.1016/j.procs.2019.08.146>.
- [34] S. Ali, Y. Hafeez, M. Humayun, N. S. M. Jamail, M. Aqib, and A. Nawaz, "Enabling recommendation system architecture in virtualized environment for e-learning," *Egyptian Informatics Journal*, vol. 23, no. 1, pp. 33–45, 2022, doi: <https://doi.org/10.1016/j.eij.2021.05.003>.
- [35] S. Missaoui, F. Kassem, M. Viviani, A. Agostini, R. Faiz, and G. Pasi, "LOOKER: a mobile, personalized recommender system in the tourism domain based on social media user-generated content," *Pers Ubiquitous Comput*, vol. 23, no. 2, pp. 181–197, 2019, doi: 10.1007/s00779-018-01194-w.
- [36] W. Shafqat and Y.-C. Byun, "A Context-Aware Location Recommendation System for Tourists Using Hierarchical LSTM Model," *Sustainability*, vol. 12, no. 10, 2020, doi: 10.3390/su12104107.
- [37] G. Cai, K. Lee, and I. Lee, "Itinerary recommender system with semantic trajectory pattern mining from geo-tagged photos," *Expert Syst Appl*, vol. 94, pp. 32–40, Apr. 2018, doi: 10.1016/J.ESWA.2017.10.049.
- [38] X. Sun, Z. Huang, X. Peng, Y. Chen, and Y. Liu, "Building a model-based personalised recommendation approach for tourist attractions from geotagged social media data," *Int J Digit Earth*, vol. 12, no. 6, pp. 661–678, Apr. 2019, doi: 10.1080/17538947.2018.1471104.
- [39] L. Zhong, L. Yang, J. Rong, and H. Kong, "A Big Data Framework to Identify Tourist Interests Based on Geotagged Travel Photos," *IEEE Access*, vol. 8, pp. 85294–85308, 2020, doi: 10.1109/ACCESS.2020.2990949.
- [40] H. Huang, "Context-Aware Location Recommendation Using Geotagged Photos in Social Media," *ISPRS International Journal of Geo-Information* 2016, Vol. 5, Page 195, vol. 5, no. 11, p. 195, Apr. 2016, doi: 10.3390/IJGI5110195.
- [41] S. A. Mohd Selamat, S. Prakoonwit, R. Sahandi, W. Khan, and M. Ramachandran, "Big data analytics—A review of data-mining models for small and medium enterprises in the transportation sector," *Wiley Interdiscip Rev Data Min Knowl Discov*, vol. 8, no. 3, p. e1238, May 2018, doi: 10.1002/WIDM.1238.
- [42] A. Ghosal, A. Nandy, A. K. Das, S. Goswami, and M. Panday, "A Short Review on Different Clustering Techniques and Their Applications," in *Emerging Technology in Modelling and Graphics*, 2020, pp. 69–83.
- [43] I. Memon, L. Chen, A. Majid, M. Lv, I. Hussain, and G. Chen, "Travel Recommendation Using Geo-tagged Photos in Social Media for Tourist," *Wirel Pers Commun*, vol. 80, no. 4, pp. 1347–1362, 2015, doi: 10.1007/s11277-014-2082-7.
- [44] W. Höpken, M. Müller, M. Fuchs, and M. Lexhagen, "Flickr data for analysing tourists' spatial behaviour and movement patterns," *Journal of Hospitality and Tourism Technology*, vol. 11, no. 1, pp. 69–82, Apr. 2020, doi: 10.1108/JHTT-08-2017-0059.
- [45] K. N. S. Behara, A. Bhaskar, and E. Chung, "A DBSCAN-based framework to mine travel patterns from origin-destination matrices: Proof-of-concept on proxy static OD from Brisbane," *Transp Res Part C Emerg Technol*, vol. 131, p. 103370, 2021, doi: <https://doi.org/10.1016/j.trc.2021.103370>.
- [46] M. Grbovic et al., "E-commerce in Your Inbox: Product Recommendations at Scale," Jun. 2016, doi: 10.1145/2783258.2788627.
- [47] Z. Xu, L. Chen, Y. Dai, and G. Chen, "A Dynamic Topic Model and Matrix Factorization-Based Travel Recommendation Method Exploiting Ubiquitous Data," *IEEE Trans Multimedia*, vol. 19, no. 8, pp. 1933–1945, 2017, doi: 10.1109/TMM.2017.2688928.
- [48] F. O. Isinkaye, Y. O. Folajimi, and B. A. Ojokoh, "Recommendation systems: Principles, methods and evaluation," *Egyptian Informatics Journal*, vol. 16, no. 3, pp. 261–273, 2015, doi: <https://doi.org/10.1016/j.eij.2015.06.005>.
- [49] Z. Ghaemi and M. Farnaghi, "A Varied Density-based Clustering Approach for Event Detection from Heterogeneous Twitter Data," *ISPRS Int J Geoinf*, vol. 8, no. 2, 2019, doi: 10.3390/ijgi8020082.
- [50] W. Yin, Y. Sun, and J. Zhao, "Personalized Tourism Route Recommendation System Based on Dynamic Clustering of User Groups," in *2021 IEEE Asia-Pacific Conference on Image Processing, Electronics and Computers (IPEC)*, 2021, pp. 1148–1151. doi: 10.1109/IPEC51340.2021.9421158.
- [51] E. Torstensson, "Comparing neighborhood and matrix factorization models in recommendation systems: Saving the user some clicks," 2019.
- [52] S. Kalloori, F. Ricci, and M. Tkalcic, "Pairwise Preferences Based Matrix Factorization and Nearest Neighbor Recommendation Techniques," in *Proceedings of the 10th ACM Conference on Recommender Systems*, 2016, pp. 143–146. doi: 10.1145/2959100.2959142.
- [53] C. Xu, "A novel recommendation method based on social network using matrix factorization technique," *Inf Process Manag*, vol. 54, no. 3, pp. 463–474, 2018, doi: <https://doi.org/10.1016/j.ipm.2018.02.005>.
- [54] S. Bin and G. Sun, "Matrix Factorization Recommendation Algorithm Based on Multiple Social Relationships," *Math Probl Eng*, vol. 2021, p. 6610645, 2021, doi: 10.1155/2021/6610645.
- [55] R. Wang, H. K. Cheng, Y. Jiang, and J. Lou, "A novel matrix factorization model for recommendation with LOD-based semantic similarity measure," *Expert Syst Appl*, vol. 123, pp. 70–81, 2019, doi: <https://doi.org/10.1016/j.eswa.2019.01.036>.
- [56] C. C. Aggarwal, "Evaluating recommender systems," in *Recommender systems*, Springer, 2016, pp. 225–254.
- [57] P. Pirasteh, D. Hwang, and J. J. Jung, "Exploiting matrix factorization to asymmetric user similarities in recommendation systems," *Knowl Based Syst*, vol. 83, pp. 51–57, 2015, doi: <https://doi.org/10.1016/j.knosys.2015.03.006>.
- [58] K. H. Lim, "Recommending Tours and Places-of-Interest Based on User Interests from Geo-Tagged Photos," in *Proceedings of the 2015 ACM SIGMOD on PhD Symposium*, 2015, pp. 33–38. doi: 10.1145/2744680.2744693.
- [59] G. Boeing, "Clustering to Reduce Spatial Data Set Size," *SSRN Electronic Journal*, Mar. 2018, doi: 10.48550/arxiv.1803.08101.

- [60] T. Luo, X. Zheng, G. Xu, K. Fu, and W. Ren, "An Improved DBSCAN Algorithm to Detect Stops in Individual Trajectories," *ISPRS Int J Geoinf*, vol. 6, no. 3, 2017, doi: 10.3390/ijgi6030063.
- [61] R. Duan, C. Jiang, and H. K. Jain, "Combining review-based collaborative filtering and matrix factorization: A solution to rating's sparsity problem," *Decis Support Syst*, vol. 156, p. 113748, 2022, doi: <https://doi.org/10.1016/j.dss.2022.113748>.

Input Value Chain Affect Vietnamese Rice Yield: An Analytical Model Based on a Machine Learning Algorithm

Thi Thanh Nga Nguyen¹, NianSong Tu², Thai Thuy Lam Ha^{3*}

Faculty of Management and Economics, Kunming University of Science and Technology, Kunming, 650093, China^{1,2}
Dong Thap University, 870000, Dong Thap, Vietnam³

Abstract—Input value chains greatly affect rice yield, however previous related studies were mainly based on empirical survey and simple statistics, which lacked generality and flexibility. The article presents a new method to predict the influence of input value chain on rice yield in Vietnam based on a machine learning algorithm. Input value chain data is collected through field surveys in rice-growing households. We build a predictive model based on the neural network and swarm intelligence optimization algorithm. The prediction results show that our proposed method has an accuracy of 96%, higher than other traditional methods. This is the basis for management levels to have orientation on the input supply value chain for Vietnamese rice, contributing to the development of the Vietnamese rice brand in the world market.

Keywords—Value chains; Vietnamese rice; machine learning; neural network

I. INTRODUCTION

A value chain is a sequence of activities in which the product passes through all the activities in order and at each activity, the product acquires some value [1]. Value chain development plays a very important role in the development of Vietnam's agriculture. The role of the value chain manifests itself in aspects such as promoting the improvement of productivity and quality of agricultural products, being a basic solution for product distribution and consumption, and increasing the attractiveness of investment in agriculture, etc. With underdeveloped agriculture in Vietnam, the role of the value chain is becoming more and more important. The effectiveness of the value chain depends on the cooperation of the members of the chain. When participating in cooperation in the value chain, members enjoy many benefits, especially the conditions to reduce costs, improve productivity and product quality, reduce sourcing time, be stable in production, etc. If participating in the global value chain, members also enjoy higher benefits, have conditions to increase productivity, improve product quality, have the opportunity to easily penetrate international markets, and increase profits, etc. In Vietnam, developing linkage cooperation along the value chain model is a condition for agricultural development. More than 75% of our agricultural products have to go through intermediaries or foreign brands to approach the international market. Therefore, many people combine to form a value chain, which will attract the participation of suppliers, distributors, and processing companies [2][3][4].

With favorable natural conditions, Vietnam has become a powerhouse in rice exports, just behind India and Thailand. According to UN FAO data, in 2017, Vietnam had more than 80 rice-exporting enterprises, accounting for about 20% of global rice exports [5]. However, because Vietnamese rice brands are not outstanding enough in the international market, although the export volume is high, it is mainly in the low and medium-quality segments. To overcome this problem and create sustainable development for the rice industry, the Vietnamese government is finalizing many drafts of the Regulation on the management of national certification marks for Vietnamese rice. Along with that, the development of stages in the rice value chain is also invested and interested. In the current Vietnamese rice industry, the value chain is mainly vertical. The main interlinked actors are input, production, conversion, distribution, and consumption. The input value chain is the opening stage and determines the output and productivity of Vietnamese rice [6][7]. Therefore, research to assess the impact of factors in the input value chain affecting Vietnamese rice is extremely necessary.

In recent years, along with the development of computers, artificial intelligence, and machine learning algorithms have been born that have solved countless problems of statistical analysis in economics that traditional analytical methods have not been able to achieve. Machine learning makes data processing, calculation, and analysis faster and more accurate, helping economic researchers' approach and evaluate hot issues [8][9][10]. Valendin et al. [11] used recurrent neural networks to analyze customers. They propose a new approach by using the history of individual customer transactions and relevant contextual factors to predict future behavior, and linking the characteristics of the individual and customer. This approach can help managers capture seasonal trends and buying dynamics. Chen et al. [12] designed a manufacturing enterprise environmental cost control system using the decision tree algorithm of machine learning. This method can realize the optimization of the circular economy value chain, and put forward important suggestions for the control of environmental cost schemes. Liu et al. [13] explored the application of artificial intelligence in global value chains. The results confirm that there is a significant positive correlation between artificial intelligence and the industry's global value chain. Liu et al. [14] established an economic risk prediction model using artificial intelligence algorithms based on the analysis of global value chains. This method can realize its trend prediction and

provide an important theoretical reference for global value chain economic risks.

Traditional methods of studying the effects of value chains on products are mainly based on empirical surveys and simple statistics, which lack generality and flexibility, leading to many non-conforming conclusions, even imprecise. Therefore, applying intelligent assessment methods to value chain analysis is essential, it can solve some problems existing in traditional methods. This study proposes a new method of analyzing the input value chain affecting the yield of Vietnamese rice based on a machine learning method. First, we collect data through actual survey sources. Next, based on a new machine learning algorithm to build a predictive model, to improve the accuracy of the model, an optimization algorithm is applied to optimize the parameters. Finally, experiments to evaluate the effectiveness of the proposed model.

II. METHOD

A. Data Collection and Processing

In this study, data were collected from rice-growing households in the Mekong Delta of Vietnam including Kien Giang, Long An, An Giang, Dong Thap, and Soc Trang provinces. Information and data were collected through direct interviews with rice growers, soil quality statistics, and from input suppliers such as agricultural mechanical engineering companies, companies providing seeds and plant protection drugs. Data collection is based on trained collaborators and under the supervision of the research team. We use random sampling in combination with different geographic zoning, this combination will increase the generality for many regions. In addition, we conducted interviews with long-term rice growers and experts to assess, and gain practical experience and the current situation, thereby deepening our understanding of the actual situation in the data collection area. Finally, we selected input data to build predictive models including soil quality, water source, seed supply, fertilizer supply, agricultural medicine supply, science and technology, access to credit, age of homeowners, number of years in occupation, and qualification of homeowners.

Since the collected data is heterogeneous, it is necessary to normalize the data to enhance the training process of the model. In this paper, we use the method of max normalization to normalize the data [15], this method will select the largest number to return to 1, and the remaining numbers will be proportional to the range from 0 to 1.

B. Extreme Learning Machine

The training set has N samples $(\mathbf{x}_i, \mathbf{t}_i)$, $\mathbf{x}_i = [x_{i1}, x_{i2}, \dots, x_{in}]^T \in \mathbf{R}^n$, $\mathbf{t}_i = [t_{i1}, t_{i2}, \dots, t_{im}]^T \in \mathbf{R}^m$, the mathematical expression of extreme learning machine (ELM) [16][17][18] is shown in Equation (1).

$$f_{ELM-L}(\mathbf{x}) = \sum_{j=1}^L \beta_j g(\mathbf{w}_j \cdot \mathbf{x}_i + b_j) = \mathbf{t}_i; b_j, \beta_j \in \mathbf{R} \quad (1)$$

here, $\mathbf{w}_j = [w_{j1}, w_{j2}, \dots, w_{jn}]^T \in \mathbf{R}^n$ is the input weight, L is the hidden layer nodes, b_j is the bias, β_j is the output weight,

and $g(\bullet)$ is the activation function. Equation (1) and Equation (2) are the same.

$$\mathbf{H}_1 \beta_1 = \mathbf{T} \quad (2)$$

here,

$$\mathbf{H}_1(\mathbf{w}_1, \dots, \mathbf{w}_L, b_1, \dots, b_L, \mathbf{x}_1, \dots, \mathbf{x}_N) = \begin{bmatrix} g(\mathbf{w}_1 \cdot \mathbf{x}_1 + b_1) & \dots & g(\mathbf{w}_L \cdot \mathbf{x}_1 + b_L) \\ \vdots & & \vdots \\ g(\mathbf{w}_1 \cdot \mathbf{x}_N + b_1) & \dots & g(\mathbf{w}_L \cdot \mathbf{x}_N + b_L) \end{bmatrix}_{N \times L} \quad (3)$$

$$\beta_1 = \begin{bmatrix} \beta_1^T \\ \vdots \\ \beta_L^T \end{bmatrix}_{L \times m} \quad \mathbf{T} = \begin{bmatrix} \mathbf{t}_1^T \\ \vdots \\ \mathbf{t}_j^T \end{bmatrix}_{N \times m} \quad (4)$$

\mathbf{T} is the actual value matrix.

The β_1 is calculated by the Equation (5).

$$\beta_1 = \mathbf{H}_1^+ \mathbf{T} \quad (5)$$

here, \mathbf{H}_1^+ is the Moore Penrose matrix of \mathbf{H}_1 .

C. Differential Squirrel Search

The differential squirrel search (DSS) method was presented in 2021 [19]. This approach combines the differential evolution and the squirrel search algorithm. Originally, the squirrel's position is determined at random. Its fitness is measured by the fitness function and is similar to the quality of the food supply found by the squirrel at that place. Then, the best position \mathbf{PS}_{nt} is in the fitness values. We record the three best position values $\mathbf{PS}_{\text{at}}(1:3)$, the remaining locations $\mathbf{PS}_{\text{nt}}(1:\text{NP}-4)$ are believed to have yet to find any food sources. In the presence of a predator, squirrels shifted courses at random while foraging. Equation (6) depicts the revised locations of the squirrels on the acorn trees.

$$\mathbf{PS}_{\text{at}}^{\text{new}} = \begin{cases} \mathbf{PS}_{\text{at}}^{\text{old}} + d_g \cdot G_c (\mathbf{PS}_{\text{ht}}^{\text{old}} - \mathbf{PS}_{\text{at}}^{\text{old}} - P_{\text{avg}}), & r_1 \geq P_{\text{dp}} \\ \text{random position}, & \text{otherwise} \end{cases} \quad (6)$$

where d_g is the random gliding distance, P_{avg} is the average of all squirrels position, P_{dp} is the predator presence probability, G_c is the gliding constant.

The authors use the crossover method to increase the diversity of squirrels and avoid entering local minima, and Eq. (7) depicts its mathematical model.

$$\mathbf{PS}_{\text{at},j}^{\text{cr}} = \begin{cases} \mathbf{PS}_{\text{at},j}^{\text{new}}, & \text{if } (\text{rand}_j \leq \text{Cr}) \text{ or } j = j_{\text{rand}} \quad j = 1, 2, 3, \dots, D \\ \mathbf{PS}_{\text{at},j}^{\text{old}}, & \text{if } (\text{rand}_j > \text{Cr}) \text{ or } j \neq j_{\text{rand}} \quad i = 1, 2, 3, \dots, \text{NP} \end{cases} \quad (7)$$

where $\mathbf{PS}_{\text{at},j}^{\text{new}}$ and $\mathbf{PS}_{\text{at},j}^{\text{old}}$ are new and old positions, NP is the population size, $\mathbf{PS}_{\text{at},j}^{\text{cr}}$ is the positions of the squirrels after

crossover operation, D is the dimension of the problem, $j_{rand} \in [1, D]$ is a random value, $rand_j \in [0, 1]$, and $Cr=0.5$.

The position of the squirrels in the normal trees is updated as shown in Eq. (8).

$$PS_{nt}^{new} = \begin{cases} PS_{nt}^{old} + d_g \cdot G_c (PS_{at}^{old} - PS_{nt}^{old}), & r_2 \geq P_{dp} \\ \text{random position,} & \text{otherwise} \end{cases} \quad (8)$$

where $r_2 \in [0, 1]$ is a random number.

The new positions of the remaining squirrels are shown in Eq. (9).

$$PS_{nt}^{new} = \begin{cases} PS_{nt}^{old} + d_g \cdot G_c (PS_{ht}^{old} - PS_{nt}^{old}), & r_3 \geq P_{dp} \\ \text{random position} & \text{otherwise} \end{cases} \quad (9)$$

The Eq. (10) is the crossover algorithm.

$$PS_{nt,i,j}^{cr} = \begin{cases} PS_{nt,i,j}^{new}, & \text{if } (rand_j \leq Cr) \text{ or } j = j_{rand} & j = 1, 2, 3, \dots, D \\ PS_{nt,i,j}^{old}, & \text{if } (rand_j > Cr) \text{ or } j \neq j_{rand} & i = 1, 2, 3, \dots, NP \end{cases} \quad (10)$$

The new positions of the squirrels in the hickory trees are updated by Eq. (11).

$$PS_{ht}^{new} = PS_{ht}^{old} + d_g \cdot G_c (PS_{ht}^{old} - PS_{at}^{avg}) \quad (11)$$

D. Propose an Algorithm based on ELM and DSS

ELM uses a random method to initialize the parameters of the input layer and the hidden layer, and calculates the output weight through the Moore Penrose matrix. Since it does not need to iteratively update parameters, the running time of the model is greatly reduced, and it is an efficient neural network algorithm. However, due to the way of random input parameters, it will bring algorithm uncertainty, and the model cannot be guaranteed to be in the optimal state. Therefore, the input parameters need to be optimized to improve the accuracy and stability of the model. DSS has been proved to be an efficient optimization algorithm. Therefore, this study uses DSS algorithm to optimize the input parameters of ELM, and proposes an algorithm called DSS-ELM. The optimization process of the algorithm is shown in Fig. 1.

Algorithm 1: DSS-ELM algorithm

Random initialization parameters

for $i=1:Imax$

 Calculate the PS_{at} by Eqs. (6,7)

 Calculate the PS_{nt} by Eqs. (8,9,10)

 Calculate the PS_{ht} by Eq. (11)

 Update parameters.

end for

Output optimized w , and b of the RFRA.

III. RESULT

Survey data includes 378 rice farmers, rice farms, and rice farming cooperatives. For rice farmers, the labor force is

mainly family members. With rice farms, hired labor is the main source. Farmers still produce rice based on experience, and following habits, but most have had the support of local agricultural extension organizations in technical advice. However, focusing on convenience is still deeply rooted in households' awareness, and economic efficiency and productivity are not high. From there, it shows that individual rice-producing households still face many difficulties to increase rice productivity. With large-scale farms or cooperatives, the organization of production is quite modern with the application of many mechanized machines and basic technical staff.

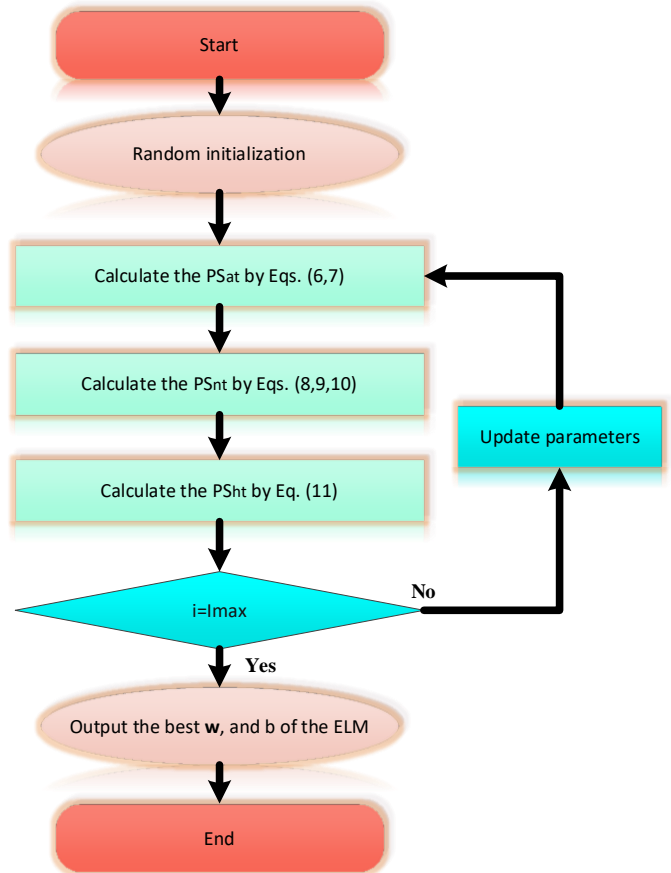


Fig. 1. DSS-ELM algorithm flowchart.

The data is divided into two classes. One class is the households that have achieved the desired yield after harvesting the rice and the other class is the households that have not achieved the desired yield. We randomly split it into a training set of 60% and a test set of 40%. Through the proposed algorithm, we build a training model to predict rice yield based on the input value chain. Fig. 2 shows the optimization process of the rice yield prediction model based on DSS-ELM. Here, we choose the number of iterations to be 100. We see that by the 15th iteration, the model has reached the maximum optimal level, the model converges quickly, and the error from 10% to 4%. Experimental results show that the DSS algorithm can optimize the model quickly, the model converges quickly and improves the classification ability. This result proves that DSS is an optimal algorithm with fast convergence speed, a good choice for parameter optimization

problems. Using DSS to optimize the parameters of the ELM algorithm helps to improve the prediction accuracy of ELM. From there, it gives reliable results and serves as a reference for researchers or experts, and managers in the rice industry.

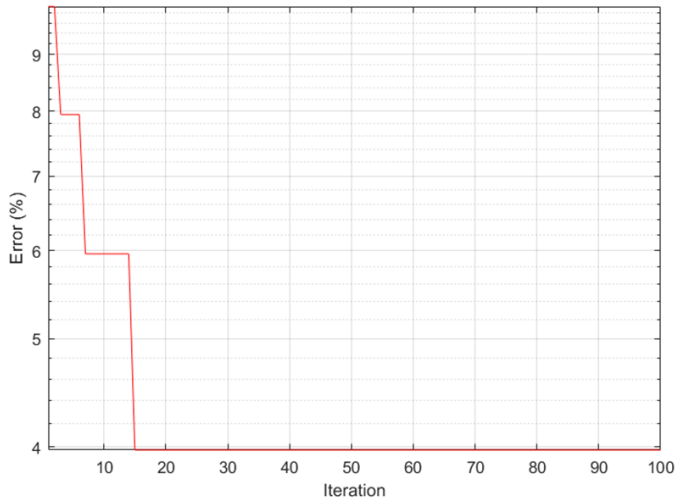


Fig. 2. Optimization process of DSS-ELM.

TABLE I. PREDICTION ACCURACY OF EACH CLASS

Class	Accuracy (%)
1	95.5
2	96.8
Overall	96.0

The two classes are labeled as 1 and 2. Table I is the accuracy of each class, the results show that the accuracy is high, with the accuracy of class 1 being 95.5%, and the accuracy of class 2 being 96.8% and the overall accuracy was 96%. Fig. 3 shows the difference between the samples of the two classes. We can see, the difference between the predicted number and the actual number is very small, only 6 out of 151 samples are wrong. From there, it shows that the model has good predictive results, and can predict well about rice yield based on input value chain data. This can be considered one of the important methods to support rice-growing households in choosing suitable inputs and orienting a particular rice-growing area. At the same time, it is also the basis for local authorities and managers to have specific orientations and directions to develop wet rice farming in Vietnam.

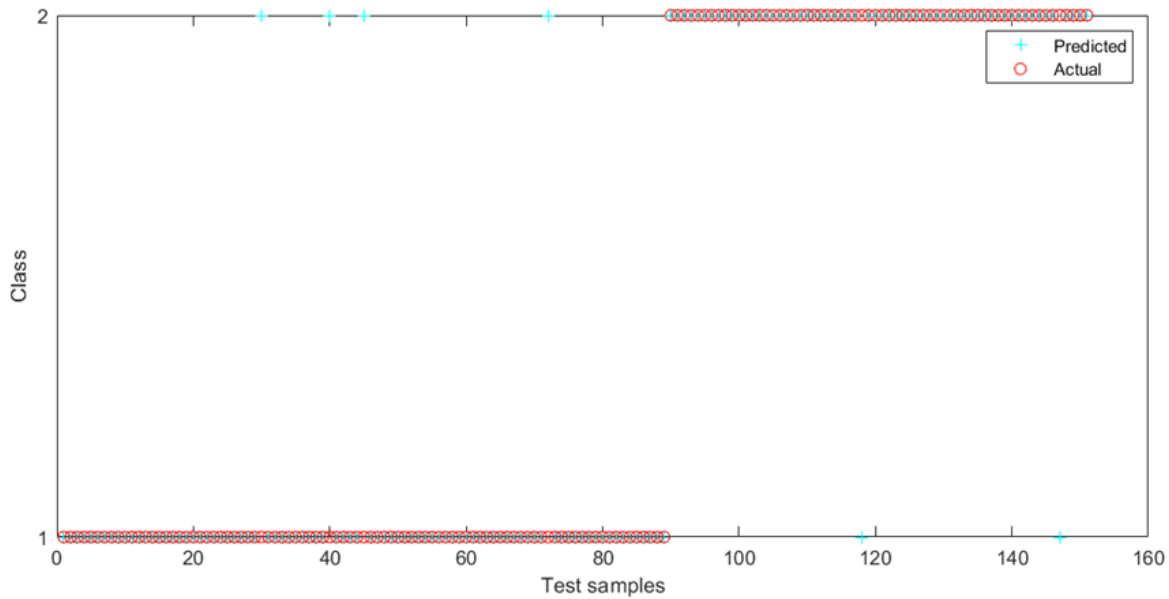


Fig. 3. Deviation between samples.

IV. DISCUSSION

A. Key Characteristics of Input Value Chains affecting Rice Yield

In this study, we take into account the characteristics affecting Vietnamese rice yield including soil quality, water source, seed supply, fertilizer supply, agricultural medicine supply, science and technology, access to credit, age of homeowners, number of years in occupation, and qualification of homeowners. The value chain of fertilizer supply, agricultural medicine supply, seed supply, and science and technology have a great influence on rice yield. They are also mentioned in studies around the world such as those of Amjath et al. [20], Darakeh et al. [21], and Katsu et al. [22].

For fertilizer supply, Vietnam is a country that actively produces fertilizers for agriculture, and becomes the main source of fertilizer for the rice industry. The main source of urea fertilizer supply is from enterprises such as Phu My fertilizer, Ca Mau protein, Ha Bac fertilizer, etc. The main source of phosphate fertilizer is the Lam Thao factory, and Long Thanh factory. In addition, there are a few enterprises producing and supplying organic and micro-organic fertilizers. However, the supply of fertilizer in Vietnam has not yet met the actual demand. According to recent statistics in three years, Vietnam imported 4.5 million tons of fertilizers of all kinds.

As for the supply of agro-pharmaceuticals, the market value of pesticides in Vietnam is about \$900 million, and the growth

rate is 6.8 %/year. There are more than 300 companies manufacturing and processing agro-pharmaceuticals in the whole country, but this number only meets 25% of the demand. The main supply comes from imports, and the supply from China accounts for 40% of the market share. Agro-pharmaceuticals are distributed through sales channels of enterprises and agents. The choice of agro-pharmaceuticals is usually based on self-drawing experiences and the introduction of neighboring households along with advertising information of agents. The capital for buying agricultural drugs is also limited, so it also greatly affects the yield of rice.

The supply of rice seeds is mainly through three main sources: farmers who self-seed, farmers who buy seeds from high-yielding fields, and farmers who buy seeds from seed centers. Farmers leave seeds for themselves, accounting for 10% of the number of seeds used, most of them are small production households, and do not accept large costs. Moreover, the seed dealers are quite difficult to reach. Seeds from high-yielding fields account for about 65%. The rest are people who buy seeds from seed centers across the country.

For technical-technological information sources, farmers associated with enterprises, enterprises are an important transfer channel in science and technology to rice growers through the regular organization of training sessions on the application of scientific and technical advances to production. For the remaining households, the source of access to science and technology mainly relies on pesticide companies, agricultural extension centers, and mass media.

B. Compare with other Models

Traditional methods commonly used to build models in economics include logistic regression (LR)[23], and support vector machine (SVM) [24][25]. In this study, we compare our proposed method with ELM, LR, and SVM methods. The comparison results are shown in Table II and Fig. 4. It can be seen that DSS-ELM has higher accuracy than other methods. Specifically, DSS-ELM is 6% higher than the ELM method, 4% higher than the SVM method, and 8.6% higher than the LR method. The LR and SVM algorithms use the Sigmoid function as a non-linear factor, thereby performing the classification problem. The ELM algorithm uses a neural network that simulates the human nervous system, through random weights and bias values, and then relies on the Moore-Penrose matrix to calculate the output weights. In this study, we use the swarm intelligence optimization method combined with the random parameters of ELM to conduct parameter optimization, thereby increasing the predictive ability of the algorithm. The results of the experiment proved that our proposal is accurate, and suitable for the problem of predicting rice yield in Vietnam based on the input value chain.

TABLE II. ACCURACY OF THE MODELS

Models	Overall accuracy (%)
LR	87.4
SVM	92.1
ELM	90.0
DSS-ELM (This study)	96.0

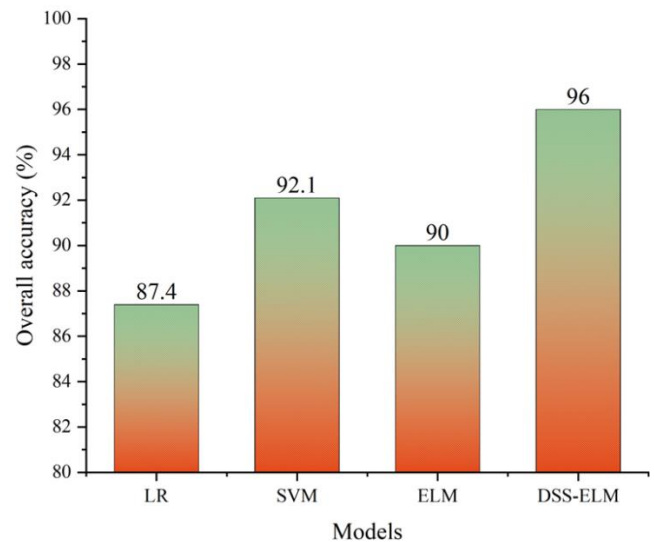


Fig. 4. Results of comparing the accuracy of the methods.

V. CONCLUSION

This study proposes a method to predict the effect of rice yield based on the input value chain and machine learning algorithm. The data surveyed by the research team from rice-growing households. The results show that the model has good predictive ability about the influence of the input value chain on rice yield. Our proposed method is also more accurate than methods such as ELM, SVM, and LR. This is the basis for management levels to have orientation on the input supply value chain for Vietnamese rice.

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REFERENCES

- [1] Kano, L., Tsang, E. W., & Yeung, H. W. C. (2020). Global value chains: A review of the multi-disciplinary literature. *Journal of international business studies*, 51, 577-622.
- [2] Nguyen, T. A. T., & Jolly, C. M. (2020). Global value chain and food safety and quality standards of Vietnam pangasius exports. *Aquaculture reports*, 16, 100256.
- [3] Dang-Xuan, S., Nguyen-Viet, H., Pham-Duc, P., Unger, F., Tran-Thi, N., Grace, D., & Makita, K. (2019). Risk factors associated with *Salmonella* spp. prevalence along smallholder pig value chains in Vietnam. *International journal of food microbiology*, 290, 105-115.
- [4] Vu, N. H., Bui, T. A., Hoang, T. B., & Pham, H. M. (2022). Information technology adoption and integration into global value chains: Evidence from small-and medium-sized enterprises in Vietnam. *Journal of International Development*, 34(2), 259-286.
- [5] <https://www.fao.org/home/en>.
- [6] My, N. H., Demont, M., Van Loo, E. J., de Guia, A., Rutsaert, P., Tuan, T. H., & Verbeke, W. (2018). What is the value of sustainably-produced rice? Consumer evidence from experimental auctions in Vietnam. *Food Policy*, 79, 283-296.
- [7] Reardon, T., Chen, K. Z., Minten, B., Adriano, L., Dao, T. A., Wang, J., & Gupta, S. D. (2014). The quiet revolution in Asia's rice value chains. *Annals of the New York Academy of Sciences*, 1331(1), 106-118.

- [8] Dauvergne, P. (2022). Is artificial intelligence greening global supply chains? Exposing the political economy of environmental costs. *Review of International Political Economy*, 29(3), 696-718.
- [9] Vinuesa, R., Azizpour, H., Leite, I., Balaam, M., Dignum, V., Domisch, S., ... & Fuso Nerini, F. (2020). The role of artificial intelligence in achieving the Sustainable Development Goals. *Nature communications*, 11(1), 233.
- [10] Boustani, N. M. (2022). Artificial intelligence impact on banks clients and employees in an Asian developing country. *Journal of Asia Business Studies*, 16(2), 267-278.
- [11] Valentin, J., Reutterer, T., Platzer, M., & Kalcher, K. (2022). Customer base analysis with recurrent neural networks. *International Journal of Research in Marketing*, 39(4), 988-1018.
- [12] Chen, M., Liu, Q., Huang, S., & Dang, C. (2022). Environmental cost control system of manufacturing enterprises using artificial intelligence based on value chain of circular economy. *Enterprise Information Systems*, 16(8-9), 1856422.
- [13] Liu, Y., & Song, P. (2022). Creating Sustainable Cultural Industries: The Perspective of Artificial Intelligence and Global Value Chain. *Journal of Environmental and Public Health*, 2022.
- [14] Liu, S., & Liu, F. (2022, September). Research on economic risk model of global value chain based on Artificial Intelligence. In *2022 2nd International Conference on Computer Science, Electronic Information Engineering and Intelligent Control Technology (CEI)* (pp. 705-708). IEEE.
- [15] Van Gassen, S., Gaudilliere, B., Angst, M. S., Saeys, Y., & Aghaeepour, N. (2020). CytoNorm: a normalization algorithm for cytometry data. *Cytometry Part A*, 97(3), 268-278.
- [16] Huang, G., Huang, G. B., Song, S., & You, K. (2015). Trends in extreme learning machines: A review. *Neural Networks*, 61, 32-48.
- [17] Zhang, G., Li, Y., Cui, D., Mao, S., & Huang, G. B. (2020). R-ELMNet: Regularized extreme learning machine network. *Neural Networks*, 130, 49-59.
- [18] Qing, Y., Zeng, Y., Li, Y., & Huang, G. B. (2020). Deep and wide feature based extreme learning machine for image classification. *Neurocomputing*, 412, 426-436.
- [19] Jena, B., Naik, M. K., Wunnava, A., & Panda, R. (2021). A Differential Squirrel Search Algorithm. In *Advances in Intelligent Computing and Communication* (pp. 143-152). Springer, Singapore.
- [20] Amjath-Babu, T. S., Krupnik, T. J., Thilsted, S. H., & McDonald, A. J. (2020). Key indicators for monitoring food system disruptions caused by the COVID-19 pandemic: Insights from Bangladesh towards effective response. *Food security*, 12(4), 761-768.
- [21] Darakeh, S. A. S. S., Weisany, W., Diyanat, M., & Ebrahimi, R. (2021). Bio-organic fertilizers induce biochemical changes and affect seed oil fatty acids composition in black cumin (*Nigella sativa* Linn). *Industrial Crops and Products*, 164, 113383.
- [22] Katsu, Y., Kato, K., Abe, S., & Miyazawa, K. (2021). Seed source effects on germination, growth, and yield of carrots under natural farming. *Journal of Horticultural Research*, 29(2), 117-126.
- [23] Zhu, Y., Xie, C., Sun, B., Wang, G. J., & Yan, X. G. (2016). Predicting China's SME credit risk in supply chain financing by logistic regression, artificial neural network and hybrid models. *Sustainability*, 8(5), 433.
- [24] Zhang, H., Shi, Y., Yang, X., & Zhou, R. (2021). A firefly algorithm modified support vector machine for the credit risk assessment of supply chain finance. *Research in International Business and Finance*, 58, 101482.
- [25] Liu, Y., & Huang, L. (2020). Supply chain finance credit risk assessment using support vector machine-based ensemble improved with noise elimination. *International Journal of Distributed Sensor Networks*, 16(1), 1550147720903631.

Cybersecurity in Healthcare: A Review of Recent Attacks and Mitigation Strategies

Elham Abdullah Al-Qarni

Department of Computing and Information Technology
University of Bisha
Bisha-Saudi Arabia

Abstract—Cyberattacks on several businesses, including those in the healthcare, finance, and industrial sectors, have significantly increased in recent years. Due to inadequate security measures, antiquated practices, and sensitive data, including usernames, passwords, and medical records, the healthcare sector has emerged as a top target for cybercriminals. Cybersecurity has not gotten enough attention in the healthcare sector, despite being crucial for patient safety and a hospital's reputation. In order to prevent data breaches that could jeopardize the privacy of patients' information, hospitals must deploy the proper IT security measures. This research article reviews many scholarly publications that look at ransomware attacks and other cyberattacks on hospitals between 2014 and 2020. The report summarizes the most recent defensive measures put forth in scholarly works that can be used in the healthcare industry. Additionally, the report provides a general review of the effects of cyberattacks and the steps hospitals have taken to manage and recover from these disasters. The study shows that cyberattacks on hospitals have serious repercussions and emphasizes the significance of giving cybersecurity a priority in the healthcare sector. To combat cyberattacks, hospitals must have clear policies and backup plans, constantly upgrade their systems, and instruct employees on how to spot and handle online threats. The article comes to the conclusion that putting in place suitable cybersecurity safeguards can reduce the harm brought on by system failures, reputational damage, and other associated problems.

Keywords—Cybersecurity; healthcare industry; malware; ransomware; DoS; DDoS

I. INTRODUCTION

The healthcare sector is very concerned about security, especially on the internet, where cyberattacks are becoming more common and sophisticated. Access control violations, assaults that inject and execute malware, and denial of service (DoS) attacks are some of the most frequent threats to healthcare security. In contrast to Distributed Denial of Service (DDoS) assaults, which employ numerous hosts to attack a system, DoS attacks include a single source that floods the target system with requests. This makes it difficult to pinpoint the attack's origin. Patients may suffer as a result

of these attacks, and healthcare organizations may suffer reputational damage [1].

Another major threat to the healthcare sector is malware, which virtually always comes in new varieties. Ransomware is one malware family that healthcare institutions are becoming worried about. Ransomware was listed second on a list of cybersecurity dangers to healthcare companies in a poll by the Healthcare Information and Management Systems Society (HIMSS), with 17% of respondents reporting having been the victim of a ransomware attack [2].

Healthcare businesses have been the subject of several high-profile cyberattacks in recent years. For instance, a ransomware assault that affected the Irish Health Service Executive (HSE) in 2021 severely disrupted healthcare services [3]. Similar to this, over 150 nations were impacted by the WannaCry ransomware assault in 2017, which forced the UK's National Health Service (NHS) to reschedule procedures and cancel appointments [4].

Healthcare institutions must put robust cybersecurity safeguards in place to stop cyberattacks and safeguard sensitive patient data. Many healthcare institutions, however, continue to lack adequate security protocols, leaving them open to intrusions. Only 44% of healthcare businesses, according to a study by the Ponemon Institute, have a thorough security policy in place [5].

Based on responses from 167 healthcare cybersecurity specialists, Fig. 1 shows the survey's ranking of cyberattacks in 2021. The author's method involved doing a content assessment of scientific papers from 2014 to 2020 that discussed malware, DoS, and social engineering attacks on hospitals.

There are five sections in the paper. Hospitals that experienced cyberattacks from 2014 to 2020 are covered in Section II. Hospitals can apply the measures discussed in Section III to lessen or prevent a cyberattack. Results and discussion are presented in Section IV, and the paper is wrapped up in Section V.

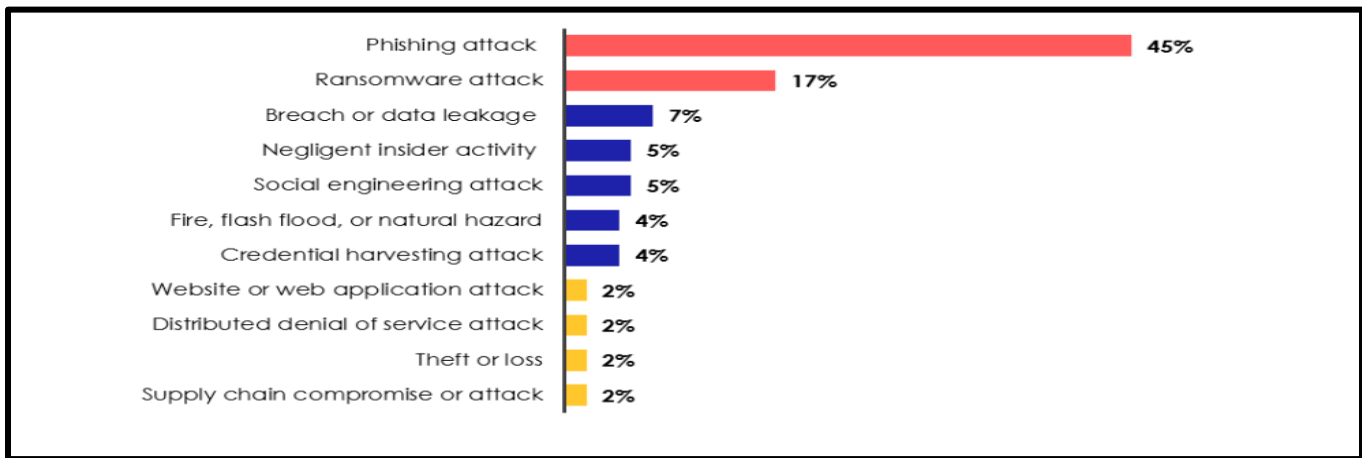


Fig. 1. A list of the most significant cyberattacks for 2021 [2].

II. CYBERSECURITY IN HEALTHCARE SYSTEMS

In this section, we'll talk about a number of hospitals that experienced cyberattacks, the steps we took to deal with the situation, and the effects of the attacks.

Table I gives a summary of cyberattacks on hospitals, including ransomware and distributed denial of service (DDoS), as well as the results. For instance, on March 20, 2014, a DDoS attack targeted Boston Hospital, causing a network outage that lasted two weeks and adversely disrupting hospital operations. In 2016, ransomware that used social engineering techniques struck Lukas Hospital and Hollywood Presbyterian Medical, disrupting the systems and making patient data unusable. In 2020, ransomware attacks affected three hospitals, one each in the Czech Republic, the United States, and London. Boston Children's Hospital had the longest attack duration, lasting 14 days, while Champaign-Urbana Public Health District had the shortest, lasting only four days.

The table shows that the effects are harsh regardless of the attack strategies and tactics used by cybercriminals. Therefore, if cybersecurity was given top priority in the healthcare sector, system failures, reputational damage, and other related problems might be lessened.

Table II lists the methods that hackers use to attack the healthcare sector as well as the defenses used by hospitals to fend against and recover from attacks. All of these institutions, which were targets of various cyberattacks, including those at Boston Hospital, Lukas Hospital, Brno Hospital, and Hancock Hospital, followed the same course of action: they shut down their systems to limit the harm. The table demonstrates that hospitals did not have defined strategies or backup plans to deal with intrusions, demonstrating a disregard for cybersecurity. For instance, Brno Hospital continued to run Windows XP into 2020. This emphasizes how important it is for healthcare businesses to address cybersecurity and implement preventative steps to lessen and eliminate online dangers.

Information on the ransom payments made by hospitals to hackers to recover access to their systems is shown in Table

III. In comparison to attempting to restore compromised information technology systems without the decryption key needed to remove the infection, paying the ransom may be less detrimental to operations and profit margins. Boston Hospital spent the most to restore its systems, close to \$600,000, and Champaign-Urbana Public Health District spent the second-most, \$350,000. The least amount was paid by Hollywood Presbyterian Medical, at \$17,000. Although paying a ransom may incur financial costs, it is preferable to endangering lives, tarnishing one's image, or disclosing private information. Hospitals should put patients' safety first, even if doing so would inspire hackers to undertake additional cyberattacks. It is crucial that hospitals.

Fig. 2 illustrates how cyberattacks are divided into three distinct attack categories.

1) *Injection attack*: A web application may be "injected" with malicious data by an attacker, affecting the way it operates by directing it to execute certain commands. Injection is one of the early varieties of web-based attacks. Malware is an illustration of an injection attack. According to [6], malware is any computer code written with the purpose of gaining unauthorized access to digital devices and IT infrastructures. This is done by breaching the security measures protecting them and taking advantage of security flaws. Three distinct malware subtypes were discernible:

a) *SamSam*: Initially appearing in late 2015, a ransomware malware, primarily targets the healthcare sector. SamSam specializes in using RDP, FTP, and Java-based web server vulnerabilities to access the victims' machines [7].

b) *Locky*: It is a ransomware family that uses a hybrid cryptosystem and was launched in 2016. Its mechanism of operation involves scanning the victim's drives, such as network drives, for particular file types to encrypt them using RSA and AES [8].

c) *Netwalker*: Also known as Mailto, is a type of attack where the attacker uses the victim's network to encrypt all Windows-based devices. The attacker can use either phishing emails or executable files that travel throughout networks to carry out his attack [9].

TABLE I. EXAMPLE OF HOSPITALS EXPOSED TO CYBER-ATTACKS

Targeted system/ Region, Year	Cyber Attack Category	Result	Source
Boston Children's Hospital/ Boston, 2014	DDoS	For a period of two weeks, the hospital's network was inactive, seriously disrupting everyday operations and leading to the closure of the fundraising website.	[21]
Lukas Hospital/ Germany, 2016	Social engineering & Malware	High-risk surgeries were postponed by the hospital while they evaluated and sanitized their infected servers and computer systems.	[19] & [21]
Hancock regional hospital/ United States, 2018	Malware (SamSam)	The backup files are permanently destroyed.	[19]
Hollywood Presbyterian Medical Center/ Los Angeles, 2016	Malware (Locky) & phishing	Staff employees were unable to access patient information, X-rays, and other devices during the attack and were unable to use backup systems to restore the data.	[22]
Champaign-Urbana Public Health District/ United States, 2020	Malware (NetWalker)	In order to provide updates on COVID-19, the organization blocked its website and used its Facebook page instead.	[27]
Brno University Hospital/ Czech Republic, 2020	Ransomware	The hospital's IT network was completely shut down as a result of a significant service disruption, preventing personnel from accessing patient records, X-rays, and other devices. Handwritten notes and transfer procedures had to be used by the hospital, which may have compromised patient safety and slowed down operations. Two further hospital departments had to be shut down as a result, including the motherhood department and the children's hospital.	[17]
Hammersmith Medicines Study/ London, 2020	Ransomware	Birth dates, insurance numbers, and passport information were among the many private details stolen from patient records.	[17]

TABLE II. METHODS OF CYBER-ATTACK ON HOSPITALS AND RESPONSES TO CYBERATTACKS

Hospital	Attack method	Response	Source
Boston Children's Hospital	The hospital network was targeted by hackers who attempted to breach it by focusing on "exposed ports and services," as well as launching a phishing email campaign that specifically targeted hospital employees.	The hospital took the measure of stopping all web-facing programs, including email services, to effectively close all firewall entry points and prevent staff members from accidentally clicking on a malicious link.	[18]
Lukas Hospital	Technique for social engineering	All systems have been turned off. Backups were used to restore systems.	[19] & [20]
Hancock regional hospital	The hackers utilized the Microsoft Remote Desktop Protocol to infiltrate the administrative account of a hardware vendor.	Turn off all desktop and network systems.	[19]
Hollywood Presbyterian Medical	NAN	Pay a ransom	[20]
Champaign-Urbana Public Health District	NAN	Employees exchanged information using their systems and networks.	[23]
Brno University Hospital	Exploiting vulnerability in the WindowsXP operating system.	Shut down the entire information technology network	[17]
Hammersmith Medicines Study	Use of the ransomware-as-a-service model.	NAN	[17]

TABLE III. AMOUNTS PAID BY HOSPITALS TO RESTORE THEIR SYSTEMS

Hospital	Financial Cost	Source
Boston Children's Hospital	\$300,000 - \$600,000	[18] & [24]
Hancock regional Hospital	\$50,000	[25]
Hollywood Presbyterian Medical	\$17,000	[20]
Champaign-Urbana Public Health District	\$350,000	[26]
Hammersmith Medicines Study	No ransom was paid	[17] & [27]

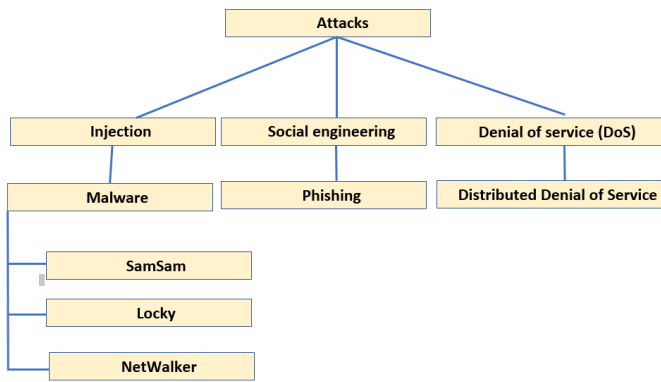


Fig. 2. Cybersecurity attacks classification.

2) Social engineering: It is a method where an attacker uses interpersonal interactions to prey on psychological flaws in the victim to persuade them to divulge critical information to the attacker [10]. Phishing is a type of social engineering that hackers employ to trick their victims into divulging sensitive information like usernames, passwords, bank account details, etc. This is accomplished by tricking the user into clicking on a link to a false website or downloading a malicious program.

3) Denial of service attack: It is a type of cyberattack that mostly focuses on consuming resources, including memory or computing power. Both wireless and cable connections can be used to carry out this assault [11]. A particular kind of DoS assault that targets websites is known as a distributed denial-of-service attack. To assault a single victim, an attacker uses malicious script that has been placed on several other computers. The website is intended to become inoperable [12].

III. MITIGATION STRATEGIES

As indicated in Fig. 3, we will cover risk classifications and the most recent techniques hospitals can use to lessen the effects of cyberattacks in this section.

According to [13], risk is the potential for loss or harm if an attacker exploits a security hole. An operational risk associated with online activities that threatens information assets, resources for information and communication technology, and technological assets and may cause material damage to an organization's tangible and intangible assets, business interruption, or reputational harm is another comprehensive definition of cybersecurity risk [14]. Risk reduction and risk avoidance are two alternatives provided by risk mitigation strategies. Preventative measures are used in mitigation strategies to lessen the possibility or impact of a cyberattack. These tactics are focused on locating and addressing any weak spots and security risks in the organization's rules and information. Risk-mitigation measures can include putting in place infiltration detection systems and protection barriers, as well as updating software and hardware often and training staff on best practices for cyber security.

A. A Proactive Incident Response (IR)

Planning and preparation, detection, analysis, and evaluation, containment and eradication, recovery, and post-incident activities are the six steps that make up this procedure. The firm must first establish its security policy and incident response capability. This involves putting together a team to manage incidents and acquiring the necessary tools and supplies. In the second stage, an event is automatically detected using tools like network- or host-based intrusion detection systems or manually using manual requirements like alerting users to problems. In the third stage following the incident, the incident response team analyzes and verifies the incident. Implementation of containment strategies, such as sandboxing, occurs in the fourth stage. In stage five, the administrator will check that the systems are operating normally and correct any issues to prevent future occurrences. After an incident, a meeting should be held as the final step. The purpose of this meeting is to advance technology and gain knowledge [15].

B. Secure Architecture based on Blockchain Technology and Artificial Intelligence

Five layers make up the suggested architecture for a safe system based on artificial intelligence and blockchain technology. The first layer, referred to as the "data layer, gathers information from patient sensors, including temperature and heartbeat. Additionally, malware samples are gathered in this layer and sent to the malware analysis layer. Tools like Pestudio and Process Explorer are used in the second layer, known as malware analysis, to examine the malware. The second layer's harmless samples are included in the third layer's intelligence, which checks them for security flaws using artificial intelligence techniques like support vector machines (SVM) and random forests (RF). Data transferred from Layer 3 is safely stored in Layer 4, the Blockchain layer. Hospitals, pharmacies, laboratories, and ambulances are examples of healthcare data recipients at the applications layer (layer three) [16].

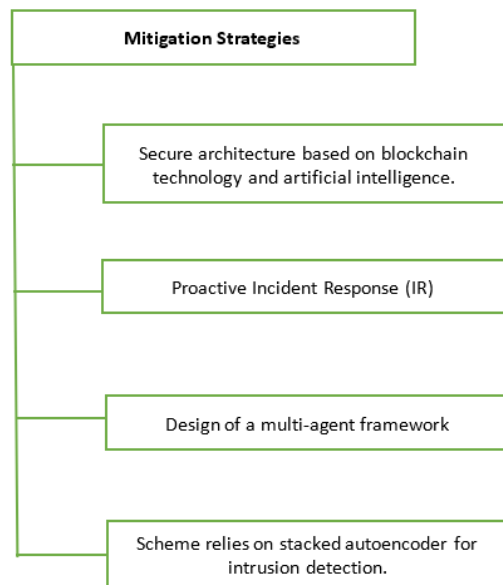


Fig. 3. Proposed strategies to mitigate cyber-attacks.

C. Design of a Multi-Agent Framework

The framework is created in two steps. First, five system agents need to be made. Patient, nurse, doctor, ambient, and database agents. The next step is to provide a tiered architecture that classifies agents according to their data storage and power capabilities. The wireless sensor network platform was utilized in this framework [16].

D. Scheme Relies on Stacked Autoencoder for Intrusion Detection

Scheme's framework for intrusion detection uses stacked autoencoders. Data pre-processing, feature extraction, and intrusion behavior determination make up the method's three steps. Infiltration behavior is defined at the Data Pre-Processing phase. A stacked autoencoder is used in the feature extraction stage to get parameter weights for various features. The XGBoost algorithm is used in the Intrusion Behavior Determination stage to determine if a behavior is normal or intrusive.

IV. RESULTS AND DISCUSSION

As healthcare companies become more popular targets for hackers, cyberattacks against hospitals are on the rise, according to the evaluation of scholarly articles done for this research paper. Because of its outmoded practices, weak security measures, and sensitive data, the healthcare sector is a prime target for hackers. These attacks can have serious effects, including harm to patients, harm to the reputation of healthcare organizations, and monetary losses.

The study also outlines a number of research papers' protection against cyberattacks and solutions that healthcare institutions might use. These tactics comprise staff training, routine system updates, and the application of cutting-edge security tools like intrusion detection systems and firewalls. According to the study, hospitals should prioritize cybersecurity and have detailed strategies and backup plans to deal with intrusions.

Hospitals are vulnerable to attacks because of insufficient security standards, according to the assessment of scholarly studies. The majority of healthcare firms do not have a thorough security strategy, which shows a disregard for cybersecurity. The study recommends that healthcare institutions take proactive steps to safeguard sensitive patient data and lessen the effects of system errors, reputational damage, and other related problems.

V. CONCLUSIONS AND FUTURE WORKS

This study concludes by emphasizing the urgent necessity for healthcare institutions to address cybersecurity in order to prevent data breaches that could jeopardize patient information. Hospital cyberattacks can have serious repercussions, so healthcare companies need to create clear policies and backup plans to cope with these situations. The report provides a summary of hospital cyberattacks from 2014 through 2020, including ransomware assaults, and offers many tactics hospitals might employ to lessen or prevent a hack.

Future studies can concentrate on creating innovative techniques and tools to defend healthcare companies against

cyberattacks. For instance, research may look into how to employ machine learning and artificial intelligence to detect and stop cyberattacks on hospitals. Additionally, studies might look into how cyberattacks affect patient security and consider the moral ramifications of data breaches in the healthcare sector.

Overall, the importance of cybersecurity in the healthcare sector is highlighted in this research study, and healthcare companies must take proactive steps to safeguard sensitive patient data. Healthcare institutions must emphasize cybersecurity given the increase in cyberattacks on hospitals in order to limit losses from system failures, reputational damage, and other associated problems.

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REFERENCES

- [1] Mirkovic, J., & Reiher, P. (2004). A taxonomy of DDoS attack and DDoS defense mechanisms. *ACM SIGCOMM Computer Communication Review*, 34(2), 39-53.
- [2] Healthcare Information and Management Systems Society, "2021 HIMSS Healthcare Cybersecurity Survey Report," 2022. [Online]. Available: <https://www.himss.org/resources/2021-himss-healthcare-cybersecurity-survey-report>. [Accessed: 18-Apr-2023].
- [3] M. O'Brien, "Ireland's Health Service Executive hit by ransomware attack," *The Guardian*, 14 May 2021. [Online]. Available: <https://www.theguardian.com/world/2021/may/14/irelands-health-service-executive-hit-by-ransomware-attack>. [Accessed: 18-Apr-2023].
- [4] A. Osborn, "NHS cyber-attack: GPs and hospitals hit by ransomware," *BBC News*, 12 May 2017. [Online]. Available: <https://www.bbc.com/news/health-39899646>. [Accessed: 18-Apr-2023].
- [5] Ponemon Institute, "Sixth Annual Benchmark Study on Privacy & Security of Healthcare Data," 2016. [Online]. Available: <https://www.ponemon.org/library/2016-ponemon-institute-benchmark-study-on-privacy-security-of-healthcare-data>. [Accessed: 18-Apr-2023].
- [6] M. Ashawa and T. Morris, "Understanding and Mitigating Malware Attacks," in *Proceedings of the 11th International Conference on Cyber Warfare and Security (ICWS 2019)*, vol. 1, pp. 1-10, 2019.
- [7] V. Arora, A. Varshney, A. Arora, and N. Shukla, "Assessment of SamSam Ransomware Attack on Healthcare Sector and Way Forward," *Journal of Information Privacy and Security*, vol. 15, no. 1, pp. 1-12, 2019.
- [8] S. Almashhadani, T. Almarshad, and A. Al-Salman, "Ransomware: The Past, Present, and Future," in *Proceedings of the 3rd International Conference on Computer Applications & Information Security (ICCAIS 2019)*, vol. 1, pp. 1-6, 2019.
- [9] Gómez-Hernández, J. A., García-Teodoro, P., & Díaz-Verdejo, J. E. (2022). Analysis of Netwalker Ransomware: Detection, Prevention and Recovery. *Computers & Security*, 106, 102556.
- [10] W. Wang, Y. Zeng, X. Zhang, X. Xu, Y. Xiang and X. Shen, "A Survey on Social Engineering Attacks and Defenses in Online Social Networks," in *IEEE Communications Surveys & Tutorials*, vol. 22, no. 2, pp. 1342-1372, Secondquarter 2020, doi: 10.1109/COMST.2020.2974247.
- [11] Singh, R., Singh, S., & Saini, D. (2019). Denial of Service Attacks: Impact, Detection, and Mitigation Techniques. *Journal of Network and Computer Applications*, 135, 62-80. <https://doi.org/10.1016/j.jnca.2019.02.015>.
- [12] Singh, A., Kumar, A., & Tyagi, S. (2020). A Comparative Analysis of Detection and Mitigation Techniques against Distributed Denial of Service Attacks. In *Proceedings of the International Conference on Smart Technologies in Computing and Communication* (pp. 259-269).

- Springer.
- [13] Kandasamy, P., Perumal, M., & Naresh, R. (2022). Cybersecurity Risks and Their Mitigation Strategies for Healthcare Industry. In *Cybersecurity and Privacy Issues in Industry 4.0* (pp. 19-37). Springer, Singapore.
- [14] Strupczewski, A. (2021). Cybersecurity Risk Management in the Healthcare Industry. In *Handbook of Research on Information Security and Cyber Threats in the Fourth Industrial Revolution* (pp. 103-116). IGI Global.
- [15] Y. He, X. Lu, Y. Yao, W. Zhang and W. Tang, "A Cyber Security Incident Response System with Automated Forensics and Orchestration," in *IEEE Access*, vol. 10, pp. 113773-113786, 2022, doi: 10.1109/ACCESS.2022.3140703.
- [16] Alabdulatif, A., Ahmad, A., Khan, M. K., Azeem, A., Al-Khateeb, A., & Al-Salman, A. (2022). A secure architecture based on blockchain technology and artificial intelligence for healthcare applications. *Future Generation Computer Systems*, 127, 487-495. <https://doi.org/10.1016/j.future.2021.09.0>.
- [17] Ramadan, R. A., Aboshosha, B. W., Alshudukhi, J. S., Alzahrani, A. J., El-Sayed, A., & Dessouky, M. M. (2021). Cybersecurity and Countermeasures at the Time of Pandemic. *Journal of Advanced Transportation*, 2021, 1-19. doi: 10.1155/2021/6627264.
- [18] Wilner, A. S., Luce, H., Ouellet, E., Williams, O., & Costa, N. (2021). From public health to cyber hygiene: Cybersecurity and Canada's healthcare sector. *International Journal: Canada's Journal of Global Policy Analysis*, 76(4), 522-543. doi: 10.1177/002070202111067946.
- [19] Argaw, S. T., Troncoso-Pastoriza, J. R., Lacey, D., Florin, M.-V., Calcavecchia, F., Anderson, D., Burleson, W., Vogel, J.-M., O'Leary, C., Eshaya-Chauvin, B., & Flahault, A. (2020). Cybersecurity of Hospitals: Discussing the challenges and working towards mitigating the risks. *BMC Medical Informatics and Decision Making*, 20(1), 146. doi: 10.1186/s12911-020-01161-7.
- [20] Paul III, D. P., Spence, N., Bhardwa, N., & PH, C. D. (2018). Healthcare facilities: another target for ransomware attacks.
- [21] Cox, J. (2018, January 19). The Cyber Attack—From the POV of the CEO. *Hancock Regional Hospital*. <https://www.hancockregionalhospital.org/2018/01/cyber-attack-pov-ceo/>
- [22] Coventry, L., & Branley, D. (2018). Cybersecurity in healthcare: A narrative review of trends, threats and ways forward. *Maturitas*, 113, 48-52. doi: 10.1016/j.maturitas.2018.04.008.
- [23] Saleous, H., Ismail, M., AlDaajeh, S. H., Madathil, N., Alrabae, S., Choo, K.-K. R., & Al-Qirim, N. (2022). COVID-19 pandemic and the cyberthreat landscape: Research challenges and opportunities. *Digital Communications and Networks*, S2352864822001274. doi: 10.1016/j.dcan.2022.06.005.
- [24] Ghayoomi, H., Laskey, K., Miller-Hooks, E., Hooks, C., & Tariverdi, M. (2021). Assessing resilience of hospitals to cyberattack. *DIGITAL HEALTH*, 7, 2055207621105936. <https://doi.org/10.1177/20552076211059366>.
- [25] Burrell, D. N., Aridi, A. S., McLester, Q., Shufutinsky, A., Nobles, C., Dawson, M., & Muller, S. R. (2021). Exploring System Thinking Leadership Approaches to the Healthcare Cybersecurity Environment. *International Journal of Extreme Automation and Connectivity in Healthcare (IJEACH)*, 3(2), 20-32. <https://doi.org/10.4018/IJEACH.2021070103>.
- [26] Strasburg, J., & Hinshaw, D. (2020). Cybercriminals Sweep In to Take Advantage of Coronavirus. *The Wall Street Journal*, 24.
- [27] Mahadevan, P. (2020). Cybercrime Threats during the COVID-19 pandemic. *Global Initiative Against Transnational Organized Crime*, Switzerland.

Deep Feature Detection Approach for COVID-19 Classification based on X-ray Images

Ayman Noor¹, Priyadarshini Pattanaik², Mohammed Zubair Khan³, Waseem Alromema⁴, Talal H. Noor⁵

College of Computer Science and Engineering, Taibah University, Madinah, Saudi Arabia¹

Department of Computer Science & Engineering-School of Engineering and Technology (SET), Sharda University²

Department of Computer Science and Information, Taibah University, Medina 42353, Saudi Arabia^{3,4}

College of Computer Science and Engineering, Taibah University, Yanbu, Madinah, Saudi Arabia⁵

Abstract—The novel human Corona disease (COVID-19) is a pulmonary sickness brought on by an extraordinarily outrageous respiratory condition crown 2. (SARS -CoV-2). Chest radiography imaging has a significant role in the screening, early diagnosis, and follow-up of the suspected individuals due to the effects of COVID-19 on pneumonic-sensitive tissue. It also has a severe impact on the economy as a whole. If positive patients are identified early, the spread of the pandemic illness can be slowed. To determine whether people are at risk for illnesses, a COVID-19 infection prediction is critical. This paper categorizes chest CT samples of COVID-19 affected patients. The two-stage proposed deep learning technique produces spatial function from images, so it is a very expeditious manner for image category hassle. Extensive experiments are drawn by considering the benchmark chest-Computed Tomography (chest-CT) image datasets. Comparative evaluation reveals that our proposed method outperforms amongst other 20 different existing pre-trained models. The test outcomes constitute that our proposed model achieved the best rating of 97.6%, 0.964, 0.964, and 0.982 concerning the accuracy, precision, recall, specificity, and F1-score, respectively.

Keywords—COVID-19; coronavirus; deep learning; classification; chest X-ray images; DenseNet-121; XG-Boost classifier; EfficientNet-B0

I. INTRODUCTION

COVID-19 has become a global health emergency of concern since it was first identified in December 2019. It is generating unheard-of societal and economic devastation. According to the WHO report, by March 29, 2021, there were 126,890,643 afflicted people worldwide, 2,778,619 of whom passed away. There is a severe scarcity of medical resources as a result of the global COVID-19 pandemic, which has put tremendous strain on healthcare institutions. Coronavirus pneumonia has been known as COVID-19 since its discovery, and it is both exceedingly contagious and harmful [1][2]. Pneumonia could arise if the signs get worse. Major health problems and the failure of numerous organs may ensue from this. Additionally, the patient is at risk of getting severe pneumonia. Medical practitioners, governments, organizations, and nations from all over the world face significant difficulty in trying to diagnose people with COVID-19 as soon as possible. Even though immunological testing is generally accessible, COVID-19 is frequently identified via RT-PCR, or Real-Time Polymerase Chain reaction (rt Chain Reaction). Images of patients' lungs can be used to detect the harmful effects of

COVID-19 and ensure prompt treatment rather than depending on RT-PCR, which has a low susceptibility (60-70%) and is also a time-consuming procedure. When providing care for patients who have COVID-19, it is imperative to closely observe how a patient's status evolves. When used in conjunction with additional diagnostic testing, medical imaging techniques like Computed Tomography (CT) and chest X-rays can be used to monitor the patient's progress and confirm the diagnosis of COVID-19 pneumonia. These images demonstrate the rapid onset of ground-glass opacities following the onset of COVID-19 symptoms.

Artificial Intelligence (AI) is broad term for several methods intended to simulate human thought and behavior (AI). The development of methods that enable powerful computers to recognize complex patterns and connections in empirical data is the focus of a branch of artificial intelligence known as "Machine Learning" (ML) [4]. To acquire greater power and flexibility, Deep Learning (DL) draws inspiration from biological neural networks. In contrast to typical ML approaches [8], which are restricted in their ability to handle complicated problems like the classification of medical images, DL is inspired by biological neural networks to achieve better power and flexibility.

A significant collection of images that have been tagged is necessary for a DL-based detection or classification system to function well. Deep Feature Detection (DFD) and Transfer Learning (TL) are the best alternatives to using a limited sample size of images when a large sample size is not practical TL. Teaching a language involves using strategies that have already been learned to get around unexpected barriers (TL). TL is a method that can be used to build a new machine learning model, not a particular category of algorithms. The model will be able to apply the knowledge and skills it has acquired from prior training to novel circumstances [3][4][5]. The data must be organized by file type, just like in the previous step. Another application for TL is the extraction of deep feature data. Instead of manually changing the CNN's activation layers, feature vectors can be extracted using pre-trained CNN models. Installations of lower-level layers activate deeper layers that contain higher-level components crucial for detecting visuals [6].

The article addresses the above gaps including limited training data, class imbalance, interpretability challenges, robustness to variations, and transferability issues across

populations. To address these gaps, there is a need for more large datasets, improved model interpretability, better handling of class imbalance, enhanced robustness to image variations, and increased transferability to different populations. Addressing these gaps is vital for enhancing the accuracy and reliability of deep learning models in COVID-19 classification using X-ray images.

To distinguish between patients with COVID-19 infection and healthy people, this work presents a DFD-based method that makes use of XG-Boost [6][7]. The whole article is briefly reviewed in Section II, and the database and different methodologies are explained in Section III. In Section IV, the proposed work is introduced and the whole experimental work with results is explained in Section V. Section VI discusses the findings and Section VII concludes the research work with future outlook.

II. REVIEW WORK

Recently, researchers observed imaging patterns on chest CT to detect COVID-19. Lunagariya et al. [24] used TL to train Squeeze Net, DenseNet-121, and ResNet18 to distinguish between Covid-19-infected and non-infected individuals using CXR photos and were successful in identifying COVID-19. Gravitational search optimization-DenseNet121-COVID-19 was proposed by Khan et al. [19] suggested CoroNet, a deep CNN built on the Xception paradigm, as a way to distinguish Covid-19 from CXRs. The COVID-19 and Multiclass Xception models are used to categorize pneumonia in this study. H. Panwar et al. [20] introduce a novel method that combines deep learning techniques with gradient-weighted Class Activation Mapping (grad-CAM) for the swift identification of COVID-19 cases using chest X-ray and CT-scan images. The authors propose a color visualization technique to enhance the interpretability of the deep learning model's findings. The article showcases the experimental results, highlighting the potential of their approach in quickly and accurately detecting COVID-19 cases based on medical imaging data. Luz et al. [21], the authors discuss their efforts to develop a deep-learning model that can accurately and efficiently detect COVID-19 patterns in X-ray images. The authors detail their approach, and techniques employed, and present the outcomes of their experiments conducted to train and assess the model's performance. The article emphasizes the potential of deep learning methods in aiding the detection and diagnosis of COVID-19 through X-ray imaging technology. J. Zhang et al. [22] used 100 CXRs from COVID-19 cases and pre-trained weights from the ImageNet database to build their ResNet-based model. With an f-score of 0.72, their top model could distinguish between CAP and COVID-19 infection. Eduardo Luz et al. [23] demonstrated a DFE-based hierarchical categorization technique using EfficientNet models [11][12]. Classifiers are located between the tree's nodes, whereas target categories are located at the tree's leaves. At the root node, one classifier was used to separate the Normal and Pneumonia patients, while another classifier was used at a higher level to separate the Pneumonia patients only.

III. DATABASE AND METHOD ANALYSIS

The COVID-19, Pneumonia, and Healthy Chest X-ray PA Dataset [9][10] is being used in this study, and it was available

in April 2021. This data set contains 4575 images divided into three groups of 1525 images each. The images were obtained from a variety of web resources by the dataset's creator. The dataset contains chest X-ray Poster Anterior (PA) images and is divided into three categories (covid, pneumonia, and normal). GitHub, Radiopaedia, The Cancer Imaging Archive (TCIA), and the Italian Society of Radiology were used to collect 613 X-ray images of COVID-19 cases (SIRM). Rather than having the data independently enhanced, a dataset with 912 already-augmented images was obtained from Mendeley. 1525 images were obtained from the Kaggle repository and the NIH dataset. To validate a proposed technique, the experimental dataset is divided into two parts: training and testing. The remaining 30% of the images are used to test the effectiveness of the proposed technique, while the training set consists of 70% randomly selected images (i.e., 3202). (i.e., 1373). The assessment measure for each pre-trained model is created by combining ten cycles of a training-testing assessment in which different sets of randomly selected images are used for both the supplied model's training and testing.

The training set comprised 70% of the total dataset, while the test set comprised 30%. The dataset was further divided into three sections: learning, validation, and testing. To employ the transfer learning strategy, following are used:

EfficientNet-B0: Unlike custom, the EfficientNet-B0 [4][5][6] scaling method uses a set of predetermined scaling coefficients to gradually increase the network's resolution, depth, and width. EfficientNet-B0[4][5] scales the network's resolution, depth, and width using a compound coefficient. Compound scaling [6][9][11] was developed based on the idea that a larger input image requires more levels and channels in the networks to expand the available field and capture fine details on the larger image.

DenseNet-121: As a CNN's layers increase, the "vanishing gradient" problem becomes more common. As an alternative to using it, DenseNets-121[6][7] modifies the traditional CNN architecture and reduces the connections between the various layers. The name "Densely Connected Convolutional Network" is appropriate because each layer in the network is densely connected.

Tune the XG-Boost Classifier [7]: To accurately predict the outcome, the XG-Boost Classifier's parameters must be tweaked. The procedure for tuning is fully described in XG-Boost Classifier Tuning Algorithm 2, the maximum depth (MD), number of estimators (classification trees), and learning rate (LR) of each classification tree are XG-Boost classifier tuning parameters.

IV. PROPOSED TECHNIQUE

Fig. 1 shows the proposed architecture. A two-step process is used to retrieve the X-ray image characteristics. In the first stage, a pre-trained model is used to extract features from a collection of all X-ray images [13]-[18]. After the features have been collected, they are ranked using the Recursive Feature Elimination method. Finally, it is decided to keep only the top-ranked characteristics. The following describes the two-stage feature extraction process using Algorithm 1 (Deep Feature Detection).

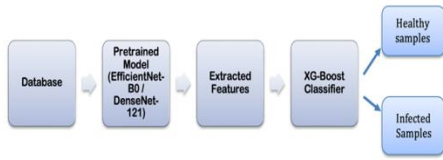


Fig. 1. Proposed two-stage deep feature detection technique.

The algorithm "Deep Feature Detection" is designed to extract deep features from a set of images using a pre-trained model. It takes as input a pre-trained model (M), a set of N images (I1, I2, ..., IN), and the desired size for the resized images (K*K). The procedure involves removing non-convolutional layers from the pre-trained model to create a modified model (MR). An empty array called DF is initialized to store the extracted deep features. For each image in the set, the algorithm resizes it to the desired size and passes it through the modified model to obtain the features. These features are then flattened and added to the DF array. The algorithm also includes a step for ranking the features based on an unspecified criterion. Finally, the algorithm selects the features with a rank value of 1 and stores them in the selected features array. The output of the algorithm is a 2D array representing the selected deep features (DF).

Algorithm 1: Deep Feature Detection

Input: Pretrained Model (i.e. M), Set of 'N' Images I1 .. IN, Required Image Size (i.e., K*K) Output: A 2D array of chosen deep features is produced (i.e., DF)

```

Procedure:
MR ← Remove_Non_Conv_Layers (M)
DF = []
for i=1 to N do
  Resize image Ii to size (K*K) features ← MR (Ii)
  features ← Flatten (features) DF.append (features)
feature_rank ← FeatureRanking (DF) selected_features = DF[feature_rank==1]
    
```

Algorithm 2: Tune XG-Boost Classifier

Input: 2D array of class labels and selected features, Output: Best Parameters for Tuning the XGBoost Model

```

Procedure:
Acc_array = []
for max_depth = 3 to 5 do
  for learning_rate = 0.1 to 0.5 (step size 0.2) do
    for n_estimator = 300 to 800 (step size 50) do:
      accuracy ← K_Fold_XGBoostModelEvaluation (Folds=10, max_depth, learning_rate, n_estimators)
    acc_array [max_depth, learning_rate, n_estimators] ← Accuracy
  Select combinations of Parameters from acc_array which gives the highest accuracy.
    
```

V. EXPERIMENTAL RESULTS

The dataset [9], which was released in April 2021, is used for testing. This data set includes 4575 photos divided into

three groups of 1525 images each. These images as shown in Fig. 2 were obtained by the dataset's creator from a variety of web resources.

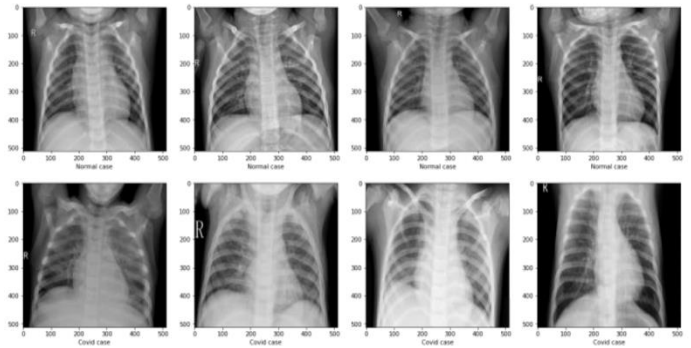


Fig. 2. Healthy and infected input dataset.

Using 10-fold cross-validation, the prediction accuracy of suggested experiments is investigated. The prediction accuracy of the XG-Boost Classifier, when trained using deep features detected using the DenseNet-121 model, is shown in Fig. 3, Table I, Table II, and Table III for various configurations of the Depth of the Tree, Learning Rate, and Number of Estimators variables. The model's classification accuracy is highest when trained with the values 0.3, 350, and 5 for the LR, MD, and classification trees, respectively. While, the prediction accuracy of the XG-Boost Classifier, when trained using deep features detected using the EfficientNetB0 model, is shown in Fig. 4 for various configurations of the Depth of the Tree, Learning Rate, and Number of Estimators variables. The model's classification accuracy is highest when trained with the values 0.3, 350, and 5 for the LR, MD, and classification trees, respectively.

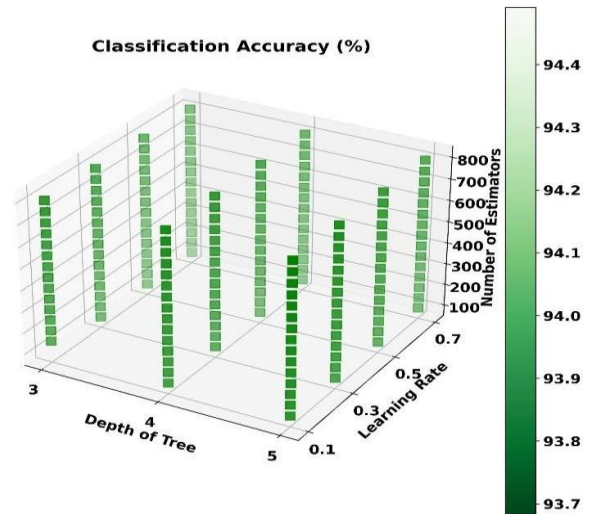


Fig. 3. XGBoost classifier's prediction accuracy for different tree depths, learning rates, and estimator counts when the classifier is trained using deep features from the DenseNet-121 model.

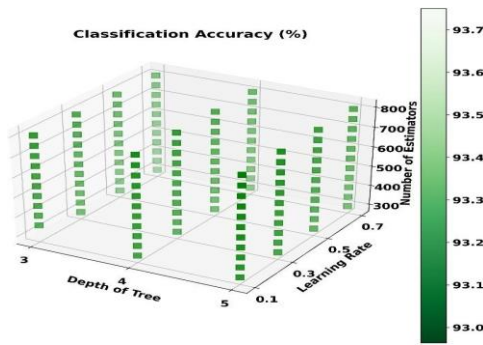


Fig. 4. XGBoost classifier's prediction accuracy for different tree depths, learning rates, and estimator counts when the classifier is trained using deep features taken from the EfficientNet-B0 model.

A. Model Name: DenseNet121 XG-Boost Balance Tune Results 128

Results-1:

Maximum depth is 3,

The learning rate is 0.1, 0.3, 0.5, and 0.7

Estimators range from 100 to 800

Accuracy Obtained: 0.94468524

TABLE I. ACCURACY OF DENSENET-121 WITH XG-BOOST CLASSIFIER, DEPTH 3 IN AN ESTIMATOR RANGE FROM 100 TO 800

Estimator	MD -3, LR. -0.1	MD -3, LR. -0.3	MD -3, LR. -0.5	MD -3, LR. -0.7
100	0.93025599	0.93769063	0.93921999	0.93987358
150	0.93746847	0.93878569	0.94053004	0.94271443
200	0.93877996	0.93922429	0.94183867	0.9422744
250	0.93987215	0.94163083	0.94249656	0.9422787
300	0.94205796	0.94096864	0.94337375	0.94249799
350	0.9416208	0.94074934	0.94424665	0.94271443
400	0.94249369	0.94075221	0.94424808	0.94249513
450	0.94227583	0.94053148	0.94468524	0.94271443
500	0.94293086	0.94096864	0.94424951	0.94205796
550	0.94315302	0.94140437	0.94403021	0.94205796
600	0.9422744	0.9411865	0.94381235	0.94205796
650	0.94315016	0.94096577	0.94403021	0.94227726
700	0.94292799	0.94074791	0.94403021	0.94271443
750	0.94271013	0.94074791	0.94402878	0.94293372
800	0.94292942	0.94074791	0.94424808	0.94249656

Results-2:

Maximum depth: 4,

Learning Rate: 0.1, 0.3,0.5,0.7

No of Estimators: from 100 to 800

Accuracy Achieved: 0.94489594

TABLE II. ACCURACY OF DENSENET-121 WITH XG-BOOST CLASSIFIER, DEPTH 4 IN AN ESTIMATOR RANGE FROM 100 TO 800

Estimator	MD -3, lr. -0.1	MD -3, lr. -0.3	MD -3, lr. -0.5	MD -3, lr. -0.7
100	0.93680914	0.94359305	0.94052718	0.94227583
150	0.94009431	0.94381092	0.94074647	0.94271299
200	0.94118364	0.94402878	0.9411822	0.94227583
250	0.9416208	0.94358875	0.94205796	0.94205653
300	0.94358445	0.94337232	0.94249656	0.94249369
350	0.94402305	0.94359019	0.9420594	0.9422744
400	0.94446164	0.94293516	0.9416208	0.94271299
450	0.94467951	0.94315446	0.9416208	0.94205653
500	0.94467808	0.94315446	0.9420594	0.94227583
550	0.94423948	0.94337232	0.94249656	0.94227583
600	0.94467664	0.94337089	0.94227726	0.94227726
650	0.94467664	0.94359019	0.94249656	0.94205796
700	0.94467664	0.94402735	0.94271586	0.9416208
750	0.94489594	0.94358875	0.94249656	0.94271443
800	0.94467808	0.94336945	0.94271586	0.94293229

Result-3:

Maximum Depth: 5,

Learning Rate: 0.1, 0.3,0.5,0.7

No of Estimators from 100 to 800

Accuracy Achieved: 0.94491027

TABLE III. ACCURACY OF DENSENET-121 WITH XG-BOOST CLASSIFIER, DEPTH 5 IN AN ESTIMATOR RANGE FROM 100 TO 800

Estimator	MD -3, LR. -0.1	MD -3, LR. -0.3	MD -3, LR. -0.5	MD -3, LR. -0.7
100	0.93681487	0.94206656	0.9422744	0.93987501
150	0.93922142	0.94425381	0.94205653	0.94009145
200	0.9416294	0.94381808	0.94380662	0.94009145
250	0.94184727	0.94469098	0.94424665	0.94074791
300	0.94206656	0.94425238	0.94402735	0.94074934
350	0.94272016	0.94491027	0.94424521	0.94052718
400	0.94337662	0.94425525	0.94468381	0.94030931
450	0.94403165	0.94403308	0.94402591	0.94031218
500	0.94468954	0.94359449	0.94402591	0.94030931
550	0.94424951	0.94403021	0.94358732	0.94053004
600	0.94468668	0.94424951	0.94380518	0.94074791
650	0.94446738	0.94403165	0.94380518	0.94052861
700	0.94403021	0.94424951	0.94380518	0.94053004
750	0.94446881	0.94490597	0.94380518	0.94009431
800	0.94403165	0.94490454	0.94402305	0.94031361

B. Model Name: EfficientNetB0_XG-Boost_Balance_Tune_Results_128

Results-1:

Maximum depth: 3,

Learning Rate-0.1, 0.3,0.5, 0.7

No of Estimators from 300 to 800

Accuracy Achieved: 0.93750143

TABLE IV. ACCURACY OF EFFICIENTNETB0 WITH XG-BOOST CLASSIFIER, DEPTH 3 IN AN ESTIMATOR RANGE FROM 100 TO 800

Estimator	MD -3 , lr. -0.1	MD -3 , lr. -0.3	MD -3 , lr. -0.5	MD -3 , lr. -0.7
300	0.92963823	0.9331384	0.93531705	0.9329191
350	0.9296368	0.93313697	0.93531705	0.93248051
400	0.93029039	0.93226551	0.93640924	0.93313697
450	0.93094399	0.93226264	0.93640781	0.93226408
500	0.93138258	0.93204478	0.93662711	0.93248194
550	0.93203618	0.93226264	0.93706427	0.93248051
600	0.93203904	0.93269837	0.93706427	0.93269694
650	0.93247621	0.9333534	0.93706427	0.93247764
700	0.93269551	0.9333534	0.9375	0.93247907
750	0.93269551	0.93335197	0.93706427	0.93225978
800	0.93313267	0.93356983	0.93750143	0.93225978

Table IV showcases the performance of the EfficientNetB0 model combined with an XG-Boost classifier of depth 3 and an estimator range from 100 to 800, achieving an accuracy of 0.93750143.

Result-2:

Maximum depth: 4,

Learning Rate: 0.1, 0.3,0.5,0.7

No of Estimators from 300 to 800

Accuracy Achieved: 0.933357

TABLE V. ACCURACY OF EFFICIENTNETB0 WITH XG-BOOST CLASSIFIER, DEPTH 4 IN AN ESTIMATOR RANGE FROM 100 TO 800

Estimator	MD -3 , lr. -0.1	MD -3 , LR. -0.3	MD -3 , LR. -0.5	MD -3 , LR. -0.7
300	0.93095259	0.93161048	0.93270124	0.93116902
350	0.93160905	0.93182691	0.93292054	0.93160618
400	0.93138975	0.93182835	0.93292054	0.93160618
450	0.93160761	0.93204764	0.93270267	0.93138832
500	0.93204191	0.93204621	0.93204621	0.93138975
550	0.93225978	0.93270411	0.93182835	0.93138832
600	0.93269837	0.93313984	0.93204621	0.93138832
650	0.93291624	0.93313984	0.93204764	0.93138832
700	0.93291767	0.93313984	0.93161191	0.93138832
750	0.93291624	0.9333577	0.93161048	0.93138832
800	0.93291624	0.93313984	0.93204908	0.93138832

Results-3:

Maximum depth: 5,

Learning Rate: 0.1, 0.3,0.5,0.7

No of Estimators from 300 to 800

Accuracy Achieved: 0.93314557

TABLE VI. ACCURACY OF EFFICIENTNETB0 WITH XG-BOOST CLASSIFIER, DEPTH 5 IN AN ESTIMATOR RANGE FROM 100 TO 800

Estimator	MD -3 , LR. -0.1	MD -3 , LR. -0.3	MD -3 , LR. -0.5	MD -3 , LR. -0.7
300	0.93007539	0.93095545	0.93160618	0.93205194
350	0.92985609	0.93117475	0.93117045	0.93248911
400	0.93029326	0.93139405	0.93117045	0.93292627
450	0.93051542	0.93183121	0.93117045	0.93314557
500	0.93160475	0.93204908	0.93095115	0.93292627
550	0.93116902	0.93204908	0.93160475	0.93270841

600	0.93138975	0.93204908	0.93160475	0.93249054
650	0.93138832	0.93182978	0.93160475	0.93205481
700	0.93138975	0.93161048	0.93182261	0.93249054
750	0.93160905	0.93161048	0.93204048	0.93249054
800	0.93160905	0.93161048	0.93204048	0.93249054

VI. DISCUSSION

The whole experimental procedure rebels that by considering different techniques, such as DenseNet-121 with XG-Boost Classifier, and EfficientNetB0 technique with different depth range 3- 5, the estimator range from 100 to 800, we achieved different results, as shown in Table I to VI. Table I shows that the technique named DenseNet-121 with XG-Boost Classifier with depth 3 outreaches an accuracy of 0.94468524 in 450 Estimator. Similarly, by changing the depth to 4 with the same DenseNet-121 with XG-Boost Classifier, the accuracy reaches 0.94489594 in the 750 range of estimator. By using EfficientNetB0 with XG-Boost Classifier, we can have a comparison with the other techniques and find the differentiation of accuracies in different estimators' range with diverse depth values. The learning rate for all the techniques with different depths and estimators are numbered with values of 0.1, 0.3, 0.5, and 0.7. Fig. 5 depicts the accuracy of several pre-trained models as well as customized XG-Boost models that incorporate characteristics collected by method 1. The proposed technique is compared with various existing state of art techniques i.e. VGG16, VGG19, InceptionResNet-V2, InceptionV3, MobileNetV2, ResNet101V2, ResNet50V2, Xception, and hence the proposed technique was found to have the highest accuracy in finding the COVID infection. The modified XG-Boost model was trained using Algorithm 1 and EfficientNetB0 features, which explains its accuracy of 0.976, or 97.6% which explains its accuracy of 0.976, or 97.6%. This is the best result as compared to previously proposed algorithms given in [22] [23].

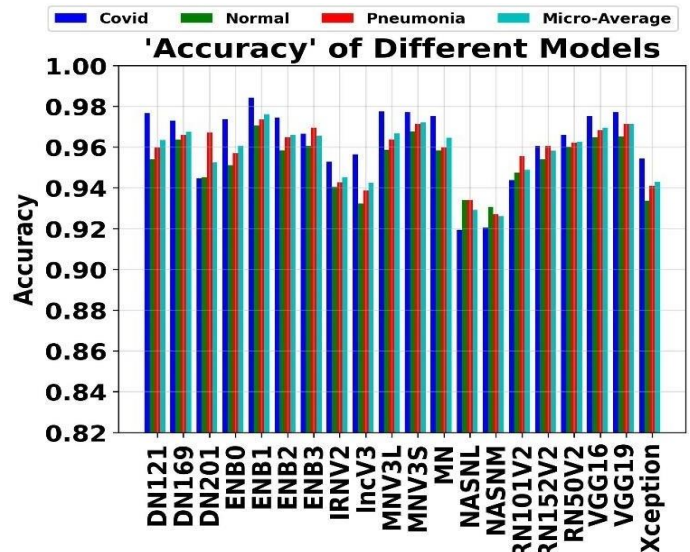


Fig. 5. Accuracy of tuned XGBoost models trained using deep features detection technique and various pre-trained models.

VII. CONCLUSION

A Deep Feature Detection based method for identifying pneumonia and the COVID-19 virus in patients is

demonstrated using chest X-rays. After lung area segmentation, this article describes a two-stage method for extracting deep features from X-Ray images. These characteristics are then used to train the XG-Boost classifiers to distinguish between pneumonia patients, healthy people, and people infected with COVID-19. When the results of 20 different pre-trained models are compared, it is clear that using EfficientNetB0 for deep feature detection results in the best detection accuracy, precision, recall, specificity, and F1-score. The following values correspond to these criteria: 97.6%, 0.964, 0.964, and 0.982. These findings support the proposed strategy's efficacy. The tables show that the proposed diagnostic testing model was better than the competitive models. The proposed testing model is a technological alternative to COVID-19 testing tools. A CNN method for COVID-19 can be used to test image classification with a large dataset and complete with symptoms.

REFERENCES

- [1] Ravi, V., Narasimhan, H., Chakraborty, C. and Pham, T.D, "Deep learning-based meta-classifier approach for COVID-19 classification using CT scan and chest X-ray images", *Multimedia systems*, 28(4), pp.1401-1415, 2022.
- [2] Aggarwal, P., Mishra, N.K., Fatimah, B., Singh, P., Gupta, A. and Joshi, S.D., "COVID-19 image classification using deep learning: Advances, challenges, and opportunities", *Computers in Biology and Medicine*, p.105350, 2022.
- [3] Das, A., "Adaptive UNet-based Lung Segmentation and Ensemble Learning with CNN-based Deep Features for Automated COVID-19 Diagnosis", *Multimedia Tools and Applications*, 81(4), pp.5407-5441, 2022.
- [4] Trinh, Q. H., Nguyen, M. V., & Nguyen-Dinh, T. P. "Res-Dense Net for 3D Covid Chest CT-Scan Classification", In *International Conference on Image Analysis and Processing*, pp. 483-495, 2022.
- [5] Yildirim, M., Eroglu, O., Eroglu, Y., Çinar, A. and Cengil, E., "COVID-19 Detection on Chest X-ray Images with the Proposed Model Using Artificial Intelligence and Classifiers", *New Generation Computing*, pp.1-15, 2022.
- [6] Kaya, M. and Eris, M., "D3SENet: A hybrid deep feature extraction network for Covid-19 classification using chest X-ray images", *Biomedical Signal Processing and Control*, pp.104559, 2023.
- [7] Thamer, S.A. and Alshmmri, M.A., "Effective Diagnosing of Covid-19 from CXR Images Using Deep Learning Approaches and Optimized XG Boost Model", *JOURNAL OF ALGEBRAIC STATISTICS*, Vol.13, No.2, pp.1236-1250, 2022.
- [8] Pattanaik, P.A., Khan, M.Z. and Patnaik, P.K., "ILCAN: a new vision attention-based late blight disease localization and classification", *Arabian Journal for Science and Engineering*, Vol.47, No.2, pp.2305-2314, 2022.
- [9] Luz, E., Silva, P., Silva, R., Silva, L., Guimarães, J., Miozzo, G., Moreira, G. and Menotti, D., "Towards an effective and efficient deep learning model for COVID-19 pattern detection in X-ray images. *Research on Biomedical Engineering*, Vol. 38, No.1, pp.149-162, 2022.
- [10] Pattanaik, P.A., "Automated Segmentation for Knee Joint MRI Images Using Hybrid UNet+ Attention", In *2022 IEEE Trends in Electrical, Electronics, Computer Engineering Conference (TEECOCN)*, pp. 56-61, 2022.
- [11] Luz, E., Silva, P., Silva, R., Silva, L., Guimarães, J., Miozzo, G., Moreira, G. and Menotti, D., "Towards an effective and efficient deep learning model for COVID-19 patterns detection in X-ray images", *Research on Biomedical Engineering*, Vol. 38, No. 1, pp.149-162, 2022.
- [12] A. Haghaniifar, M. M. Majdabadi, Y. Choi, S. Deivalakshmi, and S. Ko, "COVID-CXNet: Detecting COVID-19 in frontal chest X-ray images using deep learning," *Multimed. Tools Appl.*, vol. 81, no. 21, pp. 30615–30645, Sep. 2022, doi: 10.1007/s11042-022- 12156-z.
- [13] M. Shorfuzzaman, M. Masud, H. Alhumyani, D. Anand, and A. Singh, "Artificial Neural Network-Based Deep Learning Model for COVID-19 Patient Detection Using X-Ray Chest Images," *J. Healthc. Eng.*, vol. 2021, 2021, doi: 10.1155/2021/5513679.
- [14] M. D. K. Hasan et al., "Deep Learning Approaches for Detecting Pneumonia in COVID-19 Patients by Analyzing Chest X-Ray Images," *Math. Probl. Eng.*, vol. 2021, 2021, doi: 10.1155/2021/9929274.
- [15] J. Li, D. Zhang, Q. Liu, R. Bu, and Q. Wei, "COVID-GATNet: A Deep Learning Framework for Screening of COVID-19 from Chest X-Ray Images," in *2020 IEEE 6th International Conference on Computer and Communications, ICC 2020, 2020*, pp. 1897–1902, doi: 10.1109/ICCC51575.2020.9345005.
- [16] D. Dansana et al., "Early diagnosis of COVID-19-affected patients based on X-ray and computed tomography images using deep learning algorithm," *Soft Comput.*, 2020, doi 10.1007/s00500-020-05275-y.
- [17] K. Hammoudi et al., "Deep Learning on Chest X-ray Images to Detect and Evaluate Pneumonia Cases in the Era of COVID-19," *J. Med. Syst.*, vol. 45, no. 7, 2021, doi: 10.1007/s10916-021-01745-4.
- [18] A. U. Ibrahim, M. Ozsoz, S. Serte, F. Al-Turjman, and P. S. Yakoi, "Pneumonia Classification Using Deep Learning from Chest X-ray Images During COVID-19," *Cognit. Comput.*, 2021, doi 10.1007/s12559-020-09787-5.
- [19] A. I. Khan, J. L. Shah, and M. M. Bhat, "CoroNet: A deep neural network for detection and diagnosis of COVID-19 from chest x-ray images," *Comput. Methods Programs Biomed.*, vol. 196, 2020, doi 10.1016/j.cmpb.2020.105581.
- [20] H. Panwar, P. K. Gupta, M. K. Siddiqui, R. Morales-Menendez, P. Bhardwaj, and V. Singh, "A deep learning and grad-CAM based color visualization approach for fast detection of COVID-19 cases using chest X-ray and CT-Scan images," *Chaos, Solitons and Fractals*, vol. 140, 2020, doi: 10.1016/j.chaos.2020.110190.
- [21] E. Luz et al., "Towards an effective and efficient deep learning model for COVID-19 patterns detection in X-ray images," *Res. Biomed. Eng.*, vol. 38, no. 1, pp. 149–162, Mar. 2022, doi: 10.1007/s42600-021-00151-6.
- [22] C. Zhang et al., "ResNet or DenseNet? Introducing dense shortcuts to ResNet," in *Proceedings - 2021 IEEE Winter Conference on Applications of Computer Vision, WACV 2021, 2021*, pp. 3549–3558, doi: 10.1109/WACV48630.2021.00359.
- [23] Luz, E., Silva, P., Silva, R., Silva, L., Guimarães, J., Miozzo, G., Moreira, G. and Menotti, D., "Towards an effective and efficient deep learning model for COVID-19 patterns detection in X-ray images", *Research on Biomedical Engineering*, Vol. 38, No.1, pp.149-162, 2022.
- [24] Lunagariya, M. and Katkar, V., "Light Weight Approach for COVID-19, Pneumonia Detection from X-Ray Images using Deep Feature Extraction and XGBoost", In *2022 Second International Conference on Computer Science, Engineering and Applications (ICCSEA)*, pp. 1-5, 2022.

Data Sharing using PDPA-Compliant Blockchain Architecture in Malaysia

Hasventhran Baskaran¹, Salman Yussof², Asmidar Abu Bakar³, Fiza Abdul Rahim⁴

Australian Matriculation Department, Sunway College, Bandar Sunway, Malaysia¹

Institute of Informatics and Computing in Energy, Universiti Tenaga Nasional, Kajang, Malaysia^{2,3}

Advanced Informatics Department, Razak Faculty of Technology and Informatic, Kuala Lumpur, Malaysia⁴

Abstract—Data privacy is undoubtedly the biggest concern for the modern society. Data privacy is also becoming a key policy in data protection regulations. Organizations assemble massive amount of personal data of the users for monetary and political purposes. These data can be sold for commercial purpose without the prior knowledge or permission from the respective data owners. This can be mitigated by having blockchain to provide a much-needed transparency. However, blockchain's own transparency becomes its own disadvantage when data owners want to be completely anonymous. Blockchain's transparent nature will be conflicting with non-linkability. Since the data in blockchain is publicly viewable, any personal data or private transactions being processed through blockchain will be exposed to every node in the network. Hence, blockchain implementations also must comply with privacy acts such as Personal Data Protection Act (PDPA) to have privacy by design and by default. Hence, this paper proposes a PDPA-compliant blockchain architecture for data trading that provides complete control of data and anonymity to the users. A prototype is created using various tools to implement the proposed architecture. This study presents anonymous data sharing for users, data access, data delete features to verify the correctness of the proposed architecture.

Keywords—Blockchain; smart contract; legitimacy; access protocol; retention protocol; data processor; data subject; data user; blockchain regulations

I. INTRODUCTION

Sharing data is one of the most basic operations being performed on the Internet. Data can be shared to one or many depending on the need for the operation [1]. Nowadays, data is being considered as a valuable asset due to the growth of Internet of Things (IoT), cloud computing and big data [2]. There are many benefits of data sharing that underlines its importance. For example, data sharing can benefit enterprises, research and also our society [3]. Enterprises can reduce their inefficiencies, increase collaborations and open up new ventures between businesses. Researchers can build more connections and collaboration with other researchers. This will allow them to work on novel research topics rather than repeating existing works. The society can benefit through information shared to increase economic benefits, improved innovations and higher rates of advancement in technology and medical research.

However, there are some issues with data sharing that concerns the parties involved in it. Data integrity and user anonymity are very serious aspects of data sharing that

regularly concern the data owners. Data owners might have less trust on data management solutions due to the fear of their personal data being exposed and exploited without their permissions. It is also possible for data sharing to result in the violation of the users' privacy and losing control over the data produced by the users themselves [4].

We chose blockchain as the solution to tackle the issues that rise with data sharing. The users' concerns with data sharing mentioned previously can be handled by blockchain. Blockchain is a distributed ledger technology that was popularized by cryptocurrency applications. It is a ledger that consists of a record of transactions. From information technology perspective, blockchain can be seen as a database. This technology is designed to facilitate distributed transactions without depending on a central point of authority. Multiple users can make changes to the ledger simultaneously. The ledger will be stored in multiple nodes that participates in the blockchain network.

Blockchain technology rose to popularity with the rise of Bitcoin and many cryptocurrencies followed the suit. Cryptocurrencies are a virtual coin that holds a certain value that can be monetized. Users can buy, sell, and trade these cryptocurrencies with blockchain. Blockchain is immutable in nature so it will preserve data integrity. This enables data integrity to be preserved and prevent any false transactions.

Since blockchain is decentralized and transparent, any transactions happening in the network will be publicly available to all users. Blockchain eliminates the need for a trusted third party and ensure the data ownership of the users by enforcing smart contracts. Users do not have to worry about their data being exploited because the usage and the users of data can be defined by the data owners using smart contract. These features give the users an increased control and trust over their data. The core concept can also be used to enable users to trade their data in return for money in Malaysian context. Instead of sending cryptocurrencies through blockchain, users can also trade different types of data through blockchain.

However, some additional components need to be added to a generic blockchain architecture to protect user's data privacy due to blockchain's transparent nature. Users' personal data could be publicly viewable if it is shared on blockchain. Users also should be able to control how much and to whom their data can be exposed to. Blockchain addresses' linkability; also needs to be handled to not expose the identities of the users.

Personal Data Protection Act 2010 (PDPA) in Malaysia is an act that enforces the regulation of the processing of personal data concerning commercial transactions. A bill relating to the PDPA of Act 709 was passed by the Malaysian Parliament on 16th May 2011. Following this, the Personal Data Protection Department was established under the Ministry of Communications and Multimedia Commission (MCMC). PDPA is applicable to any person who processes and collects data for commercial purposes. Hence, this research discusses the current blockchain ecosystem in Malaysia and proposes the first PDPA-compliant blockchain architecture for data trading purposes in Malaysia.

Hence, this paper discusses the current blockchain ecosystem in Malaysia and proposes the first PDPA-compliant blockchain architecture for data trading purpose in Malaysia. This paper contains six sections. Section I is the introduction and explains the need for implementing a user centric data privacy protection for data trading on blockchain platform. Section II provides the relevant works done in relation to data privacy and blockchain. Section III introduces our proposed PDPA-compliant blockchain architecture. Section IV discusses implementation and testing of the proposed blockchain architecture using tools such as Multichain, Solidity, Truffle and PYPSV (Python library). Section V provides the conclusion for this paper.

II. RELATED WORKS

This section discusses the definition of data privacy and the types of profitable data associated with it. It also discusses briefly about blockchain technology and its components, data management solutions with blockchain, and the relevance of PDPA to blockchain.

A. Data Privacy

The concern for data privacy is ever increasing among us today, considering the amount of big data generated by our daily life activities. Data privacy is also becoming a key policy in data protection regulations.

We are witnessing massive developments in statistics and computer science that enable computers to analyse and interpret data automatically. These processed data are being used by computers for decision making and knowledge discovery. Nowadays, we can see computers are used for decision making in various sectors. The shift from decision making by humans to automated decision making will raise multiple issues and leave a huge impact.

When thousands or millions of individual data are combined together, they can form digital profiles of people using the particular service. This data can be used for monetary purpose or to shift tides in politics. Some types of data that can be used for these purposes are as follows [5, 8]:

- Age
- Gender
- Address
- Job Title
- Ethnicity

- Religion
- Salary
- Personality traits

While the concept of privacy is very subjective due to the difference in individuals and their cultures, it shares a common theme of having the “right to be alone” [6]. Smith et al. defines privacy as the concern of an individual regarding the access to his/her identifiable personal information [7]. The ISO_IEC_15408-2_2008 standard is referred to identify the data privacy properties. The standard is stating anonymity, pseudonymity, unlinkability and unobservability as the required properties.

Anonymity is when the data user or subject who own the data might act without releasing their user identity to others such as users, subjects, or objects. If a subject is anonymously performing an action, another subject will not be able to determine either the identity or even a reference to the identity of the user employing the subject.

Pseudonymity is when a subject can be referred back directly by being related to a reference (alias) held by the Data Controller, or by providing an alias that will be used for processing purposes. The alias could be in the forms such as an account number or smart contract ID if it's a blockchain implementation. Both pseudonymity and anonymity protect the identity of the user, but in pseudonymity a reference to the user's identity is maintained for accountability or other purposes.

Unlinkability is intended to protect the user identity against the linking of the operations done by the user. Unlinkability requires that different operations cannot be related. For example, the user associated with the operation, or the terminal which initiated the action, or the time the action was executed.

A number of techniques can be applied to implement unobservability. The information might be allocated to a single randomly chosen part of the system/architecture/nodes such that an attacker does not know which part of the system/architecture/nodes should be attacked. An alternative system might distribute the information such that no single part of the system/architecture/nodes has sufficient information that, if circumvented, the privacy of the user would be compromised. It can be achieved by methods such as cryptography and encryption

B. Blockchain Technology

Blockchain is a type of distributed ledger technology that contains the transactions shared by participating parties in the network. Blockchain maintains an immutable record of this transactions with a P2P network where the copy of the ledger is duplicated to all the participating nodes [9]. Every node gets to keep a copy of the ledger. Transactions in blockchain are validated and authorized by these nodes using a consensus algorithm.

Blockchain can be separated into four types, public, private, hybrid and consortium based on usability [10]. There are different trade-offs for each type. There are various consensus algorithms such as Proof of Work, Proof of Stake, and Proof of

Byzantine Fault Tolerance that can be used by blockchain to verify the transactions made [11].

Blockchain also eliminates the need for a trusted third party by providing digital trust through its smart contract [12]. Users are not required to share any personal information to make transactions through blockchain. Transactions are verified by comparing the provided keys as no authority figure is needed. These features enable blockchain to be a good platform to introduce user-centric data management solutions.

C. Data Management Solutions using Blockchain

Since data market places are becoming a common phenomenon, there is a great need for data management solutions that satisfies users. Data management solutions in blockchain are already witnessing increased adoption. Blockchain is a suitable platform for data sharing because of its decentralization architecture and the ability to have a system that eliminates the need for a trusted third-party.

Bajoudah et al. proposed a decentralized marketplace that facilitates IoT data brokering among selected nodes. This will require minimal trust since the smart contract is enforced to carry out the instructions sent by the user and the transaction details are recorded on a public network [13]. They are using Ethereum's public network and smart contract to mediate the interaction among data producers and consumers. This method ensures complete transparency and non-repudiability.

The authors in [14] proposed a data trading framework based on smart contract using machine learning and blockchain. The authors enforce data trading centers to not be able to retain the shared data during the data trading process with their solution. Hence, the framework is designed to eliminate the need for a trusted third party and give complete control to the data producers. An off-chain download mechanism and challenge response mechanism to download the purchased data and to authenticate data owner are incorporated into the framework.

A consortium blockchain-based data trading framework for the Internet of Vehicles (IoV) was proposed by Chen et al. in [15]. They applied an iterative double auction mechanism that induces users to submit bids and decide the amount of data to trade and its price. The proposed framework's algorithm also extracts the hidden information of participants gradually to ensure their privacy is protected.

The authors mentioned above provided great data management solutions with blockchain. However, the PDPA has a set of regulations that has to be complied by those who makes data-centric solutions. Both regulations definitely affect the way previous researchers dealt with data, especially personal information. Hence, these solutions do not comply fully with key principles of PDPA such as the right to be forgotten and the need for a data controller.

Onik et al. has proposed a solution to have a privacy-aware blockchain for personal data sharing and tracking that complies with European Union's General Data Protection Regulation (GDPR) [16]. Any businesses or organizations that deal with EU subjects has to comply with GDPR even if they are outside the EU. GDPR ensures the protection of its citizens' personal

data regardless of the territories [19,20]. The proposed system in [16] stores personal data on off-chain storage and successfully tracks the data movement between the parties involved in the data sharing transaction. However, due to the tracking feature, it does not satisfy one of the properties of data privacy which is unlinkability. Hence, the proposed architecture in this paper takes non-linkability as a fundamental feature and build upon it. The architecture aims to provide complete anonymity and control to the data producers/owners.

D. PDPA, Blockchain and Data Trading

Malaysia's PDPA is an Act that regulates the processing of personal data in regards to commercial transactions. It was gazetted in June 2010. The penalty for not complying to PDPA is between RM100,000 to 500,000 and/or between 1 to 3 years imprisonment. The importance of PDPA as provided by the Department of Personal Data Protection [17] is as follows:

- To enhance public confidence and trust with ongoing enforcement
- To avoid and minimize the incidents of data breach
- To increase the efficiency and governance of personal data
- To ensure prudence and integrity in personal data handling

Data Subjects are the owners of the data being uploaded to the blockchain architecture. Data Processors are the third parties that are interested to buy data produced by Data Subjects. Data controller is the authority figure that can verify transactions and help make data trading for data user and Data Subject [18]. There should be at least one Data Controller to enforce the rights of the Data Subjects.

Data controllers must obtain explicit consent from users before making any transfer of the data to the Data Processors [18]. The controllers are also required to have a list of consents given by the Data Subjects. This rule can be applied by getting smart contracts from the data and storing the transaction details in the blockchain.

PDPA also encourages PDPA's Retention and Access Principles mandate that data can be modified or erased to comply with legal requirements as mentioned in Section 34, 35, 36 and 37 of PDPA [18]. This conflicts with blockchain's immutable nature that emphasizes on data integrity. Data cannot be modified or erased from blockchain.

However, it can be solved by storing the data on off-chain storage instead on the blockchain. The PDPA sections mentioned earlier also can be enforced by having functions in the smart contract that can access or delete data required by the Data Subjects. PDPA is also applicable only when the data breach happens in Malaysia. This can be enforced by having an off-chain storage in Malaysia.

III. PROPOSED BLOCKCHAIN ARCHITECTURE

A PDPA compliant blockchain architecture is proposed based on the discussion in our previous paper [21] where we studied the gaps between PDPA and blockchain and also the

PDPA-compliant features, and PDPA [18] as shown in Table I.

TABLE I. PDPA COMPLIANT FEATURES

Feature	PDPA	Description
Smart Contracts	Right to erasure and modification, consent to collect data	Both regulations emphasizes on enabling the users to erase or modify the data shared by them. Both regulations requires for the consent to be collected from the users before collecting their data.
Stealth Address [22]	Not Associated	By using stealth address, only the sender and receiver can determine where a data was sent. They allow and require the sender to create random one-time addresses for every transaction on behalf of the recipient. This provides complete anonymity.
Off-chain storage [23-25]	Right to erasure, Territorial limitation	Data on blockchain cannot be erased. However, this can be solved by using off-chain storage. The PDPA can only be enforced if the data storage or breach happens in Malaysia. A off-chain storage in Malaysia will ensure immediate enforcement of PDPA.
Data Controllers	Having data controller is recommended	Data Controllers are needed to enforce or process the data on behalf of the Data Subjects. A minimum of 2 Data Controllers are needed for a Data Subject.

Table I provides the explanation for the PDPA features implemented in our proposed architecture. This section provides the detailed description of the blockchain based PDPA-compliant Data Sharing architecture. This study uses a permissioned blockchain where three stakeholders, Data Subject, Data Controllers and Data Processors form the blockchain network.

The key terms such as Data Subject, Data Controllers and Data Processor are used here and explained below:

- Data Subjects are the data producers.
- Data Controllers are the legal entities that determines the purpose of the data processing and enforces the smart contracts on behalf of the Data Subjects.
- Data Processors are the third-party companies that process data on behalf of the Data Controller.

These terms are from the PDPA as the blockchain architecture is designed to be PDPA compliant. The architecture is designed to have the implementation of key principles of PDPA as the core features. Our definition of data in this proposed architecture is subjective. It can be any type of data that the users want to share. The data type can vary from personal information, bank transactions, energy consumption data, health information and etc.

The architecture enables Data Subjects to share data produced by them to a Data Controller in return for a monetary or point-based reward. The reward received by the Data Subjects can be stored in their preferred digital or

cryptocurrency wallet depending on the type of reward given to them. Data Processors can purchase these datasets from the Data Controller for data processing purpose.

Fig. 1 shows the proposed blockchain architecture. This architecture implements stealth address, an access protocol and a retention protocol. It comprises of three layers, user layer, system management layer and storage layer. The green dotted lines indicate the interactions of the nodes with blockchain. The solid lines indicates the interaction between the stakeholders. Stealth Address (SA), Access Protocol (AP) and Retention Protocol (RP) are used for the interaction between nodes. AP and RP are explained in sub-section 2 of this section and the implementation is shown in sub-section B under System Implementation and Testing. Components used in the proposed blockchain architecture are described below:

- Node: Data Subjects, Data Controllers and Data Processors.
- Block: A new block is generated and added to the existing blockchain each time data sharing happens successfully among the nodes.
- Block header: A block header stores hash of the previous block, transaction time, transaction ID and data encoding style.
- Transaction data: Storing of smart contract ID and hash of the shared data.
- Consensus algorithm: Round-robin mechanism provided by Multichain.

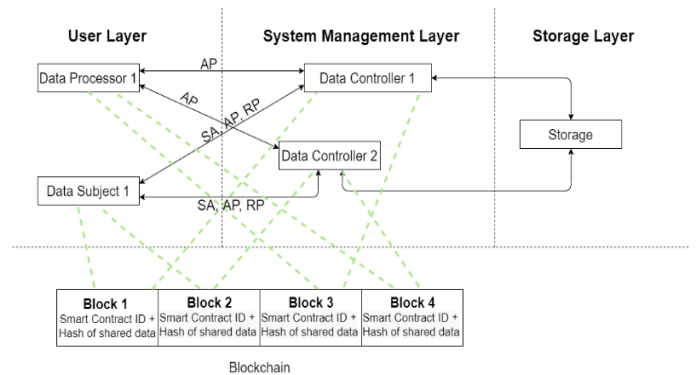


Fig. 1. Proposed blockchain architecture.

1) *User layer*: Each time Data Subjects want to share some data, they can choose the amount and the types of data to be shared. The system then creates a smart contract with their preferred data types. Then a one-time stealth address is created for users to send their smart contract to the blockchain and Data Processor. Users’ smart contract ID and transaction details will be stored in blockchain. The data shared by them will be stored in an off-chain storage. Data Processors exist in this layer to purchase Data Subject’s data from the Data Controllers.

2) *System management layer*: In this layer, data controller enables Data Subjects to claim reward for the data they shared

by providing the smart contract ID related to the dataset. Access protocol (AP) facilitates the data exchange between Data Subject, Data Processor and data user. Users send their smart contract ID linked to the dataset they want access to and data controller retrieves the dataset based on it. Retention protocol (RP) is very crucial in exercising Data Subject's rights to erase their data by providing the smart contract ID linked to the particular dataset. Retention protocol is only available for Data Subjects. Both AP and RP are enforced by data controller in this layer.

3) *Storage layer*: An off-chain storage is used to store the data as it enables PDPA to be enforced should any data breach happens. Once, the user has shared the data to the Data Processor, the data will be sent to the off-chain storage and the transaction details are stored in the blockchain. Since the data is stored in off-chain storage, it is easier to apply AP and RP to access or delete the user's data. Off-chain data is erasable and the remainder of the hash of the shared data will be useless and unidentifiable. This can be ensured by cross-checking the hashes generated after the modification and deletion. This makes the storage layer to comply with PDPA's principle to enable users to modify and erase their data.

4) *Creation of blocks*: Any transaction in the blockchain will only be added to a block after the creation of the genesis block. The architecture shown in Fig. 1 assumes the genesis block is already created during the instantiation of the blockchain. Then, it shows the block creations and the transactions related to them. The contents and the interaction between the nodes during the block creation are explained below.

- Block1: Data Subject1 shares data to Data Controller1. Block is created after consensus is achieved from the Data Subject1 and Data Controller1. The smart contract ID and the hash of the shared data is stored in the block.
- Block2: Data Subject1 shares data to Data Controller2. Block is created after consensus is achieved from the Data Subject1 and Data Controller2. The smart contract ID and the hash of the shared data is stored in the block.
- Block3: Data Processor1 retrieves data from Data Controller1. Block is created after consensus is achieved from the Data Processor1 and Data Controller1. The smart contract ID and the hash of the shared data is stored in the block.
- Block4: Data Processor1 retrieves data from Data Controller2. Block is created after consensus is achieved from the Data Processor1 and Data Controller2. The smart contract ID and the hash of the shared data is stored in the block.

Stealth Address (SA), Access Protocol (AP) and Retention Protocol (RP) are used for the interaction between nodes. The execution of AP and RP are explained below.

Access Protocol can be used in three different methods. The first two different ways can be used by Data Subject only, where the Data Subject can trigger the AP to create a new dataset or access already shared data. The last method is for Data User to buy dataset from Data Controller. Table II describes the components needed to complete the Access and Retention protocol.

TABLE II. PROTOCOL COMPONENTS FOR AP AND RP

DSi	Data Subject is the Data Producer / Owner
DCi	Data Controller determines the purpose of the data processing and enforces the smart contracts on behalf of the Data Subjects.
DPI	Data Processors are the third-party companies that buys data from Data Controller
BC	Blockchain
OCS	Off-chain storage
MSG	Data sent by Data Subjects (e.g: duration and the types of data to be shared)
MSGhash	Hash of the data sent by the Data Subject
DDC	Data sent by Data Controller
SCiID	Smart Contract ID
PSCiID	Previous Smart Contract ID
TiID	Transaction ID
RD	Request for data
PR	Points based reward
DR	Data Price Rate
P	Payment
E	Notice of data erasure

a) *Access protocol for sending new dataset*:

- DSi creates a smart contract to send a new dataset, MSG. The smart contract is being sent to DCi with SCiID, TiID, and MSG. The SCiID is stored by DSi for future reference.
- DCi stores the SCiID, TiID, and MSGhash in BC for auditing purpose.
- MSG and the associated SCiID is stored in OCS for future processing, access or deletion.
- DCi pays PR for the MSG shared by the DSi.

Fig. 2 shows the first method of AP to be used by Data Subject to send a new dataset to the Data Controller.

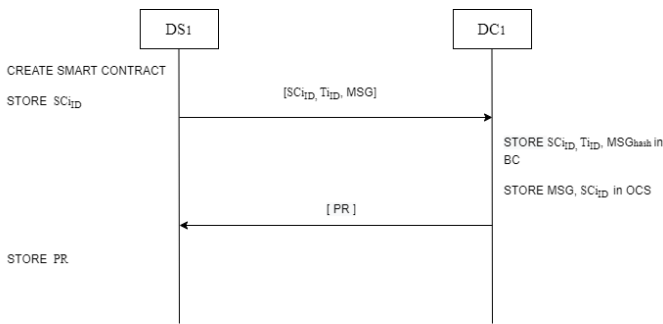


Fig. 2. Data subject sending data using AP.

b) Access Protocol for requesting previously shared data:

- DSi creates a smart contract to request for previously shared dataset, MSG. The smart contract is being sent to DCi with SCiD, TiD, and MSG that contains PSCiD. The SCiD is stored by DSi for future reference.
- DCi checks the match for PSCiD in OCS to look if matches with any data.
- If there is any match with PSCiD, the MSG associated to it is retrieved.
- The SCiD and TiD is stored in for the current transaction is stored in BC for auditing purpose.
- DCi sends DDC that contains the previously shared MSG to the DSi.

Fig. 3 shows the first method of AP to be used by Data Subject to send a new dataset to the Data Controller.

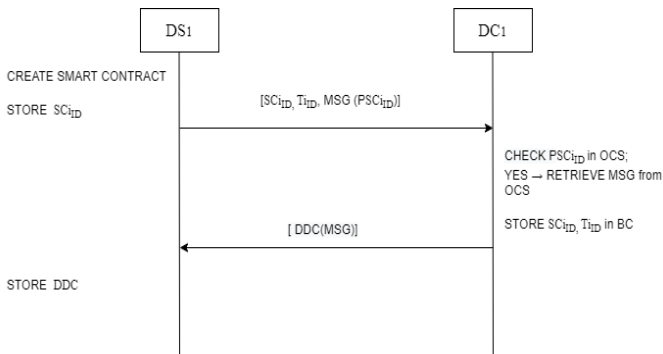


Fig. 3. Data subject using AP to access shared data.

AP is limited in terms of functionality for Data Processor, as shown in Fig. 4.

c) Access Protocol for data purchase:

- DPi creates a smart contract to request for some data. The smart contract is sent to DCi with SCiD, TiD, and DR. The SCiD is stored by DPi for future reference.
- The SCiD and TiD is stored in for the current transaction in BC for auditing purpose.
- The DCi issues the payment of DR for the data requested by the DPi.
- The DPi then pays the DR to the DPi.

- The DPi DDC from the OCS and sends it to DPi.

Fig. 4 shows the method of AP used by Data Processor to buy a dataset from the Data Controller.

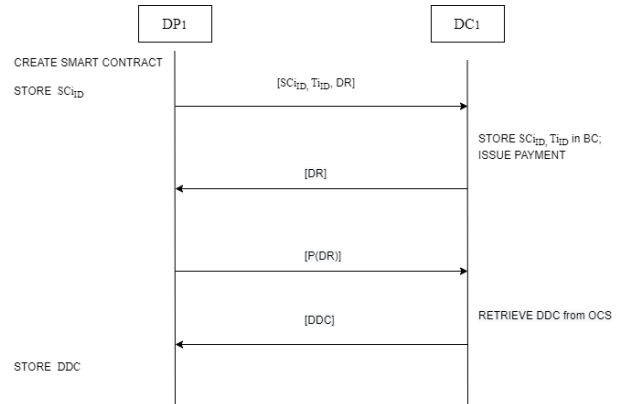


Fig. 4. Data processor requesting data using AP.

d) Retention Protocol:

- DSi creates a smart contract to request of deletion for previously shared dataset, MSG. The smart contract is being sent to DCi with SCiD, TiD, and MSG that contains PSCiD. The SCiD is stored by DSi for future reference.
- DCi checks the match for PSCiD in OCS to look if matches with any data.
- If there is any match with PSCiD, the MSG associated to it is erased.
- The SCiD and TiD is stored in for the current transaction is stored in BC for auditing purpose.
- DCi sends E to DSi to complete the transaction.

Fig. 5 shows how RP is used by Data Subject to erase previously shared dataset to the Data Controller.

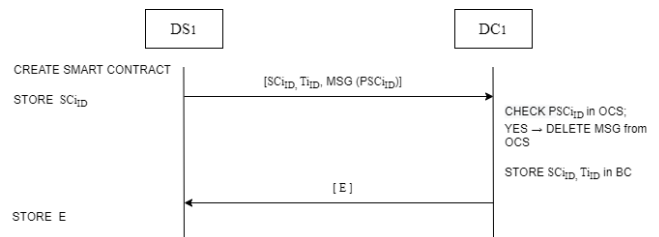


Fig. 5. Data subject requesting the data to be deleted using RP.

IV. IMPLEMENTATION AND TESTING

This section explains the implementation and testing of the proposed architecture. In the first sub-section, case study for the architecture is discussed. In the following subsection, system implementation and testing of the proposed architecture is explained.

A. Case Study: Data Management Scenario

This case study test is done by referring to a similar case study implemented by the authors in [16]. A use case scenario is described with three different situations to further explain the

PDPA-compliant blockchain architecture. The three situations explained here are: Data Subject-controller data sharing scenario, Data Processor-controller data sharing scenario and data deletion scenario.

a) *Data subject-controller data sharing scenario:* Every time the Data Subjects send a set of data to the Data Processor, the transaction details and smart contract ID will be stored in the blockchain and in their local storage. For any set of data, it will be linked with the smart contract's ID. The data controller separates the data into data shared by user, hash value generated for the shared data, transaction ID and smart contract ID. A combination of smart contract ID and data shared by user is stored in the off-chain storage. The combination of generated hash value and smart contract ID are stored in a new block and added to the current blockchain.

An appropriate amount of reward for the shared data will be sent to the Data Subject's temporary address created by stealth address mechanism. Then, the Data Subject can transfer the reward to their digital or cryptocurrency wallet. The transfer of the reward to the user's personal wallet will not be recorded on the blockchain as it happens internally on the end device.

When a Data Subject sends a request with AP to data controller to get a copy of a specific set of data, the data controller will verify and grant the request by the Data Subject. Data controller proceeds to check for the data by using the smart contract ID and its matching data in the off-chain storage. If a match is found, the data controller will send a copy of the requested data by retrieving it from the off-chain storage. Transaction details will be stored in the blockchain for auditing purpose.

2) *Data processor-controller data sharing scenario:* A Data Processor sends a request with AP to Data Controller to get a copy of a specific set of data from the off-chain storage. Data controller will verify and grant the request. Then, the data controller will send a copy of the requested data by retrieving it from the off-chain storage. Transaction details will be stored in the blockchain for auditing purpose. When Data Processor executes the access protocol, they need to pay the Data Controller corresponding to the amount of data they need access to. The payment could be in fiat currency.

3) *Data deletion scenario:* Data Subject sends a request to data controller with relevant Smart Contract ID to erase their data. Data controller will verify and grant the request. After the verification, the data controller searches for any data associated with the Smart Contract ID provided by the user in the off-chain storage. Any data found with matching Smart Contract ID will be erased and the transaction details are stored in blockchain.

B. System Implementation and Testing

This sub-section presents a pilot implementation scenario of the PDPA-compliant blockchain architecture with various tools. The tools used here are Multichain (for network setup with off-chain storage), Remix IDE and Solidity (for writing smart contract), Truffle suite (to test the smart contract) and

pyspv library from python (to build stealth address functionality).

1) *Node and network setup:* A private network with one Data Subject, two controllers and one Data Processor is set up on the blockchain platform with Multichain 2.1.2 [26] as shown in Fig. 6. We have implemented the prototype of the architecture on four computers. The details are as follows:

- Data Controller 1: Windows 10 64-bit, i5-9400F @ 2.90GHZ, Acer Predator Orion 3000.
- Data Controller 2: Windows 10 64-bit, i5-8300H @ 2.30GHZ, Acer Nitro 5.
- Data Subject: Windows 10 64-bit, i7-4600U @ 2.10GHZ, HP Elitebook 840.
- Data Processor: Windows 10 64-bit, A12-9720P @2.70GHZ, HP Laptop 15-bw0xx.

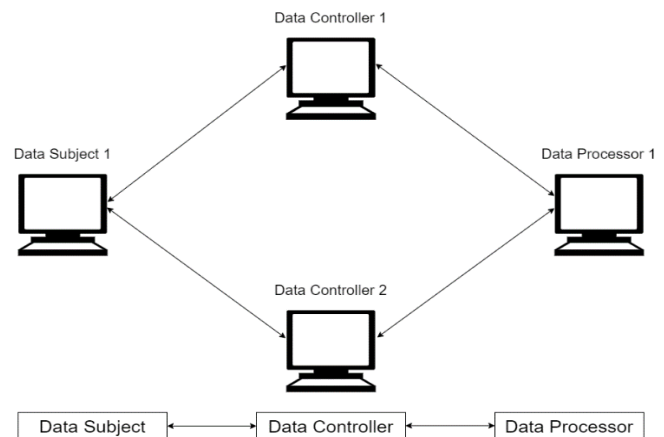


Fig. 6. Experimental network setup.

Multichain is mainly selected due to its off-chain storing mechanism. The built-in off-chain feature enables easy management of data among the nodes. Multichain also helps to add the hash of the off-chain data to the existing block.

Since this is a private network, the consensus only requires minimum difficulties to be achieved. No nonce is used and the consensus is achieved with a round robin mechanism since the node identities are known in a private blockchain. Masking of the node identity will be explained in subsection 3. Multichain is used here for its off-chain storage and easy blockchain deployment capability.

An example of data stored in the off-chain storage is shown in Fig. 7. This is retrieved by the Data Processor1 node after getting the permission from the Data Controller1 to subscribe to the data stream that contains this dataset. The status of off-chain section is shown as true to indicate that the data is being stored in the off-chain storage.

```
"offchain" : true,  
"available" : true,  
"data" : {  
  "text" : "Name: Hasventhran, Age:26, Gender: Male, Address: Selangor, Malaysia"  
},  
"confirmations" : 1,  
"blocktime" : 1626973259,  
"txid" : "d0057749f30abd82fd714aea34e03641099f2b3c13229f13c4a3a88ffff8573"
```

Fig. 7. Data stored in off-chain storage.

2) Smart contract:

The smart contract has four functions that helps AP and RP to be applied in the blockchain architecture. This contract was written in Solidity language with Remix IDE. The contract was tested with Truffle Suite on Geth's Ropsten test network. A few researchers have already used Truffle to test their smart contracts [27 - 31].

Algorithm I: Pseudocode for Data Sharing Smart Contract

```
contract DataSharing{
/*Defining variables and their types*/
int ContractId
string memory name
int age
string memory gender
string memory address
int expiry_date

User[] internal users;
uint public currentID equal to 1010;
RETURN currentID

FUNCTION create_data(string name, int age, string gender,string user_address,
int expiry_date){
Set name = name in name
Set age = age in age
Set gender = gender in gender
Set user_address = user_address in user_address
Set expiry_date = expiry_date in expiry_date
Increment currentID by one when this function is called
RETURN currentID
}

FUNCTION search_data(int ContractId) return (name, age, string
gender,user_address, int expiry_date){
Call find_data and pass ContractId to ContractId
Set i = ContractId
RETURN name = name in users[i]
RETURN age = age in users[i]
RETURN gender = gender in users[i]
RETURN user_address = user_address in users[i]
RETURN expiry_date = expiry_date in users[i]
}

FUNCTION delete_data(uint id) {
Call find_data and pass ContractId to id
Set i = id
delete users[i]
}

FUNCTION find_data(uint ContractId) {
Get the value of ContractId
FOR i = 1 to user's length step 1 DO
IF users[i] in ContractId equal to ContractId
RETURN i
ELSE
PRINT "Smart Contract ID does not exist!"
ENDIF
ENDFOR
}
```

The pseudocode above reflects the smart contract written to facilitate the data sharing in the proposed architecture. We referred to the template written by authors in [32] to write the pseudocode for our proposed smart contract. The four functions written in the contract are *create_data*, *search_data*, *delete_data* and *find_data*. There are seven variables named *ContractId*, *name*, *age*, *gender*, *address*, *expiry_date* and *currentID*. An array named *users* is created to contain the instances of the structure, *User*.

In the function *create*, users can fill in the data they want to share. For testing purpose, four personal information such as

name, age, gender and address are chosen to be shared by the user. The expiry date of the data is also set by the users (in the format of DDMMYY) to prevent the data from being kept longer than necessary. If users only wish to share their name, they can fill in the remaining fields with "NIL" or "0". Once the user creates their data, the variable *currentID* is incremented by 1.

In the function *search_data*, index of the structure *User* that we need is retrieved. *User* enters their index/smart contract ID and passes it to the function *find_data*. A for-loop statement is then used to find if the smart contract ID entered by the user exists in record. If there is no relevant entry, an error message is displayed and cancels the current execution. This function is called as the Access Protocol in the architecture.

In the function *delete_data*, users enter their smart contract ID. The function takes a single argument and calls the function *find_data* to get the index of the structure in the users array. If the relevant index/smart contract ID is found, the data associated to the index is deleted.

Algorithm II: Truffle test case for smart contract

```
const DataSharing = artifacts.require('DataSharing.sol');

contract('DataSharing',() => {
let datasharing = null;
before(async() => {
datasharing = await DataSharing.deployed();
});

it('Creating new dataset', async () => {
await datasharing.create('Hasventhran', 26, 'Male',
'Malaysia', 110721);
const user_data = await
datasharing.search_data(1010);
assert(user_data[0].toNumber() === 1010);
assert(user_data[1] === 'Hasventhran');
assert(user_data[2].toNumber() === 26);
assert(user_data[3] === 'Male');
assert(user_data[4] === 'Malaysia'
assert(user_data[5] === '110721');
});

it('Deleting a dataset', async () => {
await datasharing.delete_data(1010);
try {
await datasharing.search_data(1010);
} catch(e) {
assert(e.message.includes('Smart
Contract ID does not exist!'));
return;
}
assert(false);
});

it('Should NOT delete a dataset with non-existing details', async
() => {
try{
await datasharing.delete_data(1010);
} catch(e){
assert(e.message.includes('Smart
Contract ID does not exist!'));
return;
}
assert(false);
});
});
```

A test case was written in Javascript to test the smart contract's correctness in the architecture. Three public functions of the smart contract, *create_data*, *search_data* and *delete_data* were included in the test case as shown above. The

function *find_data* is not included as it is an internal/private function of the smart contract to access the smart contract ID assigned to the user. *search_data* is a function that depends on the value passed by *find_data*. Successful test of *search_data* ensures the passing of *find_data*.

In the first *it* function in the test case, *create* is tested by adding smart contract ID and five different values according to the data types defined in the smart contract. The *search_data* function is also defined in this function as it can be tested along with the *create_data* and *delete_data* functions. Successful test of these two functions ensures the passing of *search_data*.

The *delete_data* function is separated into two *it* functions. The first function tests whether the dataset is correctly deleted after obtaining the smart contractID from the *search_data* function. If the smart contract ID does not exist, it should be able to display an error message. The second *it* function checks for the smart contract's correctness in not deleting data with non-existing details.

The contract is tested on Ropsten network of Geth with the truffle command, *truffle test*. As shown in Fig. 8, all three *it* functions of the test has successfully passed the test. Hence, the correctness of the smart contract is ensured. Hence, it can be deployed in the architecture to enforce AP and RP.

```
C:\Users\ASUS>cd Desktop\TestContract
C:\Users\ASUS\Desktop\TestContract>truffle test
Using network 'test'.

Compiling your contracts...
=====
> Compiling .\contracts\DataSharing.sol
> Compiling .\contracts\Migrations.sol
> Artifacts written to C:\Users\ASUS\AppData\Local\Temp\test--17100-V6RQ7uf9c5Sd
> Compiled successfully using:
   - solc: 0.5.16+commit.9c3226ce.Emscripten.clang

Contract: DataSharing
  ✓ Creating new dataset (613ms)
  ✓ Deleting a dataset (758ms)
  ✓ Should NOT delete a dataset with non-existing details (253ms)

3 passing (2s)
```

Fig. 8. Successful test of smart contract.

3) *Stealth address*: A python script is written to test stealth address. This python script uses the *pyspv* library to run the stealth address functions. This script is tested on a simulated blockchain and it is explained below. Data Controller is mentioned as Data User in the code sections.

```
def main () :
    Data_User_key=pyspv.keys.PrivateKey.create_new()

    Data_User_public_key=Data_User_key.get_public_key(
        True)
    print("Data_User's public key=",Data_User_public_key.as_hex())
```

Code Snippet 1 Creating Data Controller's public key

Python's *pyspv* library is used to test stealth address functions. Data Controller's public and private key is created through the code shown in the code snippet 1.

```
Data_Subject_key = pyspv.keys.PrivateKey.create_new()
Data_Subject_public_key=Data_Subject_key.get_public_key(True)
Data_Subject_shared_secret_point=Data_User_public_key.multiply(
    Data_Subject_key.as_int())
print("Ephemeral key (Data_User needs this to redeem) = ",
    Data_Subject_public_key.as_hex())
```

Code Snippet 2 Data Subject creating new key for Data Controller

The same method applies for the Data Subject in the section of code below. The Data Subject's public and private key is also created and shown in code snippet 2. The Data Subject wants to pay/send data to the Data Controller. So, the Data Controller gives the Data Subject his/her public key. Then, the Data Subject creates a new key and multiplies the Data Controller's public key with his/her private key and sends her public key to the Data Controller as shown in the code in code snippet 2.

```
import hashlib
hasher = hashlib.sha256()
hasher.update(Data_Subject_shared_secret_point.pubkey)
shared_secret = hasher.digest()
print("Shared secret =", pyspv.bytes_to_hexstring(shared_secret,
    reverse=False))
```

Code Snippet 3 Hashing the shared secret

The next task is to hash the shared secret. Python's *hashlib* library is used to hash the shared secret with SHA256 algorithm. This is done by the code in code snippet 3.

```
new_Data_User_public_key=Data_User_public_key.add_constant(int.from_bytes(shared_secret, 'big'))
print("New_Data_User Public Key = ",
    new_Data_User_public_key.as_hex())
print("New_Data_User=",new_Data_User_public_key.as_address(pyspv.Bitcoin))
```

Code Snippet 4 Adding shared secret to Data Controller's public key

After hashing the shared secret, it is added to the Data Controller's public key. This will be used later to compute the Data Controller's private key. This is done by the code in code snippet 4.

```
Data_User_shared_secret_point=Data_Subject_public_key.multiply(Data_User_key.as_int())
```

Code Snippet 5 Computing the private key to Data Controller

```
hasher = hashlib.sha256()
hasher.update(Data_User_shared_secret_point.pubkey)
shared_secret_by_Data_User = hasher.digest()
print("Data User figured out the shared secret =",
    shared_secret_by_Data_User == shared_secret)
```

Code Snippet 6 Producing the shared secret by hashing private key

In order to compute the private key to the new Data Controller public key, the Data Controller has work to do as

shown in code snippet 5. First, the Data Controller multiplies the ephemeral key produced by the Data Subject by his private key. Then, the shared key is produced by the Data Controller by hashing the private key as shown in code snippet 6.

```
new_Data_User_key=Data_User_key.add_constant(int.from_bytes(shared_secret_by_Data_User, 'big'))
new_Data_User_computed_public_key=new_Data_User_key.get_public_key(True)
print("Data_User figured out the correct private key =",new_Data_User_computed_public_key.pubkey==new_Data_User_public_key.pubkey)
```

Code Snippet 7 Adding the Shared Secret to the Private Key

Finally, Data Controller adds the shared secret to his private key as shown in code snippet 7. This works because, given $Q = dG$, then $(d+n)G = dG + nG = Q + nG$ and the Data Subject computed $Q + nG$ above and sent data to the Data Controller, but now the private key $d+n$ is known.

V. CONCLUSION

This research aimed to produce a PDPA-compliant user-centric privacy preserving features for blockchain based data sharing architecture. Blockchain was chosen to be the platform to develop the data sharing architecture, due to its inherent privacy properties and also flexibility of implementing other features on top of it. Based on the gaps identified by literature review, features such as private blockchain, use of data controllers, stealth address, smart contracts (with access and retention protocols), and off-chain storage are identified to produce the proposed architecture with user control being given importance. The results indicate that the implemented features fulfil the required PDPA regulations.

The proposed blockchain architecture is developed mainly to comply with PDPA in Malaysia. The architecture is appropriate to be followed for Malaysian context. It is acceptable to use the proposed architecture to develop any data management solutions using blockchain in Malaysia. However, the proposed architecture may not be suitable to be used in a general manner globally due to different data protection regulations all around the world.

The proposed blockchain architecture is developed by combining existing privacy preserving and user-centric components. Moreover, the proposed architecture can be used by blockchain developers to develop data management solutions without worrying about the potential breach of privacy. This is because the proposed architecture adheres to the "privacy by design" principle.

This research proposed a user-centric privacy preserving blockchain architecture for data sharing according to existing data protection regulations. Hence, to better understand the effectiveness of the architecture, future studies can implement the architecture for various type of data sharing solutions across multiple fields. These new solutions derived from the proposed architecture can also be modified according to compliance with each country's data privacy protection regulations.

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REFERENCES

- [1] Pandey, V. and Kulkarni, U., Effective data sharing with forward security: Identity based ring signature using different algorithms. 2017 International Conference on Intelligent Computing and Control (I2C2), 2017.
- [2] Jin, H., Luo, Y., Li, P. and Mathew, J., A Review of Secure and Privacy-Preserving Medical Data Sharing. IEEE Access, 7, pp.61656-61669, 2019.
- [3] Data Republic, The importance of data sharing, <https://www.datarepublic.com/resources/resources-guides/the-importance-of-data-sharing-for-all-organizations>, Accessed 18th July 2021.
- [4] OECD iLibrary, Risks and challenges of data access and sharing, Enhancing Access to and Sharing of Data : Reconciling Risks and Benefits for Data Re-use across Societies, <https://www.oecd-ilibrary.org/sites/15c62f9c-en/index.html?itemId=/content/component/15c62f9c-en>, Accessed 7th August 2021.
- [5] M. Kosinski, D. Stillwell and T Graepel, "Private traits and attributes are predictable from digital records of human behavior", Proc. Nat. Acad. Sci. USA, vol. 110, pp. 5802-5805, 2013.
- [6] [20] S. D. Warren and L. D. Brandeis, "The right to privacy", Harvard Law Rev., vol. 4, no. 5, pp. 193-220, 1890.
- [7] H. J. Smith, T. Dinev and H. Xu, "Information privacy research: An interdisciplinary review", MIS Quart., vol. 35, no. 4, pp. 989-1015, 2011.
- [8] Wickramaarachchi, W., Alhaj, Y. and Gunsekera, A., Effective Privacy-Preserving Iris Recognition. 2019 IEEE 4th International Conference on Image, Vision and Computing (ICIVC), 2019.
- [9] Belen Saglam, R., Aslan, C., Li, S., Dickson, L. and Pogrebna, G., A Data-Driven Analysis of Blockchain Systems' Public Online Communications on GDPR. 2020 IEEE International Conference on Decentralized Applications and Infrastructures (DAPPS), 2020.
- [10] Parizo, C., 2021. What are the 4 different types of blockchain technology?, <https://searchcio.techtarget.com/feature/What-are-the-4-different-types-of-blockchain-technology>, Accessed 25th July 2021.
- [11] GeeksforGeek, Consensus Algorithms in Blockchain, <https://www.geeksforgeeks.org/consensus-algorithms-in-blockchain/>, Accessed 9th May 2021.
- [12] Baskaran, H., Yussof, S. and Rahim, F., A Survey on Privacy Concerns in Blockchain Applications and Current Blockchain Solutions to Preserve Data Privacy, 2020.
- [13] Bajoudah, S., Dong, C. and Missier, P., Toward a Decentralized, Trust-Less Marketplace for Brokered IoT Data Trading Using Blockchain. 2019 IEEE International Conference on Blockchain (Blockchain), 2019.
- [14] Xiong, W. and Xiong, L., Smart Contract Based Data Trading Mode Using Blockchain and Machine Learning. IEEE Access, 7, pp.102331-102344, 2019.
- [15] Chen, C., Wu, J., Lin, H., Chen, W. and Zheng, Z., A Secure and Efficient Blockchain-Based Data Trading Approach for Internet of Vehicles. IEEE Transactions on Vehicular Technology, 68(9), pp.9110-9121, 2019.
- [16] Onik, M., Kim, C., Lee, N. and Yang, J., Privacy-aware blockchain for personal data sharing and tracking. Open Computer Science, 9(1), pp.80-91, 2019.
- [17] Department of Personal Data Protection, <https://www.pdp.gov.my/jpdpy2/assets/2020/01/Introduction-to-Personal-Data-Protection-in-Malaysia.PDF>, Accessed 24th July 2021.

- [18] Personal Data Protection Act 2010 (Act 709). Malaysia: Parliament of Malaysia, 2010.
- [19] Edwards, J., 6 business benefits of data protection and GDPR compliance, <https://searchdatabackup.techtarget.com/tip/6-business-benefits-of-data-protection-and-gdpr-compliance>, Accessed 17th July 2021.
- [20] General Data Protection Regulation (GDPR), General Data Protection Regulation (GDPR) – Official Legal Text. <https://gdpr-info.eu>, Accessed 25th April 2021.
- [21] Baskaran, H., Yussof, S., Rahim, F. and Bakar, A., Blockchain and the Personal Data Protection Act 2010 (PDPA) in Malaysia. 2020 8th International Conference on Information Technology and Multimedia (ICIMU), 2020.
- [22] Patrick, What are Stealth Addresses?, Mycryptopedia. Available at: <https://www.mycryptopedia.com/everything-need-know-stealth-addresses/>, Accessed 19th April 2021.
- [23] Kumar, R., Marchang, N. and Tripathi, R., Distributed Off-Chain Storage of Patient Diagnostic Reports in Healthcare System Using IPFS and Blockchain. 2020 International Conference on COMMunication Systems & NETworkS (COMSNETS), 2020.
- [24] Li, H. and Han, D., EduRSS: A Blockchain-Based Educational Records Secure Storage and Sharing Scheme. IEEE Access, 7, pp.179273-179289, 2019.
- [25] Kumar, R. and Tripathi, R., A Secure and Distributed Framework for sharing COVID-19 patient Reports using Consortium Blockchain and IPFS. 2020 Sixth International Conference on Parallel, Distributed and Grid Computing (PDGC), 2020.
- [26] Multichain.com. 2021. MultiChain for Developers | MultiChain, <https://www.multichain.com/developers/>, Accessed 15th May 2021.
- [27] Wang, S., Li, D., Zhang, Y. and Chen, J., Smart Contract-Based Product Traceability System in the Supply Chain Scenario. IEEE Access, 7, pp.115122-115133, 2019.
- [28] Gupta, R., Shukla, A. and Tanwar, S., AaYusH: A Smart Contract-Based Telesurgery System for Healthcare 4.0. 2020 IEEE International Conference on Communications Workshops (ICC Workshops), 2020.
- [29] Patidar, K. and Jain, S., Decentralized E-Voting Portal Using Blockchain. 2019 10th International Conference on Computing, Communication and Networking Technologies (ICCCNT), 2019.
- [30] Ranganathan, V., Dantu, R., Paul, A., Mears, P. and Morozov, K., A Decentralized Marketplace Application on the Ethereum Blockchain. 2018 IEEE 4th International Conference on Collaboration and Internet Computing (CIC), 2018.
- [31] BouSaba, C. and Anderson, E., Degree Validation Application Using Solidity and Ethereum Blockchain. 2019 SoutheastCon, 2019.
- [32] Kirit, N. and Sarkar, P., EscrowChain: Leveraging Ethereum Blockchain as Escrow in Real Estate, ResearchGate, 2017.

Assessing the Impact and Effectiveness of Cybersecurity Measures in e-Learning on Students and Educators: A Case Study

Ala'a Saeb Al-Sherideh^{1*}, Khaled Maabreh², Majdi Maabreh³, Mohammad Rasmi Al Mousa⁴, Mahmoud Asassfeh⁵

Department of Cyber Security-Faculty of Information Technology, Zarqa University, Zarqa, Jordan^{1,4,5}

Department of Data Science and Artificial Intelligence-Faculty of Science and Information Technology, Irbid National University, Irbid, Jordan²

Department of Information Technology-Faculty of Prince Al-Hussein Bin Abdallah II for Information Technology, The Hashemite University, Zarqa, Jordan³

Abstract—As e-learning has become increasingly prevalent, cyber security has become a major concern. e-Learning platforms collect and store large amounts of sensitive information, such as personal data and financial information, making them attractive targets for cybercriminals. To address these challenges and concerns, e-learning platforms must implement a comprehensive cyber security strategy that includes strong access controls, data encryption, regular software updates, and student training to help them identify and prevent insider threats. This research aims at investigating and determine how satisfied students are with e-learning security and privacy, as well as whether these concerns affect the overall standard of education. A sample study is presented to assess both the impact of the security framework on students' academic achievements and the student's satisfaction with the security countermeasures in an e-learning system. Statistical analysis showed that the use of security and cyber security countermeasures had a significant effect on the frequent use and participation of students in the contents of the system. Furthermore, encouraging feedback and communication from students about their e-learning experience to share their concerns, questions, and suggestions can help in addressing any security issues or concerns, as well as increasing students' participation in the e-learning content.

Keywords—e-learning; security; cyber security; privacy; countermeasure; Moodle; education

I. INTRODUCTION

Technological advancements have significantly impacted the field of education, particularly with the rise of online learning (e-learning). e-Learning refers to the use of digital technology to deliver educational content over the internet [1]. With e-learning, students can access learning materials and participate in classes and discussions from virtually anywhere, using their computers or mobile devices. Technological advancements include high-speed internet connections, learning management systems, video conferencing software, and mobile applications. These tools have made it possible for educators to create engaging and interactive online courses that can be accessed by students all around the world. Furthermore, students can learn at their own pace, review materials as often as they need to, and access course materials anytime, anywhere. Additionally, online learning can be less expensive than traditional classroom-based learning since it eliminates the

need for travel and other associated expenses. In the age of technological advancement and transformation in the field of education, and for the considerations mentioned above, the significance of improving the security environments for e-learning systems is growing daily.

Now-a-days, many universities have turned to electronic learning as an efficient solution for providing on-demand learning to their instructors and students. Therefore, and because e-learning primarily depends on Internet technology to achieve its function, information security and cybersecurity become hot topics in the e-learning environment to avoid vulnerabilities and security weaknesses regarding user privacy and content protection [1]. As a result, cybersecurity becomes a key concern when dealing with user privacy, authentication, and confidentiality [7][24][25]. Thus, there is an increasing and significant need for the adoption of strong security countermeasures to protect users' information against any malicious attack. The rest of this study is organized as follows: the next section introduces a background about the e-learning platforms and their impact on security. Section III discusses the related works, the study objectives, and hypothesis is presented in Section IV, Section V states the results and finally, the conclusion is drawn in Section VI.

II. BACKGROUND

Security in e-learning refers to the protection of the system and data from unauthorized access, alteration, or destruction. Cybersecurity, on the other hand, refers to the protection of digital systems, networks, and data from cyber threats such as hacking, malware, phishing, and ransomware attacks. In the context of e-learning, cybersecurity involves protecting e-learning platforms from such attacks, ensuring the integrity of the data, and minimizing the risk of data breaches.

A. e-Learning Platform Architecture

The architecture of an e-learning platform is designed to provide a seamless user experience while ensuring that all data is stored securely and managed efficiently. It typically includes several key components that are integrated to deliver content and services to users. The main components of an e-learning architecture are [2][3]:

1) **User Interface:** Front-end component that users interact with to navigate the platform, access courses, and manage their profiles.

2) **Application Server:** The middleware layer that connects the user interface with the e-learning platform's back-end. It receives requests from the user interface, processes them, and sends back responses.

3) **Database:** The back-end component provides a centralized storage location that stores all data related to courses, users, progress tracking, and other information.

4) **Content Management System:** The component that manages course content, including the creation, editing, and delivery of course materials.

5) **Learning Management System:** The component that manages the delivery of courses and tracks user progress. It provides features such as course enrollment, tracking, and reporting.

6) **Authentication and Authorization:** Manages user authentication and authorization to ensure that only allowed users can access the e-learning system.

7) **Security:** Responsible for ensuring the e-learning is secure from external threats, including attacks on user data and platform infrastructure.

B. Moodle e-Learning System

Moodle is a popular open-source e-learning platform used by many educational institutions and organizations around the world. Irbid National University (INU) as a case study in this research uses the Moodle e-learning system. The Moodle database schema includes a set of tables and relationships that define how data is stored and organized within the system. Some of the key tables in the Moodle database schema include, for example, the Users table, which stores information about each user in the system, including their first and last name, username, password, email address, and role. The courses table stores information about each course in the system, including its name, description, start and end dates, and visibility settings. Grades: This table stores information about the grades earned by each user in each course. It includes fields for the user ID, course ID, module ID, and grade value. Tables in the database schema are linked together through a series of relationships that define how data is accessed and manipulated within the system. Moodle supports the use of a distributed database architecture, where the database layer is designed to be abstracted from the rest of the system, which means that it can be replaced with different database solutions depending on the needs of the installation. With the distributed database, the data is distributed across multiple nodes, providing greater scalability and fault tolerance than a single database instance [4]. Moreover, it can improve security by replicating data across multiple servers or nodes, making it more difficult for hackers to access or manipulate the data.

C. Security Challenges on e-Learning Arising from the COVID-19 Pandemic

Since the educational process is based primarily or fully on online platforms, the risks presented by e-learning cybersecurity attacks significantly increased during the

coronavirus epidemic. Electronic educational tools' reliability and accessibility are now essential, as teaching is impossible without them [5]. Recently, important steps have been taken to create an appropriate legislative framework to ensure an acceptable level of cybersecurity is obtained in Jordan. Jordan is globally ranked 73 on the Global Security Index. They established a National Center for Cybersecurity to strengthen the policies and procedures [6]. The education infrastructure comprises universities, colleges, schools, libraries, teachers, and students. Education infrastructure is more critical when compared to other systems because, for example, universities are designed as open spaces for research and information, making them vulnerable to cyber-attacks even by using simple methods like email attachments [3][13]. So, new cybersecurity measures for educational institutions are necessary. An approach to managing educational resources must take into account the current global environment by adopting new strategies that give digital educational resources far greater consideration [5].

D. Security Issues in e-Learning

e-Learning faces several security issues that organizations and individuals need to be aware of. Some of these issues are:

1) **Data privacy:** One of the biggest concerns in e-learning is data privacy [7][8][24][25]. e-Learning platforms store a vast amount of sensitive information, including personal information such as names, addresses, and email addresses, as well as sensitive information such as course progress and assessment results [9].

2) **Cybersecurity:** e-Learning platforms are susceptible to cybersecurity threats, such as hacking, phishing, and malware attacks [10][26][27]. Hackers may target e-learning platforms to gain access to sensitive data or disrupt the system.

3) **Identity theft:** Identity theft is a severe security issue in e-learning. Hackers may steal personal information to impersonate a user and gain access to e-learning platforms [11].

4) **Intellectual property:** e-Learning platforms contain valuable intellectual property, including course materials, videos, and assessments [12].

Therefore, e-learning platforms must implement robust security measures to protect sensitive data and intellectual property from cybersecurity threats. Organizations and individuals must also be aware of these security issues and take appropriate precautions to safeguard their information [14]. This research aims to evaluate the degree to which students are satisfied with e-learning security and privacy as well as to examine whether these issues have an impact on the overall quality of education. Measuring the effect of e-learning security on the academic environment is a complex task because other factors can affect it, such as the technology used, how students trust learning as online than others, and the student's background on security challenges and cyberspace.

In conclusion, this research focuses on responding to the following study questions:

- What are the students' attitudes toward e-learning security?

- Does e-learning security affect the quality of education?
- Does the security of the e-learning system influence the students' achievements?
- Do the students trust e-learning content?

III. RELATED WORKS

In recent years, there has been an increasing amount of research regarding online learning education. Several studies have begun to examine e-learning regarding design and efficiency. Other earlier studies have concentrated on how the e-learning environment affects student achievement [15][16], while others have discussed and analyzed the performance of those systems. The need for secure online learning environments has given rise to many studies that aim to address the growing significance of the security and sensitivity of an e-learning system's contents. Habib et al. [1] discuss cybersecurity issues related to the e-learning management system, the significance of e-learning, and the database management system also presented, along with the methods that lessen them. Their paper has provided some remedies for obtaining data integrity and recommends that government agencies provide more financial funding to improve the quality of the e-learning system. A survey of the current protections of e-learning systems based on the source of vulnerabilities is presented by Satria et al. [17] They categorize the open-source learning systems as vulnerable points because these systems have suffered many attacks due to security problems. Emad and Mustafa [18] discuss DB integrity and data confidentiality using access control policies and data encryption as two of the main pillars in building information systems.

As e-learning systems are increasingly used by universities due to the low costs associated with education, Ioan et al. [19] presented the security issues related to these platforms. Such issues can be used by cybercriminals for phishing and spamming activities. They suggest law authority enforcement cooperate with academia and private sectors fight to these threats. Anghel and Pereteanu [20] illustrated different approaches that manage the cyber security issues related to e-learning systems. They also showed some practice examples concerning cyber security management techniques and suggested implementing security policies and procedures accepted by individuals to overcome those security threats. The effectiveness of e-learning as well as the potential security issues are discussed by Nguyen et al. [21]. Suggested countermeasures to deal with the security attacks are also outlined. The main recommended countermeasure to make the users feel secure was cryptography.

By reviewing previous studies related to the subject of this research, the researchers focus on the security issues that threaten e-learning systems and suggest effective solutions to mitigate the security attack on the contents of those systems [22]. This research will investigate the security of a database server, which contains the user information and the cyberspace through which this information travels.

IV. STUDY OBJECTIVES AND HYPOTHESIS

The study of security in e-learning should equip students with the necessary knowledge and skills to protect themselves and their data, while also promoting the responsible and ethical use of e-learning systems. Important aspects of security and cybersecurity in e-learning systems include:

- Understanding the potential security threats, where students should be able to identify the various types of security threats that can affect e-learning systems, such as hacking, phishing, and malware attacks.
- Knowledge of security measures: Students should learn about the various security measures that can be implemented to protect e-learning systems, such as encryption, firewalls, and multi-factor authentication.
- Learning how to protect personal information: e-Learning students should be taught how to safeguard their personal information, such as usernames, passwords, and credit card details, from theft or misuse.
- Familiarity with data protection regulations: Students should be familiar with data protection laws and regulations that govern e-learning systems, such as the General Data Protection Regulation (GDPR).
- Awareness of ethical considerations: e-Learning students should be taught about ethical considerations regarding the use of e-learning systems, such as respecting the privacy of other students, not plagiarizing content, and using technology responsibly.
- Preparation for emergencies: Students should be taught how to respond to emergencies, such as a cyber-attack or a system failure, and how to protect themselves and their data in such situations.

To evaluate the current situation of the e-learning system as a case study, find the strengths and weaknesses points in the security structure of those systems, and propose suitable recommendations that would improve the services provided, this study aims to suggest and investigate the security measures that are needed to evaluate the satisfaction and acceptance of students towards e-learning services. The measurement process will be analyzed through the following hypothesis: The use of e-learning systems that prioritize security and privacy are more likely to be perceived positively by students and may result in higher levels of engagement, satisfaction, and academic achievement.

A. Methods and Procedures

Methods and procedures are standardized and systematic approaches used to solve problems or answer questions in a study field. They involve a step-by-step process that helps to ensure that the solution is accurate, reliable, and repeatable. The process typically involves the next steps and methods observed:

- Collecting the necessary information on the e-learning security measures and students' perceptions of them.

- Designing a questionnaire that addresses the study's objectives.
- Selecting the right sample of respondents.
- Analyzing the information gathered and concluding the findings.

B. The Population of the Study

As the population of a study refers to the group of individuals that the research is focused on, it must determine the generalizability and validity of the research findings. Since studying the whole population is costly and impractical, a sample is selected to observe and measure the study hypotheses. The population of this study consisted of undergraduate students enrolled in four faculties at the Irbid National University, Jordan. The students are chosen from the second year or higher because they are expected to have some experience using the e-learning system. Their age range is 19 to 23 years old. In this study, the margin of accepted error is assumed to be five, the confidence level needed is 95% and the response distribution is expected to be 80%. Based on the study's objectives, time availability, research budget, and degree of precision, the sample size is 200 students out of 1000 in the four colleges.

C. Sample of the Study

A small-scale survey was created based on the study objectives to measure how students trust the Moodle e-learning system's security and privacy. Two hundred (200) students were chosen at random to receive the questionnaire. One hundred eighty four (184) respondents correctly completed it. The demographic distribution of the students by field of study is shown in Table I.

TABLE I. TOTAL RESPONDENTS BY COLLEGE

Collage	Male	Female	Total Number	Percentage
Faculty of science and information technology	50	28	78	42.40
Faculty of Business Administration and Finance	27	24	51	27.71
Faculty of Nursing	9	19	28	15.22
Faculty of Law	16	11	27	14.67
Total	102	82	184	100

By monitoring the response rate which exceeds 90%, we hope that the sample accurately reflects the population interested in the study.

D. Questionnaire Items

An online survey was used to investigate students' opinions about the security and privacy of the e-learning system operated by Irbid National University. The online survey has been circulated via Facebook and WhatsApp groups. The survey includes 25 questions, distributed as follows: Questions 1–5 were used to collect general information (e.g., gender, year of study, familiarity with using internet resources). Questions 6–15 were used to collect information about students' attitudes toward the level of satisfaction with the current security measures used in the e-learning system. Finally, questions 16–25 were used to measure students' attitudes regarding the influence of the e-learning system with the current security and

privacy procedures on their achievements. To facilitate the measurement of the study's hypotheses, questions 6–25 are grouped into eleven categories, as shown in Table II.

E. Study Hypotheses

Ho: e-Learning platforms that are hosted on secure servers do not affect the levels of user trust and confidence.

Ha: e-Learning platforms that are hosted on secure servers will lead to higher levels of user trust and confidence.

V. RESULTS AND DISCUSSION

This study uses a 5-point Likert scale because it balances variation in responses and nuanced opinions while remaining simple and easy to use [23]. Meanwhile, respondents are less likely to become confused or overwhelmed when faced with a complex or lengthy survey. It also lessens the central tendency bias and makes the measurement process easier. Table II shows the percentage of the student responses for each group (strongly agree, agree, strongly disagree, disagree, and do not know). The "do not know" response is used for missing answers or a student's actual answer to some study questions.

As shown in Table II, 56% of students are satisfied with the current security level, which is considered a low indication regarding security and cybersecurity. This may be due to several reasons, including a lack of awareness, which can lead to confusion and frustration and may result in lower levels of satisfaction with the security level, or students may feel that their data is not being adequately protected. Another possible reason may regard some technical issues, such as slow load times or frequent errors, which may lead to dissatisfaction among students. To address these issues, educators and institutions need to prioritize student security and take steps to ensure that students are fully informed and aware of the security measures in place. This can include providing clear and concise instructions on how to use security features, regularly updating security measures, and being transparent about how student data is collected and used. Additionally, educators and institutions should regularly gather feedback from students and take steps to address any issues or concerns that arise.

Data in Table II indicates that there is a reluctance among students to use the system in the event of security attacks (88%), while their confidence increases when the system adopts strict countermeasures (69%). Furthermore, if students perceive the e-learning system as insecure, they may be more likely to seek out alternative ways of accessing course content and resources, such as through unsecured channels or external websites. This could increase the risk of data breaches and compromise the security of student data. Therefore, it is important for educators and institutions to take student concerns about e-learning system security seriously and to take steps to address them. This can include implementing additional security measures, such as two-factor authentication or data encryption, and providing clear and transparent information about how student data is collected, stored, and used. Educators and institutions can help to build trust and confidence among students in the security of e-learning systems. This, in turn, can lead to increased engagement and academic achievement, as students feel more comfortable and

secure in using the system to access course materials and interact with their peers and instructors. By adopting these measures, educators and institutions can demonstrate their commitment to student data privacy and security, fostering trust and confidence among students in the e-learning environment. As long as more than 90% of students expressed their desire to take intensive courses relating to cybersecurity and its latest developments. More than 86% of students, as shown in Table II, concur that improving the security of the Moodle e-learning platform will increase student achievement and engagement, which may either directly or indirectly improve their academic performance.

The use of personal devices in e-learning systems has become increasingly popular in recent years. With the proliferation of smartphones, tablets, and laptops, students now have access to a wide range of digital devices that can be used to support their learning. However, there are also some potential drawbacks to using these devices. One concern, as expressed by 64% of respondents, is that it can increase the risk of data breaches and cyber-attacks due to the potential for unsecured devices and networks. So, it is important for educators and institutions to carefully consider how to effectively integrate these devices into their teaching and learning strategies and to ensure that all students have equal access to learning resources and opportunities. Cloud-based storage allows data to be stored securely on remote servers

rather than on individual devices. This means that if a student's device is lost or stolen, their data remains safe and can be accessed from another device. Additionally, cloud-based storage can provide automatic backups of data, reducing the risk of data loss. 67% of students indicated this positively. Enhancing the security countermeasures in the e-learning system can potentially enhance student engagement and achievement. When students feel that their data is secure, they may be more likely to actively engage with the e-learning system and its resources, leading to increased achievement. By implementing the necessary security measures, students may feel more confident in using the Moodle e-learning system and its resources. This, in turn, can lead to increased engagement and achievement, as 86% of students state.

Social engineering is indeed an important aspect of e-learning security that should not be overlooked. 92% of students, report having encountered social engineering-related problems and affirm that intensive training boosts their confidence in the e-learning system and helps them protect their data. Protecting students from such issues requires a combination of technical and educational measures, including educating them about the tactics used by cybercriminals, such as phishing and pre-texting baiting. Providing two or more forms of authentication, including a strong password and a one-time code, makes it more difficult for cybercriminals to gain access to accounts.

TABLE II. RESULTS OF THE STUDY SURVEY

Response Option	Strongly Agree	Agree	Strongly Disagree	Disagree	Do not know
The current Moodle e-learning system is considered a secure and effective learning tool.	0.29	0.27	0.2	0.22	0.02
Students who report concerns about e-learning systems security may be less likely to use the system frequently which could lead to reduced engagement and academic achievement.	0.43	0.45	0.07	0.03	0.02
Students who perceive e-learning systems as secure may be more likely to use the system frequently and engage with it more effectively.	0.41	0.44	0.08	0.06	0.01
Students who are required to use strong security measures such as strong passwords or two-factor authentication may perceive the system as more secure and trustworthy.	0.33	0.36	0.11	0.14	0.06
Students who receive training on e-learning system security best practices may be more likely to engage with the system and use it effectively and may also report higher levels of trust and confidence.	0.47	0.44	0.02	0.04	0.03
Students who receive regular updates and communication about the e-learning system's security can help them feel more informed about the security measures, leading to more positive attitudes and trust.	0.41	0.43	0.03	0.07	0.06
Students who receive training on cyber security practices and awareness may be more likely to protect their personal data and privacy.	0.51	0.41	0.01	0.03	0.04
The use of personal devices in e-learning systems can increase the risk of data breaches and cyber-attacks due to the potential for unsecured devices and networks.	0.31	0.33	0.16	0.19	0.01
e-Learning systems that use cloud-based storage and security measures can help protect student data and privacy when using personal devices and networks.	0.34	0.33	0.15	0.1	0.08
Enhancing the security countermeasures in the Moodle e-learning system will enhance the student's engagement and achievement.	0.42	0.44	0.03	0.05	0.06
Providing training to students on how to recognize and avoid phishing or fraudulent emails and other forms of cybercrime is an important step in promoting digital safety and security. It can help to develop better digital literacy skills and create a safer online environment for all users.	0.49	0.45	0.01	0.03	0.02

A. Statistical Analysis

The data collected is analyzed using descriptive statistics to summarize their frequency and distribution. The study sample and variables were described using frequencies and standard deviations. To ascertain whether there were any statistically significant differences between the study group means, the one-way analysis of variance (ANOVA) was also utilized to prove the study hypothesis. All statistical analyses were performed using SPSS version 25.0. It specifically evaluates the null hypothesis, thus if there are at least two group means that are statistically significantly different from one another, the alternative hypothesis (Ha) will be accepted.

According to the statistical analysis shown in Table III, the "Strongly Agree" group has the highest mean (0.40), followed by the "Agree" group (0.39). Strongly disagree, disagree, and do not know with respective mean values of 0.07, 0.08, and 0.03. The research reveals that the 'Strongly Agree group' has the highest standard deviation (0.074), which is relatively small and indicates less dispersion than the means of the other groups. Because of this, there is a large statistical difference between the groups. A low standard error indicates that the data points in a sample are tightly clustered around the sample mean, suggesting that the sample accurately represents the population being studied and that the estimated value is closer to the true population parameter. An ANOVA test for the study variables at a 0.95 confidence interval is figured in Table IV. The value of P (9.03518E-23) is less than 0.05, which indicates that the probability of obtaining the observed test statistic under the null hypothesis is very low, and hence, the null hypothesis is unlikely to be true. Consequently, there is evidence to imply that there is a statistically significant difference between the means of the variables for at least one of the groups being compared. As a result, the alternative hypothesis (Ha) has been accepted and the null hypothesis (Ho) has been rejected. So, e-learning platforms that are hosted on secure servers will lead to higher levels of user trust and confidence.

TABLE III. DESCRIPTIVE STATISTICS OF THE STUDY VARIABLES

Groups	Count	Sum	Average	Variance	Std. Dev.	Std. Error
Strongly agree	11	4.41	0.400909	0.005529	0.0743	0.02241
Agree	11	4.35	0.395454	0.003887	0.0623	0.01879
Strongly disagree	11	0.87	0.079090	0.004509	0.0671	0.02024
Disagree	11	0.96	0.087272	0.004561	0.0675	0.02036
Do not know	11	0.41	0.037272	0.000581	0.0241	0.00727

TABLE IV. ANOVA TEST FOR THE STUDY VARIABLES AT A = 0.05

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.456109	4	0.36402	95.4495	9.03518	2.55717
Within Groups	0.190690	50	0.00381	614	E-23	915
Total	1.6468	54				

VI. CONCLUSION AND FUTURE WORK

With the increasing popularity of e-learning, there has been a corresponding rise in security and cybersecurity concerns. This is because e-learning platforms and tools store and transmit sensitive information, such as personal identification details, financial information, and intellectual property. Therefore, e-learning platforms are also vulnerable to cyber threats due to the large amounts of data they handle, the use of multiple devices and networks, and the diversity of users.

This research aims at exploring whether e-learning security and privacy concerns have an effect on the overall standard of education and can provide valuable insights into the relationship between cybersecurity and educational outcomes. The effectiveness of the security framework on students' academic achievement and their satisfaction with the security countermeasures in an e-learning system are both evaluated using a sample study that is presented. Statistical analysis finding suggests that implementing security and cybersecurity countermeasures can positively impact students' engagement with a system. Encouraging feedback and communication from students about their e-learning experience can be an effective way to address any security issues or concerns and improve their engagement with the e-learning content. By actively seeking and listening to feedback, instructors, and administrators can identify potential areas of vulnerability in the system and take steps to improve security measures.

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REFERENCES

- [1] H. Ibrahim, S. Karabatak, and A. A. Abdullahi, "A study on cybersecurity challenges in e-learning and database management system," in 2020 8th International Symposium on Digital Forensics and Security (ISDFS), 2020, pp. 1-5.
- [2] Moodle. (2023, Feb-27-2023). Moodle - Open-source learning platform. Available: <https://moodle.org/>.
- [3] A. M. Udroui, "The cybersecurity of elearning platforms," in Conference proceedings of eLearning and Software for Education «(eLSE), 2017, pp. 374-379.
- [4] K. Maabreh and A. Al-Hamami, "Implementing new approach for enhancing performance and throughput in a distributed database," Int. Arab J. Inf. Technol., vol. 10, pp. 290-296, 2013.

- [5] T.-M. G. Răzvan BOLOGA, "Cybersecurity for Online Learning," in *Cybersecurity -Challenges and Perspectives In Education*, C. C. Ioan-Cosmin MIHAI, Gabriel PETRICĂ, Ed., ed Romania: Romania Association for Information Security Assurance, 2020.
- [6] TresconSyberSec. (2022, Feb-27-2023). World Cybersecurity Summit. Available: <https://tresconglobal.com/conferences/cyber-sec/jordan/>
- [7] M. Alier, M. J. Casañ Guerrero, D. Amo, C. Severance, and D. Fonseca, "Privacy and E-learning: A pending task," *Sustainability*, vol. 13, p. 9206, 2021.
- [8] A. M. Gabor, M. C. Popescu, and A. Naaji, "Security Issues Related To E-Learning Education," *International Journal of Computer Science and Network Security (IJCNS)*, vol. 17, p. 60, 2017.
- [9] T. Husain and A. Budiyantera, "Analysis of Control Security and Privacy Based on e-Learning Users," *SAR Journal*, vol. 3, pp. 51-58, 2020.
- [10] A. Г. Тецький and O. I. Морозова, "Cybersecurity aspects of E-learning platforms," *Radioelectronic and Computer Systems*, pp. 93-97, 2020.
- [11] D. Korać, B. Damjanović, and D. Simić, "A model of digital identity for better information security in e-learning systems," *The Journal of Supercomputing*, pp. 1-30, 2021.
- [12] Z. Mingaleva and I. Mirskikh, "The protection of Intellectual property in educational process," *Procedia-Social and Behavioral Sciences*, vol. 83, pp. 1059-1062, 2013.
- [13] F. Salahdine and N. Kaabouch, "Social engineering attacks: A survey," *Future Internet*, vol. 11, p. 89, 2019.
- [14] O. L. Academy. (2023, Feb-28-2023). eLearning Security: How to Keep Data Protected in Your Open Source LMS. Available: <https://www.openlms.net/blog/products/elearning-security-how-to-keep-data-protected-open-source-lms/>
- [15] K. S. Maabreh, "The impact of e-learning usage on students' achievements: a case study," *International Journal of Knowledge and Learning*, vol. 12, pp. 193-203, 2018.
- [16] J. Paul and F. Jefferson, "A comparative analysis of student performance in an online vs. face-to-face environmental science course from 2009 to 2016," *Frontiers in Computer Science*, vol. 1, p. 7, 2019.
- [17] S. Mandala, A. Abdullah, and A. Ismail, "A survey of e-learning security," in *International Conference on ICT for Smart Society*, 2013, pp. 1-6.
- [18] E. F. Khalaf and M. M. Kadi, "A survey of access control and data encryption for database security," *JKAU: Eng. Sci.*, vol. 28, pp. 19-30, 2017.
- [19] I.-C. Mihai, Ș. PRUNĂ, and G. PETRICĂ, "A COMPREHENSIVE ANALYSIS ON CYBER-THREATS AGAINST ELEARNING SYSTEMS," *eLearning & Software for Education*, vol. 3, 2017.
- [20] M. Anghel and G. Pereteanu, "Cyber Security Approaches in E-Learning," in *INTED2020 Proceedings*, 2020, pp. 4820-4825.
- [21] N. Huu Phuoc Dai, A. Kerti, and Z. Rajnai, "E-learning security risks and its countermeasures," *Journal of Emerging research and solutions in ICT*, vol. 1, pp. 17-25, 2016.
- [22] M. Jouini, L. B. A. Rabai, and A. B. Aissa, "Classification of security threats in information systems," *Procedia Computer Science*, vol. 32, pp. 489-496, 2014.
- [23] C. Heumann and M. S. Shalabh, *Introduction to statistics and data analysis*: Springer, 2016.
- [24] A. S. Al-Sherideh, R. Ismail, F. A. Wahid, N. Fabil, & W. Ismail. (2018). Mobile government applications based on security and privacy: a literature review. *International Journal of Engineering and Technology (UAE)*.
- [25] A. S. Al-Sherideh, R. Ismail. (2020). Motivating path between security and privacy factors on the actual use of mobile government applications in Jordan. *International Journal on Emerging Technologies*.
- [26] M. R. Al-Mousa, M. Al Zaqebah, A. S. Al-Sherideh, Mohammed. Al-Gghanim, G. Samara, S. Al-Matarneh, M. R. Asassfeh. (2022). Examining Digital Forensic Evidence for Android Applications. In *2022 23rd International Arab Conference on Information Technology (ACIT)*.
- [27] M. Al-Khateeb, M. Al-Mousa, A. Al-Sherideh, D. Almajali, M. Asassfeh, & H. Khafajeh. (2023). Awareness model for minimizing the effects of social engineering attacks in web applications. *International Journal of Data and Network Science*, 7(2), 791-800.

Things of Interest Recommendation with Multidimensional Context Embedding in the Internet of Things

Shuhua Li¹, Jingmin An²

School of Computer, Guangdong University of Science and Technology, Guangdong, China¹
School of Information Science and Technology, Dalian Maritime University, Dalian, China²

Abstract—The emerging Internet of Things (IoT) makes users and things closely related together, and the interactions between users and things generate massive context data, where the preference information in time, space, and textual content is embedded. Traditional recommendation methods (e.g., movie, music, and location recommendations) are based on static intrinsic context information, which lacks consideration regarding real-time content and spatiotemporal features, failing to adapt to the personalized recommendation in IoT. Therefore, to meet users' interests and needs in IoT, a novel effective and efficient recommendation method is urgently needed. The paper focuses on mining users' things of interest in IoT via leveraging multidimensional context embedding. Specifically, to address the challenge from massive context data embedding different user preference information, the paper employs Convolutional Neural Networks (CNN) to mine the intrinsic content information of things and learn their represent. To solve the real-time recommendation problem, the paper proposes a real-time multimodal model embedded into location, time, and some instant content information to track the features of users and things. Furthermore, the paper proposes a matrix factorization-based framework using the regularization method to fuse real-time context embedding and intrinsic information embedding. The experimental results demonstrate the proposed method tailored to IoT is adaptable and flexible, and able to capture user personalized preference effectively.

Keywords—Internet of things; things of interest; multidimensional context embedding; intrinsic information; instant information; matrix factorization

I. INTRODUCTION

The emerging Internet of Things (IoT) is promoting the growth of connected things (e.g., sensors, actuators, and mobile devices), which makes a large amount of data available from interactions between users and things. The data includes time, locations, textual contents, and interaction records. In addition, in IoT, some context data is changing over time to time, such as users' locations, and things' function availability (things in use or not in use), and in term of that one, the data could be divided into intrinsic context and instant context. Therefore, the data is characterized by massive, multidimensional, and variant. To accelerate proactively searching and promote convenient life from the massive and overloaded data, an intelligent and automated method capable of deeper understanding and mining the information is needed for personalized recommendations in IoT. The things

recommendations tailored to IoT should put more emphasis on users' and things' states under different scenarios and time besides historical interactive preferences. Hence, the things recommendation is more complex than the conventional recommender systems like movie recommendations [1-4], music recommendations [5-7], and other location recommendations [8-10].

In IoT, each user has its own unique behavior pattern, and the things of interest and interactive behaviors usually vary with time in a day, and these behaviors are regular and cyclical. To clearly observe users' real behaviors, the paper conducts an example for the spatiotemporal feature analysis on the real datasets from CASAS¹, which is a database collected from a smart home environment. Due to the space limitation, only three users' behavior records are shown on the locations and time. In Fig. 1, the three users interact with similar things except for their own locations, such as latitudes and longitudes. And Fig. 2 depicts the three users' action frequencies in the different time period are unique: user 1 usually interacts with things in the morning and afternoon, user 2 at noon, and user 3 in the early morning and evening. Consequently, the recommendation in IoT is personalized independence, context-dependence, real-time, and complexity. The following are the main challenges of achievement for things recommendations in IoT.

- *Mining and indicating things intrinsic content information.* When users decide to use a thing, they always make a primary assessment that the function of the thing meets interest or not. The descriptions of functional features are derived from the textual contents of things. Failure to mine and indicate the intrinsic content of things may result in some inaccurate recommendation results.
- *Highly dynamic.* In IoT, the locations and interests of users and the availability of things are dynamic, calling for the model capable of adapting to the changes in real-time and presenting the most timely recommendation results.
- *Data sparsity.* Compared with massive things in IoT, the things generating interactions with each user are limited, namely, the density of user-thing rating matrix

¹<http://ailab.wsu.edu/casas/datasets/>

is quite low. Therefore, under this circumstance, it is difficult to sharply explore what users may be interested in.

In light of the challenges above, the paper proposes a matrix factorization framework fusing multidimensional context embedding (McEMF), including time, intrinsic textual content, and instant location and status information to address the recommendations in IoT. Specifically, to represent and learn users' periodic behavior regularly, the paper develops a temporal-user-thing rating matrix to record interactions between users and things. Then the rating matrix is used to implement the users' preference model. To mine and indicate the things intrinsic content, the paper employs CNN to learn intrinsic content embedding, which could be used to measure the semantic relationships on the functions of things. And leveraging the semantic relationships, users' preferences could be further explored with CF. To embed instant information, the paper adopts a particle filtering-based tracking method to capture the latest states of users and things. The benefit of instant information embedding is that it could help the recommender system enhance the efficiency of real-time state awareness and solve the cold-start problem. Indeed, data sparsity is a critical problem for historical data based recommender systems, and the textual content, location information, and time information are fused into the model to effectively alleviate the problem of data sparsity.

To sum up, the main contributions of the proposed McEMF are as follows:

- McEMF is a personalized things recommendation method tailored to IoT. By taking multidimensional contexts into account, McEMF captures both intrinsic content and instant information, addressing time awareness.
- Intrinsic contents and instant information are fused with improved matrix factorization technique (MF). In particular, the paper develops a CNN-based method to concatenate textual content and real-time states of things, and the real-time locations of users can constantly updated in the model to estimate the geographical relationships between things and users.
- The paper implements experiments to validate and evaluate the performance of the proposed McEMF on a real-world IoT database. The experimental results demonstrate that McEMF outperforms state-of-the-art baseline methods in effectiveness and efficiency, and it achieves the capability of IoT recommendation in real-time.

The rest of the paper is organized as follows. The paper reviews the related researches on things recommendation and IoT-oriented things recommendation in Section II. The paper presents the proposed McEMF model and describes the technical details of each procedure in Section III. The paper gives the experimental settings and reports the evaluated results of performance in Section IV. The paper is concluded in Section V.

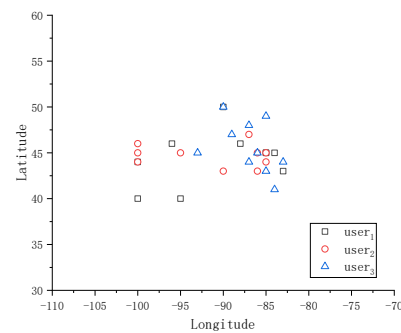


Fig. 1. Distributions of interactions between users and things.

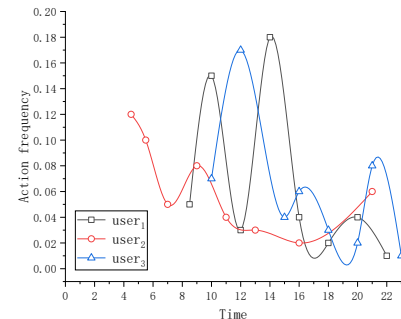


Fig. 2. Probabilities of interactions between users and things.

II. RELATED WORKS

A. Things Recommendation

At present, things recommendation is a hot academic issue, and it not only benefits the person but also the third-party business. The recommender could proactively recommend users some things that they may be interested in or need, and the third-party business could also obtain more potential preferences of users. Traditional recommendation systems employ two kinds of techniques in general. One is collaborative filtering (CF) technique, and the achievement of many popular recommendation methods is based on CF to learn user preference on things from user daily records. The CF techniques are divided into the memory-based CF and the model-CF. The works [11, 12] adopt the memory-based CF, namely, they use the data collected from user behavior records to compute the similarity of users or things, to recommend things of interest for users, called as user-based CF and item-based CF respectively. Besides, the studies [3, 4, 13-15] leverage the model-based CF (e.g., Matrix Factorization) in the recommendation system. They treat each thing as an item and conduct a user-item matrix to learn the user preference on things, and each user and thing in the matrix are indicated with a k -dimensional latent vector respectively. MF has become one of the most popular techniques in the personalized recommendation, due to its effectiveness and efficiency for large sparse user-item rating matrix. Focusing on solving the problem of data sparsity, [16, 17] employ singular value decomposition (SVD) for matrices, and [18-20] propose a non-negative MF to handle high-dimensional and sparse data collected from industrial applications. Meanwhile, probabilistic MF (PMF) [21] is proposed and shown good achievements. Different from previous works with the explicit

rating as feedback, [22,23] propose a second-order decomposing method to treat feedback records as implicit information. Another technique is content-based filtering, which works with the profiles of users or things in historical behavior records and recommends things in terms of the similarity from profiles. Study [10] presents a CF fusing the contents of users and things, and it recommends preference things according to the satisfaction of similar users for different things. [24, 25] expand the contents of things, associating some geographical information and social information with the contents, for recommendations. These methods alleviate the data sparsity problem to some extent. Recently, a few works integrate more context information, and they achieve better performance. Among them, some works [26-30] combine contexts with CF. e.g., [30] proposes a social spatio-temporal PMF framework, which exploits things similarity and user similarity via modeling the social space, geographical space and things category space, to achieve recommendations. The others [31-33] employ neural networks to fuse contexts, such as, [33] proposes a multisource fusion recommendation model, which jointly considers user preference, geographical information, and social information modeled by performing network representation. However, the methods above only consider some intrinsic information or historical records and ignore the important real-time or instant information that could play an important role for recommendations in IoT. For example, a chef cooks in a restaurant during the day and in the kitchen at home at night, and in this situation, people have different spatiotemporal characteristics that change over time to time, and obviously, traditional recommendation systems fail to it.

B. Things Recommendation in IoT

Time is a critical factor in modeling recommenders, as data is changing from time to time, and some works [27,29,32,34,35] have shown the importance of temporal features for the improvement of the efficiency of the recommenders. In IoT, the growth of data is exponential, and they have obvious temporal features. Therefore, when modeling user preference, temporal information is essential. Recently, there are few works on things recommendation systems in IoT. Research [36] proposes a Trinity method, and the method constructs three categories of graphs related things

from things usage records, namely, user-thing graph, time-thing graph, and location-thing graph, to mine possible user preference. The author in [37] presents a STUnion model, whose core work is two created graphs. One is the spatiotemporal graph that represents the relationships between users, things, time, and locations. Another is the social graph that indicates the social relationships of users. And the two graph relationships are used to model the user preferences on things with a linear combination. Recently, [38] proposes a time-aware smart thing recommendation model, which integrates user preferences and different social relationships between objects learned via graph embedding. And then, to capture more potential relationships between users and things, [39] models the influences of geographical, social, manufacturer, and economic factors on interactions and integrates them in the recommender system by deriving transition probabilities. These methods above take advantage of spatial information and temporal information in the recommenders. However, they are insufficient for real-time information. Compared with traditional web data, physical things and users are more dynamic in IoT, thus the recommendation model tailored to IoT should be able to adapt up-to-date information. Consequently, the paper focuses on achieving a real-time recommendation system in the paper, and proposes a things-recommendation method with multidimensional context embedding, which captures intrinsic information and instant information, to make more accurate recommendations.

III. MULTIDIMENSIONAL CONTEXT EMBEDDING FOR THINGS RECOMMENDATIONS

In this section, the paper develops a multidimensional context embedding framework fusing intrinsic information and instant information as Fig. 3 and gives the procedures in detail. The proposed framework employs the historical interactive records (data) between users and things to model user preference. Meanwhile, it captures the instant information on locations of users and states (availability) of things for fitting the historical user preference to make the most up-to-date recommendations. Specifically, the framework consists of four procedures: (1) problem definition and notations in the framework; (2) intrinsic information embedding model; (3) real-time information embedding model; (4) fused model.

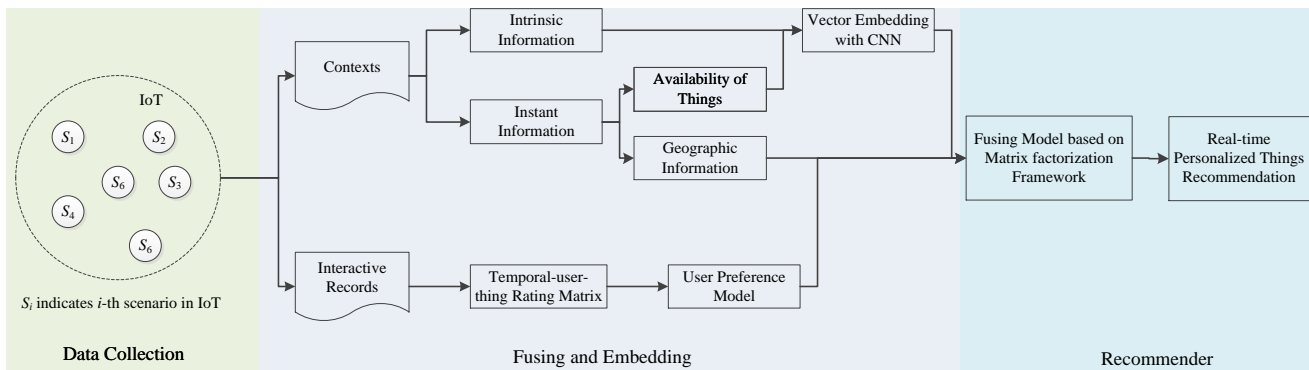


Fig. 3. Overview of the system framework.

A. Problem Definition and Notations

Formally, a thing’s interactive record is created when a person interacts with a particular thing. Let U be a set of users, $u_i \in U$, and T a set of things, $t_j \in T$, and the record is represented as a pairwise $r_{ij}=(u_i, t_j)$, which forms a matrix $r_{ij} \in R|U||T|$. Besides, for each record, some context information is considered, such as, temporal information that indicates when the interaction happens, and spatial information that indicates where the interaction happens, and the profiles of things that indicate the functions of things. Each record is a quadruple of User, Thing with a certain function, Timestamp, Location as the following definitions.

Definition 1 (Things Interactive Record) Let $U=\{u_1, u_2, \dots, u_m\}$, $T=\{t_1, t_2, \dots, t_n\}$, $L=\{l_1, l_2, \dots, l_p\}$, and $I=\{r_1, r_2, \dots, r_q\}$ represent the set of users, things, locations, and timestamps, respectively, where each t_j has a bag of keywords C_d indicating its function review. An interactive record of a thing t is denoted by $h \in H=\{h_1, h_2, \dots, h_j\}=\{<u, t, l, r> | u \in U \wedge t \in T \wedge l \in L \wedge r \in I\}$, indicating that user u uses thing t in the location l at timestamp r .

Definition 2 (Three-Level Time Granularity) According to our life experiences, users behave periodically in daily life. Specifically, people (users) may regularly stay at the workplace on weekdays and at the entertainment places or home on the weekends, namely, each user may have a different periodic behavior pattern on weekdays and weekends respectively. Let the temporal states $\Gamma =\{weekday, weekend\}$. Furthermore, one day is divided into 24 hours, thus $2*24=48$ temporal units I can be obtained, and $r \in I \in \Gamma$. The paper exploits the three types of time to learn the temporal features of interactions.

Definition 3 (Temporal-User-Thing Rating Matrix) In a record h , the timestamp r is cyclical, therefore, matrix $R|U||T|$ is extended to $R|U||T, I, l, ru, t, r \in R|U||T, I, l$. Note that due to location l with random and real-time, it is not suitable for merging into the matrix $R|U||T, I$ indicating the historical interaction records. Location l is a piece of instant information.

$R|U||T, I$ is a sparse matrix, and user historical preference is approximately expressed as $R_{|U||T, I} \approx p_u^T q_{t, r}$, where p_u and $q_{t, r}$ are the user latent k -dimensional vector and the thing latent k -dimensional vector at timestamp r , respectively. The

proposed framework is to predict the missing entities, and it will recommend the things with the bigger predicted ratings to given users. The major notations in the framework are summarized in Table I.

B. Intrinsic Information Embedding Model

When a user uses a specific thing, he/she mainly considers whether the functions of the thing can meet his/her needs or not. Therefore, the paper proposes an intrinsic information embedding model to represent the functional features of things as the low-dimensional vectors so that the model could learn the semantic relationships between things. The descriptions on things’ functions are captured from the textual content, and CNN is employed for intrinsic information embedding. More specifically, as Fig. 4 illustrates. Given a text with C_d , each word c_z in C_d will be represented by an n -dimensional vector leveraging a non-static word embedding function. Supposing that there are N words in C_d , an $N \times n$ embedding matrix of C_d could be constructed, represented as:

$$\prod(C_d) = \Phi(c_1) \oplus \Phi(c_2) \oplus \dots \oplus \Phi(c_N), \quad (1)$$

where $\prod(C_d)$ indicates the $N \times n$ embedding matrix of C_d , and $\Phi(c_z)$ is a word embedding function to map the c_z into an n -dimensional vector, and \oplus is the concatenation operator. The model inputs the word embedding into CNN, and uses convolution layers with filter windows of unigram, bigram and trigram, where the model applies a convolution operation to the inputs. Each convolution filter applies a filter f_j to a window of s words to generate a new feature z_j^k :

$$z_j^k = F(\prod(C_d) * f_j + b_j), \quad (2)$$

TABLE I. NOTATIONS IN THE FRAMEWORK

Notation	Description
U, T, L, I	user set, things set, location set, and timestamp set.
r, I, Γ	the timestamp, the temporal unit, and the temporal state, $r \in I \in \Gamma$.
$R_{ U T, I}$	temporal-user-thing rating matrix, $r_{u, t, r} \in R_{ U T, I}$.
$p_u, q_{t, r}$	user latent vector, thing latent vector at r .
k	the dimension of the latent vector.
$q_{t, r}^*$	the real-time thing latent vector.
$[y_{u, t, r}]$	the user preference matrix.
$[g(u, t, r)]$	the user-thing geographical relationship matrix.

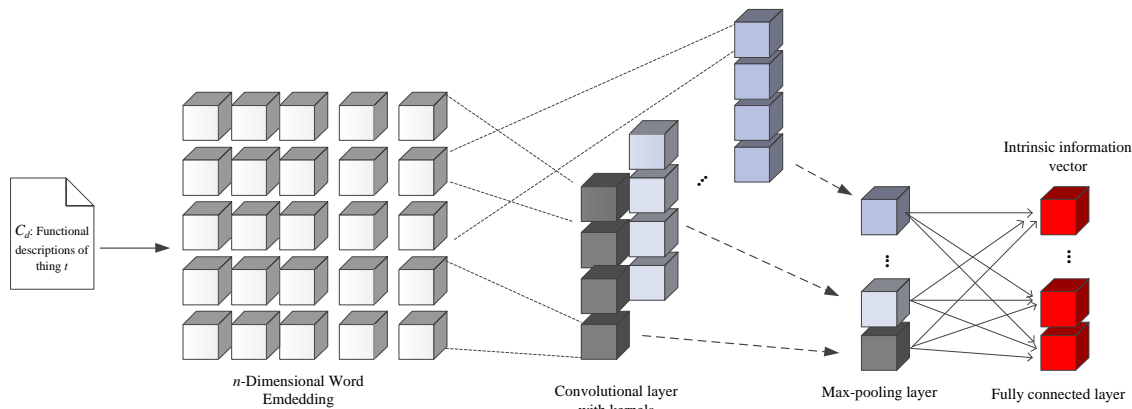


Fig. 4. The representation learning model of the intrinsic information.

where F is the activation function, and inspiring by [40], in Eq. (2), Rectified Linear Units (ReLU) is used as the activation function. $*$ is the convolution operation, and b_j is a bias term. Furthermore, the model sorts the biggest value from each feature map in the max-pooling layer:

$$\mathcal{L}_h = \{\ell_1, \ell_2, \dots, \ell_{n_f}\}, h \in \{1,2,3\}, (3)$$

where ℓ_j denotes the feature corresponding to filter f_j , and there are n_f filters. For each ℓ_j :

$$\ell_j = \max\{z_j^1, z_j^2, \dots, z_j^{N-s+1}\}. (4)$$

Afterward, the max-pooling layer \mathcal{L}_1 , \mathcal{L}_2 , and \mathcal{L}_3 are concatenated:

$$\mathcal{L} = \mathcal{L}_1 \oplus \mathcal{L}_2 \oplus \mathcal{L}_3. (5)$$

The model feeds \mathcal{L} obtained by max-pooling into the fully connected layer to integrate the intrinsic information embedding vector of the functional features of the thing t $q_t^{intrinsic}$:

$$q_t^{intrinsic} = F(W_{intrinsic} \times \mathcal{L} + B_{intrinsic}), (6)$$

where $W_{intrinsic}$ is the weight corresponding to \mathcal{L} , and $B_{intrinsic}$ denotes a bias term. $W_{intrinsic}$, $B_{intrinsic}$, and other parameters in the model are trained together with McEMF via backpropagation. $q_t^{intrinsic}$ is a high-level feature vector combining non-linearly $n_{intrinsic}$ feature vectors of the thing's functions.

C. Real-time Information Embedding Model

$p_u^T q_{t,r}$ could capture user preference things only based on the past interactive records and could not make use of some instant information to meet user real-time needs. To tackle the issue, the paper proposes an instant information embedding model for recommender in IoT. There are two main kinds of instant information in IoT, namely, two subproblems that need to be solved. One is the thing's availability, which indicates a thing in use or not in use at timestamp r , and that is because a thing could not be used by multiple users at the same time in general (e.g., Automatic Teller Machine, ATM). To address the subproblem, the paper firstly employs a particle filtering [41] to track the latest things' availability and continuously refine the functions of things, obtaining the instant information embedding vector of the thing t $q_t^{instant}$ with $n_{instant}$ -dimensional features. Then $q_t^{intrinsic}$ and $q_t^{instant}$ are fused into a new $(n_{intrinsic} + n_{instant})$ -dimensional vector $V_{t,r}$:

$$V_{t,r} = q_t^{intrinsic} \oplus q_t^{instant}. (7)$$

$V_{t,r}$ is input into the fully connected layer to synthesize a high-level feature vector $q_{t,r}^*$:

$$q_{t,r}^* = F(W \times V_{t,r} + B), (8)$$

where W is the weight corresponding to $V_{t,r}$ inside layer, and B denotes a bias term and $q_{t,r}^*$ is a high-level vector including the intrinsic functional features and instant functional features, indicating the real-time features of thing t at timestamp r .

Another one is the users' locations, which are used to measure the geographical relationships between users and things, and according to Tobler's First Law of Geography [42]: "near things are more related than distant things". Thus, users intuitively tend to use nearby things. To address this subproblem, the users' locations l_p at timestamp r is tracked and the geographical relationships between users and things geo-tagged l'_j are computed as follows:

$$D_r(u, t, r) = \begin{cases} 1 & , l_p \text{ and } l'_j \text{ in same region at } r \\ 1 + \frac{d(l_p, l'_j) + d(c(u), c(t))}{2 \times \min} & , \text{otherwise} \end{cases} (9)$$

where the paper partitions the regions based on the things' coordinates (longitudes and latitudes). Each region has a region center, and when both user u and thing t are in the same region, they have the same region center, assuming the geographical relationship as 1. Otherwise, the paper computes the geographical relationship by leveraging two types of distances. $d(l_p, l'_j)$ is the distance between user u and thing t , and $d(c(u), c(t))$ corresponds to the distance between the region centers of user u and thing t , and \min indicates the minimum distance between different region centers. Furthermore, the geographical influences $g(u, t, r)$ is as $g(u, t, r) \propto \frac{1}{D_r(u, t, r)}$. Therefore, the user real-time interactive preference $y_{u,t,r}$ is given as:

$$y_{u,t,r} = p_u^T q_{t,r} \cdot g(u, t, r). (10)$$

D. Fused Model

In this section, the paper proposes a comprehensive framework based on MF with regularization (McEMF). The user real-time interactive preference $y_{u,t,r}$ is used to be close to the historical interaction rating $r_{u,t,r}$ for the user preference model. Moreover, the paper employs the Frobenius norm to fuse $q_{t,r}^*$ into the framework for the influence of the functional features of things, and adopts the regularizations to avoid over-fitting. Specifically, the objective function is as follows:

$$\mathcal{G} = \frac{1}{2} \sum_{u \in U, t \in T, r \in I} (r_{u,t,r} - y_{u,t,r})^2 + \frac{\lambda_q}{2} \sum_{t \in T} \sum_{r \in I} \sum_{l \in I} \|q_{t,r} - q_{t,r}^*\|^2 + \frac{\lambda_p}{2} \sum_{u \in U} \|p_u\|^2 + \frac{\lambda_v}{2} \sum_{t \in T} \sum_{r \in I} \sum_{l \in I} \|q_{t,r}\|^2, (11)$$

where λ_q is a trade-off parameter, which balances the importance between the user preference model and the real-time functional features of things. When λ_q is equal to zero, the objective function ignores the influence of the functional features, and a bigger λ_q means that $q_{t,r}^*$ is closer to $q_{t,r}$. λ_p and λ_v are the regularization coefficients. When λ_p and λ_v are limited to zero, the objective function tends to over-fit the training dataset, and when λ_p and λ_v approach to infinite, it tends to under-fitting. For the framework optimization, the paper uses gradient descent in u and t to find a minimum of

the objective function as follows:

$$u \leftarrow u - \delta \cdot \frac{\partial G}{\partial u} \quad (12)$$

and

$$t \leftarrow t - \delta \cdot \frac{\partial G}{\partial t}, \quad (13)$$

where δ is the learning rate. After optimizing the framework, the user personalized preferences on things in real-time could be found by computing the rating given the interactive records, intrinsic information embedding, and instant information embedding. Then a recommendation list is constructed via sorting the rating for each user at a specific time period.

Time complexity analysis: The time complexity analysis of the framework is divided into three parts. The first one is the time for updating the user and thing latent vectors, which takes $O(k2|R|+k3(|U|+|T|))$. The second one is the time for updating a CNN embedding things' information, and the complexity is $O(nf \times N \times n \times |T|)$. The third one is the time complexity for updating a fully connected layer, which takes $O(|W| \times |T|)$. Therefore, the total time complexity is $O(k2|R|+k3(|U|+|T|)+nf \times N \times n \times |T|+|W| \times |T|)$ for per given data.

IV. EXPERIMENTS

A. Experimental Setup

1) *Dataset:* The paper leverages CASAS datasets, which are augmented with the dataset as in [36, 37] collected from a smart home environment for a period of four months. The environment contains six diverse categories: entertainment, office, cooking, transportation, medical, and house appliances. And the users with less than 10-time records and things that are used less than five times are eliminated to reduce abnormal data. To the end, these datasets contain 1020 users, 855 things, and 108650 interactive records, illustrated in Table II. The paper separates the data into 8:2 ratio as training data and testing data, respectively. Then, some abnormal data filtered out is selected to validate the proposed model on the cold-start problem.

TABLE II. STATISTICS OF THE DATASET

Dataset	Users	Things	Categories	Records	Density
CASAS	228635	10256	6	1586507	6.8×10^{-4}

2) *Evaluation metrics:* As the proposed model generates a recommendation list for each user in real-time, the users will receive different recommendation results at different time period. The recommendation list is denoted as $\mathcal{Y}_i = \{\psi_i^1, \psi_i^2, \dots, \psi_i^K\}$, where ψ_i^j is the j -th recommended thing in terms of the rating and $i = (u, r)$. Therefore, the paper evaluates the proposed model via leveraging two ranking-based metrics: Recall@K and mean reciprocal rank (MRR).

Recall@K means the proportion of the things related to the ground-truth things in the top-K recommendation results. The Recall@K is defined as:

$$\text{Recall@K} = \frac{1}{|S_{test}|} \sum_{i=1}^{|S_{test}|} \frac{|\mathcal{R}_i \cap \mathcal{Y}_i|}{|\mathcal{R}_i|}, \quad (14)$$

where \mathcal{R}_i is the ground-truth things, and S_{test} represents the testing dataset, $\mathcal{R}_i \in S_{test}$.

MRR is a metric for ranking position. It refers to that in the recommendation list, the more things related to the ground-truth things are ranked in the front, the better the recommendation results are. MRR is defined as:

$$\text{MRR} = \frac{1}{|S_{test}|} \sum_{i=1}^{|S_{test}|} \frac{1}{\text{rank } i}, \quad (15)$$

where $\text{rank } i$ means the ranking position of the relevant thing in \mathcal{Y}_i found together from \mathcal{R}_i and \mathcal{Y}_i for the first time.

3) *Baseline methods:* To evaluate the performance of the proposed model, the paper selects the following classical and state-of-the-art methods as the baseline methods:

MF: A classical and popular collaborative filtering method for things of interest recommendation.

STUnion [37]: The method uses the context information to create a spatiotemporal graph and a social graph, which are linearly combined to model the user preference things.

KGE[39]: The method proposes to fuse various things social relationships via graph embedding for enhancing user preference predictions.

SORec[40]: The method proposes to represent richer relationships between users and things by contexts and integrate them in the recommender system.

McEMF: The proposed method.

4) *Parameter settings:* In McEMF, there are four set parameters, including $\lambda_q, \lambda_p, \lambda_v$, and δ . The paper uses the grid search method to adjust the parameters and finally sets $\lambda_q = 1$, regularization coefficients $\lambda_p = \lambda_v = 0.1$, and $\delta = 0.01$. In other compared baseline methods, the paper tries the best to ensure that their parameters are consistent with the original papers.

B. Discussion of Baselines

To further elaborate on the contributions and innovations of McEMF, the paper shows the difference between baselines as Table III illustrated. MF is a classical and popular collaborative filtering method without fusing any contexts, and it could only depend on the historical interactions to learn user preferences, which fails to overcome the data sparsity and meet users' real-time demand. The others, such as STUnion, KGE, and SORec, consider intrinsic context factors like spatiotemporal and social information etc, however, they ignore the instant information that can indicate users' real-time demands and fail to achieve the best things recommendation under different scenarios and time. The specific performance evaluation is given in the next section.

C. Experimental Results

Firstly, the paper evaluates the performance of all methods with top-5 recommendation things in different dimensions, $k=\{5, 10, 20, 40\}$. The results are shown in Table IV. McEMF

outperforms all other baselines on both Recall@5 and MRR. Specifically, the popular STUnion, KGE, SORec, and the proposed McEMF are superior to the classical MF. Besides, McEMF achieves 51.12% improvement over MF. When k is smaller, the performance of STUnion, KGE, SORec, and McEMF is closer, however, when k is bigger and $k=20$, the other baselines are inferior to McEMF, obviously. The reason is that McEMF naturally integrates more real-time information into the recommender system, such as the real-time geographical relationships and the real-time availability of things, which play an important role in things of interest recommendation in IoT. There is little difference between KGE and SORec, because both of them fuse multiple intrinsic context information. It can observe that McEMF achieves the best performance when $k=20$, hence let $k=20$ in the next experiments.

Then, the paper evaluates the performance of all methods with top- K recommendation things in the dimension $k=20$. The results are illustrated in Table V. From the results, it can observe that the longer recommendation lists recommenders give, the higher recall recommenders can achieve. McEMF achieves better performance compared with the other baselines on MRR and Recall with different K . Moreover, when $K=1$, McEMF achieves 29.20% improvements over SORec respectively, which implies McEMF could give the best recommendation result in real-time. With the increase of K , the changing rates of Recall and MRR are slowing down. The reason may be that there is little difference in user preferences for things at the end of the lists when the recommended lists reach a certain length.

Furthermore, the paper evaluates the performance of the proposed McEMF for the cold-start problem. The paper adopts the eliminated data, where the number of the interactive records of a user is $n=\{1, 3, 5\}$. The results are shown in following Table VI. Obviously, for the cold-start problem, McEMF has outstanding advantages compared with other baselines, which benefits from real-time information embedding. In particular, when $n=1$, McEMF achieves 32.79% improvement over SORec, respectively. MF that ignores the context information is the worst among all methods.

TABLE III. THE DIFFERENCE BETWEEN BASELINES

Methods	Intrinsic context			Instant context	
	Social	Spatiotemporal	Content	Users' states	Things' states
MF					
STUnion	√	√			
KGE	√	√			
SORec	√	√	√		
McEMF	√	√	√	√	√

TABLE IV. TOP-5 RESULTS OF RECOMMENDATIONS IN DIFFERENT DIMENSIONS

k	metrics	MF	STUnion	KGE	SORec	McEMF
5	Recall@5	0.2524	0.3505	0.3603	0.3617	0.3603
	MRR	0.1552	0.2310	0.2412	0.2489	0.2416
10	Recall@5	0.2546	0.3505	0.3603	0.3617	0.3635
	MRR	0.1587	0.2310	0.2412	0.2489	0.2485
20	Recall@5	0.2581	0.3505	0.3603	0.3617	0.3705
	MRR	0.1601	0.2310	0.2412	0.2489	0.2596
40	Recall@5	0.2577	0.3505	0.3603	0.3617	0.3690

MRR	0.1593	0.2310	0.2412	0.2489	0.2572
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TABLE V. TOP-K RESULTS OF RECOMMENDATIONS IN THE DIMENSION $K=20$

metrics	MF	STUnion	KGE	SORec	McEMF
Recall@1	0.0324	0.1206	0.1420	0.1429	0.1876
MRR	0.0175	0.0797	0.1248	0.1250	0.1589
Recall@5	0.2581	0.3505	0.3603	0.3617	0.3705
MRR	0.1601	0.2310	0.2412	0.2489	0.2596
Recall@10	0.3150	0.4442	0.4748	0.4756	0.4903
MRR	0.2364	0.3526	0.3665	0.3666	0.3812
Recall@20	0.3345	0.4608	0.4893	0.4897	0.5147
MRR	0.2555	0.3687	0.3815	0.3820	0.3995

TABLE VI. GIVEN-N RESULTS OF RECOMMENDATIONS IN THE DIMENSION $K=20$

n	metrics	MF	STUnion	FST	KGE	SORec	McEMF
1	Recall@5	0.0096	0.0305	0.0770	0.0766	0.0767	0.1033
	MRR	0.0042	0.0210	0.0489	0.0482	0.0479	0.0627
3	Recall@5	0.0131	0.0354	0.0805	0.0800	0.0801	0.1094
	MRR	0.0079	0.0253	0.0525	0.0511	0.0510	0.0660
5	Recall@5	0.0168	0.0465	0.1062	0.1053	0.1056	0.1122
	MRR	0.0102	0.0313	0.0867	0.0856	0.0854	0.0977

Next, the paper examines the sensitivity of McEMF to parameters λ_q , λ_p , and λ_v . The paper conducts three sets of experiments. Fig. 5 shows that the performance is changing with λ_q when fixing $\lambda_p = \lambda_v = 0.1$. It can observe that the performance is sensitive to λ_q . At first, Recall@5 and MRR are increasing with λ_q and then decreasing after $\lambda_q = 1$. Therefore, it is believed that $\lambda_q = 1$ is the optimal setting. When λ_q is smaller, McEMF will degenerate into the classical MF as expected. Fig. 6 shows that the performance is changing with λ_p when fixing $\lambda_q = 1$ and $\lambda_v = 0.1$. It can observe that both Recall@5 and MRR achieve the best performance somewhere near $\lambda_p = 0.1$. Fig. 7 illustrates that the performance is changing with λ_v when fixing $\lambda_q = 1$ and $\lambda_p = 0.1$. It can observe that both Recall@5 and MRR achieve the best performance somewhere near $\lambda_v = 0.1$.

To evaluate the impact of the instant contextual embedding and the intrinsic information embedding to the proposed McEMF, the paper excludes the intrinsic information embedding from the model, denoted as McEMF/intrinsic, the instant contextual embedding from the model, denoted as McEMF/instant, and both the instant contextual embedding and the intrinsic information embedding from the model, denoted as McEMF/instant_intrinsic, respectively. The comparison results are shown in Fig. 8. McEMF outperforms McEMF/intrinsic, McEMF/instant, and McEMF/instant_intrinsic, which indicates both the instant contextual embedding and the intrinsic information embedding effectively promote the recommendation effects. Furthermore, McEMF/intrinsic is superior to McEMF/instant, which implies that the real-time information play a more important role than the intrinsic information in IoT scenarios.

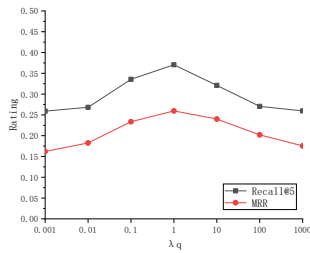


Fig. 5. Recall@5 and MRR for different λ_q .

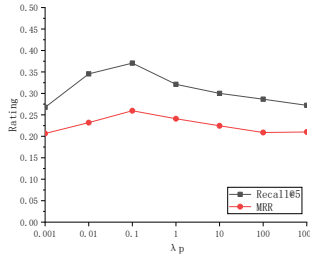


Fig. 6. Recall@5 and MRR for different λ_p .

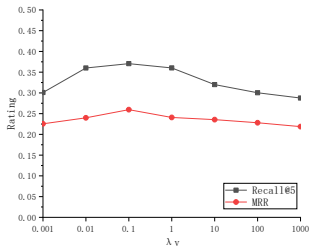


Fig. 7. Recall@5 and MRR for different λ_v .

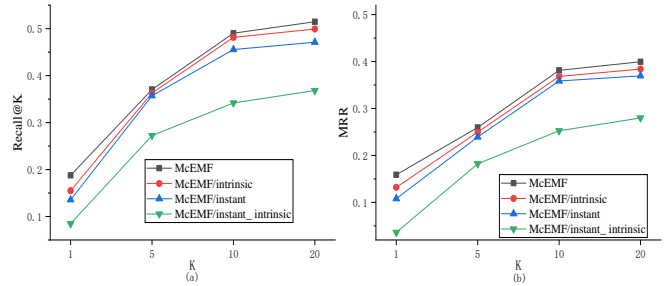


Fig. 8. The comparison of the impacts of the instant contextual embedding and the intrinsic information embedding to McEMF.

The paper uses the traditional Control Variate Technique to adjust the hyper-parameters of CNN in McEMF, as shown in Table VII. As it can see, the optimal combination of the parameters is Cross features + Hidden layers (512-256-128-64-1, ReLUs, Normal initializer, Dropout). From the results, the following conclusions can be inferred. (1) The number of neural units and hidden layers are not the most crucial factors for recommendation performance, and less hidden layers could avoid over-fitting. (2) Both activation function and initializer play an important role, because a proper activation or initializer can adjust the data distribution fed in each layer well. (3) Dropout and L2 regular are widely used to avoid over-fitting, and in the experiments, Dropout has more advantages.

TABLE VII. THE HYPER-PARAMETERS ADJUSTMENT OF CNN IN MCEMF

Hyper-parameters of hidden layers		Recall@1	MRR	Recall@5	MRR	Recall@10	MRR	Recall@20	MRR
Activation Functions	Tanh	0.1335	0.1127	0.3116	0.2003	0.4289	0.3210	0.4478	0.3286
	ReLU	0.1876	0.1589	0.3705	0.2596	0.4903	0.3812	0.5147	0.3995
Initializers	Uniform	0.1606	0.1325	0.3412	0.2294	0.4622	0.3565	0.4840	0.3757
	Normal	0.1876	0.1589	0.3705	0.2596	0.4903	0.3812	0.5147	0.3995
Number of layers and neural units	2048-1024-512-256-1	0.1822	0.1489	0.3677	0.2459	0.4882	0.3779	0.5002	0.3898
	1024-512-256-128-1	0.1851	0.1516	0.3658	0.2450	0.4896	0.3785	0.5010	0.3923
	512-256-128-64-1	0.1876	0.1589	0.3705	0.2596	0.4903	0.3812	0.5147	0.3995
Regular Terms	L2reg	0.1821	0.1514	0.3894	0.2555	0.4891	0.3801	0.5112	0.3973
	Dropout	0.1876	0.1589	0.3705	0.2596	0.4903	0.3812	0.5147	0.3995

V. CONCLUSION

The user-thing interactions in real IoT scenarios are dynamic and sparse, which is a challenge for things of interest recommendations. To solve the challenge, the paper proposes a recommendation model with multi-dimensional context embedding, which learns the user preferences in real-time by fusing the instant information and the intrinsic information into the matrix factorization framework. In the proposed model, the paper employs CNN to model the functional

features of things. As conventional rating matrices fail to represent the temporal features, the paper proposes a temporal-user-thing rating matrix, which is used to model user preference via integrating the instant geographical information. The paper evaluates the performance of the proposed model through experiments on real-world IoT datasets. The paper compares the model with other state-of-the-art methods on three sets of experiments, as Table III, Table IV, and Table V. The results demonstrate that the effectiveness and efficiency of the proposed model.

Though the proposed model achieves an improvement for things recommendations in IoT, its performance is still limited by the interaction data sparsity. Therefore, the future work will focus on investigating a novel method against data sparsity.

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REFERENCES

- [1] S. Aramuthakannan, M. R. Devi, S. Lokesh, R. Manimegalai, "Movie recommendation system via fuzzy decision making based dual deep neural networks," *J. Intell. Fuzzy Syst.*, vol.44, no.3, pp. 5481-5494 2023.
- [2] Y. Liu, J. Miyazaki, "Knowledge-aware attentional neural network for review-based movie recommendation with explanations," *Neural Comput. Appl.*, vol.35, no.3, pp.2717-2735, 2023.
- [3] Z.Z.Darban, M.H.Valipour, "GHRS: Graph-based hybrid recommendation system with application to movie recommendation," *Expert Syst. Appl.*, vol.200, pp. 116850, 2022.
- [4] W. Sun, J.H.Jiang, Y.B. Huang, J.L. Li, Mengmeng Zhang, "An Integrated PCA-DAEGCN Model for Movie Recommendation in the Social Internet of Things," *IEEE Internet Things J.*, vol.9, no.12, pp. 9410-9418, 2022.
- [5] Z.Y. Liu, W. Xu, W.P. Zhang, Q.Q. Jiang, "An emotion-based personalized music recommendation framework for emotion improvement," *Inf. Process. Manag.*, vol.60, no.3, pp. 103256, 2023.
- [6] J. Yi, Y.C. Zhu, J.Y. Xie, Zhenzhong Chen, "Cross-Modal Variational Auto-Encoder for Content-Based Micro-Video Background Music Recommendation," *IEEE Trans. Multim.*, vol.25, pp.515-528, 2023.
- [7] H. Weng, J.J. Chen, D.J. Wang, X. Zhang, D.J. Yu, "Graph-Based Attentive Sequential Model With Metadata for Music Recommendation," *IEEE Access*, vol.10, pp.108226-108240, 2022.
- [8] W.J. Chang, D. Sun, Q.D. Du, "Intelligent Sensors for POI Recommendation Model Using Deep Learning in Location-Based Social Network Big Data," *Sensors*, vol.23, no.2, pp. 850, 2023.
- [9] Z.Dong, X.W. Meng, Y.J. Zhang, "Exploiting Category-Level Multiple Characteristics for POI Recommendation," *IEEE Trans. Knowl. Data Eng.*, vol.35, no.2, pp. 1488-1501, 2023.
- [10] J.F. Fang, X.F. Meng, X.Y. Qi, "A top-k POI recommendation approach based on LBSN and multi-graph fusion," *Neurocomputing*, vol.518, pp. 219-230, 2023.
- [11] M. Ye, P.F. Yin, W.C. Lee, and D.L. Lee, "Exploiting geographical influence for collaborative point-of-interest recommendation," in *Proc. 34th Int. Conf., ACM SIGIR.*, 2011, pp. 325-334.
- [12] Q. Yuan, G. Cong, Z.Y. Ma, A.X. Sun, and N.M. Thalmann, "Time-aware point-of-interest recommendation," in *Proc. 36th Int. Conf., ACM SIGIR.*, 2013, pp. 363-372.
- [13] D. Lian, C. Zhao, X. Xie, G. Sun, E. Chen, and Y. Rui, "GeoMF: joint geographical modeling and matrix factorization for point-of-interest recommendation," in *Proc. 20th Int. Conf., ACM SIGKDD.*, 2014, pp. 831-840.
- [14] B. Liu, Y. Fu, Z. Yao, and H. Xiong, "Learning geographical preferences for point-of-interest recommendation," in *Proc. 19th Int. Conf., ACM SIGKDD.*, 2013, pp. 1043-1051.
- [15] Y. Liu, W. Wei, A. Sun, and C. Miao, "Exploiting geographical neighborhood characteristics for location recommendation," in *Proc. 23rd Int. Conf., ACM CIKM.*, 2014, pp. 739-748.
- [16] S. Zhang, W.H. Wang, J. Ford, F. Makedon, and J.D. Pearlman, "Using singular value decomposition approximation for collaborative filtering," in *Proc. 7th Int. Conf., IEEE Computer Society (CEC)*, 2005, pp. 257-264.
- [17] Y. Koren, "Collaborative filtering with temporal dynamics," in *Proc. 15th Int. Conf., ACM SIGKDD.*, 2009, pp. 447-456.
- [18] X. Luo, M.C. Zhou, S. Li, and M.S. Shang, "An inherently non-negative latent factor model for high-dimensional and sparse matrices from industrial applications," *IEEE Trans. Ind. Inf.*, vol. 14, no. 5, pp. 2011-2022, 2018.
- [19] X. Luo, M.C. Zhou, S. Li, Z.-H. You, Y. Xia, and Q.S. Zhu, "A non-negative latent factor model for large-scale sparse matrices in recommender systems via alternating direction method," *IEEE Trans Neural Netw. Learn. Syst.*, vol. 27, no. 3, pp. 524-537, 2016.
- [20] X. Luo, M.C. Zhou, Y. Xia, and Q.S. Zhu, "An efficient non-negative matrix factorization-based approach to collaborative-filtering for recommender systems," *IEEE Trans. Ind. Inf.*, vol. 10, no. 2, pp. 1273-1284, 2014.
- [21] R. Salakhutdinov and A. Mnih, "Bayesian probabilistic matrix factorization using Markov chain Monte Carlo," in *Proc. 25th Int. Conf., ACM ICML.*, 2008, pp. 880-887.
- [22] X. Luo, M.C. Zhou, S. Li, Y. Xia, Z.-H. You, and Q.S. Zhu, "Incorporation of efficient second-order solvers into latent factor models for accurate prediction of missing QoS data," *IEEE Trans. Cybern.*, vol. 48, no. 4, pp. 1216-1228, 2018.
- [23] X. Luo, M.C. Zhou, S. Li, Z.-H. You, Y. Xia, Q.S. Zhu, H. Leung, "An efficient second-order approach to factorizing sparse matrices in recommender systems," *IEEE Trans. Ind. Inf.*, vol. 11, no. 4, pp. 946-956, 2015.
- [24] S.N. Xing, F.A. Liu, Q.Q. Wang, X.H. Zhao, and T.L. Li, "Content-aware point-of-interest recommendation based on convolutional neural network," *Appl. Intell.*, vol. 49, no. 3, pp. 858-871, 2019.
- [25] D.Q. Yang, D.Q. Zhang, Z.Y. Yu, and Z. Wang, "A sentiment-enhanced personalized location recommendation system," in *Proc. 24th Int. Conf., ACM HT.*, 2013, pp. 119-128.
- [26] J.D. Zhang and C.Y. Chow, "GeoSoCa: Exploiting Geographical, Social and Categorical Correlations for Point-of-Interest Recommendations," in *Proc. 38th Int. Conf., ACM SIGIR.*, 2015, pp. 443-452.
- [27] G.H. Li, Q. Chen, B.L. Zheng, N.Q.V. Hung, P. Zhou, and G.F. Liu, "Time-aspect-sentiment Recommendation Models Based on Novel Similarity Measure Methods," *ACM Trans. Web*, vol. 14, no. 2, pp. 5:1-5:26, 2020.
- [28] Z.Y. Zhang, Y. Liu, Z.J. Zhang, and B. Shen, "Fused matrix factorization with multi-tag, social and geographical influences for POI recommendation," *World Wide Web*, vol. 22, no. 3, pp. 1135-1150, 2019.
- [29] X. Xiong, S.J. Qiao, Y.Y.Li, N. Han, G. Yuan, and Y.Q. Zhang, "A point-of-interest suggestion algorithm in Multi-source geo-social networks," *Eng. Appl. Artif. Intell.*, vol. 88, pp. 1-11, 2020.
- [30] M. Davtalab and A. A. Alesheikh, "A POI recommendation approach integrating social spatio-temporal information into probabilistic matrix factorization," *Knowl. Inf. Syst.*, vol.63, no.1, pp. 65-85, 2021
- [31] Sh.L. Li, J.B. Zhou, T. Xu, H. Liu, X.J. Lu, and H. Xiong, "Competitive Analysis for Points of Interest," in *Proc. 26th Int. Conf., ACM SIGKDD.*, 2020, pp. 1265-1274.
- [32] L. Gao, Y.H. Li, R.X. Li, Z.L. Zhu, X.W. Gu, and O. Habimana, "STRNet: A Time-aware Point-of-interest Recommendation Method based on Neural Network," in *Proc. 2019 Int. Conf., IEEE IJCNN.*, 2019, pp. 1-8.
- [33] .H.X. Hu, Zh.W. Jiang, Y. Zhang, H. Wang, and W. Wang, "Network Representation Learning-Enhanced Multisource Information Fusion Model for POI Recommendation in Smart City," *IEEE Internet Things J.*, vol.8, no.12, pp.9539-9548, 2021.
- [34] Y.F. Zhang, M. Zhang, Y. Zhang, G.K. Lai, Y.Q. Liu, H.H. Zhang, and S.P. Ma, "Daily-Aware Personalized Recommendation based on Feature-Level Time Series Analysis," in *Proc. 24th Int. Conf., World Wide Web*, 2015, pp. 1373-1383.
- [35] X.R. Wang, A. McCallum, "Topics over Time: A Non-Markov Continuous-Time Model of Topical Trends," in *Proc. 12th Int. Conf., ACM SIGKDD.*, 2006, pp. 424-433.
- [36] L. Yao and Q.Z. Sheng, "Exploiting latent relevance for relational learning of ubiquitous things," in *Proc. 21st Int. Conf., ACM CIKM.*, 2012, pp. 1547-1551.

- [37] L. Yao, Q.Z. Sheng, B. J. Gao, A. H. H. Ngu, and X. Li, "A Model for Discovering Correlations of Ubiquitous Things," in *Proc. 13th Int. Conf., IEEE Computer Society (CIDM)*, 2013, pp. 1253-1258.
- [38] Y.Y. Chen, M.X. Zhou, Z.W. Zheng, D. Chen, "Time-Aware Smart Object Recommendation in Social Internet of Things," *IEEE Internet Things J.*, vol. 7, no.3, pp. 2014-2027, 2020.
- [39] P. Mahajan, P.D. Kaur, "Smart object recommendation (SORec) architecture using representation learning in Smart objects-Based Social Network (SBSN)," *J. Supercomput.* vol.77, no.12, pp.14180-14206, 2021.
- [40] V. Nair and G.E. Hinton, "Rectified Linear Units Improve Restricted Boltzmann Machines," in *Proc. 27th Int. Conf., ACM ICML*, 2010, pp. 807-814.
- [41] L. Yao, Q.Z. Sheng, "Particle filtering based availability prediction for web services," in *Proc. 9th Int. Conf., Springer ICSOC*, 2011, pp. 566-573.
- [42] W. R. Tobler, "A Computer Movie Simulating Urban Growth in the Detroit Region," *Economic Geography*, vol. 46, pp. 234-240, 1970.

Reinforcement Learning-based Aspect Term Extraction using Dilated Convolutions and Differential Equation Initialization

Yuyu Xiong¹, Mariani Md Nor², Ye Li³, Hongxiang Guo^{4*}, Li Dai^{5*}

Postgraduate Department, Henan Agricultural University
Zhengzhou, 450046, China^{1,3,4,5}

Faculty of Education, Languages, Psychology & Music, SEGi University
Kuala Lumpur, Petaling Jaya, 47810, Malaysia^{1,2}

Abstract—Aspect term extraction is a crucial subtask in aspect-based sentiment analysis that aims to discover the aspect terms presented in a text. In this paper, a method for ATE is proposed that employs dilated convolution layers to extract feature vectors in parallel, which are then concatenated for classification downstream. Reinforcement learning is used to save the ATE model from imbalance classification, in which the training procedure is posed as a sequential decision-making process. The samples are the states; the network, and the agent; and the agent gets a more significant reward/penalty for correct/incorrect classification of the minority class compared with the majority class. The training phase, which typically employs gradient-based approaches, including back-propagation for the learning process, is tackled. Thus, it suffers from some drawbacks, including sensitivity to initialization. A novel differential equation (DE) approach that uses a clustering-based mutation operator to initiate the BP process is presented. Here, a winning cluster is identified for the current DE population, and a new updating strategy is used to generate candidate solutions. The BERT model is employed as word embedding, which can be included in a downstream task and fine-tuned as a model, while BERT can capture various linguistic properties. The proposed method is evaluated on two English datasets (Restaurant and Laptop) and has achieved outstanding results, surpassing other deep models (Restaurant: Precision 85.44%, F1-score 87.35%; Laptop: Precision 80.88%, F1-score 80.78%).

Keywords—Aspect term extraction; sentiment analysis; differential evolution; reinforcement learning; BERT

I. INTRODUCTION

Sentiment analysis (SA) [1] is a challenging task in NLP that aims to extract overall sentiment from a single sentence or document. However, sentence-level SA doesn't reflect specific features or attributes that a user likes or dislikes. Aspect-based sentiment analysis (ABSA) provides a solution by specifying sentiment at a fine-granular level, giving sentiment to each phrase property. Aspect term extraction (ATE) is a component of ABSA that identifies every particular characteristic or aspect of the good or service being addressed. AT is a textual entity, a sequence of tokens within a sentence that must be referred to explicitly within the text. Such data is vital and frequently mandates an educated decision-making procedure [2].

From the literature, the ATE approaches can be categorized as lexicon-based methods [3], machine learning methods [4], and deep learning approaches [5]. Traditional ATE approaches mainly use feature engineering methods, including part-of-speech [6] and bag-of-words [7], to train machine learning classifiers, including SVM and Naïve Bayesian. Generally, traditional approaches have two shortcomings. First, they mainly do not utilize semantic information in keywords, rules, or features, forcing them not to regard relationships between sentences. Second, handmade rules and feature extraction are not flexible, resulting in inferior generalization ability [8]. DNNs have earned significant success in numerous industries since the introduction of neural networks in recent years [9-12]. ATE works have moved from feature engineering approaches to DNN approaches. Deep learning-based approaches for ATE typically hire RNN [13, 14], CNN [15-17], RecNN [18], and Memory Networks [19]. Besides the direct uses of various DNNs, the attention mechanism coupled with DNNs is increasingly popular. Other kinds of ATE approaches include embedding techniques and transfer learning. The BERT model [20, 21] is the language model, superior to other language models, which captured the benefit of the statement proposed in transformers [22], which is being applied extensively and utilized in NLP studies [23, 24]. Deep learning-based ATE approaches have shown promising results in identifying and extracting aspect terms from textual data. However, the performance of these models is greatly affected by the imbalance of the datasets. Imbalanced datasets are common in the ATE task, as the number of aspect terms in a sentence is typically small compared to the number of non-aspect terms. This can lead to biased models that are unable to capture the underlying distribution of the data. Another challenge faced by deep learning-based ATE approaches is the sensitivity to initialization during the training phase. The quality of the initial weights of a neural network greatly affects its ability to learn meaningful representations from the input data. Poor initialization can lead to suboptimal performance, and in some cases, the model may fail to converge.

Data imbalance is a significant challenge in ATE, as it can lead to a drop in performance. There are two methods to tackle class imbalance: algorithm-level and data-level [25]. The data-level approach involves under-sampling or over-sampling methods, or both, to counteract the negative impact of class

imbalance. SMOTE [26] and NearMiss [27] are examples of under-sampling and over-sampling methods, respectively. Algorithm-level approaches raise the weight of the minority class through decision threshold adjustment [28], ensemble learning [29], and cost-sensitive learning [30]. Deep-learning approaches have also been proposed to address imbalanced classification. Research has focused on understanding the discriminative characteristics of imbalanced data while maintaining inter-class and inter-cluster margins, and developing a method based on the bootstrapping algorithm that balances data in convolutional networks per mini-batch [31]. Deep reinforcement learning (DRL) has been used in various domains to improve classification performance by eliminating noisy data and discovering better features. However, there have been few studies that apply DRL to classify imbalanced data, despite its suitability for this task. DRL's learning approach, which employs a reward function that discriminates between classes by imposing penalties on minority classes or rewarding them with greater rewards, makes it particularly well-suited for imbalanced data classification.

In the field of neural network methods, gradient-based algorithms like back-propagation have traditionally been used to find the optimal weights [32]. However, these methods can be limited by issues like initialization of parameters and getting stuck in local optima [33, 34]. A potential solution to these problems is to use meta-heuristic algorithms like DE [9], which have been successfully adapted to various optimization problems. DE operates through three main steps: mutation, crossover, and selection, with the mutation operator being particularly significant. By utilizing DE to optimize the learning process, it may be possible to overcome the limitations of gradient-based algorithms and achieve better model performance.

This paper suggests a framework for ATE founded on BERT word embedding, a clustering-based DE algorithm, and a reinforcement learning-based training algorithm. The suggested ATE model contains three dilated convolution layers, aiming to extract rich features in parallel, then concatenated for final classification. The ATE model should classify every word in three classes $\{B, I, O\}$, where B, I show the beginning and non-beginning words of an aspect term, and O means non-aspect terms. Since the number of members in class O is more significant than those in the remaining classes (B and I), the classifier assigns the majority of members to class O , resulting in an unbalanced classification that dramatically reduces system efficiency. Reinforcement learning is used to solve this issue, and design ATE as a guessing game with sequential decision-making steps. At each stage, the agent uses a training instance to represent the environmental state and then, guided by a policy, performs a three-class classification operation. The classifier will accept a positive reward if the operation is completed; otherwise, it will get a negative reward. The minority class receives higher compensation than the majority class. During the sequential decision-making process, the agent's objective is to classify the samples as precisely as possible in order to collect the maximum number of cumulative rewards. An enhanced DE technique is presented based on clustering for weight initialization in order to identify a favorable region in the

search space from which to launch the BP algorithm in all networks. Here, the best candidate solution in the best cluster is chosen as the starting solution in the mutation operator, and a new updating technique is used to generate candidate solutions. The proposed technique is assessed using two English benchmark datasets (Restaurant + Laptop), the experimental findings of which show that the suggested model outperforms its competitors.

Following is a summary of the model's contributions:

- An ensemble of dilated convolutions is provided for the ATE model, enabling the model to extract valuable features from text to make a better decision for classification.
- The proposed model uses BERT word embedding to automatically learn and extract complicated and meaningful text representation from the input data.
- A reinforcement learning architecture is provided for the ATE problem in order to address imbalanced classification.
- As an alternative to random weight systems for model weights, an encoding method is created, and a starting value is computed using an enhanced DE algorithm.

The article's body has the following structure: In Section II, a review of the literature on ATE works is presented. In Section III, further depth into the suggested approach is delved. Section IV provides the experimental results and necessary analyses. Section V represents the conclusion of this article.

II. RELATED WORKS

To date, numerous domains have seen the proposal of a wide range of approaches for SA [35-37]. The majority of current tasks focus on detecting sentiments within single sentences or documents. Due to the limited availability of labeled datasets, supervised learning methods are commonly used, with few exceptions such as the unsupervised clustering method [38, 39]. Turney [40] suggested the utilization of an unsupervised learning method. To do this, the phrases containing adverbs or adjectives are initially evaluated for their semantic direction. Then, by examining the correlation between the average semantic orientation scores, the review can be classified as "recommended" or "not recommended." Pang and Lee [40] introduced a supervised machine learning technique to categorize the sentiment of movie reviews. They employed various linguistic features, such as part-of-speech tags, the presence of adjectives, unigrams, bigrams, etc., and trained them on machine learning classifiers such as Maximum Entropy and Naive Bayes. Pang et al. [35] proposed using a star rating system for movie reviews and argued that the labels derived from it were not independent. They suggested that the system should assign equal ratings to comparable reviews, and submitted a meta-algorithm that uses the connection among labels to improve the multi-class categorization outcome. Meanwhile, Kim and Hovy [41] used a probabilistic technique to identify a paragraph's comment and comment owner and employed the WordNet resource to determine word-level sentiments for sentiment categorization in a sentence. Lastly, Ganu et al. [42] conducted aspect category sentiment

categorization in restaurant reviews by identifying six primary restaurant categories and classifying the reviews into one of four sentiment categories. Moreover, they showed that the review's textual content is a superior signal to the other meta-information. Go et al. [43] adopted a sentiment classifier by comparing PoS tags and N-grams with emoticon data. However, their suggested model does not use the data provided by emoticons. They remove emoticons from the tweet, so if the testing data has an emoticon, it does not impact the classifier because there was no emoticon in the training data.

According to the literature, ABSA has recently garnered the interest of scholars worldwide. [44, 45]. In 2014, the first dataset, SemEval-2014 [46], was shared, addressed ABSA's challenges, and provided a particular benchmark configuration. For additional improvement of the issues, two more datasets, SemEval-2015 [47] and SemEval2016 [47], on ABSA were. These datasets introduced the ABSA problem in multiple fields, including laptops, restaurants, hotels, cameras, and languages such as Arabic, English, Chinese, and Dutch.

The task of ATE which is a crucial part of ABSA has captured the attention of many researchers. Liu et al. [48] presented a solution to the ATE problem through the application of RNNs in their research. They discovered that the LSTM-RNN technique was more effective than the Conditional Random Field with many features (CRF) method, which relied on a multitude of features. Majumder et al. [49] integrated positional-based account data from other ATs in their research to classify aspect terms. The aim was to enable the method to recognize the position of other parts-of-speech words and their associated sentiment-carrying phrases, thus avoiding being sidetracked by them. Their modifications led to better performance and introduced a new approach for the laptop and restaurant domains. Yin et al. [50] employed word embeddings in the dependency path to acquire word representations. Xu et al. [51] proposed the DE-CNN model, which incorporates a dual embedding mechanism consisting of domain-specific and general-purpose embeddings. Xu et al. [52] fine-tuned BERT [53] on a specialized dataset to obtain advanced word embeddings. Yin et al. [54] created a word

embedding approach that exploits positional dependence to take into account both positional setting and reliance correlations. They utilized assorted neural network architectures to capture diverse factors of the mission, such as illustrating the association between a unit and its appropriate sentiment term in a sequence identification system [55], and transfiguring the task into a Seq2Seq problem to grab the all-purpose objective of the entire sentence for identifying the part with more crucial contextual data [56]. Since annotating every component of an expression can be a time-intensive task, unsupervised ATE models have been widely advocated by analysts [57]. He et al. [58] put forward an autoencoder design for neural network-powered methods that diminishes insignificant terms to amplify the consistency of extracted features. By employing this approach, Luo et al. [59] coerced sememes to enhance lexical semantics during the creation of phrase representations. Tulkens and Cranenburgh [60] offered a solution named CAT, which uses a POS tagger and in-domain word representations to find component terms. The POS tagger discovers nouns as candidate features before using a contrastive attention technique to choose features. Shi et al. [61] formulated the ATE problem as a self-supervised contrastive learning task to discover feature representations that are more precise.

III. METHOD

A. Word Embedding

BERT [20] is a word embedding model often fine-tuned from a layer for various classification tasks and trained on huge datasets, like Wikipedia, to produce contextual word representations. Fine-tuning enables the use of the problem-specific meaning with a trained generic meaning and trains it for classification tasks. The general BERT architecture is shown in Fig. 1. In BERT, representations are jointly conditional on the left and proper context in all layers thanks to a bi-directional transformer. In contrast to Word2Vec and GloVe models, which create an embedding in one direction to disregard contextual differences, BERT produces an embedding in both directions.

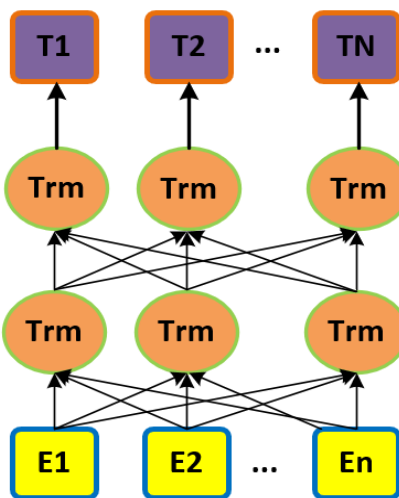


Fig. 1. Structure of the BERT model.

B. Prediction

Fig. 2 depicts the structure of the suggested ATE model. The model receives a sentence $s = [w_1, w_2, \dots, w_n]$ as input, where w_i are the words, and n is the maximum number of words in a sentence and passes it to the BERT model. The output of the DistilBERT model is the embedding matrix $M = [e_1; e_2; \dots; e_n]$, where e_i is the embedding of the word w_i . Three dilated convolution layers are employed on the matrix M working in parallel. Each of the three branches independently extracts a feature vector from the sentence. After obtaining text features by convolution, the rich features are extracted by max pooling to simplify the network's computational complexity. Finally, the connection obtained from the Maxpooling layers enters the MLP network for classification. The output of MLP is a vector whose length is $3 \times n$, as every word w_i should be classified into three classes $\{B, I, O\}$, where B, I show the beginning and non-beginning words of an aspect phrase, and O shows non-aspect words.

As most words from a sentence are in class O than two other classes, the classifier faces the problem of imbalanced classification, which drastically decreases system performance. A sequential decision issue is created using the imbalanced classification Markov decision process (ICMDP) to solve this.

The neural network weights are initialized in Step 0 through pre-training with the enhanced DE algorithm. In Step 1, a sample (s_t) is randomly selected from the dataset, which is part of the RL environment. The network processes the sample in Step 2. In Step 3, the network's prediction (action a_t) is

returned to the environment to obtain the next sample (s_{t+1}) and its corresponding reward r_t in Step 4. The transition $\{s_t, a_t, r_t, s_{t+1}\}$ is then stored in the replay memory in Step 5. Multiple transitions are stored in the replay memory until a minibatch of transitions can be randomly drawn for updating the network weights in Step 7, after being drawn in Step 6. This process is repeated until the network is capable of correctly classifying the input sample. The algorithm stops when the number of episodes has been reached.

C. Pre-Training

At this stage, the weights of the proposed model are initialized. For this, an enhanced differential evolution method boosted by a clustering scheme and a novel fitness function is introduced.

a) *Clustering-based Differential Evolution*: The enhanced DE algorithm employs a clustering-based mutation and updating technique to improve the optimization performance.

The proposed mutation operator, which draws inspiration from [62], pinpoints a potential area in the search space. The k-means algorithm is used to partition the current population P into k clusters, each of which covers a distinct area of the search space. The number of clusters is chosen at random from the range $[2, \sqrt{N}]$. After clustering, the best cluster is identified as the lowest mean fitness of its samples. An illustration of this procedure for a toy problem with 19 potential solutions separated into three clusters is shown in Fig. 3.

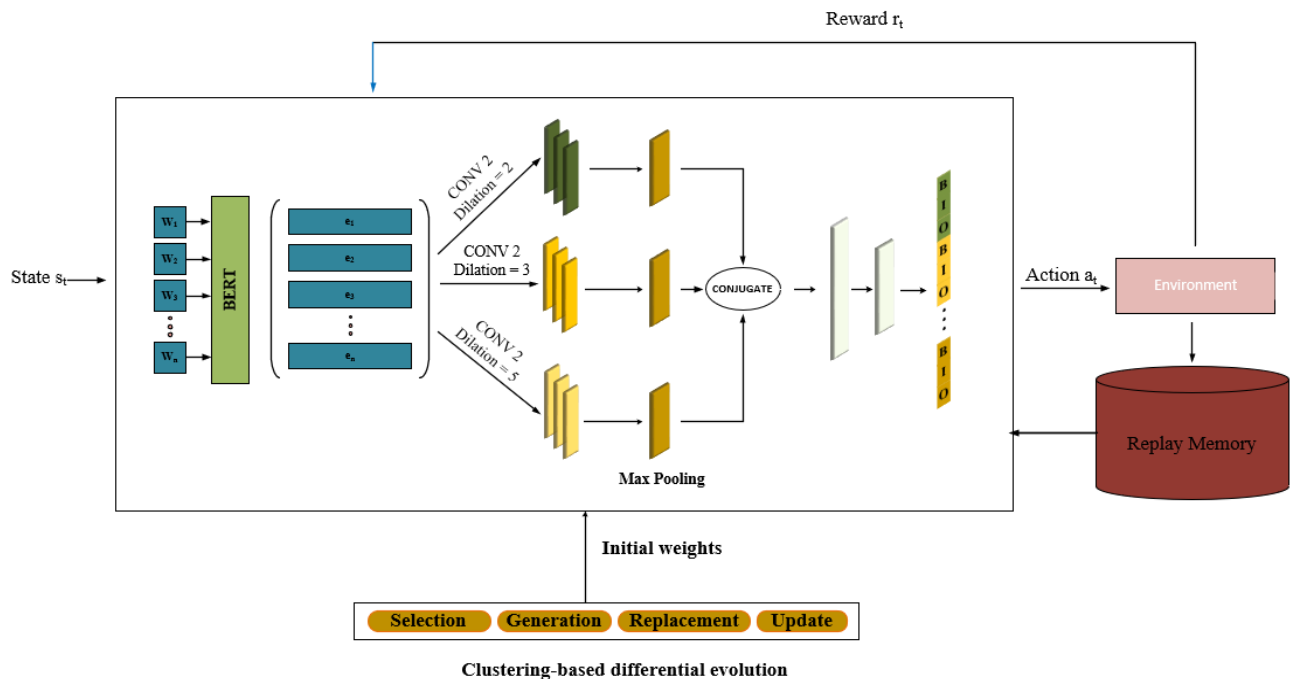


Fig. 2. Overview of the proposed ATE model.

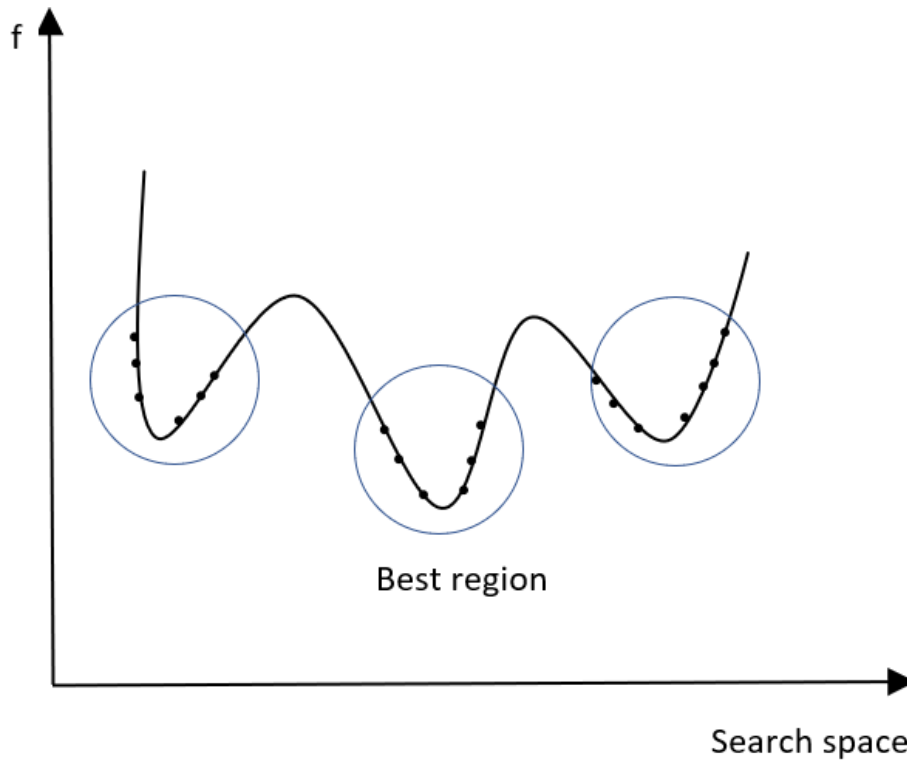


Fig. 3. Population clustering in search space to find the optimal region.

The proposed clustering-based mutation is defined as

$$\vec{v}_i^{clu} = \vec{win}_g + F(\vec{x}_{r_1} - \vec{x}_{r_2}) \quad (1)$$

where \vec{x}_{r_1} and \vec{x}_{r_2} are two randomly chosen candidate solutions from the current population, and \vec{win}_g is the best solution in the promising region. Note that \vec{win}_g is not necessarily the best solution for the population.

After generating M new solutions by clustering-based mutation, the current population is updated based on GPBA [63]; proceedings are as follows:

- 1) *Selection*: Create k individuals randomly to serve as the algorithm's initial seeds.
- 2) *Generation*: generate M solutions with clustering-based mutation as set v^{clu} .
- 3) *Replacement*: Select M solutions randomly from the existing population to comprise set B . Update: Select the top M solutions from $v^{clu} \cup B$ as set B' . The new population is found by $(P - B) \cup B'$.

b) *Encoding Strategy*: The primary structure of the proposed model includes three convolutional layers and a feed-forward network. As illustrated in Fig. 4, all weights and

bias terms are arranged into a vector to form a candidate solution in the proposed DE algorithm.

c) *Fitness Function*: To calculate the quality of a candidate solution, the fitness function is defined as

$$F = \frac{1}{\sum_{i=1}^N (y_i - y'_i)^2} \quad (2)$$

where N shows the number of training examples, y_i and y'_i are the i -th target and output predicted by the model, respectively.

D. Deep Q-Network Training

This article employs RL to tackle ATE. Each sentence in the training set represents a state of the environment, and the network serves as the agent that executes a series of classifications on all sentences. When the agent predicts the class label of a sentence, it takes action, where the sentence observed at the t^{th} time-step is the state s_t , and the classification performed is a_t . In return, the environment offers a reward, r_t , to guide the agent. The rewards are assigned such that classifying a sample from the majority class yields a lower absolute value than the minority class. The reward function can be expressed as:



Fig. 4. Encoding strategy in the proposed algorithm.

$$r_t(s_t, a_t, y_t) = \frac{1}{n} \times \sum_{i=1}^n r_{w_i} \quad (3)$$

where r_{w_i} is the reward received for classifying the word w_i , which is described as:

$$r_{w_i} = \begin{cases} +1, \hat{y}_{w_i} = y_{w_i} \text{ and } y_{w_i} \in \{D_B \cup D_I\} \\ -1, \hat{y}_{w_i} \neq y_{w_i} \text{ and } y_{w_i} \in \{D_B \cup D_I\} \\ \lambda, \hat{y}_{w_i} = y_{w_i} \text{ and } y_{w_i} \in D_O \\ -\lambda, \hat{y}_{w_i} \neq y_{w_i} \text{ and } y_{w_i} \in D_O \end{cases} \quad (4)$$

where D_B and D_I represent the larger class and D_O denotes the smaller class. Properly/improperly classifying a sample from the larger class results in a reward of $+1/-1$, where $0 < \lambda < 1$. In the deep Q-learning approach, the agent's aim is to choose actions that maximize the predicted future rewards. The future rewards are discounted by a factor of γ at each subsequent time step, where

$$R_t \sum_{t'=t}^T \gamma^{t'-t} r_{t'} \quad (5)$$

where T shows the last time-step of the episode. An episode ends when all the samples have been classified or the agent misclassifies a sample from the minority class. Q values, measures of state-action quality, are defined as the expected return of the following strategy π , after seeing state s and taking action a :

$$Q^\pi(s, a) = E[R_t | s_t = s, a_t = a, \pi] \quad (6)$$

The optimal action-value function equals the maximum expected reward overall strategies after seeing state s and taking action a :

$$Q^*(s, a) = \max_{\pi} E[R_t | s_t = s, a_t = a, \pi] \quad (7)$$

This function satisfies the Bellman equation, which asserts that the optimal expected return for a given action is equal to the sum of the rewards from the current action and the maximum expected return from future actions at the following time:

$$Q^*(s, a) = E[r + \gamma \max_{a'} Q^*(s', a') | s_t = s, a_t = a] \quad (8)$$

The Bellman equation is used as an iterative update to estimate the optimal action-value function:

$$Q_{i+1}(s, a) = E[r + \gamma \max_{a'} Q_i(s', a') | s_t = s, a_t = a] \quad (9)$$

During training, after a state s is shown to the network, the network outputs an action a for that state while the environment returns a reward r , and the next state becomes s' . These parameters are embodied in a tuple (s, a, r, s') that is saved into the replay memory, M . Minibatches B of these tuples are selected from the replay memory to perform gradient descent. The loss function is denoted as:

$$L_i(\theta_i) = \sum_{(s,a,r,s') \in B} (y - Q(s, a; \theta_i))^2 \quad (10)$$

where θ represents the model weights, and y , is the estimated target for the Q function. The latter is equal to the reward for the state-action combination plus the discounted maximum future Q value:

$$y r + \gamma \max_{a'} Q(s', a'; \theta_{k-1}) \quad (11)$$

Of note, the Q value for the terminal state equals zero. The gradient of the loss function at step i is calculated as:

$$\nabla_{\theta_i} L(\theta_i) = -2 \sum_{(s,a,r,s') \in B} (y - Q(s, a; \theta_i)) \nabla_{\theta_i} Q(s, a; \theta_i) \quad (12)$$

By performing a gradient descent step on the loss function, the model weights will be updated so as to minimize the error:

$$\theta_{i+1} = \theta_i + \alpha \nabla_{\theta_i} Q(s, a; \theta_i) \quad (13)$$

where α represents the learning rate of the network.

IV. EMPIRICAL EVALUATION

The SemEval-2014 English dataset is employed to analyze the proposed method [46]. The SemEval-2014 dataset is a collection of text data designed for the task of sentiment analysis and opinion mining. This dataset was part of the 8th International Workshop on Semantic Evaluation (SemEval-2014), a shared task initiative that aimed to promote research and development in natural language processing and computational linguistics. The SemEval-2014 dataset contains various subtasks, including aspect-based sentiment analysis, sentiment classification, and sentiment polarity detection. The dataset is composed of two parts, the first of which is the Laptop dataset. This dataset contains a total of 2,186 laptop reviews, each labeled with the corresponding aspect terms, aspect categories, and sentiment polarity. The aspect terms are the specific aspects of the laptop that the reviewer is commenting on, such as keyboard, battery life, or screen. The aspect categories are the broader categories that these aspects fall under, such as design features, performance, or usability. The sentiment polarity is the overall sentiment expressed by the reviewer towards the aspect, which can be positive, negative, or neutral. The second part of the SemEval-2014 dataset is the Restaurant dataset. This dataset contains a total of 3,851 restaurant reviews, each labeled with the corresponding aspect terms, aspect categories, and sentiment polarity. Similar to the Laptop dataset, the aspect terms represent specific aspects of the restaurant that the reviewer is commenting on, such as service, food quality, or atmosphere. The aspect categories are the broader categories that these aspects fall under, such as food, service, or ambience. The sentiment polarity is the overall sentiment expressed by the reviewer towards the aspect, which can be positive, negative, or neutral.

In the first experiment, ten deep learning-based approaches are compared to the algorithm, namely Baseline, System [64], DLIREC [65], IHS_RD [66], PSO-EN [67], MTNA [68], RNCRF [55], CMLA [69], E2E [2].

Table I displays the quantitative outcomes of the proposed model for two datasets. In addition to comparing the suggested method with cutting-edge algorithms, the ATE without RL method is used to assess the efficacy of the RL component on the model ATE. For the Restaurant dataset, the suggested model outperformed competing models, including E2E, resulting in an error reduction of more than 40% and 24% in the F1-score and accuracy criterion, respectively. The suggested model reduces the error rate by roughly 51% compared to ATE without RL, demonstrating the significance of the RL technique. For the Laptop dataset, the approach outperformed E2E and PSO-EN algorithms in terms of F1-

score and accuracy, so for the F1-score and accuracy criteria, the error improving rates are roughly 30.13% and 21.00%, respectively.

A. Comparison with other Metaheuristics

The improved DE algorithm is compared with a number of metaheuristic optimization algorithms. Different metaheuristics are used to obtain the initial model parameters while keeping the other model components. Seven different algorithms are used, namely standard DE [70], BA [71], COA [72], ABC [73], GWO [74], WOA [75], and SSA [76]. Table II contains the obtained results for the Restaurant and Laptop datasets. For the Restaurant dataset, the proposed model reduces error by about 31% compared to the standard DE. It clearly shows that the model has a substantial ability compared to the standard one. Also, DE offers more acceptable results than other algorithms, including ABC, GWO, and BAT. There is a minor improvement for the laptop dataset, so the error rate is reduced by around 17.17%.

B. Word Embeddings

Word embedding is a critical component of deep learning models, as incorrect embeddings can mislead the model. In this study, BERT, one of the latest embedding models, was utilized

as the word embedding. Five other word embeddings, including One-Hot encoding [77], CBOW, Skip-gram [78], GloVe [79], and FastText [80], were employed to compare various word embeddings with the model. One-Hot encoding is a vital step in converting the collected data variables into binary features, which improves the accuracy of predictions and classifications. A binary feature is generated for each class, and each sample's feature is assigned a value of 1 corresponding to its original class. The Skip-gram and CBOW algorithms use neural networks to convert a word to its word embedding vector. GloVe is a technique for aggregating global word-word co-occurrence data from a corpus. The FastText word embedding technique expands on the Skip-gram paradigm by encoding each word as an n-gram of letters instead of learning word vectors. The results of this study are presented in Table III. As anticipated, One-Hot encoding is the least effective among the others. Therefore, the proposed model's improvement rate is around 53.72% and 61.95% for the Restaurant and Laptop datasets, respectively. Due to their similar design, Skip-gram and CBOW perform almost equally across all datasets, and both outperform the GloVe word embedding. Compared to the FastText model, BERT reduces errors by 14% and 10% for the Restaurant and Laptop datasets, respectively.

TABLE I. EVALUATIONS OF THE DEEP LEARNING-BASED SYSTEMS

Model	Restaurant			Laptop		
	Precision	Recall	F1	Precision	Recall	F1
Baseline	44.69	50.49	47.26	31.40	38.05	35.64
System	78.62	82.09	81.91	68.44	74.11	72.42
DLIREC	82.15	85.12	83.11	71.50	74.53	73.59
IHS_RD	79.18	81.16	80.49	72.82	76.12	74.55
PSO-FS	80.49	86.53	83.11	71.00	74.46	72.78
PSO-EN	80.14	87.06	84.52	73.01	76.25	74.93
MTNA	82.49	84.10	83.67	74.46	76.09	75.45
RNCRF	83.02	85.78	84.05	74.09	79.36	76.83
RNCRF+F	83.02	85.98	84.90	76.26	79.56	78.42
CMLA	81.86	88.42	85.34	75.36	79.06	77.80
E2E	82.52	84.18	83.36	74.59	79.46	78.57
ATE without RL	79.10	82.19	81.16	70.09	76.15	73.84
Proposed	85.44	89.14	87.35	80.88	82.48	80.78

TABLE II. EVALUATIONS OF METAHEURISTIC ALGORITHMS

Model	Restaurant			Laptop		
	Precision	Recall	F1	Precision	Recall	F1
DE	84.41	81.10	82.20	75.69	80.12	77.90
BA	73/85	63/24	70/47	67/49	72/69	68/45
COA	68/52	61/89	64/23	59/14	68/48	63/40
ABC	78.10	70.26	75.81	69.01	75.56	72.30
GWO	49/80	50/47	49/85	32/58	40/15	37/96
WOA	67/00	55/86	60/55	52/40	61/86	57/23
SSA	65/10	53/20	60/25	50/48	58/47	54/00

TABLE III. EVALUATIONS OF VARIOUS WORD EMBEDDINGS

Model	Restaurant			Laptop		
	Precision	Recall	F1	Precision	Recall	F1
One-Hot encoding	45.20	49.46	47.23	33.96	37.20	35.64
CBOW	79.02	83.16	81.94	69.13	74.29	72.42
Skip-gram	79.14	82.13	80.15	69.29	74.82	72.79
GloVe	82.14	86.19	84.06	72.46	75.93	74.55
FastText	83.59	87.23	85.11	74.63	78.20	76.78

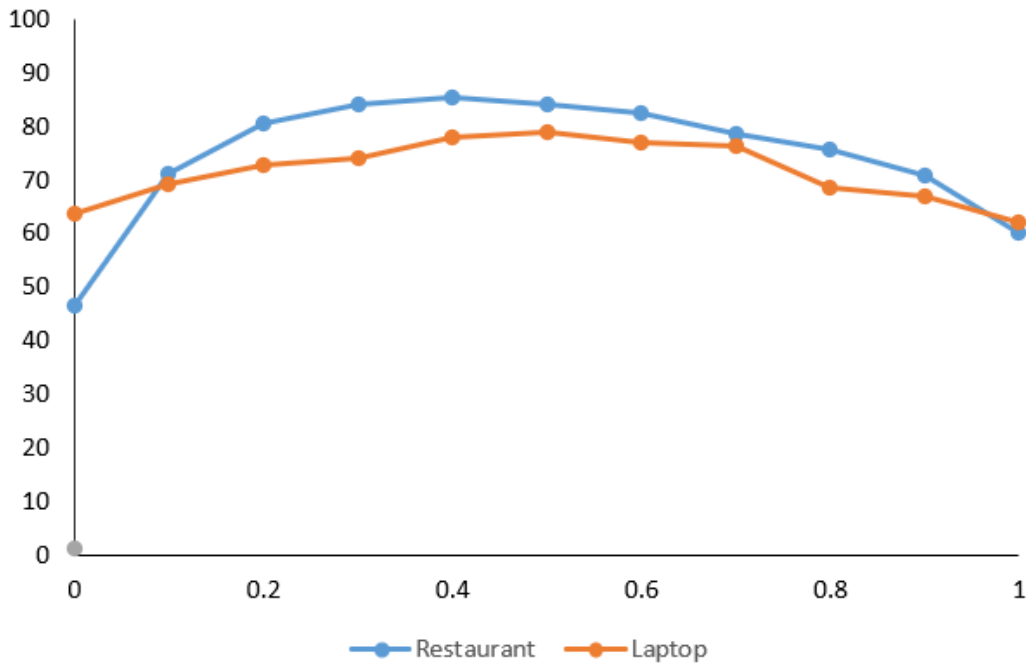


Fig. 5. The procedure of altering the criteria for each dataset by changing the value of λ .

Without RL	With RL	Real
I have to say they have one of the fastest delivery times in the city.	I have to say they have one of the fastest delivery times in the city.	delivery, times
Certainly not the best sushi in New York, however, it is always fresh, and the place is very clean, sterile.	Certainly not the best sushi in New York, however, it is always fresh, and the place is very clean, sterile.	sushi, place
We enjoyed ourselves thoroughly and will be going back for the desserts.	We enjoyed ourselves thoroughly and will be going back for the desserts .	desserts
Most importantly, it is reasonably priced.	Most importantly, it is reasonably priced .	priced
The unattractive lighting made me want to gag, the food was overpriced, there was the most awful disco pop duo performing - and my escargot looked like it might crawl off the plate.	The unattractive lighting made me want to gag, the food was overpriced, there was the most awful disco pop duo performing - and my escargot looked like it might crawl off the plate.	lighting, food, disco, pop, duo, escargot

Fig. 6. Examples of ATE output with and without reinforcement learning.

C. Impact of the Reward Function

In the suggested ATE design, appropriate rewards of +1/-1 and $+\lambda/-\lambda$ are assigned for the accurate/inaccurate identification of the dominant and subordinate classes, respectively. The value of λ is reliant on the relative proportions of the majority to minority samples, and it should decrease as the ratio increases. To evaluate the effect of λ , the ATE model's performance was assessed by initiating λ with incremental values from the set $\{0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1\}$, while holding the majority class bonus constant (Fig. 5). At $\lambda = 0$, the influence of the majority class is eliminated, and at $\lambda = 1$, both majority and minority classes have equivalent impacts. Across all metrics, model performance peaks at a λ value of 0.4 (increasing from 0 to 0.4; decreasing from 0.4 to 1). As a result, while λ needs to be adjusted to weaken the

impact of the majority class, a too-low value can impair the overall model performance.

D. Case Study

To evaluate the effectiveness of RL in the proposed ATE model, five samples were randomly selected from the SemEval-2014 dataset. The results are illustrated in Fig. 6, where the first column shows the model's output without RL, the second column represents the model's output with RL, and the third column displays the actual aspect term. The results reveal that the model without RL tends to assign a higher score to class O. On the other hand, the model with RL generates the maximum number of scores for correctly classifying classes B and I.

E. Discussion

The use of artificial intelligence in natural language processing has seen significant progress in recent years. The paper presents an approach for ATE that employs dilated convolution layers and reinforcement learning to address the problem of imbalance classification. A novel DE approach is proposed to initiate the BP process and use the BERT model as word embedding. The experimental results on two English datasets show that the suggested ATE model outperforms other systems.

However, there are some limitations that need to be addressed in future works. Firstly, the proposed method was only evaluated on two English datasets. The method's performance on other languages or domains needs to be explored to demonstrate its generalizability. Secondly, the BERT model is used, which is computationally expensive due to its large number of parameters. Although they suggest using other BERT extensions, such as the DistilBERT language model, for reducing the computing costs, it would be interesting to investigate other lightweight and efficient models for word embedding. Finally, no analysis of the extracted aspect terms, such as their relevance or coherence with the context was provided, which could have been a valuable addition to the evaluation metrics.

In addition to the aforementioned limitations, another area that could be explored in future works is the effectiveness of the proposed method on long texts. The ATE task becomes more challenging when dealing with longer texts, as there may be multiple aspects mentioned in the same text, and identifying the relevant aspects requires a more sophisticated approach. Therefore, it would be beneficial to investigate how the proposed method performs on longer texts and whether any modifications or adaptations are necessary to improve its performance. Another potential avenue for future work is to explore the interpretability of the ATE model. While the proposed approach achieved high accuracy in extracting aspect terms, it is not clear how the model makes its predictions. Understanding the reasoning behind the model's decision-making process could help to identify any biases or errors in the model and improve its performance. Furthermore, it would be interesting to investigate the impact of different hyperparameters on the performance of the proposed method. A specific set of hyperparameters was used for the experiments, and it is not clear whether these hyperparameters are optimal for all scenarios. A more thorough analysis of the impact of different hyperparameters on the model's performance could help to identify the most effective settings for different use cases.

V. CONCLUSION

In this article, the problem of ATE was handled, which was constructed from three dilated convolution layers deployed to extract feature vectors in parallel, concatenated for downstream classification. An improved DE algorithm is used for pre-training the model networks. The improved DE algorithm clusters the current population to find a suitable region in the search space and implements a new updating technique. Moreover, Reinforcement learning, which presents the training process as a sequential decision-making process, was applied

to shield the ATE model from imbalanced classification. At each stage, the agent receives samples and classifies them. The environment rewards the agent for each categorization act in which the minority class gets a greater reward than the majority class. Finally, with the help of a particular reward function and a conducive learning environment, the agent reveals the optimal strategy. The proposed models are evaluated using the Restaurant and Laptop datasets. The experimental results showed that the suggested ATE model outperformed other systems.

The BERT model typically comprises millions of parameters, increasing the computing costs associated with these models' environmental scaling. This problem can be solved using other BERT extensions, like the DistilBERT language model. The other language models with fewer parameters will be used for the following work.

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REFERENCES

- [1] S. Mukherjee, "Sentiment analysis," in *ML. NET Revealed*: Springer, 2021, pp. 113-127.
- [2] M. S. Akhtar, T. Garg, and A. Ekbal, "Multi-task learning for aspect term extraction and aspect sentiment classification," *Neurocomputing*, vol. 398, pp. 247-256, 2020.
- [3] B. Zhang, D. Xu, H. Zhang, and M. Li, "STCS lexicon: spectral-clustering-based topic-specific Chinese sentiment lexicon construction for social networks," *IEEE Transactions on Computational Social Systems*, vol. 6, no. 6, pp. 1180-1189, 2019.
- [4] S. Kiritchenko, X. Zhu, C. Cherry, and S. Mohammad, "NRC-Canada-2014: Detecting aspects and sentiment in customer reviews," in *Proceedings of the 8th international workshop on semantic evaluation (SemEval 2014)*, 2014, pp. 437-442.
- [5] [5] H. Lakkaraju, R. Socher, and C. Manning, "Aspect specific sentiment analysis using hierarchical deep learning," in *NIPS Workshop on deep learning and representation learning*, 2014, pp. 1-9.
- [6] L. Márquez and H. Rodríguez, "Part-of-speech tagging using decision trees," in *European conference on machine learning*, 1998, Springer, pp. 25-36.
- [7] Y. Zhang, R. Jin, and Z.-H. Zhou, "Understanding bag-of-words model: a statistical framework," *International journal of machine learning and cybernetics*, vol. 1, no. 1, pp. 43-52, 2010.
- [8] H. Gharagozlou, J. Mohammadzadeh, A. Bastanfard, and S. S. Ghidary, "RLAS-BIABC: A Reinforcement Learning-Based Answer Selection Using the BERT Model Boosted by an Improved ABC Algorithm," *Computational Intelligence and Neuroscience*, vol. 2022, 2022.
- [9] S. V. Moravvej, S. J. Mousavirad, D. Oliva, G. Schaefer, and Z. Sobhaninia, "An Improved DE Algorithm to Optimise the Learning Process of a BERT-based Plagiarism Detection Model," in *2022 IEEE Congress on Evolutionary Computation (CEC)*, 2022: IEEE, pp. 1-7.
- [10] S. V. Moravvej et al., "RLMD-PA: A Reinforcement Learning-Based Myocarditis Diagnosis Combined with a Population-Based Algorithm

- for Pretraining Weights," *Contrast Media & Molecular Imaging*, vol. 2022, 2022.
- [11] S. Danaei et al., "Myocarditis Diagnosis: A Method using Mutual Learning-Based ABC and Reinforcement Learning," in *2022 IEEE 22nd International Symposium on Computational Intelligence and Informatics and 8th IEEE International Conference on Recent Achievements in Mechatronics, Automation, Computer Science and Robotics (CINTI-MACRo)*, 2022, IEEE, pp. 000265-000270.
- [12] L. Hong, et al., "GAN - LSTM - 3D: an efficient method for lung tumour 3D reconstruction enhanced by attention - based LSTM," *CAAI Transactions on Intelligence Technology*, 2023, doi: <https://doi.org/10.1049/cit.12223>.
- [13] G. Bao, Y. Zhang, and Z. Zeng, "Memory analysis for memristors and memristive recurrent neural networks," *IEEE/CAA Journal of Automatica Sinica*, vol. 7, no. 1, pp. 96-105, 2019.
- [14] M. Zhang, Y. Zhang, and D.-T. Vo, "Gated neural networks for targeted sentiment analysis," in *Thirtieth AAAI conference on artificial intelligence*, 2016.
- [15] Y. Chen, "Convolutional neural network for sentence classification," *University of Waterloo*, 2015.
- [16] L. Chen, X. Hu, W. Tian, H. Wang, D. Cao, and F.-Y. Wang, "Parallel planning: A new motion planning framework for autonomous driving," *IEEE/CAA Journal of Automatica Sinica*, vol. 6, no. 1, pp. 236-246, 2018.
- [17] P. Xiang, L. Wang, F. Wu, J. Cheng, and M. Zhou, "Single-image de-raining with feature-supervised generative adversarial network," *IEEE Signal Processing Letters*, vol. 26, no. 5, pp. 650-654, 2019.
- [18] R. Socher, C. C. Lin, C. Manning, and A. Y. Ng, "Parsing natural scenes and natural language with recursive neural networks," in *Proceedings of the 28th international conference on machine learning (ICML-11)*, 2011, pp. 129-136.
- [19] J. Weston, S. Chopra, and A. Bordes, "Memory networks," *arXiv preprint arXiv:1410.3916*, 2014.
- [20] J. D. M.-W. C. Kenton and L. K. Toutanova, "Bert: Pre-training of deep bidirectional transformers for language understanding," in *Proceedings of naacL-HLT*, 2019, pp. 4171-4186.
- [21] S. V. Moravvej, S. J. Mousavirad, D. Oliva, and F. Mohammadi, "A Novel Plagiarism Detection Approach Combining BERT-based Word Embedding, Attention-based LSTMs and an Improved Differential Evolution Algorithm," *arXiv preprint arXiv:2305.02374*, 2023.
- [22] A. Vaswani et al., "Attention is all you need," *Advances in neural information processing systems*, vol. 30, 2017.
- [23] M. S. Sartakhti, M. J. M. Kahaki, S. V. Moravvej, M. javadi Joortani, and A. Bagheri, "Persian language model based on BiLSTM model on COVID-19 corpus," in *2021 5th International Conference on Pattern Recognition and Image Analysis (IPRIA)*, 2021: IEEE, pp. 1-5.
- [24] S. V. Moravvej, A. Mirzaei, and M. Safayani, "Biomedical text summarization using conditional generative adversarial network (CGAN)," *arXiv preprint arXiv:2110.11870*, 2021.
- [25] S. V. Moravvej, S. J. Mousavirad, M. H. Moghadam, and M. Saadatmand, "An lstm-based plagiarism detection via attention mechanism and a population-based approach for pre-training parameters with imbalanced classes," in *Neural Information Processing: 28th International Conference, ICONIP 2021, Sanur, Bali, Indonesia, December 8–12, 2021, Proceedings, Part III 28, 2021*, Springer, pp. 690-701.
- [26] H. Han, W.-Y. Wang, and B.-H. Mao, "Borderline-SMOTE: a new over-sampling method in imbalanced data sets learning," in *International conference on intelligent computing*, 2005, Springer, pp. 878-887.
- [27] I. Mani and I. Zhang, "kNN approach to unbalanced data distributions: a case study involving information extraction," in *Proceedings of workshop on learning from imbalanced datasets*, 2003, vol. 126, *ICML*, pp. 1-7.
- [28] J. Chen, C.-A. Tsai, H. Moon, H. Ahn, J. Young, and C.-H. Chen, "Decision threshold adjustment in class prediction," *SAR and QSAR in Environmental Research*, vol. 17, no. 3, pp. 337-352, 2006.
- [29] S. Amari, *The handbook of brain theory and neural networks*. MIT press, 2003.
- [30] A. Fernández, S. García, M. Galar, R. C. Prati, B. Krawczyk, and F. Herrera, *Learning from imbalanced data sets*. Springer, 2018.
- [31] Y. Yan, M. Chen, M.-L. Shyu, and S.-C. Chen, "Deep learning for imbalanced multimedia data classification," in *2015 IEEE international symposium on multimedia (ISM)*, 2015: IEEE, pp. 483-488.
- [32] S. V. Moravvej, M. J. Maleki Kahaki, M. Salimi Sartakhti, and M. Joodaki, "Efficient GAN-based Method for Extractive Summarization," *Journal of Electrical and Computer Engineering Innovations (JECEI)*, pp. -, 2021, doi: 10.22061/jecei.2021.8051.475.
- [33] S. Vakilian, S. V. Moravvej, and A. Fanian, "Using the cuckoo algorithm to optimizing the response time and energy consumption cost of fog nodes by considering collaboration in the fog layer," in *2021 5th International Conference on Internet of Things and Applications (IoT)*, 2021: IEEE, pp. 1-5.
- [34] S. Vakilian, S. V. Moravvej, and A. Fanian, "Using the artificial bee colony (ABC) algorithm in collaboration with the fog nodes in the Internet of Things three-layer architecture," in *2021 29th Iranian Conference on Electrical Engineering (ICEE)*, 2021: IEEE, pp. 509-513.
- [35] B. Pang and L. Lee, "Seeing stars: Exploiting class relationships for sentiment categorization with respect to rating scales," *arXiv preprint cs/0506075*, 2005.
- [36] N. C. Dang, M. N. Moreno-García, and F. De la Prieta, "Sentiment analysis based on deep learning: A comparative study," *Electronics*, vol. 9, no. 3, p. 483, 2020.
- [37] M. Wankhade, A. C. S. Rao, and C. Kulkarni, "A survey on sentiment analysis methods, applications, and challenges," *Artificial Intelligence Review*, pp. 1-50, 2022.
- [38] L. Zhuang, F. Jing, and X.-Y. Zhu, "Movie review mining and summarization," in *Proceedings of the 15th ACM international conference on Information and knowledge management*, 2006, pp. 43-50.
- [39] A. Mukherjee and B. Liu, "Aspect extraction through semi-supervised modeling," in *Proceedings of the 50th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, 2012, pp. 339-348.
- [40] P. D. Turney, "Thumbs up or thumbs down? Semantic orientation applied to unsupervised classification of reviews," *arXiv preprint cs/0212032*, 2002.
- [41] S.-M. Kim and E. Hovy, "Determining the sentiment of opinions," in *COLING 2004: Proceedings of the 20th International Conference on Computational Linguistics*, 2004, pp. 1367-1373.
- [42] G. Ganu, N. Elhadad, and A. Marian, "Beyond the stars: improving rating predictions using review text content," in *WebDB*, 2009, vol. 9, pp. 1-6.
- [43] [43] A. Go, R. Bhayani, and L. Huang, "Twitter sentiment classification using distant supervision," *CS224N project report*, Stanford, vol. 1, no. 12, p. 2009, 2009.
- [44] [44] M. Hu and B. Liu, "Mining and summarizing customer reviews," in *Proceedings of the tenth ACM SIGKDD international conference on Knowledge discovery and data mining*, 2004, pp. 168-177.
- [45] A.-M. Popescu and O. Etzioni, "Extracting product features and opinions from reviews," in *Natural language processing and text mining: Springer*, 2007, pp. 9-28.
- [46] S. Manandhar, "Semeval-2014 task 4: Aspect based sentiment analysis," in *Proceedings of the 8th international workshop on semantic evaluation (SemEval 2014)*, 2014.
- [47] M. Pontiki, D. Galanis, H. Papageorgiou, S. Manandhar, and I. Androutsopoulos, "Semeval-2015 task 12: Aspect based sentiment analysis," in *Proceedings of the 9th international workshop on semantic evaluation (SemEval 2015)*, 2015, pp. 486-495.
- [48] P. Liu, S. Joty, and H. Meng, "Fine-grained opinion mining with recurrent neural networks and word embeddings," in *Proceedings of the 2015 conference on empirical methods in natural language processing*, 2015, pp. 1433-1443.
- [49] N. Majumder, S. Poria, A. Gelbukh, M. S. Akhtar, E. Cambria, and A. Ekbal, "IARM: Inter-aspect relation modeling with memory networks in aspect-based sentiment analysis," in *Proceedings of the 2018 conference*

- on empirical methods in natural language processing, 2018, pp. 3402-3411.
- [50] Y. Yin, F. Wei, L. Dong, K. Xu, M. Zhang, and M. Zhou, "Unsupervised word and dependency path embeddings for aspect term extraction," arXiv preprint arXiv:1605.07843, 2016.
- [51] H. Xu, B. Liu, L. Shu, and P. S. Yu, "Double embeddings and CNN-based sequence labeling for aspect extraction," arXiv preprint arXiv:1805.04601, 2018.
- [52] H. Xu, B. Liu, L. Shu, and P. S. Yu, "BERT post-training for review reading comprehension and aspect-based sentiment analysis," arXiv preprint arXiv:1904.02232, 2019.
- [53] S. V. Moravvej, M. Joodaki, M. J. M. Kahaki, and M. S. Sartakhti, "A method based on an attention mechanism to measure the similarity of two sentences," in 2021 7th International Conference on Web Research (ICWR), 2021: IEEE, pp. 238-242.
- [54] Y. Yin, C. Wang, and M. Zhang, "Pod: Positional dependency-based word embedding for aspect term extraction," arXiv preprint arXiv:1911.03785, 2019.
- [55] W. Wang, S. J. Pan, D. Dahlmeier, and X. Xiao, "Recursive neural conditional random fields for aspect-based sentiment analysis," arXiv preprint arXiv:1603.06679, 2016.
- [56] D. Ma, S. Li, F. Wu, X. Xie, and H. Wang, "Exploring sequence-to-sequence learning in aspect term extraction," in Proceedings of the 57th Annual Meeting of the Association for Computational Linguistics, 2019, pp. 3538-3547.
- [57] L. Zhang, S. Wang, and B. Liu, "Deep learning for sentiment analysis: A survey," Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery, vol. 8, no. 4, p. e1253, 2018.
- [58] R. He, W. S. Lee, H. T. Ng, and D. Dahlmeier, "An unsupervised neural attention model for aspect extraction," in Proceedings of the 55th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers), 2017, pp. 388-397.
- [59] L. Luo et al., "Unsupervised Neural Aspect Extraction with Sememes," in IJCAI, 2019, pp. 5123-5129.
- [60] S. Tulkens and A. van Cranenburgh, "Embarrassingly simple unsupervised aspect extraction," arXiv preprint arXiv:2004.13580, 2020.
- [61] T. Shi, L. Li, P. Wang, and C. K. Reddy, "A simple and effective self-supervised contrastive learning framework for aspect detection," in Proceedings of the AAAI Conference on Artificial Intelligence, 2021, vol. 35, no. 15, pp. 13815-13824.
- [62] S. J. Mousavirad and H. Ebrahimpour-Komleh, "Human mental search: a new population-based metaheuristic optimization algorithm," Applied Intelligence, vol. 47, pp. 850-887, 2017.
- [63] K. Deb, "A population-based algorithm-generator for real-parameter optimization," Soft Computing, vol. 9, pp. 236-253, 2005.
- [64] D. Kumar Gupta, K. Srikanth Reddy, and A. Ekbal, "Pso-asent: Feature selection using particle swarm optimization for aspect based sentiment analysis," in International conference on applications of natural language to information systems, 2015: Springer, pp. 220-233.
- [65] Z. Toh and W. Wang, "DLIREC: Aspect Term Extraction and Term Polarity Classification System," in SemEval@ COLING, 2014, pp. 235-240.
- [66] M. Chernyshevich, "IHS R&D Belarus: Cross-domain extraction of product features using conditional random fields," in Proceedings of the 8th international workshop on semantic evaluation (SemEval 2014), 2014: Dublin, Ireland, pp. 309-313.
- [67] M. S. Akhtar, D. Gupta, A. Ekbal, and P. Bhattacharyya, "Feature selection and ensemble construction: A two-step method for aspect based sentiment analysis," Knowledge-Based Systems, vol. 125, pp. 116-135, 2017.
- [68] W. Xue, W. Zhou, T. Li, and Q. Wang, "MTNA: a neural multi-task model for aspect category classification and aspect term extraction on restaurant reviews," in Proceedings of the Eighth International Joint Conference on Natural Language Processing (Volume 2: Short Papers), 2017, pp. 151-156.
- [69] W. Wang, S. J. Pan, D. Dahlmeier, and X. Xiao, "Coupled multi-layer attentions for co-extraction of aspect and opinion terms," in Proceedings of the AAAI conference on artificial intelligence, 2017, vol. 31, no. 1.
- [70] K. V. Price, "Differential evolution," Handbook of Optimization: From Classical to Modern Approach, pp. 187-214, 2013.
- [71] X.-S. Yang, "A new metaheuristic bat-inspired algorithm," Nature inspired cooperative strategies for optimization (NICSO 2010), pp. 65-74, 2010.
- [72] X.-S. Yang and S. Deb, "Cuckoo search via Lévy flights," in 2009 World congress on nature & biologically inspired computing (NaBIC), 2009: Ieee, pp. 210-214.
- [73] D. Karaboga and B. Basturk, "A powerful and efficient algorithm for numerical function optimization: artificial bee colony (ABC) algorithm," Journal of global optimization, vol. 39, pp. 459-471, 2007.
- [74] S. Mirjalili, S. M. Mirjalili, and A. Lewis, "Grey wolf optimizer," Advances in engineering software, vol. 69, pp. 46-61, 2014.
- [75] S. Mirjalili, S. M. Mirjalili, S. Saremi, and S. Mirjalili, "Whale optimization algorithm: theory, literature review, and application in designing photonic crystal filters," Nature-inspired optimizers: theories, literature reviews and applications, pp. 219-238, 2020.
- [76] D. Bairathi and D. Gopalani, "Salp swarm algorithm (SSA) for training feed-forward neural networks," in Soft Computing for Problem Solving: SocProS 2017, Volume 1, 2019: Springer, pp. 521-534.
- [77] B. Gu and Y. Sung, "Enhanced reinforcement learning method combining one-hot encoding-based vectors for CNN-based alternative high-level decisions," Applied Sciences, vol. 11, no. 3, p. 1291, 2021.
- [78] S. V. Moravvej, M. J. M. Kahaki, M. S. Sartakhti, and A. Mirzaei, "A method based on attention mechanism using bidirectional long-short term memory (BLSTM) for question answering," in 2021 29th Iranian Conference on Electrical Engineering (ICEE), 2021: IEEE, pp. 460-464.
- [79] M. Kamyab, G. Liu, and M. Adjeisah, "Attention-based CNN and Bi-LSTM model based on TF-IDF and glove word embedding for sentiment analysis," Applied Sciences, vol. 11, no. 23, p. 11255, 2021.
- [80] U. Khalid, A. Hussain, M. U. Arshad, W. Shahzad, and M. O. Beg, "Co-occurrences using Fasttext embeddings for word similarity tasks in Urdu," arXiv preprint arXiv:2102.10957, 2021.

Research on Library Face Book Return Model based on Hybrid PCA and Kernel Function

Jianwen Shi

Fujian Chuangzheng Communications College, Library, 350007, China

Abstract—With the improvement in the quality of university education in China, the behavior of college students and school teachers to borrow and return books in the library is becoming more and more frequent. In peak periods of returning books, managers cannot even assist in returning books in time. Therefore, this research uses kernel function, multi-dimensional principal component analysis method, and multi-dimensional linear discriminant analysis method to construct a new face recognition algorithm for the automatic return of books in the university library. The test results show that the XT_2D_PL algorithm designed in this study has a face recognition rate of 96.8%. When the number of face samples of each type in the test sample set is 11, and when the number of feature dimensions is 14, the recognition rate of 96.3% reaches the highest level. However, if the sample to be processed is 500 pictures, the calculation speed is 1.072ms/per photo, higher than most comparison algorithms. The proposed face recognition algorithm has high recognition accuracy on the library face data; the calculation speed meets the needs of practical applications, and has certain practical promotion potential.

Keywords—Kernel function; multidimensional principal component analysis; face recognition; intelligent book return

I. INTRODUCTION

The traditional way of returning books in university libraries is that the returner puts his valid borrowing certificate in the designated sensing area to identify his identity, returns the book, and takes it away [1-2]. The whole process of returning books in the library is cumbersome, and book returners often forget to carry valid borrowing certificates, which lead to the failure of book return and wastes the time and energy of book returners [3]. Therefore, some university administrators and technical experts propose applying advanced face recognition technology to the library return process and building a university library intelligent return model, so that book returners do not need to carry additional documents and only use their social biometric information and the book return process can be completed [4]. However, the recognition accuracy of algorithms used in the same type of products in the current market still needs to be improved. Directly using the face recognition algorithms of these products to build an intelligent book return system may lead to face-matching errors, face recognition failures, and other problems. This is also the main gap between previous research results and market applications. Therefore, it is necessary to design an algorithm with higher facial recognition accuracy for the intelligent face book return model of college students in order to solve such problems. Therefore, it is necessary to design an algorithm with higher recognition accuracy for the

intelligent face book return model of college students. This research attempts to use multidimensional principal component analysis and multidimensional linear discriminant analysis to reduce the dimension of face data, reduce the redundant information in the image, highlight the key image features, and combine the kernel function to map the reduced data to the high-dimensional feature space, stoned a more suitable classification and recognition space, which is also the innovation of this research. The significance of this study is to improve the efficiency of library borrowing and returning books, reduce the losses caused by work errors of library management personnel, and provide useful references for improving the borrowing experience of borrowing personnel. The significance of this study is to improve the efficiency of library borrowing and returning books, reduce the losses caused by work errors of library management personnel, and provide useful references for improving the borrowing experience of borrowing personnel. The content of this article can be divided into four major sections. The second section is used to elaborate and compare relevant research at home and abroad, and to introduce the purpose of conducting this research. The third module is to design an improved model for face recognition. The main content of the fourth module is to design and carry out experiments to verify the performance of the designed library face recognition model. The main content of the fifth module is to summarize the experimental results of this study and point out the direction for future research.

II. RELATED WORKS

To apply face recognition technology to more real-life scenarios and improve identification quality, scientists and scholars have carried out a lot of related research. Timur I et al. found that hierarchical temporal memory, a new type of machine learning algorithm, performed better in some supervised learning tasks, so they proposed a hierarchical temporal memory algorithm with a learning mechanism. The important features of all images create templates, thereby greatly reducing the computer memory requirements of the algorithm and increasing the calculation speed of the algorithm. The face recognition results show that the recognition accuracy of this algorithm is significantly improved compared with the unimproved hierarchical time memory algorithm when recognizing a large amount of face data [5]. Scholar Clwa found that the face recognition algorithm can be applied to the recognition of other primates such as chimpanzees, but it cannot be applied to the recognition of rhesus monkeys, but rhesus monkeys are widely used in biomedical research and can be effectively recognized; conducive to the development of auxiliary medical research.

Therefore, researchers combine the face recognition method with face detection technology to design a new rhesus monkey face recognition algorithm. The test results show that the method has high classification accuracy [6]. Hansen et al. used the common VGG model in face recognition, the Fisherfaces algorithm, and their algorithm to recognize the face of artificially raised pigs, and found that the algorithm they designed had the highest recognition accuracy on 1553 pig face pictures [7]. Lu et al. found that the resolution of face images captured by surveillance cameras is low, which will adversely affect the performance of gallery image matching. Therefore, they proposed an improved ResNet algorithm incorporating the idea of deep coupling, using a variety of face recognition algorithms in training. The commonly used data sets are tested, and the results show that the proposed algorithm has better consistency and judgment accuracy compared with the existing algorithms [8]. Bours et al. found that autism spectrum disorder is related to the difficulty of emotional recognition of patients through face recognition technology [9]. Ahmed et al. used the Gabor wavelet transform to construct a face recognition algorithm for recognizing symmetrical face images. The test results show that the recognition accuracy of the algorithm on various face recognition task datasets is higher than that of common neural network algorithm [10]. Wu found that the recognition accuracy of many face recognition systems declined during the COVID-19 epidemic. This is because many face recognition systems were trained based on face image data with no or little occlusion. The face image recognition ability is poor. Therefore, in this study, to improve the recognition accuracy of large-area-covered face images, a face recognition algorithm integrated with the attention mechanism was designed. The test results show that the algorithm has significantly higher recognition accuracy on face image data with large area coverage than the traditional face recognition algorithm [11]. Martins et al. studied the expression performance of the parallax energy model in an expression-invariant facial recognition system and found that the model significantly improved the measurement performance compared with the accurate laser ranging map calculation results [12]. Jain et al. found that deep neural networks outperformed traditional machine learning algorithms in processing face image recognition tasks containing facial expressions, so they proposed a hybrid convolutional recurrent neural network algorithm, which consists of convolutional layers and recursive neural networks; neural network composition. The test results show that, compared with the existing algorithms with better processing performance for face recognition tasks with expressions, the algorithm can obtain higher recognition accuracy and the calculation speed can also meet most application scenarios [13].

In summary, the current artificial intelligence experts have carried out a lot of research to improve the accuracy and speed

of face recognition in different application scenarios, and have proposed some algorithms or improvement ideas that can practically solve the problem. However, due to the characteristics of face images that need to be processed in the university library's face return book model, there are fewer expressions, more environmentally redundant information, and higher image similarity, so the previous research results cannot be directly used. Therefore, this research attempts to design a targeted face recognition algorithm according to the data characteristics in the library face book return scene.

III. BUILDING A LIBRARY FACE BOOK RETURN MODEL COMBINING KERNEL FUNCTION, PCA AND LDA

A. Design of Bidirectional Linear Feature Extraction Algorithm based on 2D PCA and 2D LDA

In the face recognition problem, due to the high feature dimension in the face image data, appropriate dimensionality reduction processing will help to improve the face recognition effect [14-15]. Principal Component Analysis (PCA) is an effective and commonly used linear data dimensionality reduction algorithm, and its dimensionality reduction principle is shown in Fig. 1.

As shown in Fig. 1, this method treats the face image as a high-dimensional vector and maps the data to a lower-dimensional feature subspace according to the criterion of maximizing the variance of the principal component data after dimension reduction [16]. The Linear Discriminant Analysis (LDA) method is a classic pattern recognition method. Due to its extremely low computational complexity and simple computational logic, it can also be used to process face data [17]. The calculation principle of the LDA method is shown in Fig. 2.

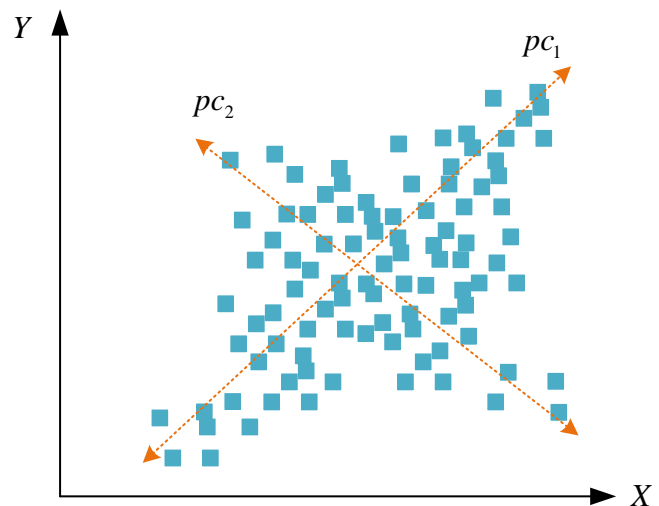


Fig. 1. Schematic diagram of PCA algorithm dimensionality reduction.

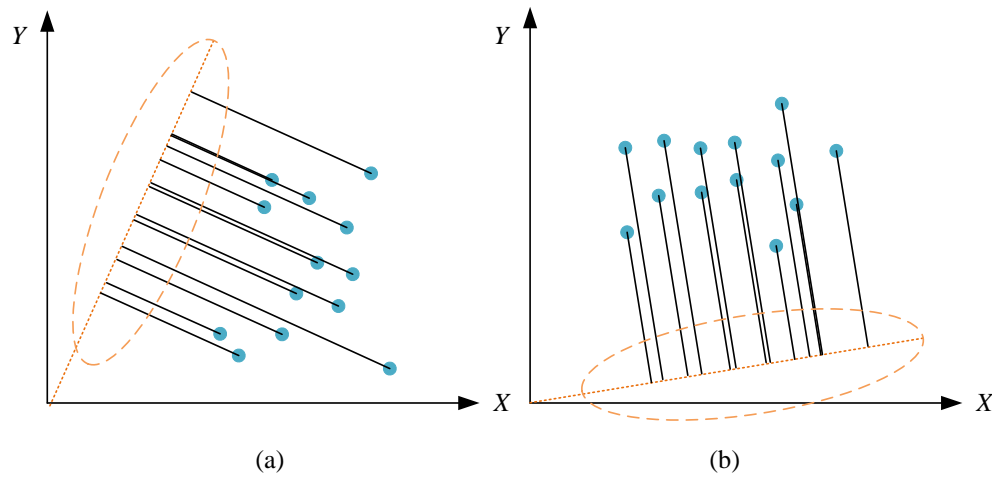


Fig. 2. Calculation schematic diagram of the LDA method.

To be processed to an optimal classification direction in a way that makes the heterogeneous samples mapped in a certain direction has the largest distance in space or the most dispersed distribution, to achieve data classification. However, PCA has the disadvantage of not using the original sample type, and LDA also has limitations when dealing with small samples [18-19]. Therefore, to improve the processing speed and processing accuracy of face data, and consider the multi-directional correlation of data, a bidirectional linear feature extraction algorithm based on two-dimensional PCA and two-dimensional LDA (hereinafter referred to as T_2D_PL algorithm) is proposed. In the T_2D_PL algorithm, the rows in the horizontal direction and the columns in the vertical direction are processed at the same time to obtain the optimal projection axis [20]. When the algorithm is applied to face image dimensionality reduction, it is equivalent to projecting the face image to the column direction, that is, two-dimensional LDA and row direction, that is, the optimal projection of 2DPCA, and according to the feature matrix variance maximization and Fisher criterion The optimization is carried out in a maximizing way so that the number of output feature vectors is greatly reduced, and the data dimensionality reduction is completed. In the T_2D_PL algorithm, if the original image is A_i , and the average image is μ , then the two can be expressed by formula (1).

$$\begin{cases} A_i = [(a_i^{(1)})^T, (a_i^{(2)})^T, \dots, (a_i^{(m)})^T]^T \\ \mu = [(v^{(1)})^T, (v^{(2)})^T, \dots, (v^{(m)})^T]^T \end{cases} \quad (1)$$

Among them $a_i^{(j)}$, $v^{(j)}$ represent the row vector of the i th sample A_i and μ the j th row respectively, then the covariance matrix G can be expressed by formula (2).

$$G = \frac{1}{N} \sum_{i=1}^N \sum_{j=1}^M (a_i^{(j)} - v^{(j)})^T (a_i^{(j)} - v^{(j)}) \quad (2)$$

Where N and M represent the total number of samples and the row vector size of the average image, respectively. It can be seen from Eq. (2) that the operation object of the image covariance matrix is the row vector of the matrix. G After the eigenvalues are decomposed, the former d eigenvectors are formed into a projected multidimensional vector space X_{opt} . In the column direction, the algorithm uses the two-dimensional LDA method to find the best projection vector Z to maximize the Fisher function, as shown in Eq. (3).

$$J(\tau) = \frac{Z^T S_{FB} Z}{Z^T S_{FW} Z} \quad (3)$$

In formula (3), S_{FB} and S_{FW} represent the inter-class scatter matrix and the intra-class scatter matrix, respectively, which are represented by formulas (4) and (5), respectively.

$$S_{FB} = N^{-1} \sum_{i=1}^C N_i (\bar{A}_i - \bar{A})(\bar{A}_i - \bar{A})^T \quad (4)$$

Eq. (4) \bar{A}_i represents the mean of the i th image sample, which is the mean \bar{A} of the total samples of all images.

$$S_{FW} = N^{-1} \sum_{i=1}^C \sum_{j \in C_i} (A_j - \bar{A}_i)(A_j - \bar{A}_i)^T \quad (5)$$

Obtaining S_{FB} and S_{FW} calculating, $S_{FW}^{-1} S_{FB}$ the optimal projection matrix can be obtained, which consists of the previous d largest eigenvalue of the calculation result. To sum up, the calculation flow of the T_2D_PL algorithm can be shown in Fig. 3.

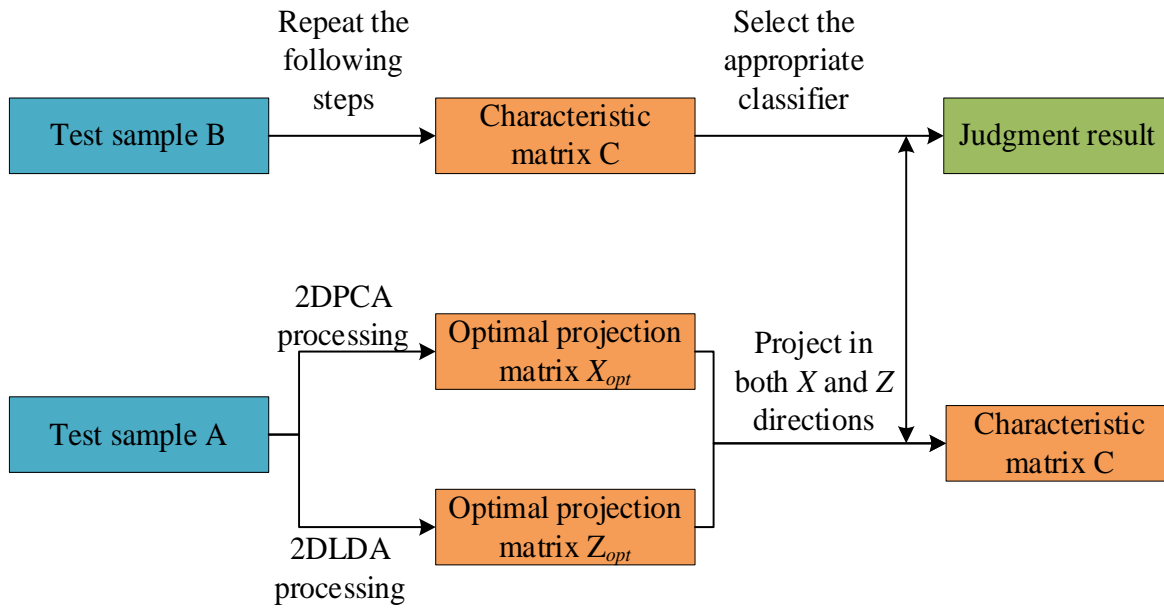


Fig. 3. T_2D_PL algorithm calculation flow chart.

As shown in Fig. 3, $m \times n$ a face image sample of size 1 is A subjected to two-dimensional PCA transformation in the row direction and two-dimensional LDDA transformation in the column direction, thereby outputting the optimal projections in the two directions X_{opt} , Z_{opt} , and then according to the two optimal projections matrix to form a feature matrix C . Projection dimension reduction B will be performed according to the optimal projection to obtain a reduced dimension matrix A . After repeating the above operations, the face image data with an appropriate dimension reduction can be output. Note that the calculation method of the feature matrix C is shown in formula (6).

$$C = Z_{opt}^T A X_{opt} \quad (6)$$

Finally, the nearest neighbor classifier is used to calculate the Euclidean distance between the two C and the k sub-processed feature matrix C_k to complete the classification of the input data. The calculation method of the Euclidean distance between the two is shown in formula (7).

$$D(C, C_k) = \sum_{i=1}^q \sum_{j=1}^d \sqrt{(C^{(i,j)} - C_k^{(i,j)})^2} \quad (7)$$

Where q and d are the number of eigenvectors selected in multiple directions, respectively. So far, the data dimensionality reduction algorithm applied to the library face recognition book return model has been constructed.

B. Design of Improved Nonlinear Feature Extraction Algorithm based on Fusion Kernel Function

At the same time, performing two-dimensional PCA processing on the horizontal direction of the pixel matrix of the image data and two-dimensional LDA processing on the vertical direction of the pixel matrix can effectively reduce the dimension and compress the image on the premise of retaining the core information of the original image as much as possible. However, the above methods are often used to process linear structural data, and the processing effect of nonlinear image data is not good. Therefore, in this study, referring to the idea of kernel function, a feature extraction method of face image data combining T_2D_PL algorithm and combined kernel function is proposed and the recognition algorithm (hereinafter referred to as improved T_2D_PL algorithm). In the improved T_2D_PL algorithm, a kernel function is introduced to deal with the non-linear data brought by facial expression, facial posture, lighting environment and other conditions, which have a negative impact on face recognition. The data processing principle of the kernel function is shown in Fig. 4.

It can be seen that for nonlinear data, it may not be possible to find an identification plane that can clearly distinguish it in the plane, because it has the property of linear inseparability, so it needs to be mapped to three or more dimensions to find a suitable dividing plane. In the algorithm, the T_2D_PL method is still used to reduce the dimensionality of the face data, which is used to delete redundant information and improve the accuracy and speed of subsequent face recognition; column-wise feature extraction and face recognition. Since the data is mapped into a more dimensional feature space by the combined kernel function, the overall time complexity of the algorithm is significantly increased, so the algorithm needs to reserve more storage space and time for data calculation when running. The following is a detailed design of the combined kernel function in the improved T_2D_PL algorithm and the calculation flow of the algorithm.

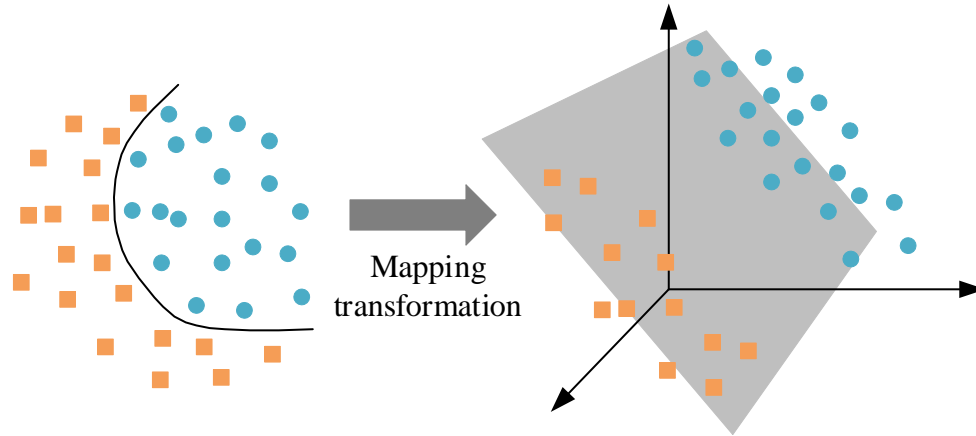


Fig. 4. The schematic diagram of the kernel function mapping processing data.

Different types of combined kernel functions will lead to different applicable objects and different sensitivity to different data processing. Specifically, the local kernel function can process local information accurately and efficiently. The global kernel function is more suitable for extracting global data information and has stronger generalization ability. For example, the Gaussian kernel function is a commonly used local kernel function. When the parameter increases, its extrapolation ability will gradually weaken, and the global data processing ability of the polynomial kernel function is better, which belongs to the global kernel function. Since the selection of the kernel function will directly affect the final recognition performance of the model, this study adopts the idea of combining kernel functions to construct the calculation kernel function in the algorithm. Specifically, it refers to a reasonable linear combination of various types of kernel functions by judging different processing requirements, so as to achieve the premise of retaining the overall information of the data, highlight the local features from different face image categories, and output more excellent judgment results. In this study, the optimal parameter combination of various single kernel functions was first tested experimentally, and then the search center was used to determine the optimal combination of kernel function parameters by grid search method, so that various weight coefficients could be tried in the future., to obtain the best recognition effect. The specific calculation steps of the improved T_2D_PL algorithm have four steps. The first is to map the dimensionality-reduced dataset to the multi-dimensional feature space using the combined kernel function. Assume that the processed input face dataset is $X = [X_1, X_2, \dots, X_M]$

and $X_i = \left[(X_i^1)^T, (X_i^2)^T, \dots, (X_i^m)^T \right]^T$ the kernel matrix K of size, $(i \times k, j \times l)$ can be calculated using Equation (8).

$$K = \Psi(X_i^k) \cdot \Psi(X_j^l) = \Psi(X_i^k) \cdot \Psi(X_j^l)^T \quad (8)$$

Eq. (8) $\Psi()$ represents the combined kernel function, which represents X_i^k the j row vector of the k image sample, X_i and l is the shape parameter of the kernel matrix. The second step is to use Eq. (9) to calculate the eigenvalues and eigenvectors of the kernel matrix.

$$Kb = b\hat{\lambda} \quad (9)$$

In Eq. (9), $\hat{\lambda}$ is the largest eigenvalue obtained by decomposing the kernel matrix, from which the previous P largest eigenvalue in descending order is selected as the eigenvector of the kernel matrix b . Then, the kernel matrix that has been mapped to the high-dimensional feature space is centered, and the feature vector $V^{(i)}$ can be calculated using Eq. (10).

$$V^{(i)} \cdot V^{(i)} = 1 \quad (10)$$

In formula (10) $i \in 1, 2, \dots, P$. Finally, extract the principal components of the row vector of the sample, and obtain the matrix after the row vector is projected by the eigenvectors in the high-dimensional kernel space. $Y_t^{(i)}$ The calculation method is shown in formula (11),

$$Y_t^{(i)} = \sum_{j=1}^M \sum_{k=1}^n \frac{\alpha_{(j-1)n+k}^{(i)}}{\sqrt{\hat{\lambda}^{(i)}}} K(X_i^l, X_j^k) \quad (11)$$

Where the first $\hat{\lambda}^{(i)}$ feature α is in the largest feature set, and i is the known mapping parameter. From this, a matrix of Y_t size can be obtained $m \times P$, and its calculation method is shown in formula (12).

$$Y_t = [Y_t^{(1)}, Y_t^{(2)}, \dots, Y_t^{(P)}] \quad (12)$$

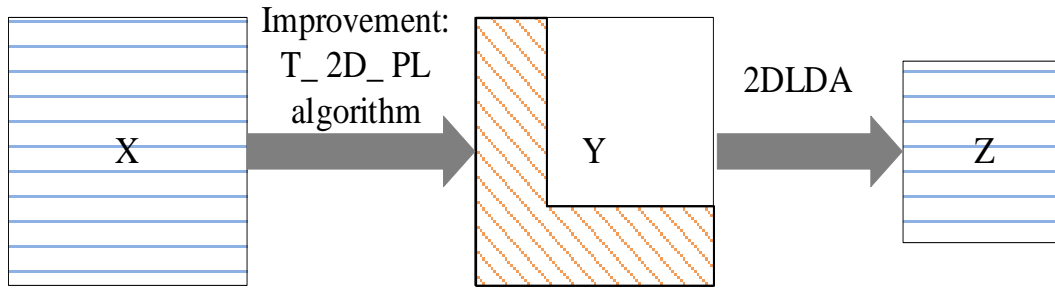


Fig. 5. Data dimensionality reduction process of T_2D_PL method.

After using the improved T_2D_PL algorithm to compress the row and column bidirectional information of the sample, the feature matrix can be obtained Y , and then the matrix is subjected to two-dimensional linear discriminant analysis (2DLDA), that is, through the classification, information of the data itself is subjected to secondary dimensionality reduction and compression, and its specific dimensionality reduction process is shown in Fig. 5.

The process shown in Fig. 5 will be explained in detail below. It is assumed that the total number of images to be processed is M the number of $M_i Y_k$ samples in the training sample of the first category. There are C two i categories $Y_j^{(i)}$ in the j image data Y_k . k A sample matrix, $\bar{Y}^{(i)}$ \bar{Y} respectively represent i the mean image information of the first-class sample and the mean matrix of all sample images, and there is the relationship of formula (13).

$$\bar{Y} = \frac{\sum_{i=1}^M Y_i}{M} \quad (13)$$

Assuming that Y is the size $m \times p$ of the image data to be tested, after mapping it to the W direction, it will form a matrix Z , and its size is $d \times p$ ($d \ll m$), then the average inter-class distance of the image data after the projection can be calculated according to formula (14).

$$H_b = \left[\sum_{i=1}^c M_i (\bar{Y}^{(i)} - \bar{Y})(\bar{Y}^{(i)} - \bar{Y})^T \right] / M \quad (14)$$

The average intra-class distance after projection can be obtained by formula (15).

$$H_w = \sum_{i=1}^c \sum_{j=1}^M (\bar{Y}_j^{(i)} - \bar{Y}^{(i)})(\bar{Y}_j^{(i)} - \bar{Y}^{(i)})^T / M \quad (15)$$

Therefore, the Fisher criterion function after projection can be expressed by Eq. (16).

$$J(Z) = \frac{W^T H_b W}{W^T H_w W} \quad (16)$$

Finally, the matrix is calculated $H_w^{-1} H_b$, and the previous largest eigenvalue in descending order d and the corresponding orthogonal eigenvector are selected to w_1, w_2, \dots, w_d form the optimal projection space of the image, which is expressed by formula (17).

$$W = [w_1, w_2, \dots, w_d] \quad (17)$$

That is to say, after the improved T_2D_PL algorithm dimensionality reduction processing, a dimensionality $d \times p$ reduction matrix of size can be obtained to represent the judgment result of the algorithm on the input data, and the calculation formula is shown in formula (18).

$$Z = W^T Y \quad (18)$$

IV. LIBRARY FACE BOOK RETURN MODEL PERFORMANCE TEST

Before putting it into a practical environment, it is necessary to test the practical performance of the model. The test core of the face-returning-book model is the face recognition ability of the algorithm that composes the model. Therefore, the improved T_2D_PL algorithm is designed in this study (hereinafter referred to as the XT_2D_PL algorithm). For the test, the data selected for the test came from 200 people from many domestic colleges and universities. Each person was photographed with 12 face images with different postures and expressions, and the image type was 112×92 a grayscale image. In the test experiment, the recognition rate and calculation time are selected as the evaluation indicators for the quality of face recognition results. To compare the relative performance of the designed algorithms, two-dimensional LDA, two-dimensional PCA, T_2D_PL algorithm, and VGG neural network algorithm are selected as comparison methods. The parameters of the two-dimensional LDA model include the number of topics, the number of iterations, and the overfitting coefficient; The two-dimensional PCA model has parameters such as target dimensionality reduction quantity and whether to perform whitening treatment; T_2D_ the parameters of PL and its derived algorithms are all the parameters of the two-dimensional LDA model and the two-dimensional PCA model; The parameters of VGG neural network mainly include the number of neurons in each layer, the type of activation function and objective function, and the parameter initialization mode. These parameters are determined by combining industry

experience and usage practices, and conducting experiments by repeatedly debugging and selecting the model with the best testing results. First, analyze the face recognition rate of 2D LDA and 2D PCA under the condition of different number of features, as shown in Fig. 6.

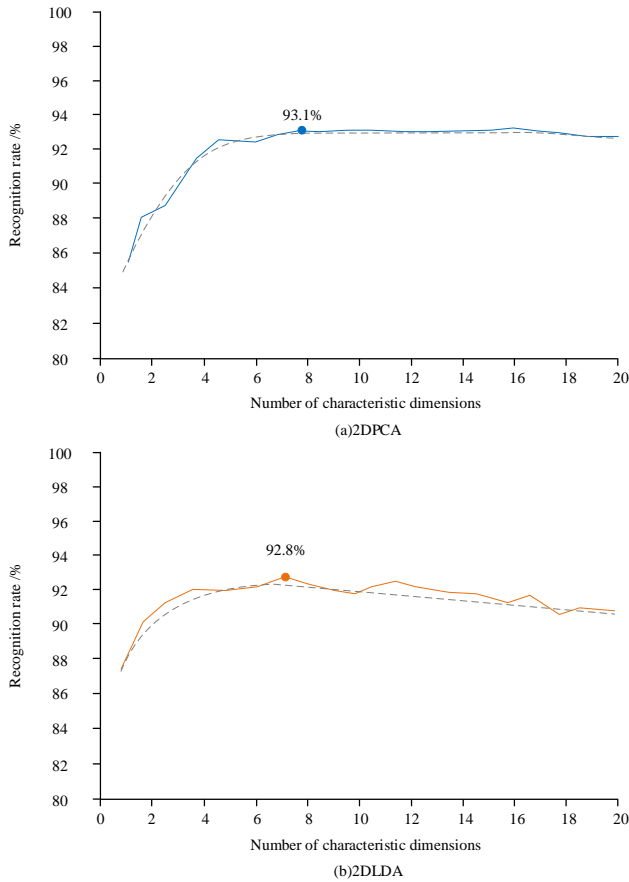


Fig. 6. Statistics of face recognition rate of 2D LDA and 2D PCA under different number of features.

In Fig. 6, “2DPCA” and “2DLDA” represent two-dimensional principal component analysis and two-dimensional linear discriminant analysis, respectively. The gray dotted line in the figure is the fitting trend line of the characteristic curve, that is, Fig. 6[(a), (b)] represents the

statistical graphs of the face recognition rate curves under different numbers of features obtained by using the 2DPCA and 2DLDA methods for face recognition processing. Observing Fig. 6, it can be seen that as the number of features of the image to be processed increases, the face recognition rate of the 2DPCA algorithm first increases and then tends to converge, and the 2DLDA first increases rapidly and then slowly decreases. When the number of feature dimensions of the 2DPCA and 2DLDA methods reaches 8 and 7, respectively, the recognition rate reaches the maximum value of 93.1% and 92.8%. The following analyzes the algorithm recognition rate when the T_2D_PL algorithm is used alone, and the number of PCA and LDA feature dimensions in the algorithm takes different combination schemes. The statistical results are shown in Table I.

Observing Table I, it can be seen that when the dimension of the linear discriminant is fixed and the dimension of the PCA feature is increased, or when the dimension of the PCA feature is fixed and the linear discriminant feature is increased, the change rule of the recognition rate is roughly the same as that in Fig. 6, both of which show a rapid growth first and then are steady and slightly down. When the PCA feature dimension and the linear discriminant feature dimension of the T_2D_PL algorithm are both 12, the recognition rate reaches the maximum value of 94.4%. Next, we will analyze the recognition rate of each algorithm when the number of samples under each type of face samples is different. The statistical results are shown in Fig. 7.

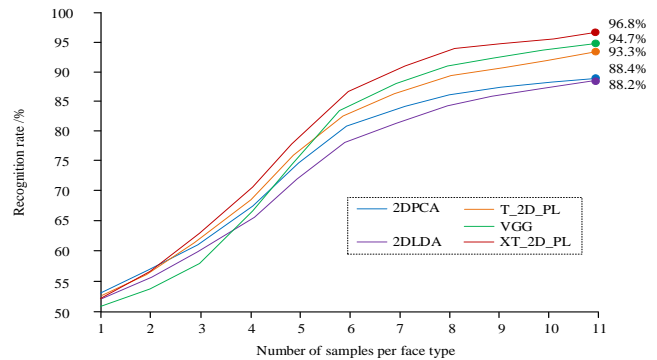


Fig. 7. The face recognition rate statistics of the algorithm under different sample numbers of each type.

TABLE I. RECOGNITION RATE STATISTICS OF T_2D_PL ALGORITHM UNDER DIFFERENT FEATURE DIMENSION NUMBER SCHEMES (UNIT: %)

PCA feature dimension	Linear discriminant feature dimension						
	3	6	9	12	15	18	21
3	64.3	77.8	81.2	80.3	81.9	81.2	80.7
6	85.2	90.9	91.0	89.5	90.2	88.3	90.5
9	88.0	90.7	91.9	90.2	90.8	89.5	90.2
12	89.2	91.8	92.8	94.4	89.7	91.4	91.3
15	89.7	91.9	92.8	93.9	91.7	91.6	90.6
18	90.1	92.4	93.2	93.7	91.2	90.9	90.2
21	89.7	92.0	92.1	93.4	90.8	90.3	90.0

The horizontal axis in Fig. 7 is used to describe the number of samples for each type of facial image in the sample to be processed, the vertical axis represents recognition rate, and different line colors represent different recognition algorithms. Observing Fig. 7, it can be seen that the trend of the recognition rate change curve of each face recognition method is generally consistent with the increase of the number of face samples in each class. When the number of face samples in each class is less than 5, the recognition rate of each recognition model increases rapidly as the number of face samples in each class increases. However, when the number of face samples in each class is 5, the recognition rate growth curve of each model basically reaches a turning point. Subsequently, the number of facial samples in each category continued to increase, and the growth rate of facial recognition rates in each model gradually slowed down, reaching its maximum value when the number reached 11. Specifically, when the number of samples for each type of face is 11, the face recognition rates of the 2DLDA, 2DPCA, T_2D_PL, VGG, XT_2D_PL algorithms are 88.2%, 88.4%, 93.3%, 94.7%, and 96.8%, respectively. When the number of face samples is small, the face recognition rate of each algorithm has a small gap, and the recognition rate of the VGG algorithm is the lowest. This is because VGG belongs to a neural network algorithm and requires a high amount of training data and diversity. Therefore, In this case, a good application effect cannot be obtained. When the number of face samples of each type is large, the recognition performance of the VGG algorithm is significantly improved, and the recognition rate is only lower than the XT_2D_PL algorithm designed in this study. Therefore, the VGG algorithm and the XT_2D_PL algorithm are grouped into a group below, and they remain in the same group with the algorithm, and the changes of their recognition rate with the feature dimension are grouped and counted. The statistical results are shown in Fig. 8.

Assuming that the number of feature dimensions in Fig. 8 is a variable x , the feature dimension parameters of the T_2D_PL algorithm are taken in the row and column directions (x, x) , and the feature dimension parameters of the XT_2D_PL algorithm have the best recognition effect after multiple debugging $(x, x-3)$. Observing Fig. 8, it can be seen that VGG and XT_2D_PL. The change pattern of facial recognition rate curve of PL algorithm is significantly different from other algorithms in different feature dimensions. VGG and XT_2D_PL. There is a significant overall positive correlation between the recognition rate of the PL algorithm and the number of feature dimensions, but in other algorithms, only when the number of feature dimensions is less than 8, there is a certain positive correlation between the recognition rate and the number of feature dimensions. After the number of feature dimensions is greater than 8, there is no significant increase in the recognition rate of each algorithm's face. With the increase in the number of feature dimensions, T performs dimensionality reduction in both column and column directions_2D. The face recognition rate of PL algorithm is significantly higher than that of using only 2DLDA algorithm or 2DPCA algorithm, because the former has more dimensionality reduction directions and can retain more original image information. Observing in Fig. 8(b), it is found

that when the number of feature dimensions is less than 4, the recognition rates of the VGG algorithm and the XT_2D_PL algorithm are both low, but increase rapidly. When the number of feature dimensions exceeds 14, the face recognition of both exceeds that of the other three algorithms, and the highest face recognition rates of the two are 95.4% and 96.3%, respectively. Finally, the computational efficiency of each algorithm is compared, and the computational time-consuming evaluation under different computational sample sizes is used. The statistical results are shown in Fig. 9.

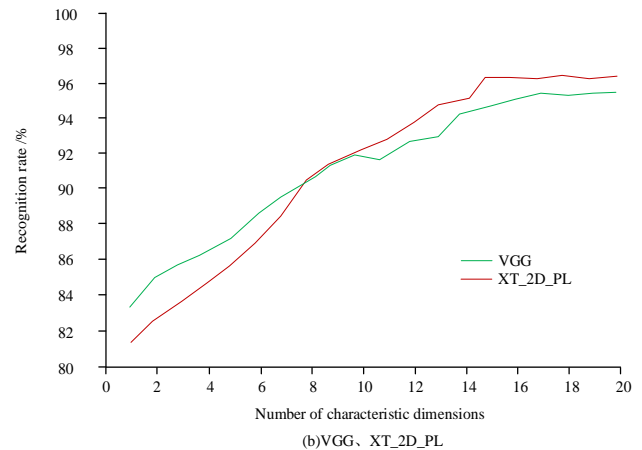
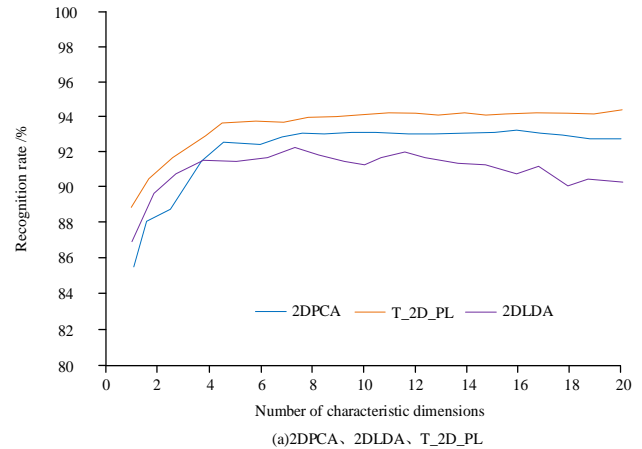


Fig. 8. Statistics of face recognition rate of each algorithm under different feature dimensions.

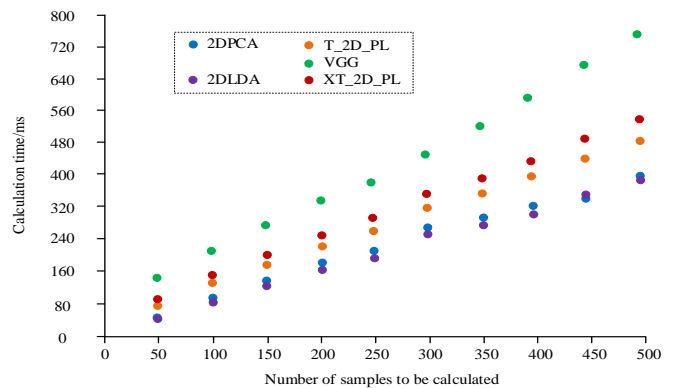


Fig. 9. The calculation of time-consuming statistics of each algorithm under different calculation samples.

The horizontal axis in Fig. 9 is used to describe the number of samples to be detected in each experiment, and the vertical axis is the calculation time of each algorithm, and the unit is ms. Analysis of Fig. 9 shows that, as a whole, with the increase of the data to be detected, the calculation time of each algorithm increases linearly, and the calculation time of the 2DLDA algorithm or the 2DPCA algorithm under various experimental schemes is significantly lower than that of other algorithms. The algorithm, mainly because it has the smallest algorithm complexity requires the fewest computational steps. The calculation time of the XT_2D_PL algorithm and the T_2D_PL algorithm is higher than the first two algorithms, and the calculation time of the XT_2D_PL algorithm is better. The calculation time of the VGG algorithm is the highest among all the experimental schemes. A large number of processing steps are required before outputting the recognition results. When the number of samples to be processed is 500 images, the computation time of 2DLDA, 2DPCA, T_2D_PL, XT_2D_PL, and VGG algorithms are 391ms, 395ms, 481ms, 536ms, and 754ms, respectively, and the calculation speed is 0.782ms/per photo, 0.79ms/per photo, 0.962ms/per photo, 1.072ms/per photo, 1.508ms/per photo. Although the face recognition speed of the library face return mode based on the XT_2D_PL algorithm is not the fastest, the calculation speed is enough to satisfy the library staff Facebook's needs.

V. CONCLUSION

The daily book return behavior of the university library occurs frequently, and a reasonably designed intelligent book return system can help improve the efficiency of the university library and save time for the majority of teachers and students on campus. In this study, the XT_2D_PL algorithm was constructed by using the kernel function and multi-dimensional principal component analysis method, and it was applied to the face recognition work in the library intelligent return system. The experimental results of the algorithm performance test show that the changing trend of the recognition rate change curve of each face recognition algorithm with the increase of the number of face samples of each type is roughly the same, and the growth rate is accelerated first, then the growth rate is greatly reduced and finally stabilized within a certain range of values. When the number of samples for each type of face is 11, the face recognition rates of the 2DLDA, 2DPCA, T_2D_PL, VGG, and XT_2D_PL algorithms are 88.2%, 88.4%, 93.3%, 94.7%, and 96.8%, respectively. When the number of feature dimensions is less than 4, the recognition rates of the VGG algorithm and the XT_2D_PL algorithm are both low, but grow rapidly. When the number of feature dimensions exceeds 14, the face recognition rates of the two algorithms exceed those of the other three algorithms, and the face recognition rates are 95.4% and 96.3%, respectively. When the sample to be processed is 500 pictures, the calculation speed of 2DLDA, 2DPCA, T_2D_PL, XT_2D_PL, VGG algorithm is 0.782ms/per photo, 0.79ms/per photo, 0.962ms/per photo, 1.072ms/per photo, 1.508ms /per photo. The experimental data proves that the library face-to-book model based on the XT_2D_PL algorithm designed in this

research has high face recognition accuracy, and the recognition speed meets the application requirements.

REFERENCES

- [1] Z. Zhang, X. Gong, J. Chen, "Face recognition based on adaptive margin and diversity regularization constraints". *IET Image Processing*, vol. 15(1), pp. 1105-1114, 2021.
- [2] S. Phawinee, J. F. Cai, Z. Y. Guo, et al. "Face recognition in an intelligent door lock with ResNet model based on deep learning". *Journal of Intelligent and Fuzzy Systems*, vol. 40(4), pp. 1-11, 2021.
- [3] C. Borg, "Word and Face Recognition Processing Based on Response Times and Ex-Gaussian Components". *Entropy*, 2021, 23(5):1-17.
- [4] F. Arnia, M. Oktiana, K. Saddami, et al. "Homomorphic Filtering and Phase-Based Matching for Cross-Spectral Cross-Distance Face Recognition". *Sensors*, 2021, 2021(21):4575-4590.
- [5] I. Timur, M. Ulan, K. Olga, et al. "On-chip Face Recognition System Design with Memristive Hierarchical Temporal Memory". *Journal of Intelligent & Fuzzy Systems*, 2018, 34(3):1393-1402.
- [6] B. Clwa "Automated face recognition of rhesus macaques". *Journal of Neuroscience Methods*, 2018, 300(4):157-165.
- [7] M. F. Hansen, M. L. Smith, L. N. Smith, et al. "Towards on-farm pig face recognition using convolutional neural networks". *Computers in Industry*, 2018, 98(6):145-152.
- [8] Z. Lu, X. Jiang, C. C. Kot "Deep Coupled ResNet for Low-Resolution Face Recognition". *IEEE Signal Processing Letters*, 2018,25(4):526-530.
- [9] C. Bours, M. J. Bakker-Huvenaars, J. Tramper, et al. "Emotional face recognition in male adolescents with autism spectrum disorder or disruptive behavior disorder: an eye-tracking study". *European Child & Adolescent Psychiatry*, 2018, 27(3-4):1-15.
- [10] S. Ahmed, M. Frikha, T. Hussein, et al. "Optimum Feature Selection with Particle Swarm Optimization to Face Recognition System Using Gabor Wavelet Transform and Deep Learning". *BioMed Research International*, 2021,3(2):1-13.
- [11] G. L. Wu, "Masked Face Recognition Algorithm for a Contactless Distribution Cabinet". *Mathematical Problems in Engineering*, 2021, 2021(2):1-11.
- [12] J. A. Martins, R. L. Lam, J. Rodrigues, et al. "Expression-Invariant Face Recognition using a Biological Disparity Energy Model". *Neurocomputing*, 2018, 297(JUL.5):82-93.
- [13] N. Jain, S. Kumar, A. Kumar, et al. "Hybrid deep neural networks for face emotion recognition". *Pattern Recognition Letters*, 2018, 115(NOV.1):101-106.
- [14] Wang S., Ge H., Yang J., et al. "Virtual samples based robust block-diagonal dictionary learning for face recognition". *Intelligent Data Analysis*, 2021, 25(5):1273-1290.
- [15] Lv S., Liang J., Di L., et al. "A probabilistic collaborative dictionary learning-based approach for face recognition". *IET Image Processing*, 2021, 15(10):868-884.
- [16] Y. Liu, J. Chen "Multi-factor joint normalization for face recognition in the wild". *IET Computer Vision*, 2021,15(6):405-417.
- [17] S. K. Thiagarajan, K. Nagarathinam, R. Soundar "An improved DFA based kernel ensemble learning machine using local feature representations for face recognition". *Journal of Intelligent and Fuzzy Systems*, 2021, 41(2021):1203-1216.
- [18] S. Xue, H. P. Ren "Single sample per person face recognition algorithm based on the robust prototype dictionary and robust variation dictionary construction". *IET image processing*, 2022, 16(3):742-754.
- [19] P. Gupta, V. Sharma, S. Varma "A novel algorithm for mask detection and recognizing actions of human". *Expert Systems with Applications*, 2022, 198(7):116823.1-116823.10.
- [20] C. Chen, X. Y. Wang, J. Chen, Q. Liu, S. L. Peng "An Active Security System Based on AR Smart Classes and Face Recognition Technology". *Journal of Internet Technology*, 2022, 23(2):245-253.

A Height Accuracy Study Based on RTK and PPK Methods Outside the Standard Working Range

Mohamed Jemai¹, Mohamed Anis Loghmari², Mohamed Saber Naceur³

Laboratoire de Télédétection et Systèmes d'Information à Référence Spatiale (LTSIRS)^{1,2,3}
Institut National des Sciences Appliquées et de Technologie (INSAT), Université de Carthage, Tunis, Tunisia^{1,3}
Institut Supérieur d'Informatique, Université de Tunis El Manar, Tunis, Tunisia²

Abstract—The aim of this paper is to study and analyze the Jack Up Vessel (JUV) foundation height accuracy, with the objective of the precise installation of an Offshore Wind Farm (OWF), based on Real Time Kinematic (RTK) and Post-Processing Kinematic (PPK) modes applied on short and long baselines length. The offshore wind farm project is located far from the coastline, not always in the standard working range of RTK. The standard allowed vertical installation tolerance for foundations is less than 10 cm. Taking into account all error sources, deformation of the vessel, motion, lever arms that impact the height measurement of the foundation, it is required that RTK and PPK perform within an accuracy less than 5 cm. In this work, all measures will be evaluated according to the tolerance specification of ± 2.5 cm. The survey GNSS tests executed during the project on board of a JUV should be able to provide answers to the following questions: Despite the critical environment, does RTK method allow reaching the theoretical specifications? Does PPK improve accuracy compared to the RTK solution? What is the influence of the baseline length? How much of the time the results fall within the range tolerance? What is the ideal logging period in which accurate and reliable results can be obtained? What is the influence of the hardware and software variants used in testing process on the results accuracy? Based on the test results and analysis a clear description of the influence of different parameters in the OWF precise height measurement in challenging environment will be exposed.

Keywords—Real time kinematic; post-processing kinematic; high-precision positioning

I. INTRODUCTION

In this paper, we deal with Differential Global Navigation Satellite System (DGNSS) solutions that have been used to reach accurate measurement at the centimeter level [1] on board a Jack Up Vessel (JUV) with the objective of the precise installation of an Offshore Wind Farm (OWF) located far from the coastline, not always in the standard working range. Indeed, many sources of errors relating to the satellite position, the orbits anomaly, the spatial environment, the satellite clock bias, the receiver clock offset, motion of JUV, will decrease the position accuracy [2-7]. To reduce the effect of these errors a differential positioning is needed, there are two emerging and developing methods for doing this [8], the first with real-time and the second with post-processing namely respectively Real Time Kinematic (RTK) and Post-Processing Kinematic (PPK) (Fig. 1).

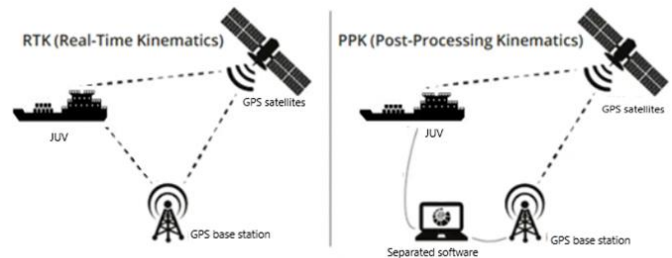


Fig. 1. RTK and PPK principle.

These two methods enhance the traditional method of deploying Ground Control Points (GCP) and become primary methods when we seek high-precision for any mapping, positioning or surveying task. It has been proven that RTK or PPK method extends the Precise Point Positioning (PPP), which needs a longer convergence time compared to differential methods, by incorporating a nearby local base station that perform and accelerate the integer ambiguity resolution, to reach a centimeter and sub-centimeter precision level [9, 10]. Therefore, the uses of GNSS have extended to many areas as Intelligent Transport System (ITS) including structural monitoring, geo-referencing of moving platforms and support for robotics and machine guidance, to name a few [11, 12]. Among the most relevant and recent works, we can cite the comparative study aimed to compare Unmanned Aerial Vehicle (UAV) based on RTK and PPK methods in mapping different surface types via five approaches: RTK Continuously Operating Reference Station (CORS) method, short-baseline PPK method obtaining corrections from a GNSS base station and three long-baseline PPK methods that obtained corrections from three Turkish RTK- (CORS) [13]. It is also promising to apply RTK-PPK to emerging industries like intelligent vehicle navigation and Low Earth Orbit (LEO) constellation augmented positioning [14].

RTK requires two receivers, a rover and a local base station, and a data radio connection between them. In this case, a local base station is placed at a known position. It can calculate the absolute distance of the satellites, based on its own position and the satellite navigation signals. It transmits the differences in distances to the rover as a differential correction. Then, the rover corrects its own distance, based on the correction data received from the base station. It is important to mention that it is not necessary to have a second receiver as a local base all the time. Alternatively, local services sharing base corrections over the Networked

Transport of RTCM via Internet Protocol (NTRIP) technology can be a good option. In case of PPK, there is no radio connection between the two receiver stations. The function of the base station, in the PPK case, is to continuously calculate the differential correction as a function of time and to store the data. The rover station stores the coordinates and data of the satellites used for its calculations as it moves. After the measurement, the data from the two stations can be compared according to the measurement times. After that, the correction can be calculated by separate software.

The present study evaluates the accuracy of the RTK and PPK methods to measure the foundation height of an Offshore Wind Farm (OWF). In standard GNSS positioning applications, it is a well-known fact that it is not possible to get the same precision for the vertical component as for the horizontal components. Indeed, since satellite sky distribution can never be homogenous on the vertical component, as there are no visible satellites under the horizon, errors on the pseudorange and phase observations propagate more adversely on the vertical component than on the horizontal components [15], which explain the strong correlation between the vertical component and some of the main systematic biases (receiver clock error and tropospheric bias). In addition, during the last decades there is a growing interest in being able to continuously monitor movements and deformations in man-made structures that have to withstand strong external forces like those in terrains that are subject to movements such as landslides, ground subsidence. Therefore, analyzing the Jack Up Vessel (JUV) foundation height accuracy in an OWF located far from the coastline, constitutes a real challenge for this work. During the project on board of a Jack Up Vessel (JUV), for the installation of OWF foundations vertical installation, tolerances of ± 10 cm are imposed. Taking into account all error sources, deformation of the vessel, motion, lever arms ... that impact the height measurement of the foundation, the vertical accuracies for GNSS must be lower than 5cm. Based on the theoretical specifications from the hardware used in this project which are Septentrio AsteRx-U & AsteRx-SB and Trimble SPS852 & SPS 855, the expected accuracy at 50 km would be 6 cm for Septentrio and 6.5 cm for Trimble. We will see later that the obtained measurements will be more precise than the indicated theoretical specifications.

According to previous works [16], the position information should be determined, in RTK mode, with accuracy in the range of centimeters in real time as the vessel sails. If the system also provides raw data in Receiver Independent Exchange (RINEX) format, it is also possible to determine the position using PPK method, with centimeter or sub-centimeter precision. In PPK mode, all calculations required for position correction are made post sailing by separate software.

During the project on board the JUV, we should be able to provide answers to the following questions: Despite the critical environment, does RTK method allow reaching the theoretical specifications? Does PPK improve accuracy compared to the RTK solution? What is the influence of the baseline length? How much of the time the results fall within the range tolerance? What is the ideal logging period in which accurate and reliable results can be obtained? What is the

influence of the hardware and software variants used in testing process on the results accuracy?

Based on the test results and analysis a clear description of the influence of different parameters in the OWF precise height measurement outside RTK working range and in challenging environment will be exposed.

II. TEST AND EXPERIMENTATION

This section describes the test and experimentation process, as well as hardware and software variants that will be used in testing process. The development of offshore energies requires ever larger cranes. For this, magic of evolution, boats have grown legs. One of these giants is the jack-up platform that has been developed for oil drilling and offshore wind. For the latter case, the location of the wind turbines must be precise and the height measurement must be accurate. The quality of the bottom having been previously studied, the foundations must rest in the intended place. For this, two factors are essential: controlling the position of the vessel and ensuring that it is stable so that the lifting is clean. To meet the first constraint a geolocation system and motion sensors are provided. Then come the feet that lift the ship and thus ensure that the crane will operate without being disturbed by the movement of the waves.

A. Test Location

Wind turbines require wind. They are therefore often installed in areas prone to strong storms. Although favorable weather windows are preferred, it is necessary to be able to withstand severe conditions. The test location is situated in the Baltic Sea in the most eastern part of Danish territorial waters and Danish Exclusive Economic Zone, directly next to the maritime border to Germany and Sweden. The closest distance to the Danish coastline (Island of Møn) ranges between 13 km and 39 km. The OWF project is located far from the coastline, not always in the standard working range of RTK.

B. Hardware GNSS Setup

The standard allowed vertical installation tolerance for foundations is less than 10 cm. Taken into account accumulative errors of other hardware in the setup required to determine the height of the foundation, it is required that the RTK performs within an accuracy of 5 cm. Based on the test results and analysis a clear definition and installation procedure (logging time, processing service, processing software and error budget) must be defined to determine the height measurement of an offshore base station outside the RTK working range. Two GNSS GA830 antennas were installed on board of the helideck of the JUV (Fig. 2), guaranteeing a clear view of the sky. The two GNSS antennas are installed close to each other and thus experience the same influence of any minor vessel movement.



Fig. 2. GA830 antenna.

For the purposes of this study, we use two Global Navigation Satellite System (GNSS) units namely Trimble and Septentrio units, five receiver brands referenced as DGPS4 (SPS852), SPS855, DGPS5 (AsteRx-U), Sept2 (AsteRx-U), Sept SB (AsteRx-SB).

We should note that the used GNSS constellation is composed from Global Positioning System (GPS), GLObal NAVigation Satellite System (GLO), Galileo (GAL) satellite system, and BeiDou (BEI) satellite system. We should note, again, that SPS852 was receiving GPS+GLO+BEI+GAL, DGPS 5 (AsteRx-U) was receiving GPS+GLO+BEI+GAL, Sept 2 (AsteRx-U) was receiving GPS+GLO+GAL and SPS855 was receiving RTX+(GPS+GLO+GAL). The AsteRx-SB remained working on RTK+(GPS+GLO+GAL)+(OSS KF B – baseline of 8 – 10 km), so it could be used as a reference.

In RTK or PPK modes, the receiver needs to know the type of antenna used at the base station in order to properly compensate for the phase center variation at the base. This information is typically included in the correction stream received from the base station. In this project, heights will be referred to the Antenna Reference Point (ARP) of DGPS5. One antenna is installed 0.080 m lower than the other antenna. Further, AsteRx units refer to ARP heights while Trimble units refer to Antenna Phase Center (APC) heights. Therefore, it is necessary to take into account the difference of 0.0885 m between ARP and APC of a GA830 antenna when comparing a Trimble receiver to an AsteRx receiver. An overview of the internal loggings and the time window is given in Table I.

TABLE I. OVERVIEW DATASETS AND TIMESLOTS USED FOR ANALYSIS

	TEST PURPOSE	TIME WINDOW OF DATASET (IN UTC TIME)
DATASET 1	Comparison RTK on different hardware units with a short baseline (± 8 km)	11/02/2021 19:00 – 12/02/2021 19:00
		13/02/2021 01:00 – 13/02/2021 21:00
		14/02/2021 01:30 – 14/02/2021 19:00
		15/02/2021 02:20 – 15/02/2021 12:00
DATASET 2	Comparison RTK (± 8 km) and RTK <i>GPSnet.dk</i> (29km from closest station)	10/02/2021 00:00 – 10/02/2021 23:59
DATASET 3	Comparison RTK (± 8 km) and PPP-RTK RTX	15/02/2021 16:00 – 16/02/2021 12:00
DATASET 4	Comparison RTK <i>GPSnet.dk</i> and PPP-RTK RTX	17/02/2021 00:00 – 17/02/2021 23:59
DATASET 5	Comparison RTK (± 8 km), PPP-RTK RTX and PPP	18/02/2021 18:00 – 19/02/2021 18:00
		20/02/2021 01:00 – 21/02/2021 01:00

C. Real Time RTK Performances

1) *Analysis of vessel settlement*: All tests are done on board of JUV in jacked up position. However, depending of the soil conditions it is possible that the legs can settle which can

have an influence on the height of the GNSS antennas since they are considered as static during the test processing. Before performing analysis on the RTK loggings, it was checked whether significant height changes could be determined during one jacked up position. Per location, the vessel was jacked up, the data was plotted for each GNSS receiver. A linear trend line is obtained and plotted on the graph (Fig. 3).

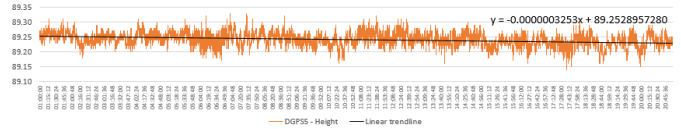


Fig. 3. Linear trendline of DGPS 5 height in function of time of Jack up 2.

The slope coefficient of this trend line was then recalculated and the average settlement per 24 h measured (Table II). To give an indication of the influence on our specific loggings during these tests, the average settlement for each logging is measured. The loggings were respectively 24 h, 20 h, 17.5 h and 9.5 h long.

TABLE II. JUV SETTLEMENT CALCULATION PER GNSS UNIT PER LOCATION

	JACK UP1 12/02-24H	JACK UP2 13/02-20H	JACK UP3 14/02-17.5H	JACK UP4 15/02-9.5H
AVERAGE SETTLEMENT PER 24 HOUR (m)				
DGP S4	-0.013	-0.039	-0.001	-0.063
DGP S5	0.006	-0.028	-0.011	-0.019
SEP T 2	0.002	-0.028	-0.011	-0.019
SEP T SB	0.006	-0.030	-0.011	-0.026
SPS8 55	0.004	-0.028	-0.006	-0.019
AVERAGE SETTLEMENT FOR EACH LOGGING (m)				
DGP S4	-0.013	-0.032	-0.001	-0.025
DGP S5	0.006	-0.023	-0.008	-0.008
SEP T 2	0.002	-0.023	-0.008	-0.008
SEP T SB	0.006	-0.025	-0.008	-0.010
SPS8 55	0.004	-0.024	-0.004	-0.008

First of all, one can observe a significantly higher value of height change for DGPS4 in two out of four locations. For the second location (Jack up 2), the settlement is high for all the devices. So, the problem arises mainly for Jack up 4. One might think this could be caused by the vessel movement and the load change due to unloading wind turbine parts. However, as mentioned before the two GNSS antennas are installed close to each other, and thus experience the same vessel movement. However, the other units do not show this same trend. If, we compare the average settlement per 24 h and the average settlement for 9.5 h logging for DGPS4-height, we note a significant difference between them, so we can think that the shorter time logging period may be the cause of this significant deviation.

For the first, third and fourth logging, it can be concluded that there is no significant settlement which has to be taken into account. All values (except for DGPS4) are 0.010 m or lower. Only on the second location, the subsidence coefficient is higher than 0.022 m for all GNSS receivers. This can be considered as a settlement. The surface might be softer at this location. However, it will not be applied to the data, since we cannot say with certainty that this is the cause of the height difference.

2) *Analysis of RTK height and standard deviation:* In the following tests, a more in-depth analysis was done to evaluate whether real time RTK performs as within ± 2.5 cm accuracy on a short baseline (<10 km), as specified in the hardware manufacturer specifications. Note that this analysis is based on in total 71 hours of data on four different locations.

As per manufacturer specifications Septentrio baseline length should be less than 40 km and Trimble baseline length should be less than 30 km (Table III). Based on these specifications, we can expect a Root Mean Square (RMS) error of respectively 18 mm (Septentrio) and 23 mm (Trimble) with a baseline of 8 km. In the below paragraphs, the results are compared to the results of the Septentrio AsteRx-SB, which is chosen as vertical reference, since it is connected to the base station (OSS KF B – baseline of 8 – 10 km) + RTK during all the performed tests.

TABLE III. MANUFACTURERS RTK SPECIFICATIONS

ASTERX-U & ASTERX-SB	Vertical accuracy 1cm + 1 ppm RMS	Open sky conditions RMS levels Baseline < 40km RTK fixed ambiguities
SPS852 & SPS 855	Vertical accuracy 15mm + 1ppm RMS	Baseline < 30km

3) *Statistics full loggings:* The average height of each logging at 8 km baseline and the difference between the units and the AsteRx-SB are listed in Table IV.

TABLE IV. RTK AVERAGE HEIGHT AND DIFFERENCE

	DGPS4 SPS852	DGPS 5 ASTERX- U	ASTERX- U SEPT 2	ASTE RX-SB	SPS855
HEIGHT (m)					
JACK UP 1	89.177	89.166	89.166	89.166	89.182
JACK UP 2	89.253	89.241	89.241	89.240	89.256
JACK UP 3	89.206	89.200	89.200	89.199	89.216
JACK UP 4	89.199	89.189	89.189	89.189	89.206
DIFFERENCE (m)					
JACK UP 1	0.011	0.000	0.000	-	0.016
JACK UP 2	0.012	0.001	0.000	-	0.015
JACK UP 3	0.007	0.001	0.001	-	0.017
JACK UP 4	0.010	0.000	0.000	-	0.018
TOTAL AVG. DIFF.	0.010	0.000	0.000	-	0.016

Note that the vessel aims to always jack up at the same keel height. For this reason, the height for each jack up is

similar. Table IV shows that the average results of all receivers lay close to each other. However, the results of Septentrio units are almost similar; we note a maximum of 0.001 m difference. The Trimble units show slightly higher differences, but the differences stay within 0.020 m, which is still within specifications. This does not mean that the Trimble results are less good than Septentrio units but indicates that the results may also differ depending on the receiver brand.

The difference of results between different GNSS brands could be caused by several factors; processing of results, usage of different antenna models. Depending on the brand and unit, Trimble relative, National Geodetic Survey (NGS) absolute or NGS relative antenna model are used. This can induce differences between ARP and APC. For the GA830 antenna, the difference between NGS relative and absolute is 0.017 mm. For Trimble SPS855 unit, Trimble relative is used, which explain the difference observed in Table IV for this unit.

The average Standard Deviation (SD) of a long logging is already at the limit of the specifications (Table V).

TABLE V. STANDARD DEVIATION OF THE UNITS ON RTK FOR EACH JACK UP

	DGPS4 SPS852 (m)	DGPS 5 ASTERX-U (m)	ASTERX-U SEPT 2 (m)	ASTER X-SB (m)	SPS8 55 (m)
JACK UP 1	0.017	0.021	0.021	0.020	0.020
JACK UP 2	0.020	0.022	0.022	0.020	0.020
JACK UP 3	0.016	0.021	0.021	0.019	0.019
JACK UP 4	0.019	0.021	0.021	0.019	0.020
Total	0.018	0.021	0.021	0.019	0.020

Table V shows that the average standard deviation of the data of the full logging is similar for all units and for a long logging it is already at the limit of manufactures specifications. The values are between 0.160 m and 0.220 m. This shows that on long term loggings, the stability of different brands is similar and within specifications.

Table VI shows how many data per second per logging are not within the ± 2.5 cm tolerance. We not that 12% up to 24% of the logged data is not within specifications, thus 76% up to 88% of the measurements during these 71 loggings at 8 km baseline are within tolerance.

TABLE VI. PERCENTAGE OF POSITIONS PER SECOND NOT WITHIN ± 2.5 CM OF THE 24 HOUR AVERAGE OF THE LOGGING, PER JACK UP

	DGPS4 SPS852	DGPS 5 ASTERX-U	ASTERX-U SEPT 2	ASTER X-SB	SPS 855
JACK UP 1	16%	22%	22%	19%	19%
JACK UP 2	18%	23%	24%	20%	23%
JACK UP 3	12%	21%	21%	17%	18%
JACK UP 4	16%	24%	24%	18%	20%

One of the scopes of the next tests was to try to define the ideal logging period in which accurate and reliable results can be obtained with a minimum of critical operational time. Below, the averages will be evaluated for 1h and 15 min periods.

4) *Statistics logging per hour*: For the statistical analysis of the data per hour, average heights and standard deviations per hour are evaluated. In total, 71 hourly average values are calculated. The minimum, maximum and average values are calculated and we estimated how much of these values are not within the predetermined tolerance of ± 2.5 cm. This is done in order to evaluate the performance of RTK when logging a specific period. The results per hour are summarized in Table VII and Table VIII. Table VII exposes the height difference between one hour average and total logging average and Table VIII exposes the standard deviation of RTK per hour.

TABLE VII. HEIGHT DIFFERENCE BETWEEN 1 HOUR AVERAGE AND TOTAL LOGGING AVERAGE

	DGPS4 SPS852 (m)	DGPS 5 ASTERX-U (m)	ASTERX -U SEPT 2 (m)	ASTE RX-SB (m)	SPS8 55 (m)
MIN	-0.024	-0.016	-0.016	-0.016	-0.018
MAX	0.016	0.018	0.024	0.017	0.020
AVERAGE	0.000	0.000	0.000	0.000	0.000
% OUTSIDE TOLERANCE (± 2.5 CM)	0.0%	0.0%	0.0%	0.0%	0.0%

TABLE VIII. STANDARD DEVIATION OF RTK RESULTS PER HOUR

	DGPS4 SPS852 (m)	DGPS 5 ASTERX-U (m)	ASTERX-U SEPT 2 (m)	ASTE RX-SB (m)	SPS855 (m)
MIN	0.000	0.000	0.000	0.000	0.000
MAX	0.025	0.032	0.032	0.029	0.025
AVERAGE	0.015	0.019	0.019	0.017	0.017
% OUTSIDE TOLERANCE (± 2.5 CM)	0.0%	1.3%	2.7%	1.3%	2.7%

Logging with RTK during 1 hour gives 100% of the time values within 0.025 m difference from the average over 24 h, with a maximum difference observed of 0.024 m over the 71 hours of data, which is in accordance but so close to the tolerance limit. The SD minimum over 1 hour is no longer that 0.000, but has maximum values of 0.032 m. We note that 97.3 to 100% of the time, the SD is less than 0.025 m, which is considered a very good percentage. There are no significant differences between the units and brands, although the Trimble SPS852 shows the best results. We can conclude that 1 hour of logging is a good period to achieve fairly accurate results.

5) *Statistics logging per 15 min*: The same exercise was done with the same data, per 15 min. For in total 285 loggings

of 15 min, the average height difference between 15 min average and 24 h average as well as the standard deviation have been calculated and analyzed. The results are summarized in Table IX.

TABLE IX. HEIGHT DIFFERENCE BETWEEN 15' AVERAGE AND 24 HOUR AVERAGE

	DGPS4 SPS852 (m)	DGPS 5 ASTERX-U (m)	AsteRx-U SEPT 2 (m)	AsteRx-SB (m)	SPS8 55 (m)
MIN	-0.053	-0.036	-0.036	-0.035	-0.032
MAX	0.029	0.029	0.031	0.023	0.027
AVERAGE	0.000	0.000	0.000	0.000	0.000
% OUTSIDE TOLERANCE (± 2.5 CM)	2%	4%	5%	2%	3%

The 15 min loggings in RTK are between 95 – 98% of the time within ± 0.025 m tolerance to total logging average. There are no significant differences between the brands and devices. The maximum average difference observed over all 15 min loggings is -0.053 m. All minimum and maximum values now exceed the ± 2.5 cm limit. This was not yet the case when analyzing the data per hour.

The minimum SD according to 15 min is no longer 0.000, but has maximum values of 0.033 m. The average SD is less than the tolerance 95.1% to 99.3% of the time (Table X). There are no significant differences between the units and brands. Overall, the height is also stable over periods of 15 min, but the period of 1 h shows higher performances.

TABLE X. STANDARD DEVIATION OF RTK RESULTS PER 15'

	DGPS4 SPS852 (m)	DGPS 5 ASTERX-U (m)	AsteRx-U SEPT 2 (m)	AsteRx-SB (m)	SPS8 55 (m)
MIN	0.000	0.000	0.000	0.000	0.000
MAX	0.031	0.030	0.033	0.030	0.033
AVERAGE	0.014	0.017	0.017	0.016	0.016
% OUTSIDE TOLERANCE (± 2.5 CM)	0.7%	3.9%	4.9%	1.8%	3.9%

6) *Trend analysis of height plot*: In the analysis below, the overall performances were analyzed by looking into detail the time series GNSS height graphs. For each logging, a graph is made per hour. The trend of the data was analyzed visually, the vertical axis shows a gridline per 5 cm and each device is visualized in its specific colour.

In Fig. 4, two graphs from two days are shown. When visually looking to the graphs, it was observed that the data sometimes show a different behavior – trend between the different brands.

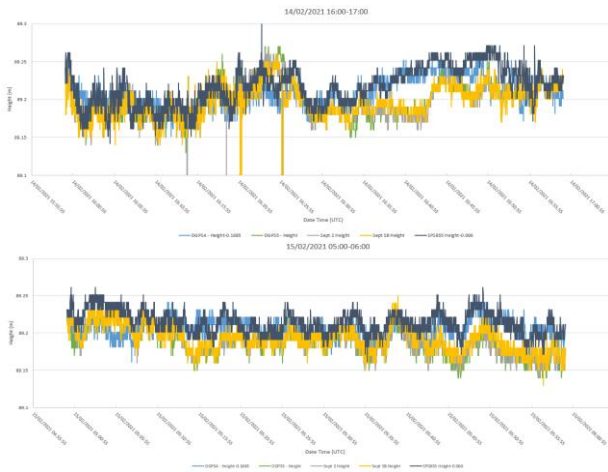


Fig. 4. Height results of five units in RTK short baseline.

Indeed, the three Septentrio units mostly match very well, despite the fact that these are two different models, which can be noted on the Sept AsteRx-SB (yellow graph) compared to the DGPS5 AsteRx-U (green graph) and Sept2 AsteRx-U (grey graph). In general the results of both Trimble resemble more to each other than to the height results of the Septentrio units, but the two Trimble units are different models as well SPS852 (light blue graph) and SPS855 (dark blue graph), which explains the small differences between the two Trimble graphs.

It can also be seen that the Trimble units in Fig. 4 are always slightly higher than the Septentrio units. Therefore, it can be said that the receivers from the same brand tend to follow the same behavior. This can be confirmed on these periods 14/02 16:41 – 16:45 and 16:48 – 16:50 as well as 15/02 05:45 – 05:50, where the difference between the Trimble and the Septentrio units achieved 0.040 m for several minutes. Knowing that the Trimble SPS855 is connected to the same GNSS antenna as the Septentrio units, this clearly proves the differences in results caused by the RTK engine and justify the use of different brands.

D. Post-Processing PPK Performances

In this section, we evaluate the PPK performance on different baseline lengths. Indeed, data is post-processing using different base stations on different distances (base line lengths). As a check, post-processing was also performed with base station OSS KF B. Base stations on land are obtained from two external correction services: GPSNET.DK and SWEPOS (Table XI).

TABLE XI. OVERVIEW BASE STATIONS FOR SINGLE BASE POST-PROCESSING

Denmark - GPSNET.DK	STEG	±30km
	FAXE	±50km
	ORHO	±60km
	GDS1	±70km
Sweden - SWEPOS	SKAN	±40km
	SMYG	±50km

Furthermore, data of 3 out of 5 receivers was post-processed: DGPS5 (AsteRx-U), Sept2 (AsteRx-U) and DGPS4 (SPS852). Data is post-processed for one jack up cycle of 24 h from 19 h on 11/02 until 19 h on 12/02. This was done in a static and kinematic way. Static post-processed data is compared to results from online post-processing services (AUSPOS and CSRS-PPP) and kinematic post-processed is compared to real time data. For post-processing, two software programs are used: Trimble Business Center (TBC) V5.10 and Qinertia V2.2.5847. Static post-processing will be done in TBC, kinematic post-processing will be done in TBC and Qinertia.

7) *Static mode:* As mentioned below, static post-processing is done in TBC with seven base stations (OSS KF B, STEG, SKAN, SMYG, FAXE, ORHO and GDS1) and one rover (DGPS 5). The static results were compared to AUSPOS and CSRS-PPP online services and were summarized on Table XII. The height of DGPS5 is sent to online services.

DGPS5 and Sept 2 are expected to have the same results since it concerns the same receiver type and the same antenna. Differences between the online services are ranging between 1 mm for the AsteRx-U to 7 mm for the SPS852. OSS KF B and all other base stations seem to match slightly better with the AUSPOS data than with CSRS-PPP data as shown on Table XIII.

Despite the superiority of AUSPOS online service, we always remain within specifications for the two online services for all baseline lengths. This shows that post-processing results match well with online services even with longer baselines (Table XIII).

TABLE XII. HEIGHT DGPS5 SENT TO ONLINE SERVICES AND POST-PROCESSED WITH DIFFERENT BASE STATIONS

	SPS852 (m)	DGPS 5 ASTERX-U (m)	SEPT 2 ASTERX-U (m)
AUSPOS	89.207	89.213	89.213
CSRS-PPP	89.200	89.211	89.212
OSS KF B (8.4KM)	89.206	89.220	89.221
STEG (29.2KM)	89.220	89.221	89.221
SKAN (42.3KM)	89.218	89.223	89.223
SMYG (49.4KM)	89.224	89.230	89.230
FAXE (51.9KM)	89.208	89.212	89.212
ORHO (62.5KM)	89.213	89.219	89.220
GDS1 (74.1KM)	89.210	89.215	89.217

TABLE XIII. DIFFERENCE BETWEEN ONLINE SERVICES AND POST-PROCESSED DATA FROM DIFFERENT BASE STATIONS

	SPS852 (m)	DGPS 5 ASTERX-U (m)	SEPT 2 ASTERX- U (m)
OSS KF B (8.4KM)			
AUSPOS	-0.001	0.007	0.008
CSRS-PPP	0.006	0.009	0.009
STEG (29.2KM)			
AUSPOS	0.013	0.008	0.008
CSRS-PPP	0.020	0.010	0.009
SKAN (42.3KM)			
AUSPOS	0.011	0.010	0.010
CSRS-PPP	0.018	0.012	0.011
SMYG (49.4KM)			
AUSPOS	0.017	0.017	0.017
CSRS-PPP	0.024	0.019	0.018
FAXE (51.9KM)			
AUSPOS	0.001	-0.001	-0.001
CSRS-PPP	0.008	0.001	0.000
ORHO (62.5KM)			
AUSPOS	0.006	0.006	0.007
CSRS-PPP	0.013	0.008	0.008
GDS1 (74.1KM)			
AUSPOS	0.003	0.002	0.004
CSRS-PPP	0.010	0.004	0.005

8) Kinematic mode

a) Trimble Business Center: Kinematic post processing was done in TBC with five base stations (OSS KF B, STEG, FAXE, ORHO and GDS1) and one rover (DGPS 5). Data will be compared to the real time DGPS 5 data.

From Table XIV, we note that all data are almost continuously in RTK Fix and does not decrease with distance. Let us also note that Post-Processed (PP) data are a bit more in RTK Fix mode than the real time solution.

TABLE XIV. PERCENTAGE OF EPOCHS IN RTK FIXED, PER BASE STATION

Real Time OSS KF B	PP OSS KF- B (m) (8.4KM)	PP STEG (m) (29.2KM)	PP FAXE (m) (51.9KM)	PP ORHO (m) (62.5KM)	PP GDS1 (m) (74.1KM)
99.92%	99.98%	99.98%	99.98%	99.98%	99.98%

Overall, data seem to follow the same trend as the real time DGPS5 data (Fig. 5). However, in the graph of Fig. 5 is visible that the datasets tend to spread up to ± 0.100 m mainly for the OSS KF B case.



Fig. 5. Kinematic post processed height data from TBC vs real time DGPS 5 data (20-21h).

Table XV gives an overview of the statistics of the kinematic post-processing of the full logging of 24 h.

TABLE XV. AVERAGES AND SD OVER 24 HOUR KINEMATIC PROCESSING

REAL TIME OSS KF B	PP OSS KF B (m) (8.4KM)	PP STEG (m) (29.2 KM)	PP FAXE (m) (51.9KM)	PP ORHO (m) (62.5KM)	PP GDS1 (m) (74.1KM)
AVERAGE HEIGHT FOR 24H					
89.166	89.153	89.191	89.189	89.193	89.191
STANDARD DEVIATION FOR 24H					
0.021	0.019	0.026	0.033	0.041	0.036
HEIGHT DIFF. WITH REAL TIME DGPS5 FOR 24H					
-	-0.013	0.025	0.023	0.027	0.025

The average of 24 h data processed at +25 km baseline show results that are 2.5 cm or more higher compared to the real time height (Table XV). Average over 24 h of the check base OSS KF B, is 1.3 cm lower. We can still deduce that the standard deviation and the differences between the real time and post-processing height increase with the baseline length. Note that the differences are higher than the static logging for the same period.

In the Table XVI, we present the difference between 1 h average and 24 h average.

When taking averages per hour, 4.2% of the time the values for STEG were outside this 2.5 cm upper/lower tolerance from the 24 h average, with a maximum absolute difference of 4.5 cm. While, this is $\pm 8.3\%$, for baseline distance of 50-75 km (FAXE, ORHO and GDS1). The maximum absolute difference for all base stations is 9.4 cm.

TABLE XVI. REAL TIME AND POST PROCESSING (TBC) STATISTICS FOR 1 HOUR LOGGINGS OVER A 24 HOUR PERIOD

	DIFFERENCE BETWEEN 1H AVERAGE AND 24H AVERAGE					
	Real time OSS KF B (m)	PP OSS KF B (m) 8.4km	PP STEG (m) 29.2km	PP FAXE (m) 51.9km	PP ORH O (m) 62.5k m	PP GDS1 (m) 74.1km
MIN	-0.012	-0.011	-0.020	-0.028	-0.018	-0.027
MAX	0.013	0.015	0.045	0.094	0.089	0.086
AVERAGE	0.000	0.000	0.000	0.000	0.000	0.000
% OUTSIDE TOLERAN CE (± 2.5 CM)	0.0%	0.0%	4.2%	8.3%	8.3%	8.3%
SD PER HOUR						
MIN	0.014	0.011	0.009	0.010	0.010	0.010
MAX	0.032	0.026	0.052	0.075	0.128	0.080
AVERAGE	0.020	0.017	0.019	0.020	0.025	0.024
% OUTSIDE TOLERAN CE (± 2.5 CM)	4.2%	4.2%	4.2%	12.5%	20.8%	20.8%

These results can mean that RTK logging during one hour with a base station at a distance of 30 km in 95.8% can be considered long enough to define the coordinate within tolerance. And for 50-75 km (FAXE, ORHO and GDS1) this percentage decreases to 91.7% and in 8.3% of the time there is a risk of reaching values that exceed the tolerance threshold.

The differences between 1 h and 24 h confirm that there is no significant difference in real time and post-processed results from shorter baseline, since real time and PP OSS KF B show similar results and are both 100% of the time within tolerance.

When looking to the SD values, an increase of percentage outside of tolerance can be noted with the baseline length. For 62 km and 74 km baseline, only $\pm 79.2\%$ of the loggings per one hour are within tolerance, which is a fairly low percentage. Note that these last distances exceed the manufacturer requirement of 40 km.

However, STEG base station is less than 40 km from the rover, which is according to the manufacturer requirements. Despite that, 4.2% of the time the value per hour is outside of the ± 2.5 cm tolerance. For this reason, it was looked more in detail what happens there. It was noted that 13-15% of all the values outside of tolerance are falling in a timepan of less than 1 hour (02:59-03:40, 04:27-04:40, 18:05-18:44). This first timepan with a lot of high values is seen in Fig. 6. This clearly shows that data is not matching despite the RTK fixed solution.

No specific reason can be given to these decreased results. It could be related with ionosphere and troposphere and thus baseline. These effects tend to increase the vertical error with baseline length. STEG with the shortest baseline (29.2 km) shows slightly less disturbance than GDS1, ORHO and FAXE.

The same exercise as done per hour, was done per 15 min. The real time and post processing statistics are summarized in Table XVII.

With a baseline of more than 25 km, averages over a period of 15 minutes, values are outside the 2.5 cm upper/lower tolerance for 13% up to 19% of the time. Heights post-processed with the base station OSS KF B are more within tolerance than the real time result (1% versus 6%). The minimum and maximum values increase significantly with the baseline length. The range of the average height values per 15' is already ± 0.200 m for base stations at 50 km or further.



Fig. 6. Kinematic post processed data from TBC vs. real time DGPS 5 data (3-4h).

TABLE XVII. REAL TIME AND POST PROCESSING (TBC) STATISTICS FOR 15' LOGGINGS OVER A 24 HOUR PERIOD

	DIFFERENCE BETWEEN 15' AVERAGE AND 24H AVERAGE					
	Real time OSS KF B (m)	PP OSS KF B (m) 8.4km	PP STEG (m) 29.2km	PP FAXE (m) 51.9km	PP OR HO (m) 62.5 km	PP GDS1 (m) 74.1km
MIN	-0.036	-0.027	-0.045	-0.039	-0.038	-0.043
MAX	0.029	0.024	0.095	0.172	0.145	0.154
AVERAGE	0.000	0.000	0.000	0.000	0.000	0.000
% OUTSIDE TOLERANCE (± 2.5 CM)	6%	1%	18%	13%	14%	19%
SD PER 15'						
MIN	0.000	0.005	0.001	0.002	0.002	0.002
MAX	0.031	0.034	0.060	0.084	0.219	0.127
AVERAGE	0.017	0.014	0.014	0.015	0.018	0.018
% OUTSIDE TOLERANCE (± 2.5 CM)	4%	3%	4%	8%	11%	13%

The SD shows the same trend, the values increase by baseline length. However, it is quite particular that the percentages of values outside of tolerance are smaller than those per hour. This is due to the fact that over short periods the SD varies little.

b) *Qinertia*: The second software that can be used for kinematic post-processing is Qinertia. Processing has been done as well with this software, to get a better view on the consistency between Post-Processing (PP) software. This also gives a better view on the reliability of the PP results. The same data were processed: DGPS 5 was processed with four base stations (STEG, FAXE, ORHO and GDS1). Data are compared to the real time DGPS 5 data.

First of all, Table XVIII shows the percentage of the time that RTK fixed solution is achieved.

TABLE XVIII. PERCENTAGE SOLUTION MODE IN RTK FIXED

Real Time OSS KF B	PP STEG (m) (29.2KM)	PP FAXE (m) (51.9KM)	PP ORHO (m) (62.5KM)	PP GDS1 (m) (74.1KM)
99.92%	85.16%	76.09%	72.68%	57.28%

RTK fixed solution decreases significantly with distance. This is a big contrast with TBC, where all base stations could achieve RTK fixed for 99.98% of the epochs. We can deduce that Qinertia has more difficulties to recover RTK fixed solution even for shorter baseline.

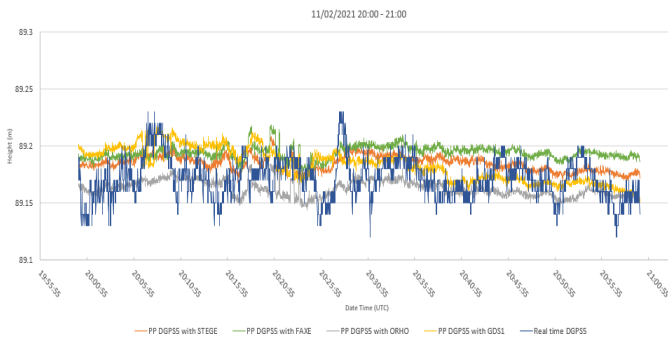


Fig. 7. Kinematic post processed data from qinertia vs real time DGPS 5 data (20-21h).

Overall, data seem to match the real time DGPS 5 data (Fig. 7). It can be observed that the real time data seems choppy, this is due to a difference in rounding between QINSy loggings and Qinertia: QINSy data has two decimals while Qinertia has three decimals.

On an average of 24 h STEG, FAXE, ORHO and GDS1 data are very close to the real time height within 1 cm. These differences are much smaller than those of TBC processed heights. The SD has much higher values, but in the same line as the TBC results. Longer is the baseline, higher is the standard deviation (Table XIX).

TABLE XIX. AVERAGES AND SD OVER 24 HOUR

REAL TIME OSS KF B	PP STEG (m) (29.2KM)	PP FAXE (m) (51.9KM)	PP ORHO (m) (62.5KM)	PP GDS1 (m) (74.1KM)
AVERAGE HEIGHT FOR 24H				
89.166	89.161	89.159	89.167	89.176
STANDARD DEVIATION FOR 24H				
0.021	0.017	0.036	0.031	0.059
HEIGHT DIFF. WITH REAL TIME DGPS5 FOR 24H				
-	-0.005	-0.007	0.001	0.010

It looks like Qinertia loses RTK fixed location even at a shorter distance. But if Qinertia achieves RTK fixed, the results are very precise. This is not the case with data processed by TBC. This can be seen by comparing Fig. 6 with Fig. 7.

From Table XX, the difference per hour with the 24 h average is still quite low for a 30 km baseline, but with longer baselines this increases. Also the difference between minimum and maximum values follows this same trend, showing a 0.137 m difference at GDS1.

ORHO shows better results than FAXE, but it must be mentioned that the data in this graph are partially distorted since the data was often not in RTK fixed. Only RTK fixed results are included in the summary in Table XX, which implies that the averages are not always based on 24 h values and 1 h of data does not always actually includes 3600 values, in case RTK Fix is lost in the meantime.

TABLE XX. REAL TIME AND POST PROCESSING (QINERTIA) STATISTICS FOR 1 HOUR LOGGINGS OVER A 24 HOUR PERIOD

	REAL TIME OSS KF B (m)	PP STEG (m) (29.2KM)	PP FAXE (m) (51.9KM)	PP ORH O (m) (62.5K M)	PP GDS1 (m) (74.1K M)
% RTK FIXED	99.92%	85.16%	76.09%	72.68%	57.28%
DIFFERENCE BETWEEN 1H AVERAGE AND 24H AVERAGE					
MIN	-0.012	-0.016	-0.039	-0.029	-0.059
MAX	0.013	0.025	0.044	0.057	0.078
AVERAGE	0.000	0.000	0.001	-0.003	-0.005
% OUTSIDE TOLERANCE (±2.5CM)	0.0%	0.0%	22.2%	12.5%	58.8%
SD PER HOUR					
MIN	0.014	0.004	0.005	0.007	0.003
MAX	0.032	0.037	0.102	0.020	0.041
AVERAGE	0.020	0.012	0.018	0.013	0.016
% OUTSIDE TOLERANCE (±2.5CM)	4.2%	4.8%	16.7%	0.0%	5.9%
HEIGHT DIFFERENCE COMPARED TO REAL TIME AVERAGE					
MIN	-	-0.030	-0.049	-0.028	-0.046
MAX	-	0.013	0.024	0.056	0.086
AVERAGE	-	-0.005	-0.006	-0.002	0.005
% OUTSIDE TOLERANCE (±2.5CM)	-	4.8%	11.1%	12.5%	35.3%

As it was suggested earlier that the RTK fixed solution from Qinertia is generally speaking better at longer distances than TBC, this is no longer valid after analyzing the data more in detail. This is also confirmed when looking at the time series graphs of Fig. 8. Indeed, a reduced availability of data can be observed, only the closest station (STEG) seems to give useful data. Further, it can be observed that data after losing RTK fixed solution can be less accurate. It should also be noted that the heights jumps can only be caused by the Qinertia engine, which is not handling data well at larger distances.

The same exercise is done at a 15 min interval (Table XXI). Here, the same remark must be made about the distortion on the data. Since the results are for quite some time not in RTK fixed, the averages are not based on 24 x 4 quarters.

The difference in height compared to the 24 h average shows the same trend as the data per hour. While real time data was 100% within tolerance, this is now only 93.7% of the time. The percentage of values outside tolerance increases. At a distance of 74 km, only 43.4% of the values are within tolerance, this rate is low even for 1 h average logging. This proves the superiority of 1 h average logging versus 15 min average logging.



Fig. 8. Kinematic post processed data from TBC vs real time DGPS 5 data (8-9h).

TABLE XXI. REAL TIME AND POST PROCESSING (QINERTIA) STATISTICS FOR 15' LOGGINGS OVER A 24H PERIOD

	REAL TIME OSS KF B (m)	PP STEG (m) (29.2K M)	PP FAXE (m) (51.9K M)	PP OR HO (m) (62.5 KM)	PP GDS1 (m) (74.1K M)
% RTK FIXED	99.92%	85.16%	76.09 %	72.6 8%	57.28%
DIFFERENCE BETWEEN 15' AVERAGE AND 24H AVERAGE					
MIN	-0.036	-0.026	-0.100	0.03 9	-0.068
MAX	0.029	0.057	0.067	0.09 4	0.092
AVERAGE	0.000	0.000	0.000	0.00 0	0.001
% OUTSIDE TOLERANCE (±2.5CM)	6.3%	3.6%	23.3%	23.2 %	56.6%
SD PER 15'					
MIN	0.000	0.000	0.000	0.00 2	0.003
MAX	0.031	0.039	0.168	0.12 9	0.192
AVERAGE	0.017	0.008	0.013	0.01 1	0.017
% OUTSIDE TOLERANCE (±2.5CM)	4.2%	3.6%	8.0%	4.2%	13.2%
HEIGHT DIFFERENCE 15' COMPARED TO REAL TIME AVERAGE 15'					
MIN	-	-0.043	-0.115	- 0.04 3	-0.054
MAX	-	0.047	0.051	0.09 5	0.110
AVERAGE	-	-0.005	-0.007	0.00 2	0.011
% OUTSIDE TOLERANCE (±2.5CM)	-	15.7%	31.5%	33.3 %	45.3%

The SD values are increasing with distance. For the longest baseline, 86.8% of the SD are smaller than 0.025 m, which is quite good. This shows that Qinertia results are in general stable over time and there is not much difference between 1 h average logging and 15 min average logging.

Height difference 15 min logging compared to real time average 15 min logging out of tolerance is 10-20% higher per 15 min than per 1h. However, the averages match well with the real time data. The extreme values show min-max ranges of respectively 0.090 m, 0.166 m, 0.138 m and 0.164m. While at 1 h averages, only GDS1 min-max range was above 0.100 m. However, we always observe an increase of the outside tolerance rate of the height difference between post-processing and real time for both 1 h and 15 min logging.

III. CONCLUSION

The tests in this work were performed to find all the elements that go into the precise measurement of the height of OWF outside the standard RTK working range. For the installation of OWF foundations vertical installation tolerances of ±10 cm are imposed. Taking into account all error sources, deformation of the vessel, motion, lever arms that impact the height measurement of the foundation, the vertical accuracies for GNSS must be lower than 5 cm. In these tests, we considered the specifications of ±2.5 cm tolerance.

Based on test results, following conclusions are made:

- GNSS units:

The statistical analysis does not show a real difference between the different units, but a finer analysis of the time series graphs shows that overall all the receivers follow the same trend. But in some periods, units from the same brand follow the same trend and show significant variations from the other brands. Sometimes these variations are bigger than the tolerance, even if the same antenna is used. This confirms that using different receivers from different brands is necessary for reliable measure.

- Baseline length:

Data of DGPS5 were post-processed with base stations on different lengths. For shorter baseline the results are similar for both RTK mode and PPK mode. This is no longer the case for longer baseline. If, we are outside the manufacturer specification range +30 km for DGPS5, the results show a clear decrease in quality, but remains mostly within the recommended standards.

- RTK vs PPK:

During the tests, it was proved that for shorter baseline; according to manufacturer specification length PPK performances exceed RTK performances, despite the fact that for longer baseline PPK results show a decrease in quality. For static post-processing, the results of the different base stations match well with online services. For kinematic post-processing, the choice of the software program is important. The percentage of epochs in RTK fixed, per base with TBC software is very interesting and it looks like Qinertia has more difficulties to recover RTK fixed solution even for shorter


baseline. But, if Qinertia achieves RTK fixed, the results are very interesting, even for a short period logging. Although, if we want to reach at least a 95% certainty of having a logging within tolerance, the logging must be longer one hour or more and the base station should be within the manufacturer specifications range.

In conclusion, this paper shows that for precise installation of an Offshore Wind Farm (OWF) located far from the coastline, and to reach better measurement quality and centimeter accuracy outside the standard working range, it is important to take into account several parameters, like statistical parameters, settlements of the device brand, baseline length, time logging interval, and the choice of the software program. This work is of utmost importance in the GNSS application process and should open new possibilities in high accuracy positioning. In future work, we will test a high precision correction services from a Virtual Reference Station (VRS) method. This VRS service can provide RTK and PPK correction based on a network of base stations which can give stable results even in larger areas (longer baselines). This should improve the performances and maximize the centimeter level availability in challenging conditions.

REFERENCES

- [1] M. Rehak, R. Mabillard, and J. Skaloud, "A micro-UAV with the capability of direct georeferencing," *ISPRS – Int Arch Photogramm Remote Sen Spatial Inform Sci XL1/W2*, pp. 317–323, 2013.
- [2] J. Leva, "An Alternative Closed Form Solution to the GPS Pseudorange Equations," *Proceedings of The Institute of Navigation (ION) National Technical Meeting*, Anaheim, CA, January 1995.
- [3] S. Bancroft, "An Algebraic Solution of the GPS Equations," *IEEE Trans. on Aerospace and Electronic Systems*, vol. AES-21, No. 7, pp. 56–59, 1985.
- [4] F. van Graas, and M. Braasch, "GPS Interferometric Attitude and Heading Determination: Initial Flight Test Results," *NAVIGATION: Journal of the Institute of Navigation*, vol. 38, No. 4, pp. 297–316, 1991.
- [5] D. Walsh, "Real-Time Ambiguity Resolution While on the Move," *Proc. of the ION Satellite Division's 5th International Meeting*, ION GPS-92, Albuquerque, NM, pp. 473–481, 1992.
- [6] J. Potter, and M. Suman, "Thresholdless Redundancy Management with Arrays of Skewed Instruments," *AGARD Monograph*, No. 224, NATO, Neuilly sur Seine, France, 1979.
- [7] A. Leick, "GPS Satellite Surveying," 3rd ed., New York: John Wiley & Sons, 2004.
- [8] Y. Taddia, F. Stecchi, and A. Pellegrinelli, "Coastal mapping using DJI phantom 4 RTK in post-processing kinematic mode," *Drones* 4:9, 2020.
- [9] P.-J.-G. Teunissen, D. Odijk, and B. Zhang, "PPP-RTK: results of CORS network-based PPP with integer ambiguity resolution," *J. Aeronaut Astronaut Aviat Ser A* 42(4): pp. 223–230, 2010.
- [10] G. Wübbena, M. Schmitz, and A. Bagge, "PPP-RTK: precise point positioning using state-space representation in RTK networks," In: *Proceedings of the 18th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS 2005)*. Long Beach, CA, pp. 13–16, 13–16 September 2005.
- [11] E. D. Kaplan, and C. Hegarty, "Understanding GPS/GNSS: Principles and Applications," Artech House Press, 2017.
- [12] E. Karlsson, and N. Mohammadiha, "A Statistical GPS Error Model for Autonomous Driving," *IEEE Intelligent Vehicles Symposium*, *Proceedings (Iv)*, pp. 754–759, June 2018.
- [13] R. Eker, E. Alkan, and A. Aydın, "A Comparative Analysis of UAV-RTK and UAV-PPK Methods in Mapping Different Surface Types," *European Journal of Forest Engineering (EJFE)*, 7(1), pp. 12-25, 2021.
- [14] A. Hauschild, and O. Montenbruck, "Precise real-time navigation of LEO satellites using GNSS broadcast ephemerides," *NAVIGATION, Journal of the Institute of Navigation* 68(2), pp. 419–432, 2021.
- [15] R. Santerre, "Impact of GPS satellite sky distribution," *Manuscripta Geodaetica*, 16, pp. 28-53, 1991.
- [16] B. Hofmann-Wellenhof, H. Lichtenegger, and E. Wasle, "GNSS-Global Navigation Satellite Systems: GPS, GLONASS, Galileo and More," Springer Science & Business Media, New York, NY, USA, ISBN 3211730176, 2007.

Analyze Transmission Data from a Multi-Node Patient's Respiratory FMCW Radar to the Internet of Things

Rizky Rahmatullah¹, Puput Dani Prasetyo Adi^{2*}, Suisbiyanto Prasetya³, Arief Budi Santiko⁴, Yuyu Wahyu⁵, B.Berlian Surya Wicaksana⁶, Stevry Yushady CH Bissa⁷, Riyani Jana Yanti⁸, Aloysius Adya Pramudita⁹
Research Center for Telecommunication, National Research and Innovation Agency (BRIN), Bandung, Indonesia^{1,2,3,4,5,6,7,8}
Master of Electrical Engineering Program, Telkom University, Bandung, Indonesia^{3,9}

Abstract—This is the development of a system that has been made, FMCW radar for human or patient breathing which will then determine the type of disease or disorder in the patient just by looking at the type of breathing. This research uses data from FMCW Radar for human or patient breathing, which is then converted to data that can be read in real-time by the public, doctors, or medical teams through a web server; the web server used is iotmedis.brin.go.id. The novelty of this study is that various types of respiratory data are taken from various points so that it will cause new analysis, namely the process of transmitting data on server traffic or uplink and downlink processes. Specific data and research novelty is how Multi patient respiratory data from OmnipreSense or FMCW Radar can be processed by a microprocessor using MQTT, and multi-patient data can be displayed on the server in real-time.

Keywords—FMCW Radar data; realtime monitoring; internet of things; transmission data; multi node

I. INTRODUCTION

Biomedical technology is overgrowing with various modes or types of research using the latest devices, such as Internet of Things (IoT) modules [12]. Some IoT modules, such as WiFi module server ESP32 [8,9] or ESP 8266 used for server communication, continue to be developed to get the best performance from previous research using FMCW radar. FMCW radar [10,11] is an active type of radar sensor that transmits continuous transmission power such as continuous wave (CW Radar); the FMCW type Radar is measured based on the difference in phase or frequency between the signal emitted and the signal received. In this study, the focus is on the patient's respiratory condition, which is monitored from the FMCW Radar [13-15], as shown in Fig. 1. The principle of this Radar can be seen in Fig. 4. and the Block Diagram of FMCW radar sensor shown in Fig. 2 and Fig. 3. This research will focus on displaying radar data and analysis on the iotmedis.brin.go.id server, multipoint. One of the analyses performed is RF Propagation Radar between patients and Radar with different distances [5,6,7].

II. THEORY

A. FMCW Radar Module and Block Diagram

Radar Frequency Modulated Continuous Wave (FMCW) [16-20] is a specific type of Radar that continuously varies the

frequency of a transmitted signal at a known rate over a set period, using a periodic linear function such as a sawtooth signal to modulate a sinusoidal radar signal [1]. An FMCW radar's unique ability to differentiate between ranges is accomplished by frequency modulating an ongoing transmission. It can even calculate range, velocity, or phase simultaneously for multiple targets using a process known as IQ demodulation and multiple chirps [2].

Furthermore, Fig. 3 shows the concept of FMCW radar for non-contact detection [3]. The splitter splits the signal generated by the FMCW signal generator. A power amplifier amplifies the signal before the transmitting antenna transmits it. Electromagnetic waves sent out from the transmitting antenna are received by the receiving antenna. Low-noise amplifiers amplify low-power signals without significantly degrading the signal-to-noise ratio (SNR).

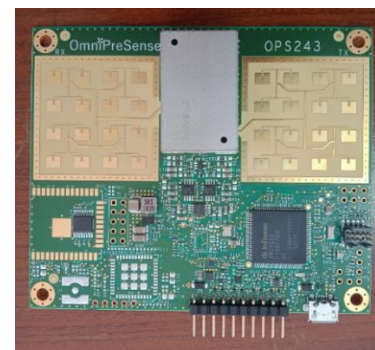


Fig. 1. OPS243-C FMCW and Doppler Radar Sensor used in this research (personal research data).

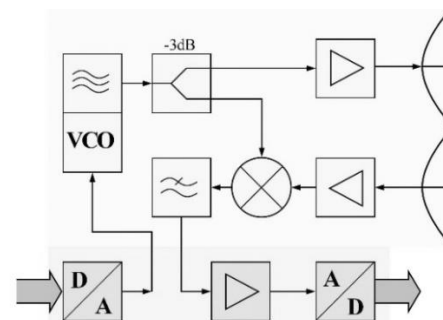


Fig. 2. Block Diagram of FMCW radar sensor (personal research data).

*Corresponding Author.

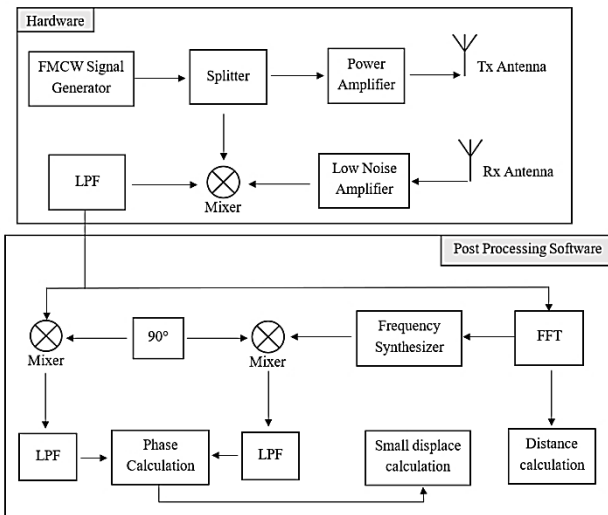


Fig. 3. The concept of FMCW Radar for non-contact detection (personal research data).

Moreover, the signal split by the splitter and FMCW signal generator is combined with the output of the low noise amplifier at the mixer. A lowpass filter (LPF) is used to filter the signal frequencies. The LPF principle is a filter that passes signals with frequencies below the cutoff frequency. After passing through the LPF, the output signal can be computed with a Fast Fourier Transform (FFT) to determine the target range. The output signal contains phase shift information. The LPF output is affected by the phase difference between reflected and transmitted waves. The formula used in this calculation is the phase difference caused by propagation delay due to target range shift.

The phase computation of the LPF output can be used to calculate a small shift. Phase processing from the LPF output is accomplished by IQ demodulation of the RF circuit. Two double-balanced mixers are combined. By changing the In-phase (I) and quadrature (Q) inputs in the branches of the IQ demodulator (1), the LPF output is combined with a reference signal [4]. Reference signals are written as (2) [4]. The phase data can then be obtained using the arctangent computation. A sinusoidal signal phase shifted by 90 from the FFT output is used as the basis for the LPF output approximation. It can determine the frequency of the output signal from the LPF by applying the FFT and performing Fourier transform computations. The phase-shifted output of an FMCW radar system is formulated as (3).

$$S_{LPF} = S_{LPFO} \cos(2\pi f_c \tau + 2\pi \frac{\Delta f \tau^2}{t_r}) \quad (1)$$

$$S_{syt} = S_{sy} \cos(2\pi \frac{\Delta f \tau^2}{t_r}) \quad (2)$$

$$\tau = 2\pi f_o^{-1} \tan^{-1} \left(\frac{E_q(t)}{E_i(t)} \right) \quad (3)$$

$$\varphi(t) = \tan^{-1} \left[\frac{Im\{Q(t)\}}{Re\{I(t)\}} \right] \quad (4)$$

B. Doppler Effect and FMCW Equation

The Doppler effect principle of this formula is used for systems on Radar, including FMCW; for that, it is necessary to

understand the formula for the Doppler effect, which is affected by the Speed of light (c). The Doppler frequency (f_r), which is determined by the Speed of light in air with the formula $c' = c/1.0003$, is slightly slower than in a vacuum, and v is the target speed, which can be written as Eq. 5. And the Doppler frequency is generally written with the formula by looking if $v < c'$ or $c' - v = c'$, and $f_d = 2v \frac{f_t}{c'}$ as the equation 6.

$$f_r = f_t \left(\frac{1 + \frac{v}{c'}}{1 - \frac{v}{c'}} \right) \quad (5)$$

$$f_d = f_r - f_t = 2v \left(\frac{f_t}{c' - v} \right) \quad (6)$$

Furthermore, in FMCW Radar, the signal is transmitted by periodically increasing and decreasing the frequency; when the echo signal is received, there will be a change in frequency or a time delay denoted by Δt . In FMCW radar, the phase and frequency differences between the transmitted and received signals are both measured. The signal from the radar position R radiates to a certain plane or object shown in Eq. (7).

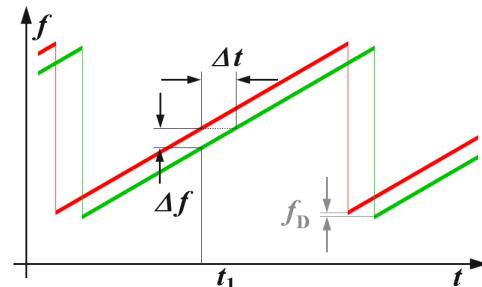


Fig. 4. Ranging with an FMCW system (personal research data).

$$R = \frac{c_0 |\Delta t|}{2} = \frac{c_0 |\Delta f|}{2 \left(\frac{df}{dt} \right)} \quad (7)$$

c_0 = Speed of light ($3 \cdot 10^8$ m/s)

Δt = delay time (s)

Δf = measured frequency difference (Hz)

R = distance between the antenna and reflecting object (ground) (m)

$\frac{df}{dt}$ = frequency shift per unit of time

Furthermore, for the Range Resolution of FMCW radar, the bandwidth BW of the transmitted signal is decisive, as in chirp radar. However, the technical possibilities of the Fast Fourier Transform are limited by time, i.e., by the duration of the sawtooth T as Eq. (8). The resolution of an FMCW radar is determined by the frequency changes that occur within this time limit.

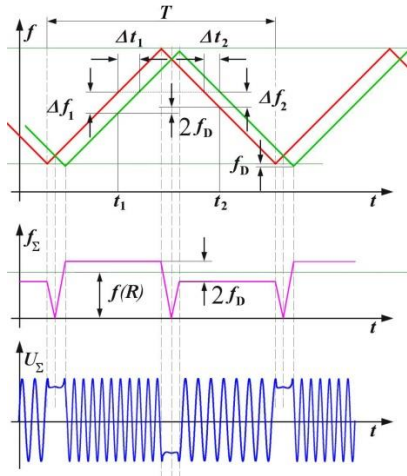


Fig. 5. Triangular modulation pattern (personal research data).

$$\Delta f_{FFT} = \frac{1}{T} = \frac{d(f)}{d(t) \cdot (f_{up} - f_{down})} \quad (8)$$

Δf_{FFT} = slightest measurable frequency difference

$\frac{d(f)}{d(t)}$ = Steepness of the frequency deviation

f_{up} = Upper frequency (end of the sawtooth)

f_{down} = Lower frequency (start of the sawtooth)

In the sinusoidal frequency modulation theory in Fig. 5, the time domain formula is obtained $y(t)$ value.

$$y(t) = \cos\{2\pi[f_c + B \cos(2\pi f_m t)]t\}, \text{ where } B = \frac{f_d}{f_m} \quad (9)$$

Moreover, Eq. (9) is applied to the condition of the radar transmission to the reflector or object, as in Eq. (10) and (11). Where δt is the time delay. Then, the transmitted signal is eliminated; this is due to the time delay and modulation index value in the data transmission process from the Radar to the object or reflector.

$$y(t) = \cos\{2\pi[f_c + B \cos(2\pi f_m(t + \delta t))](t + \delta t)\} \cos\{2\pi[f_c + B \cos(2\pi f_m t)]t\} \quad (10)$$

$$y(t) \approx \cos\{-4t\pi B \sin(2\pi f_m(2t + \delta t)) \sin(\pi f_m \delta t) + 2\delta t\pi B \cos(2\pi f_m(t + \delta t))\} \quad (11)$$

And the modulation spectrum spread (MSS) formula is as in Eq. (12) with an equal range of $0.5C/\delta t$.

$$MSS \approx 2(B+1)2(B+1)f_m \sin(\delta t) \quad (12)$$

The relationship between the adjusted Doppler frequency of the distance determination and the Doppler frequency of the moving target is shown in Eq. (13) and (14).

$$f(R) = \frac{\Delta(f_1) + \Delta(f_2)}{2} \quad (13)$$

$$f(D) = \frac{|\Delta(f_1) + \Delta(f_2)|}{2} \quad (14)$$

$f(R)$ = frequency as a measure of distance determination

$f(D)$ = Doppler frequency as a measure of the speed measurement

$\Delta(f_1)$ = frequency difference at the rising edge

$\Delta(f_1)$ = frequency difference at the falling edge

III. METHOD

The method in this research is shown in Fig. 7 by looking at a more specific step-by-step process in the flowchart, Fig. 6. while the real-time respiratory Radar is documented in Fig. 8. In the case of these radar-based respiratory patients, it is essential to understand the algorithm shown in Algorithm 1.

Algorithm 1: Radar-based respiratory system readout

```

Start
Initialize of Radar
While Radar Capture loop
  For (Patient's position ready), do
    --Capture and read respiratory patient data from Radar
    --Perform Filtering
    --Remove Noise
    --Perform respiratory motion detection
    --Calculate the respiratory frequency
    --Display the reading result
    --Pause for a few seconds to allow the next breath to be detected
  if (Respiratory patient's data is not readable)
    -- Restart the Radar Functionality and restart the detection of the respiratory patient.
  else
    -- Radar Error
  Finish
End
    
```

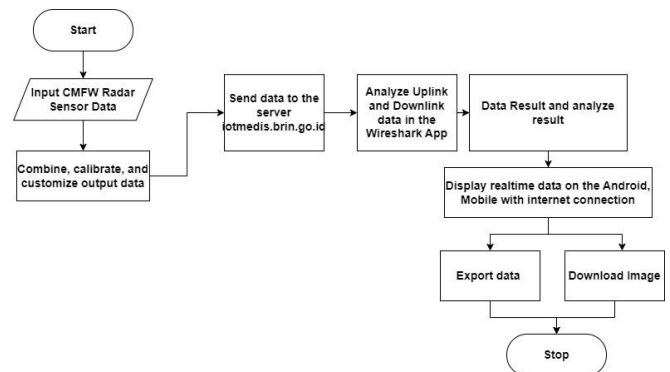


Fig. 6. Flowchart system (personal research data).

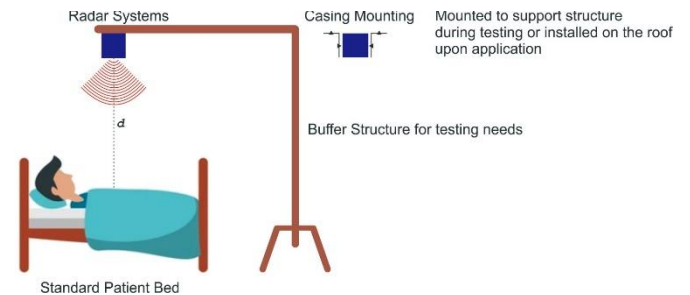


Fig. 7. Positioning of FMCW Radar during respiratory measurement (personal research data).

IV. RESULT AND ANALYSIS

The analysis results show the respirometer and magnitude of the Radar and patient with different distances, namely 30 cm, 60 cm, 100 cm, 300 cm, 450 cm, and 1000 cm or 10 meters. The respirometer and magnitude are different from each distance difference, and this is due to the Doppler frequency of the distance determination.

Fig. 9 shows the position of the FMCW Radar that has not been given a mounting case, this is for initial testing and to obtain signal accuracy.

Specifically, Data Radar for respiratory patients is shown in Fig. 10 (30 cm), Fig. 11 (60 cm), Fig. 12 (100 cm), Fig. 13 (300 cm), Fig. 14 (450 cm), Fig. 15 (1000 cm), and precisely or detail respiratory patient in Fig. 16 the difference is in the distance, which is the closest distance of 30 cm to 10 meters.



Fig. 9. Positioning of FMCW Radar on this research prototype (personal research data).

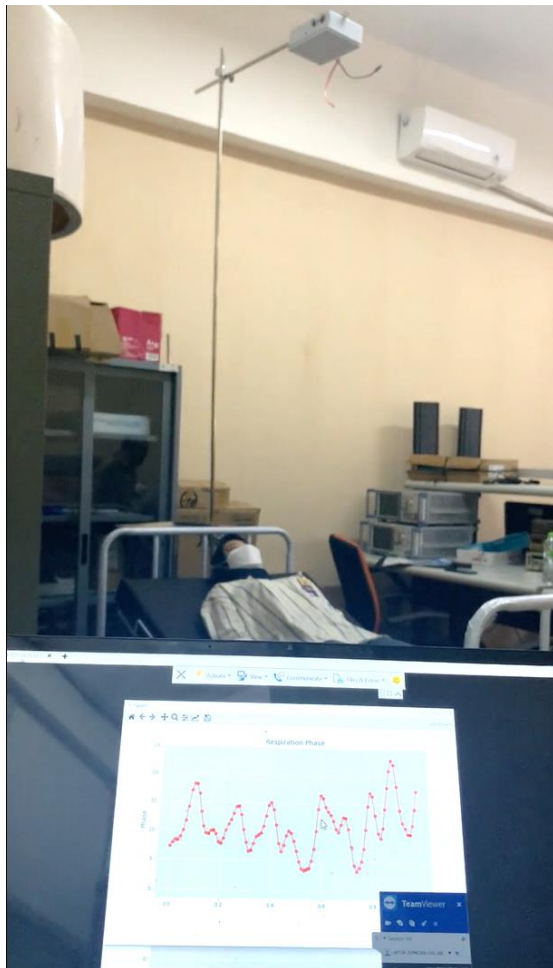


Fig. 8. Breathing GUI display of FMCW radar results (personal research data).

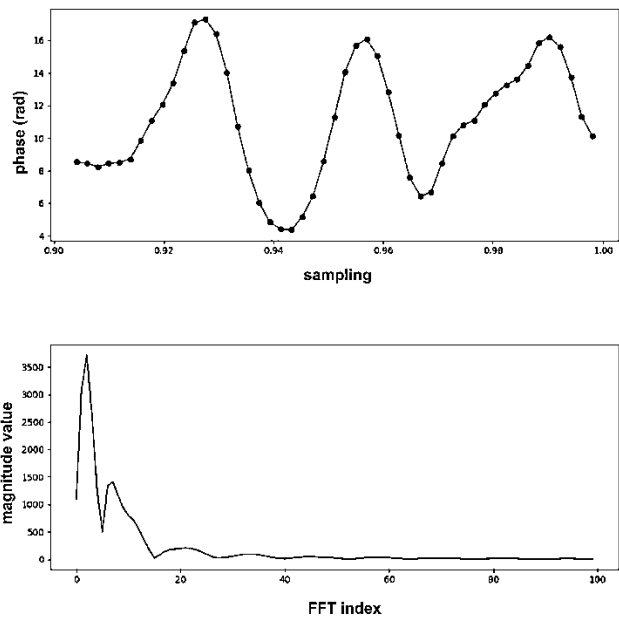


Fig. 10. Radar output for a respiratory patient at a distance of 30 cm.

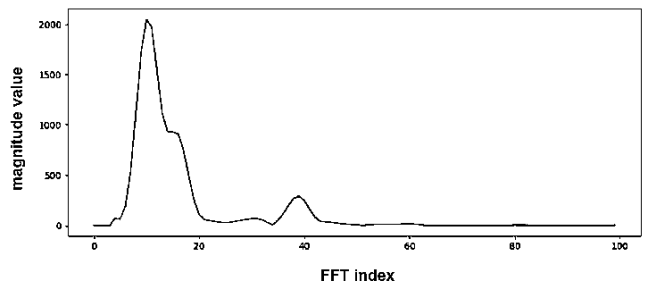
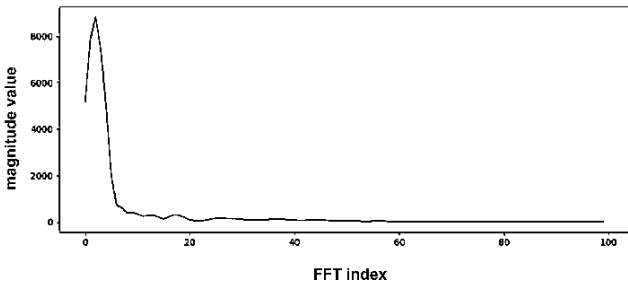
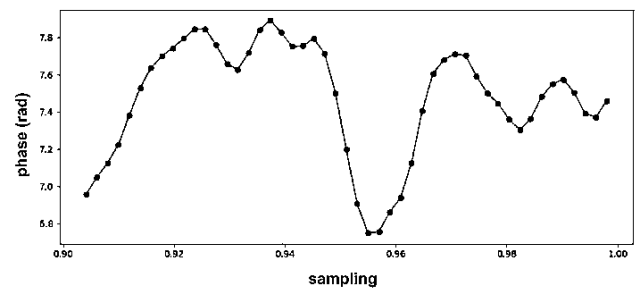
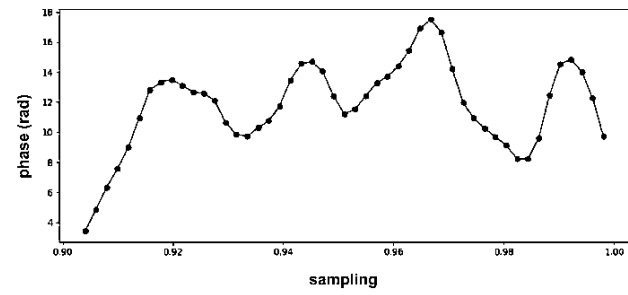


Fig. 11. Radar output for a respiratory patient at a distance of 60 cm.

Fig. 13. Radar output for a respiratory patient at a distance of 300 cm.

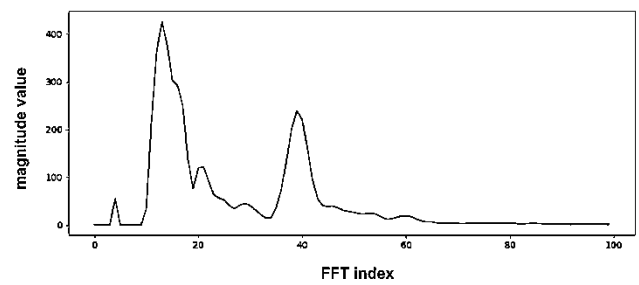
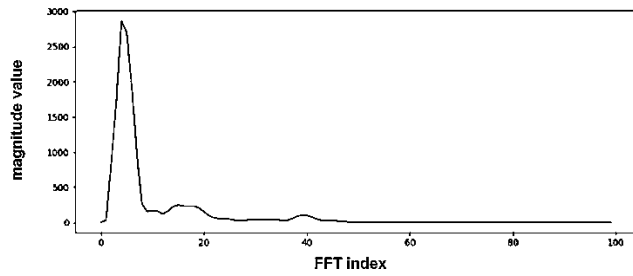
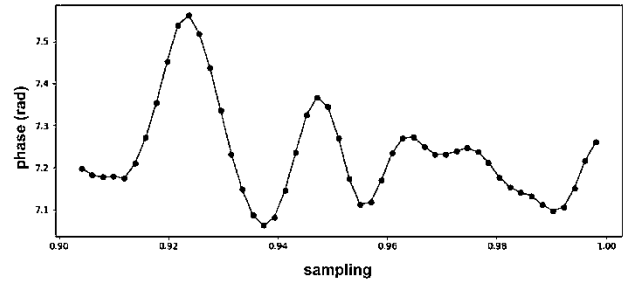
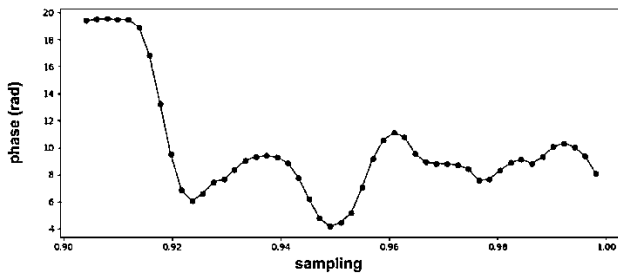


Fig. 12. Radar output for a respiratory patient at a distance of 100 cm.

Fig. 14. Radar output for a respiratory patient at a distance of 450 cm.

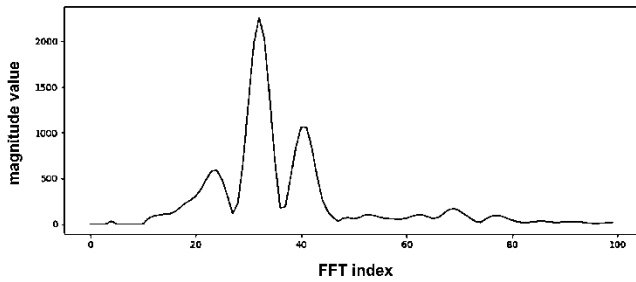
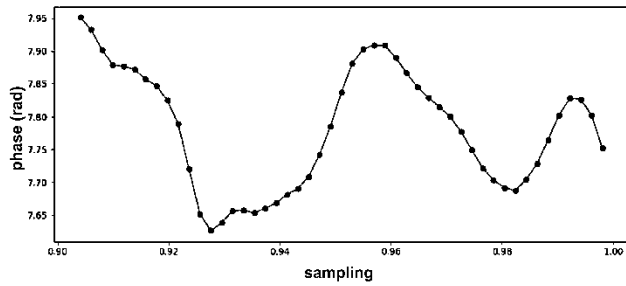


Fig. 15. Radar output for a respiratory patient at a distance of 1000 cm.

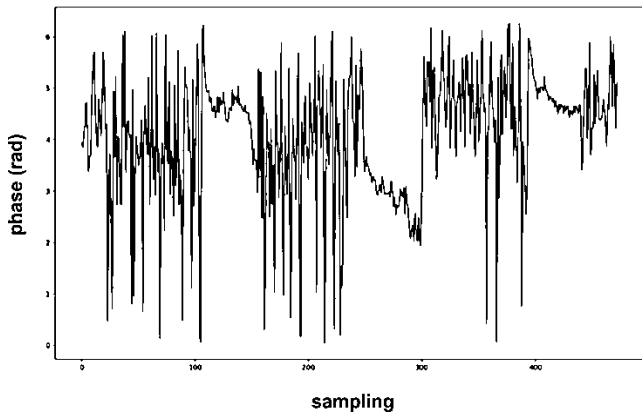


Fig. 16. Radar output for a respiratory patient detail.

Furthermore, by sending MQTT-based data, with Raspberry Pi 4 as a processor, Radar data can be displayed on the Application Server iotmedis.brin.go.id in realtime from several patients or multi-nodes, as shown in Fig. 17. In Fig. 17, sample data is taken from four different patient conditions, namely with varying conditions of breathing, in taking samples, there is a conditioning of patient breathing, namely fast breathing, slow breathing, holding the breath, and normal breathing, this is done to get different results to get the most accurate radar reading system. As for the download process, it can be done quickly. Real-time patient respiratory data can be downloaded in SVG, PNG, and CSV formats, as shown in Fig. 18.



Fig. 17. Multi-data respiratory patient from server real-time and smartphone.

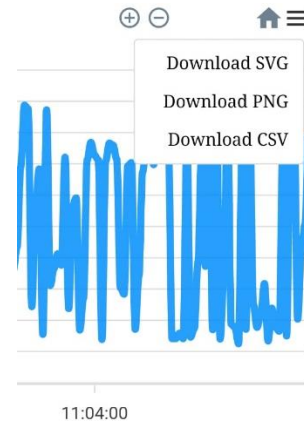


Fig. 18. Download realtime data.

V. CONCLUSION

FMCW radar can accurately detect breathing from each experiment, for example, when the patient is sitting, standing, or running results, or from differences in male and female gender who have different lung volumes. The experiments conducted produce respiratory data that is in accordance or synchronized with the FMCW radar measurement data. Next is to send breathing data to the iotmedis.brin.go.id server. While the server functions very well by displaying the respire meter and magnitude display of human or patient breathing results, this data can be viewed in real-time with Multi data Respiratory Patients' real-time use of Android and a smartphone with an internet connection. Finally, downloading real-time graphs of respiratory data can be done easily on a smartphone device. Specific data and research novelty is how Multi patient respiratory data from OmnipreSense or FMCW Radar can be processed by a microprocessor using MQTT, and multi-patient data can be displayed on the server in real-time; this process was a success and was successfully tested.

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REFERENCES

- [1] M. Skolnick, Radar Handbook, 3rd Ed., America: McGraw-Hill Education, 2008.
- [2] Axel Trange, "FMCW mmWave Radar for Detection of Pulse, Breathing and Fall within Home Care," in Degree Project in Electrical Engineering, Second Cycle, 30 Credits, Stockholm, Sweden, 2021.
- [3] Y. Wahyu, R. J. Yanti, S. Prasetya, B. B. S. Wicaksana, B. E. Sukoco, F. Ridhia, A. A. Pramudita, "24 GHz FMCW Radar for Non-Contact Respiratory Detection," in 2022 6th International Conference on Information Technology, Information Systems and Electrical Engineering (ICITISEE).
- [4] H. Pratiwi, M. R. Hidayat, A. A. Pramudita, and F. Y. Suratman, "Improved FMCW Radar System for Multi-Target Detection of Human Respiration Vital Sign," Jurnal Elektronika dan Telekomunikasi, vol. 19, no. 2, pp. 38-44, Dec. 2019. doi: 10.14203/jet.v19i3.22258. [5] Mark A Richards et al. Principles of modern Radar. Citeseer, 2010.
- [5] Adi, P.D.P. et.al, "LoRaWAN Technology in Irrigation Channels in Batu Indonesia", December 2021, Jurnal Ilmiah Teknik Elektro Komputer dan Informatika, DOI: 10.26555/jiteki.v7i3.22258.
- [6] P. D. P. Adi et al., "Application of IoT-LoRa Technology and Design in irrigation canals to improve the quality of agricultural products in Batu Indonesia," 2021 2nd International Conference On Smart Cities, Automation & Intelligent Computing Systems (ICON-SONICS), Tangerang, Indonesia, 2021, pp. 88-94, doi: 10.1109/ICON-SONICS53103.2021.9617175.
- [7] P. D. P. Adi et al., "ZigBee and LoRa performances on RF Propagation on the Snow Hills area," 2021 International Conference on Converging Technology in Electrical and Information Engineering (ICCTEIE), Bandar Lampung, Indonesia, 2021, pp. 36-41, doi: 10.1109/ICCTEIE54047.2021.9650623.
- [8] P. D. P. Adi and A. Kitagawa, "A Review of the Blockly Programming on M5Stack Board and MQTT Based for Programming Education," 2019 IEEE 11th International Conference on Engineering Education (ICEED), Kanazawa, Japan, 2019, pp. 102-107, doi: 10.1109/ICEED47294.2019.8994922.
- [9] P. D. P. Adi, A. Kitagawa and J. Akita, "Finger Robotic control use M5Stack board and MQTT Protocol based," 2020 7th International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), Semarang, Indonesia, 2020, pp. 1-6, doi: 10.1109/ICITACEE50144.2020.9239170.
- [10] M. Jankiraman, B. J. Wessels and P. Van Genderen, "Pandora multifrequency FMCW/SFCW radar," Record of the IEEE 2000 International Radar Conference [Cat. No. 00CH37037], Alexandria, VA, USA, 2000, pp. 750-757, doi: 10.1109/RADAR.2000.851929.
- [11] C. S. Chaves, R. H. Geschke, M. Shargorodskyy, R. Brauns, R. Herschel and C. Krebs, "Polarimetric UAV-deployed FMCW Radar for Buried People Detection in Rescue Scenarios," 2021 18th European Radar Conference (EuRAD), London, United Kingdom, 2022, pp. 5-8, doi: 10.23919/EuRAD50154.2022.9784490.
- [12] P.D.P.Adi, V.M.M.Siregar, "A Soil moisture sensor based on Internet of Things LoRa", Internet of Things and Artificial Intelligence Journal, Vol.1, Issue.2, 2021, May, DOI:10.31763/iota.v1i2.495.
- [13] E. Hyun, Y. -S. Jin and J. -H. Lee, "Moving and stationary target detection scheme using coherent integration and subtraction for automotive FMCW radar systems," 2017 IEEE Radar Conference (RadarConf), Seattle, WA, USA, 2017, pp. 0476-0481, doi: 10.1109/RADAR.2017.7944250.
- [14] S. Murali, K. Subburaj, B. Ginsburg and K. Ramasubramanian, "Interference detection in FMCW radar using a complex baseband oversampled receiver," 2018 IEEE Radar Conference (RadarConf18), Oklahoma City, OK, USA, 2018, pp. 1567-1572, doi: 10.1109/RADAR.2018.8378800.
- [15] M. H. Moghaddam, S. R. Aghdam, A. Filippi and T. Eriksson, "Statistical Study of Hardware Impairments Effect on mmWave 77 GHz FMCW Automotive Radar," 2020 IEEE Radar Conference (RadarConf20), Florence, Italy, 2020, pp. 1-6, doi: 10.1109/RadarConf2043947.2020.9266605.
- [16] S. Rao and A. V. Mani, "Interference Characterization in FMCW radars," 2020 IEEE Radar Conference (RadarConf20), Florence, Italy, 2020, pp. 1-6, doi: 10.1109/RadarConf2043947.2020.9266283.
- [17] T. Zhang, G. Liao, Y. Li, T. Gu, T. Zhang and C. Chen, "A Time-domain strip-map processing scheme for FMCW imaging," 2021 CIE International Conference on Radar (Radar), Haikou, Hainan, China, 2021, pp. 228-231, doi: 10.1109/Radar53847.2021.10028593.
- [18] Z. Xu, Y. Wang, J. Luo, M. Che, H. Wang and D. Zhang, "Potential of Reducing FMCW Radar Mutual-interference Using Nonlinear FM Signals," 2021 CIE International Conference on Radar (Radar), Haikou, Hainan, China, 2021, pp. 2852-2855, doi: 10.1109/Radar53847.2021.10028399.
- [19] L. Wang and J. Wang, "Radon-Fourier Transform in FMCW Radar," 2020 IEEE Radar Conference (RadarConf20), Florence, Italy, 2020, pp. 1-6, doi: 10.1109/RadarConf2043947.2020.9266324.
- [20] M. Altmann, P. Ott, N. C. Stache, D. Kozlov and C. Waldschmidt, "A Cognitive FMCW Radar to Minimize a Sequence of Range-Doppler Measurements," 2020 17th European Radar Conference (EuRAD), Utrecht, Netherlands, 2021, pp. 226-229, doi: 10.1109/EuRAD48048.2021.00065.

Performance Analysis of Prophet Routing Protocol in Delay Tolerant Network by using Machine Learning Models

Bonu Satish Kumar¹, Sailaja Vishnubhatla², Chevuru Madhu Babu³, Prof. S. Pallam Shetty⁴
Department of Computer Science & Systems Engineering, Andhra University, Visakhapatnam, India^{1,4}
Department of Computer Science, Government Degree College, Ravulapalem, India²
Department of Computer Science, SVSSC Government Degree College, Sullurupet, India³

Abstract—Delay-Tolerant Networking (DTN) or Disruptive-Tolerant Networking comes under the category of networks that works without infrastructure wireless networks. DTN is one type of computer network that provides solutions for several applications. Delay tolerant network communications are networks that are accomplished by storing packets briefly in intermediate nodes till a certain time an end-to-end route is been re-setup or regenerated. This leads to thought as Delay Tolerant Networks. The paper presents the developed models using Artificial Neural Networks (ANN) and Convolutional Neural Networks (CNN) for predicting the best alpha, beta, and gamma parameters of Probabilistic Routing Protocol for Intermittently Connected Networks (PROPHET) protocol for delay tolerant networks. The first data set is generated using ONE simulator, and the generated data is analyzed using python panda's module. From the above dataset, 80% was used for training and the remaining 20% each has been used for testing and validation. The models were developed and tested using the r2 score for both models to predict alpha, beta, and gamma parameters. Based on the predicted parameters extensive experiments were done and it was found that the ANN model is better than the CNN model. The ANN model can predict optimum alpha, beta, and gamma whereas CNN Model failed to produce accurate prediction.

Keywords—DTN; ONE; Prophet; CNN; ANN

I. INTRODUCTION

Wireless Networks are dynamic. Nowadays Wireless Networks have become a part of life to communicate with others. Delay Tolerant Network (DTN) is a type of wireless communication to communicate data. DTN is a wireless network designed to operate efficaciously in severe conditions and over very massive distances, including space area communications [1]. DTN networks are proven the most beneficial network in deep space communications. Space communications are lengthily distances of millions and hundreds of miles. So routing the data between massive distances leads to delays in transferring data, records losses, and errors. Present communication technology is not enough to handle such problems. That is wherein delay tolerant networks are introduced [2, 3].

To increase the quality of data-transferring services in large communications machine learning models are developed to predict the parameters for given inputs. The main reason for choosing DTNs is it decreases the delay and increases the

throughput of the network [4]. As routing is a tedious task in communication hence DTN networks are chosen. Machine Learning (ML) belongs to a Sub-Category of Artificial Intelligence (AI) which doesn't need to program explicitly and it takes the input as the data samples and creates its insights from the data [5]. Here, the author created models of Deep Learning (DL) which take input as throughput and delay and output alpha, beta, and gamma values without simulation. Deep Learning is a part of Machine Learning where Neural Networks (NN) are used to solve machine learning problems [6]. Neural Networks require high computational power to train the model.

Two neural network models Convolution Neural Networks (CNN) and Artificial Neural Networks (ANN) are defined for prediction. CNN is an architecture that is used for deep learning algorithms, specifically in the processing of pixel data in image processing concepts and pattern recognition in computer-related vision. The CNN also is the feed-forward network that is widely used for routing and multiple communication network tasks [7, 8]. An ANN is formed from a group of linked units or artificial neuron nodes, which are the simple model of the biological brain. ANN is the capability of paralleled processing, working with incomplete data, and memory distribution [9, 10].

In the present work, the author created machine learning models which can predict the required values just by inputting the data without simulation. The proposed paper is arranged as follows: The introduction part introduces the delay tolerant networks of the prophet routing protocol by using two machine learning models such as artificial neural networks and convolutional neural networks. The literature survey part presents the existing system. The next section methodology and simulation deals with the methods used to implement the performance of the prophet routing protocol in DTNs and shows the output using ONE simulator. The results and simulation part presents the prediction values that came from the CNN and ANN models. Comparing the above two models one is more accurate for all models and selected the best one is ANN. After doing extensive experiments, it was found that the ANN model is better than the CNN model with an accuracy of 99%. The final section deals with the conclusion of the present work and proposed a future scope of this study.

II. LITERATURE REVIEW

Delivery ratio and packet drop influence quality of service in the delay tolerant networks are found and explained [11]. They proposed a solution to maintain the quality of service in DTN. They said that providing quality service in wireless networks is a challenging task. They investigated that no researcher now talked about fairness in the delay-tolerant network to maintain the Quality of service.

Research [12] worked in DTN routing as an ML classification problem. The authors discussed a machine learning-based style to directing the route for delay tolerant networks (DTNs). They explained various machine learning classification techniques to forecast a set of adjacent nodes which have the maximum possible to distribute communication to an anticipated location based on the message of the past delivery info. Their results showed that ML classification is a workable technique to expect network traffic, reducing overhead in epidemic-based routing approaches. Their model is not concentrated on new data arriving; this is the drawback of their work.

The thought and design of a machine learning-based routing for delay-tolerant planetary systems were discussed [13, 14]. They stated that the methods of Bayesian learning and reinforcement learning are used to enhance the routing decisions. Cognitive communications prototypes are studying popular ML algorithms which may be used further to enhance the functionality of existing routing algorithms. This approach proved the adaptive aids established in opportunistic transmitting strategies. In delay-tolerant network algorithms, strategies, and applications they incorporated Machine-Learning methods that can be fixed to overwhelm such struggles [15]. ML enhances the network lifespan in delay tolerant network. ML works on DTN routing by adjusting to the network changes diminishing congestion, and cutting overhead. The authors did not work to enhance the quality of service parameters like throughput and delay.

Study [16] used the Support Vector Machines (SVM) concept in machine learning used to solve non-linear classification and regression. The network traffic predictive method proposed here with some results, they prepared a dataset by using it for testing and training. They found that their approach to finding correctness is better than detecting the attacked traffic. The inclusion of neural networks of machine learning in wireless sensor networks is a useful tool to increase network performances was suggested in [17]. Work was done on ML techniques for the prediction of routing parameters and protocol to obtain optimal performance [18]. Their results show that improvement in the quality of service has been achieved.

Extensible Provisioning Protocol (EPP) is proposed to consider specific physical attributes of collaborating mobile nodes, at the side of their positional attributes with a current message time-to-live value, and determine routing hops [19]. Their primary aim is to increase message delivery rate while keeping an optimal balance between hop count, routing overhead, and cooperation among nodes. Extensive provisioning protocol works on delivery rate, this predictability value is manipulated using a weighted function of parameters

like bandwidth, power, nodes buffer, deliverable probability, and popularity. Extensive provisioning protocol maintains high probability delivery while structured overhead ratio average hop count and balancing average latency.

Cognitive Radio Mobile Ad-hoc Networks (CR-MANETs) are proposed as an efficient quality of service protocol, where a quality of service route is formed by exploiting Deep Reinforcement Learning (DRL) [20]. The higher Packet Delivery Ratio (PDR) and lower energy consumption provides by the proposed quality of service routing protocol than the Cognitive Radio Ad-hoc On-demand Distance Vector (CR-AODV). Moreover, the cognitive radio Ad-hoc on-demand distance vector protocol spends too much energy for the Route Request Packet (RREQ) flooding, while the quality of service routing protocol just unicast an RREQ packet to the best neighbor relying on the Deep Reinforcement Learning (DRL) model, thus consuming the small energy.

A systematic and comprehensive study of investigation on various modern approaches for intensifying security in Mobile Ad-hoc Networks (MANETs) is represented in [21]. A review on routing protocol and security attacks in mobile ad-hoc networks studied different security attacks in MANET. The author also examined how different layers under the protocol stack become vulnerable to different types of attacks [22]. A different routing protocol was designed for infrastructure-less networks and described the operation of each protocol and then compared their characteristics. They classified the routing method based on the operation [23]. An Ad hoc routing protocol of table-driven and on-demand category are selected for their study [24]. This paper studied table-driven routing protocols and listed their pros and cons in various situations. Results getting from the Taguchi approach, it is conferred that one ideal setting for one response metric is not similar to another metric. Hence multiple-response metric study may yield better results as it gives one optimum setting to enhance all metrics [25]. The data transfer between air-linked devices to the ground station using Micro Aerial Vehicle (MAVlink) protocol is explained [26]. The work describes the transfer between micro aerial vehicles or unmanned aerial vehicles to ground control stations in different circumstances.

They categorized various machine learning algorithms based on security approaches in mobile ad-hoc networks. The security approaches are divided into three dimensions (3D) ML Based Intrusion Detection System (IDS), trust-based models, and attack detection models. In the existing system people who worked on DTNs simulated the model to improve the network throughput and to decrease the delay. The above models are worked to increase the throughput of the delay tolerant networks using the simulation.

III. METHODOLOGY AND SIMULATION

A. Artificial Neural Network

Artificial Neural Networks (ANNs) are simply called Neural Networks (NN), these are the computing systems that are inspired by human and animal brain process information [27]. ANNs accumulate their expertise utilizing detecting the patterns and trained similarities within the data through experience, not from programming. The architecture of ANN is

shown in Fig. 1. An ANN is formed from a group of linked units or artificial neuron nodes, which are the simple model of the biological brain.

In the ANN, each neuron is connected with weights (Coefficients) to each one to transmit signals from each other and organized in layers [28]. The coefficients decrease and increase with the strength of the signal in some thresholds. Based on the threshold the signal passes through the neurons within the unit. The output of the signal (neurons) is calculated by the non-linear equation of the sum of its input.

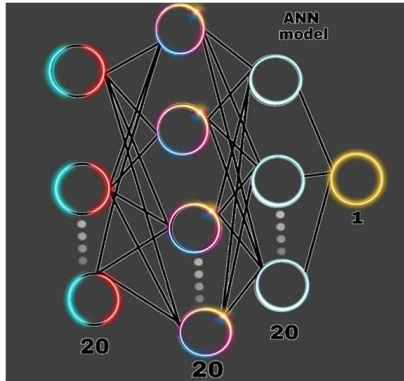


Fig. 1. Architecture of ANN.

B. Convolutional Neural Networks

The problem with regular NNs is the lack of adaptability. At the same time complexity and size of the data to be increased, and the calculation power of the model should be increased this leads to more expensive neural networks. The parameter sharing is well known that the associated weight (Coefficient) in the CNN layers is remaining fixed. The parameter sharing in the CNN layer system will be less computationally intensive than the artificial neural networks. The architecture of ANN is shown in Fig. 2.

CNN is an architecture that is used for deep learning algorithms, specifically in the processing of pixel data in image processing concepts and pattern recognition in computer-related vision [29]. CNN also shows connectivity pattern similar to a human brain just like ANN and it consists of a group of linked neurons to connect. The CNN delivers better performance with image inputs, and also with speech or audio signal inputs.

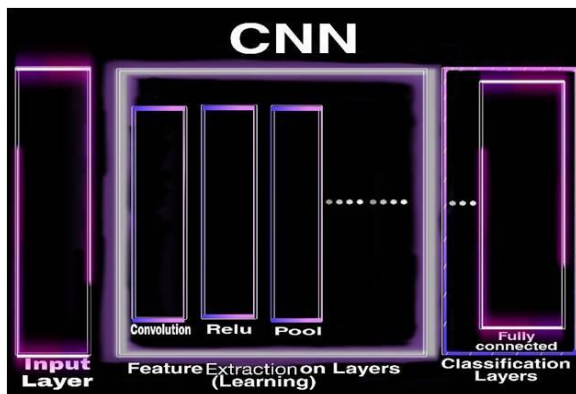


Fig. 2. Architecture of CNN.

C. Simulation

A simulation is a duplicate model that mimics the operation of a current or proposed work, imparting proof for decision-making by having the ability to test distinct situations or different scenarios or method modifications, or process changes. A network system is a set of network elements, including switches, routers users, links, and packages operating collectively to acquire some assignments. The scope of a simulation examination, can also most effectively be a system inside another system as in the case of sub-networks.

The state of a network system is the set of suitable parameters and variables that narrate the system at a precised time that incorporates the scope of the study. As an example, if the interest is in the usage of a link, then recognize the quantity of bits transmitted through the link in a second and the full capacity of the link, instead of the variety of buffers to be available for the ports in the switches connected via link.

1) *Types of simulators:* Different network simulators offer different features.

- Network Simulator2.
- Network Simulator3.
- OPNET.
- OMNeT++.
- NetSim.
- ONE.
- REAL.
- QualNet.
- J-Sim.

2) *ONE Simulator:* DTN is a communication networking pattern that enables communication in environments wherein there may be no end-to-end paths, communication opportunities come and cross and their programming languages can be very lengthy and now not even identified beforehand. Routing messages in this type of surroundings may be unique and different from traditional standard networks. This gap has created a need to find different types of new routing protocols that take efficaciously into consideration the distinct nature of these networks.

Distinct procedures may be tested and evaluated by way of simulation. So in this work, the author considers and thinks about Opportunistic Network Environment (ONE) Simulator shown in Fig. 3. Not like other delay tolerant networks simulators, which typically pay attention to routing simulation, the ONE combines delay tolerant network routing, mobility modeling, and visualization in one package deal that is effortlessly extensible and offers a rich set of reporting and studying modules. The ONE simulator is a simulation tool that is used widely by researchers operating on studies related to opportunistic and DTN networks. The default_settings.txt notepad file is essential for running or compiling the stipulated simulation.

Standardize the simulation's configuration parameters along with alpha, beta, and gamma parameters from the Internet Engineering Task Force (IETF) draft of the Prophet routing protocol wherein static values are not suitable for delay tolerant networks; that are dynamic values shown in Table I. The working environment and parameters for the simulation setup are shown in Table II.

TABLE I. IETF DRAFT PARAMETERS FOR PROPHET ROUTING PROTOCOLS

Parameter	Default Value	Description
Alpha	0.75	Predictability initialization constant
Beta	0.25	Delivery predictability transitivity scaling constant
Gamma	0.98	Predictability aging constant

TABLE II. VARIABLES FOR SIMULATION SETUP

Name of Parameter	Value
Time of Simulation	0.5hr-12hr
Node Density	40,80,120
Update interval	0.1
Interface Type	Simple Broadcast
Interface	Bluetooth
Interface Transmit Speed	2 Mbps
Transmit Range	100m
Routing Protocols	PRoPHET
Message TTL	300 minutes(5hours)
Message Generation Rate	25sec-35sec
Buffer Size	2 MB
Message Size	500 KB-1 MB
Movement Model	Shortest Path Map Based
Simulation Area Size	4500m×3400m
Load time	1Mb,2Mb,3Mb,4Mb,5Mb

D. Graphical User Interface Mode

The Graphical User Interface (GUI) additionally maintains track of noted events or activities and disposes them inside the panel of the event log. By clicking a message or a node name within the panel of the event log, more statistics may be proven approximately that message or node. The panel of event log dominance panel may be used to alter which events or activities are shown within the event log and the simulation also can be made mechanically paused in the case of some sort of activities or events.

E. Methodology

The overall algorithm for this work is as follows and the flow chart of the algorithm is shown in Fig. 4.

- Step1. Read the data from the data set.
- Step2. Processing the data.
- Step3. Apply artificial neural network.
- Step4. Apply convolution neural network.
- Step5. Evaluate and Compare the results.

A Java simulator is used to create the data, and Anaconda software is used to perform machine learning algorithms. Many people used Fuzzy Models to enhance the performance of DTN but here we used Machine Learning Models.

The following steps are discriminating the proposed methodology:

1) Reading the data:

a) By using the Pandas module imported the training Data set and testing data which was stored in Comma Separated Values (CSV) format.

b) Here, two lists are created that contain labels and targets.

2) Modifying data:

a) Using the time step of 30 apply time-series.

b) Here 30 denotes the input size to the model which is used to predict the targets.

c) Perform the Min Max Operation on the data.

d) Split the data for training and testing purposes with an 80:20 ratios.

3) Modeling: Modeling presents the detailed procedure for this study using two models such as convolutional neural networks as model-1 and artificial neural networks as model-2. The procedure of the above two models is discussed in the results and discussions.

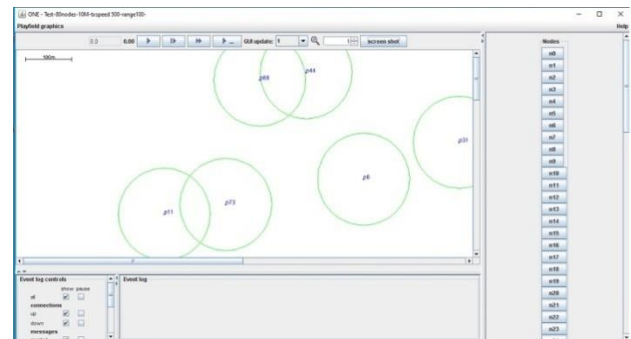


Fig. 3. ONE simulator GUI.

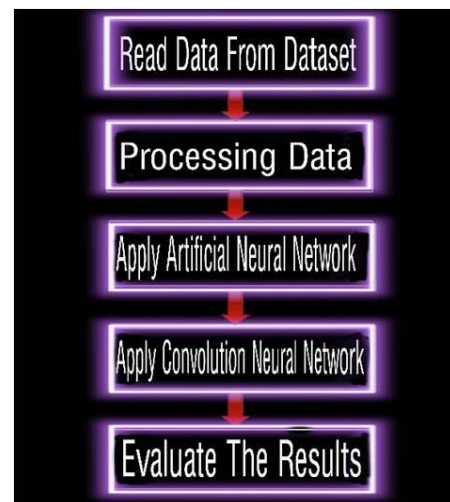


Fig. 4. Flow chart for the proposed system.

IV. RESULTS AND DISCUSSIONS

A. Convolutional Neural Networks(Model-1)

1) Model-1 (CNN):

- a) Import Sequential and Dense from Keras. models and keras.layers respectively.
- b) Initialize the Sequential Model.
- c) Add 4 dense layers with normal kernel initializer and Rectified Linear Unit (ReLU) activation function with 20, 25, 10, and 1 neurons in each respectively.
- d) Compile the model with Adaptive Moment Estimation (ADAM) optimizer and Mean_Squared_Error Loss.
- e) Fit the model with a validation split of 20% and run it for 70 epochs.
- f) Make the Predictions and compare them with actual values shown in Table III.
- g) Compute the r2 Score.
- h) Finally, this model too failed to predict the output.
- i) Now retrain the Conv1D Model with modified data for 100 epochs and a 20% validation split.
- j) Compare the predicted values with the actual values and compute the r2_score.
- k) The model worked successfully with 98% accuracy.

For this experiment, a total of five samples were used, and the samples are numbered 0, 1, 2, 3, and 4. Where the actual and predicted values obtained from the above CNN model are more similar to each other and their accuracy is approximately 98%.

TABLE III. PREDICTED AND ACTUAL VALUES OF THE CNN MODEL

Value	Actual	Predicted
0	0.835	0.820380
1	0.840	0.826132
2	0.850	0.832045
3	0.855	0.837852
4	0.860	0.843962

Added four dense layers with the return sequence of each one with 70 neurons and Epoch of 1/100, 2/100, and 3/100 for each 1 neuron add the dense layer to get the predicted output shown in Table IV. The training dataset of the CNN model is shown in Fig. 5.

```
Epoch 1/100
4/4 [=====] - 0s 57ms/step - loss: 0.1997 - val_loss: 0.5681
Epoch 2/100
4/4 [=====] - 0s 18ms/step - loss: 0.2074 - val_loss: 0.5570
Epoch 3/100
4/4 [=====] - 0s 16ms/step - loss: 0.1916 - val_loss: 0.5449
```

Fig. 5. The training data set of the CNN Model.

TABLE IV. DENSE LAYERS STEP EPOCH OF CNN MODEL

Epoch	Step	Loss	Val_Loss
1/100 (4/4)	0s 57ms	0.1997	0.5681
2/100 (4/4)	0s 18ms	0.2074	0.5570
3/100 (4/4)	0s 16ms	0.1916	0.5449

```
Accuracy score of the predictions: 0.9872868277769965
```

Fig. 6. Accuracy output of the CNN model.

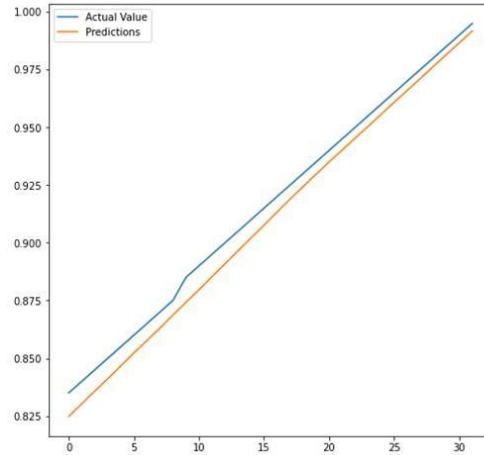


Fig. 7. Actual and predicted values of the CNN model.

Then retrain the Conv1D model with modified data for 100 epochs (1/100, 2/100, 3/100) and a 20% validation split. Compare the predicted values with the actual values and compute the r2_score. The CNN model worked successfully with an accuracy of 98% shown in Fig. 6. The graph shown in Fig. 7 represents the accuracy CNN model with actual and predicted values. The yellow line shows the predictions and the blue one shows those actual values.

B. Artificial Neural Networks(Model-2)

1) Model-2 (ANN):

- a) Import sequential and utils from TensorFlow.keras and import Flatten, Dense, Conv1D, MaxPool1D, and Dropout from TensorFlow. Keras. layers.
- b) Initialize the Sequential Model.
- c) Add 3 Conv1D Layers with kernel size (3) and ReLU activation function with 32, 64, and 128 neurons each.
- d) Add a Flattening Layer.
- e) Add three Dense Layers with ReLU activation function with 50, 20, and 1 neurons.
- f) Compile the model with mean_squared_error and Adam optimizer.
- g) Fit the model with a 20% validation split for 100 epochs.
- h) Predict the values using the model and compare with actual values and compute the r2_score shown in Table V.
- i) This model too failed to predict the outputs and gave less accuracy.
- j) Now retrain the Conv1D Model with modified data for 100 epochs and a 20% validation split.
- k) Compare the predicted values with the actual values and compute the r2_score.
- l) The model worked successfully with 99% accuracy.

TABLE V. PREDICTED AND ACTUAL VALUES OF THE ANN MODEL

Value	Actual	Predicted
0	0.835	0.830679
1	0.840	0.836426
2	0.845	0.842122
3	0.850	0.847810
4	0.855	0.853515

For this experiment, a total of five samples were used, and the samples are numbered 0, 1, 2, 3, and 4. Where the actual and predicted values obtained from the above ANN model are more similar to each other and their accuracy is approximately 99%.

The test data has been sent to the model to predict the output and the predictions have been stored in a variable as a data frame. The actual value and the predicted value have been compared to evaluate the model.

Add 3 Conv1D Layers with kernel size (3) and ReLU activation function with 32, 64, and 128 neurons each and Epoch of 1/100, 2/100, and 3/100 for each increasing neuron add the dense layer to get the predicated output shown in Table VI. The training dataset of the ANN models is shown in Fig. 8.

```
Epoch 1/100
4/4 [=====] - 1s 72ms/step - loss: 0.2069 - val_loss: 0.2005
Epoch 2/100
4/4 [=====] - 0s 20ms/step - loss: 0.0488 - val_loss: 0.1579
Epoch 3/100
4/4 [=====] - 0s 20ms/step - loss: 0.0362 - val_loss: 0.0081
```

Fig. 8. Training data set in ANN Model.

TABLE VI. DENSE LAYERS STEP EPOCH OF ANN MODEL

Epoch	Step	Loss	Val_Loss
1/100 (4/4)	1s 72ms	0.2069	0.2005
2/100 (4/4)	0s 20ms	0.0488	0.1579
3/100 (4/4)	0s 20ms	0.0362	0.0001

Now retrain the Conv1D Model with modified data for 100 epochs and a 20% validation split. Compare the predicted values with the actual values and compute the r2_score. The model worked successfully with 99% accuracy shown in Fig. 9.

```
Accuracy score of the predictions: 0.9897303879778176
```

Fig. 9. Accuracy output of the ANN model.

The actual values of the data and the predicted values of the data have been plotted into a graph to check the variance between values shown in Fig. 10.

After the predicate of the actual and predicted values using ANN and CNN models the final output should be shown in Table VII. The actual values of the data and the predicted values of the data have been differentiated with equal intervals of 0.10, 0.01, 0.01, 0.009, and 0.009.

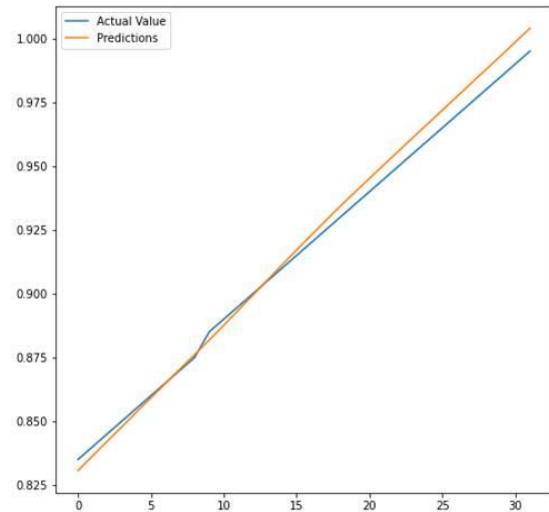


Fig. 10. Actual and predicted values of the ANN model.

TABLE VII. PREDICTED VALUES OF THE CNN AND ANN MODELS

Value	CNN Predicted	ANN Predicted
0	0.820380	0.830679
1	0.826132	0.836426
2	0.832045	0.842122
3	0.837852	0.847810
4	0.843962	0.853515

V. CONCLUSION AND FUTURE SCOPE

Prophet routing protocol is one of the extensively studied delay-tolerant network protocols. In probabilistic routing protocol for intermittently linked networks, a message is forwarded to a touch node if the touch node has a better delivery quality of being expected to the destination of the message. A delay tolerant network is a Prophet routing protocol that gives confident delivery of facts using automatic store and forward mechanisms. Delay tolerant network comes under the category of networks that works without infrastructure wireless networks. Each data packet of transmission is received and immediately forwarded if possible, but these are stored for further transmission if forwarding is not possible currently however is predicted to be possible in future transmission.

In this research work, ANN and CNN models are used to predicate the best alpha, beta, and gamma parameters of prophet routing protocol for delay tolerant networks using a dataset simulated by ONE simulator. While considering models like CNN, ANN performed well on the test dataset. Of the dataset, 80% was used for training and the remaining 20% each has been used for testing and validation. While comparing the two models (CNN and ANN) the impact of CNN is mainly on the dynamic values of all datasets with an accuracy of 98% and ANN is mainly on the dynamic values of all datasets with an accuracy of 99%. Comparing the above two models one is more accurate for all models and selected the best one is ANN with 99%. After doing extensive experiments, it was found that the ANN model is better than the CNN model with an accuracy of 99%. At the same time, the ANN model can predict

optimum alpha, beta, and gamma whereas the CNN model failed to produce accurate prediction.

The future scope should be trying to simulate a large number of datasets and trying to use predefined models like VGG-16, ResNet, and Efficient Net. Also considering the other parameters of DTN Routing Protocols to predicate the accurate results.

REFERENCES

- [1] Cerf, V., Burleigh, S., Hooke, A., Torgerson, L., Durst, R., Scott, K., ... & Weiss, H. (2007). Delay-tolerant networking architecture (No. rfc4838).
- [2] Caini, C. (2021). Delay-tolerant networks (DTNs) for satellite communications. In *Advances in Delay-Tolerant Networks (DTNs)* (pp. 23-46). Woodhead Publishing.
- [3] Mallorquí, A., Zaballos, A., & Serra, D. (2022). A Delay-Tolerant Network for Antarctica. *IEEE Communications Magazine*, 60(12), 56-62.
- [4] Verma, A., & Kumar, S. (2021). Routing protocols in delay tolerant networks: Comparative and empirical analysis. *Wireless Personal Communications*, 118(1), 551-574.
- [5] Zhou, Z. H. (2021). *Machine learning*. Springer Nature.
- [6] Janiesch, C., Zschech, P., & Heinrich, K. (2021). Machine learning and deep learning. *Electronic Markets*, 31(3), 685-695.
- [7] Park, D. C., & Choi, S. E. (1998, May). A neural network-based multi-destination routing algorithm for communication networks. In *1998 IEEE International Joint Conference on Neural Networks Proceedings. IEEE World Congress on Computational Intelligence (Cat. No. 98CH36227) (Vol. 2, pp. 1673-1678)*. IEEE.
- [8] Steur, N. A., & Schwenker, F. (2021). Next-generation neural networks: Capsule networks with routing-by-agreement for text classification. *IEEE Access*, 9, 125269-125299.
- [9] Wang, C. J., & Weissler, P. N. (1995). The use of artificial neural networks for optimal message routing. *IEEE Network*, 9(2), 16-24.
- [10] Lu, J., Li, D., Wang, P., Zheng, F., & Wang, M. (2022). Security-aware routing protocol based on artificial neural network algorithm and 6LoWPAN in the internet of things. *Wireless Communications and Mobile Computing*, 2022, 1-8.
- [11] Roy, A., Acharya, T., & DasBit, S. (2018). Quality of service in delay tolerant networks: A survey. *Computer Networks*, 130, 121-133.
- [12] Dudukovich, R., & Papachristou, C. (2018, August). Delay tolerant network routing as a machine learning classification problem. In *2018 NASA/ESA Conference on Adaptive Hardware and Systems (AHS)* (pp. 96-103). IEEE.
- [13] Dudukovich, R., Hylton, A., & Papachristou, C. (2017, October). A machine learning concept for DTN routing. In *2017 IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE)* (pp. 110-115). IEEE.
- [14] Bajpai, S., & Chauhan, A. (2022, December). Evolution of Machine Learning Techniques for Optimizing Delay Tolerant Routing. In *2022 4th International Conference on Advances in Computing, Communication Control and Networking (ICAC3N)* (pp. 294-299). IEEE.
- [15] Singh, A. K., & Pamula, R. (2021). Vehicular delay-tolerant network-based communication using machine learning classifiers. In *Architectural Wireless Networks Solutions and Security Issues* (pp. 195-208). Springer, Singapore.
- [16] Sharma, A. K., & Parihar, P. S. (2013). An effective dose prevention system to analyze and prediction of network traffic using support vector machine learning. *International Journal of Application or Innovation in Engineering & Management*, 2(7), 249-256.
- [17] Barbancho Concejero, J., León de Mora, C., Molina Cantero, F. J., & Barbancho Concejero, A. (2006). Giving neurons to sensors. QoS management in wireless sensors networks. In *ETFA 2006: IEEE Conference on Emerging Technologies and Factory Automation (2006)*, p 594-597. IEEE Computer Society.
- [18] Zafar, M. H., & Altalbe, A. (2021). Prediction of Scenarios for Routing in MANETs Based on Expanding Ring Search and Random Early Detection Parameters Using Machine Learning Techniques. *IEEE Access*, 9, 47033-47047.
- [19] Samanta, R. EPP: Enhanced PROPHET+ an efficient, cooperative, and network attributes based dtm routing protocol.
- [20] Nguyen, T. V., Tran, T. N., Huynh-The, T., & An, B. (2021). An efficient QoS routing protocol in cognitive radio MANETs: Cross-layer design meets deep reinforcement learning. In *2021 International Conference on Electronics, Information, and Communication (ICEIC)* (pp. 1-4). IEEE.
- [21] Popli, R., Sethi, M., Kansal, I., Garg, A., & Goyal, N. (2021, August). Machine Learning Based Security Solutions in MANETs: State of the art approaches. In *Journal of Physics: Conference Series (Vol. 1950, No. 1, p. 012070)*. IOP Publishing.
- [22] Poonam Sihag, Saurabh Charaya, et al., in their paper entitled, "Routing Protocol & Security Attack in MANET: A Review", 2018 IJCRT, Volume6, Issue 2 April 2018, ISSN: 2320-2882.
- [23] E.M Royer, R.Noyer and C.K.Toh, "A Review of Current Routing Protocols for Ad hoc mobile wireless Networks", *Personal Communications, IEEE*, Volume: 6, Issue: 2, pages 261-271, 1999.
- [24] Hemagowri J., Baranikumari C., Brindha B., "A Study on Proactive Routing Protocol in Ad-hoc network", *International Journal of Modern Engineering Research, National Conference on Architecture, Software Systems and Green Computing (NCASG)*, 2019, pg.01-04.
- [25] Swati Saxena, Madhavi Sinha," Single-Response metric analysis of Adaptive Fault Tolerant Replication Routing Protocol for MANETs using Taguchi Approach", *International Journal of Computer Networking, Wireless and Mobile Communications (IJCNWMC)*, Volume. 3, Issue 3, Aug 2013, pages. 105-116.
- [26] Mogili, U. R., & Deepak, B. B. V. L. (2020). An intelligent drone for agriculture applications with the aid of the MAVlink protocol. In *Innovative Product Design and Intelligent Manufacturing Systems: Select Proceedings of ICIPDIMS 2019* (pp. 195-205). Springer Singapore.
- [27] Hardesty, Larry (14 April 2017). "Explained: Neural networks". MIT News Office. Retrieved 2 June 2022.
- [28] Li, Z., Liu, F., Yang, W., Peng, S., & Zhou, J. (2021). A survey of convolutional neural networks: analysis, applications, and prospects. *IEEE Transactions on neural networks and learning systems*.
- [29] Yegnanarayana, B. (2009). *Artificial neural networks*. PHI Learning Pvt. Ltd.

DIP-CBML: A New Classification of Thai Dragon Fruit Species from Images

Naruwan Yusamran, Nualsawat Hiransakolwong

Department of Computer Science-School of Science, King Mongkut's Institute of Technology, Ladkrabang Bangkok, Thailand.

Abstract—The attractiveness of dragon fruit is that it has a strange exterior, beautiful colors, and high nutritional value. In Thailand, there is both import and export of dragon fruit. Each package for export must contain only one species of dragon fruit. From the survey, there are seven species of dragon fruit cultivated in Thailand and only some farmers can identify them on his/her farm. Therefore, this research focuses on the classification of Thai dragon fruit from laboratory images and outdoor images; which is different from the previous works which studied only laboratory images. This method was named DIP-CBML that stands for digital image processing with content-based and machine learning. The method consists of image type identification, pre-processing, red and yellow classification, image background removal, and six classes of red species classification. From the results, DIP-CBML can work with both datasets. It gave 100%, 100% and 95.53% accuracy for the image type identification, red and yellow classification, and the classification of six red species respectively. Hopefully, this research will lead to the innovation for the pre-harvest classification of Thai dragon fruit cultivars, applied to industrial applications, and robot harvesting. In the future, may add value to the yield of Thai dragon fruit cultivation.

Keywords—Dragon fruit; classification model; outdoor dataset; image pre-processing; segmentation

I. INTRODUCTION

Dragon Fruit is a fruit in the cactus family (Cactaceae) with genus *Hylocereus* Spp. and *Selenicereus* Sp. It has been planted in Thailand since 1997. With its unusual exterior and beautiful colors, it has received much attention. The advantage of dragon fruit is that it is a fruit that has high nutritional value. It can be used in the food, pharmaceutical, and cosmetic industries [1-4]. Since dragon fruit is a juicy fruit, it will be bruising and perishable in a short time after harvesting. It must be eaten or processed quickly, or storing at low temperatures for slowing down spoilage [5].

Currently, there is import and export of dragon fruit. Therefore, the agricultural standard for dragon fruit has been established by the National Bureau of Agricultural Commodity and Food Standards (ACFS), the Ministry of Agriculture, and Cooperatives of Thailand. Dragon fruit is divided into three groups by the peel color and the pulp color, namely Group 1, red peel with white pulp (*Hylocereus undatus*), Group 2, red peel with red pulp (*Hylocereus polyrhizus*) or pink pulp (*Hylocereus* spp.) and Group 3, yellow or gold peel with white pulp (*Hylocereus* sp. and *Selenicereus* sp.). The package must contain the same dragon fruit species per package [6].

From a survey on the cultivation of dragon fruit in Thailand. Loei Province located at the top of the Northeast of Thailand is the area that can harvest the most products in the country [7]. It was found that there are seven species of Thai dragon fruits planted. If divided like ACFS, the First group has two species, which are Jumbo White and Vietnamese White. The second group has four species, which are Pink, Siam Red, Taiwan Red, and Ruby Red. The third group has only one species called Israel Yellow. Each species has different care and maintenance which affects cultivation costs and selling prices.

The main problem is that only some farmers can identify the cultivars which are grown. Like the middleman, most farmers only know the color of the peel and of the pulp. As a result, the price of each species of dragon fruit is determined according to the standard in only three groups. If farmers or middlemen can classify dragon fruit species, they know how to manage production of dragon fruit, take care the produce before and after harvesting, and manage the transportation according to the specific morphology of each species. This will affect the cost and selling price, and also promote the conservation of fruit species.

However, species identification based on morphology requires a great deal of knowledge and expertise. For the general public new farmers and middlemen can identify dragon fruit species accurately and easily, the researcher has researched only the laboratory dataset [8,9] which gave a high accuracy of 98%.

Therefore, this research will present the classification of Thai dragon fruit species from images in both indoor (laboratory) and outdoor datasets. The research conducted experiments with image processing techniques, content-based techniques, machine learning, and deep learning. In the future, hopefully, this will lead to the development of innovations for the classification of Thai dragon fruit species pre or post harvesting that can be easy to use, convenient, and suitable for people. This can be applied to industrial applications and robot harvesting. It may add value to the yield of Thai dragon fruit cultivation. This paper has presented Theories and Literature Reviews in Section II, The DIP-CBML Method in Section III, Experiment Results in Section IV, Discussion in Section V, Conclusions in Section VI and Suggestion in Section VII.

II. THEORIES AND LITERATURE REVIEWS

A. Color Model

Color Model is a color system that controls the display of digital images on a digital device. Each type of color model has its own way of generating colors that have different structures. Therefore, different types of color models are used for different purposes [10]. The most popular color models in image processing are the RGB, HSV, and Lab model.

The RGB is a color system formed by the combination of primary colors. There are Red, Green, and Blue which are channels of color digital images. Each channel has 0-255 color levels [11].

The HSV is a color model which is close to the color perception of human vision. It consists of Hue (H), Saturation (S), and Value (V). Hue is the color tone defined by the angle of the color wheel. In image processing by OpenCV, the H value ranged from 0° to 180°. The S is the saturation of the color tone. If S is 0, the white color is always displayed. The V is the brightness of the tone. If the brightness value is 0, the result will be black. In OpenCV processing, S and V values ranged from 0 to 255. If both values are set to 255, it will display a pure color tone [12, 13].

The Lab color model consists of three channels. There are the L channel, a channel, and b channel. L channel is the lightness value, an a channel is a green gradation to red, b channel is a blue gradation to yellow. In OpenCV, Lab values are scaled in the range from 0 to 255 for all three channels [11, 13].

B. Digital Image Processing

Digital image processing is a process that uses a digital image as input for a specified processing purpose, such as image resizing, converting a color image to grayscale, data augmentation, etc. A digital image can be represented by $F(x,y)$ where x and y are spatial coordinates. Each coordinate is called a pixel. There are three types of images: color images, grayscale images, and binary images [14].

C. Image Pre-processes

Image pre-processing is an important step in digital image processing because the raw data from the acquisition, which is interpolated with multifactorial noise, cannot be processed immediately. Therefore, images must be done with image pre-processes to reduce those noise. For example, image segmentation is a technique that helps extract and segment desired or unwanted image data. It helps to get more specific information and it is easier to analyze information. However, processed data must be ensured that the remaining information is correct. There is no excess or missing [15]. Techniques used in image segmentation are the segmentation by thresholding-based, edge-based, area-based, and energy-based [16-18]. There are also other techniques to prepare data such as intensity estimation, geometric estimation, elementary processing, holistic processing, etc. [15].

D. Feature Extraction

Feature extraction is the process of extracting important characteristics of an image to describe all information in the

image. The feature descriptor may be all or part of the image data that can represent the whole image. In general, attributes about color, shape, size, and texture are used in image analysis or image classification. Of course, image data may not have only one attribute that can identify specific characteristics. For Image classification by machine learning, the image features will be represented by a feature vector that is a 1-dimensional array [14, 15]. In contrast for deep learning, the feature extraction process is performed automatically. The researchers are responsible for specifying the desired feature map size, making it very convenient for researchers.

E. Image Classification Model

The Image Classification Model is a classifier that was created to identify or classify groups of image data. The classifiers use rule-based classifiers which are processed under a "condition" that is defined in the IF condition THEN conclusion form. Image classification model with a content-based feature in which researchers must extract features for suit methods such as support vector machine (SVM), k-nearest neighbor (KNN) and decision trees (DT), etc. [19-24].

The deep learning model is the popular automated method. The model gives high predictive performance [25] by mimicking the operation of human neurons by building a neural network with multiple nonlinear processing layers [14, 26]. Each layer takes the result of the previous layer as input. The strength of deep learning is that it supports the extraction of ambiguous features. The model extracts feature automatically. The researcher is responsible for preparing the data that will be used for learning only. It is very convenient for researchers.

F. Literature Reviews

This research focuses on reviewing literature related to fruit classification to study methods that can be used to classify Thai dragon fruit from images. Literature reviews are found that most researchers carried out research in four major steps: data acquisition, data pre-processes, feature extraction, and classification [15, 27]. Image datasets used include both image datasets created in the laboratory [22, 24, 28-31] and image datasets created at the outdoor environment [20, 23, 32-37]. Of course, image datasets from outdoor environments are more complex than those created in laboratories. Therefore, the steps to process this type are also more complicated.

Most researchers focused on image pre-processing like image segmentation techniques to prepare image data differently. Either the graph cut method [20], the conversion of a color image to a binary image by calculating the threshold value [8, 29], or using machine learning to segment the fruit from the background. This can be applied to the detection of fruit on the tree [23, 33, 34, 36, 37]. It reduces the complexity of the image and improves efficiency in feature extraction and classification. Muresan and Oltean [28] has proposed the use of threshold values in image segmentation with the HSV color model to separate the dragon fruit from the background of the plant. The objective is to detect and count the amount of dragon fruit on the tree by the image dataset of *Hylocereus Undatus* dragon fruit species in the outdoor environment. The accuracy is more than 80%.

Jana. et al. [20] has presented the recognition of fruits from the natural image in eight types. The image data was prepared by the graph cut method, which can separate the background from the fruit very well. After the image data preparation step, color and texture features were used for fruit recognition with the support vector machine (SVM) algorithm, giving an accuracy of 83.33%.

Muhammad [22] presented the use of color, texture, shape, and size attributes in classifying four date palm species by histogram of the local binary pattern (LBP) and Weber local descriptor (WLD) data. The Fisher discrimination ratio (FDR) was used to select the top 10 most important features that gave the greatest FDR. For shape and size features, the image data were analyzed from four features, namely Major axis length, Minor axis length, Ellipse eccentricity, and Area. In total, there are 14 features with a support vector machine (SVM) which gives an accuracy of up to 99%.

Fu. et al. [23] has presented the detection of bananas on the tree with machine learning. There is an image data pre-processing to reduce the complexity of the image by using Otsu's algorithm to find threshold values for converting HSV images to binary images. In the detection process, a histogram of oriented gradients (HOG) and local binary patterns (LBP) were used to extract the shape and texture features of the banana. The experiments found that the algorithm which combines HOG, LBP, and SVM gives maximum efficiency. It has an accuracy of 100% for the training set and 89.63% for the test set.

The DIPDEEP method [8] was the classification of Thai dragon fruit from a laboratory images dataset. DIPDEEP used image processing techniques to prepare images based on a threshold value to separate the background from the dragon fruit. Then, the images were used to classify the seven cultivars using rule-based classification techniques to classify dragon fruit groups by skin color and deep learning model based on a 13-layers of convolutional neural network that starts with an RGB image size of 100x100 pixels as an input layer and ends with six output nodes. Optimizer based on Adam algorithm and set Learning rate equal to 0.001, batch size and epoch equal to 100. The accuracy of red and yellow classification was 100%, the accuracy of DIPDEEP was 98.80%. For outdoor images, the results were not satisfactory.

The CBML model [9] was the classification of Thai red dragon fruit from a laboratory images dataset. CBML method used a content-based model that uses a total of 34 attributes, consisting of two attributes of texture features from dissimilarity (D) and asm properties only directions: 0° of GLCM algorithm with RGB image and 32 attributes of color features with RGB, HSV, and AB of Lab color model, for each channel in any color model using four statistical features: mean, standard deviation, skewness, and kurtosis. Each attribute used minmaxscaler to normalize into the 0 to 1 range and uses machine learning for giving optimization results with the support vector machine (SVM), setting kernel for polynomial in 8 degrees. It has an accuracy of 100% for the training set and 98.47% for the test set. The outdoor image was not processed.

Therefore, this paper focused on modeling the classification of Thai dragon fruit species from images that support two types of image datasets; laboratory and outdoor. The required model will support pre- and post-harvest processing. Hopefully, this research will be applied to industrial applications and agriculture technology.

III. THE DIP-CBML METHOD

This paper presents algorithms to classify species of Thai dragon fruits automatically that support two types of image datasets called DIP-CBML which stands for digital image processing with content-based and machine learning. The DIP-CBML will be able to process both types of images when DIP-CBML is able to classify the image types. It makes subsequent processing work correctly according to the characteristics of the two image types which are different processes. If the DIP-CBML can classify the group of dragon fruit from the peel color which is red or yellow, the processing time was reduced because the yellow group takes shorter time to process than the red group. Therefore, the DIP-CBML structure consists of image type identification, pre-processing, red and yellow classification, image background removal, and six classes of red classification as Fig. 1.

A. Datasets

The image datasets consisted of 9,754 laboratory images and 9,067 outdoor images from [8], each image containing one dragon fruit of one species. Both datasets were taken with a mobile phone camera. The 1:1 aspect ratio was set for laboratory recording. Unlike the outdoor images, the aspect ratio is set independently, i.e., 3:4 and 9:16, resulting in different image sizes with any lighting conditions.

In addition, the characteristics of the images are different, because the images in the laboratory are an image of the post-harvest dragon fruit placed in a photographic box and used black velvet fabric in the background as Fig. 2(a), but the outdoor images are the dragon fruit growing on the tree until it is ready to be harvested as Fig. 2(b). Obviously, the outdoor images have more complex backgrounds such as sky, ground, grass, and branches, while the laboratory images have a black background.

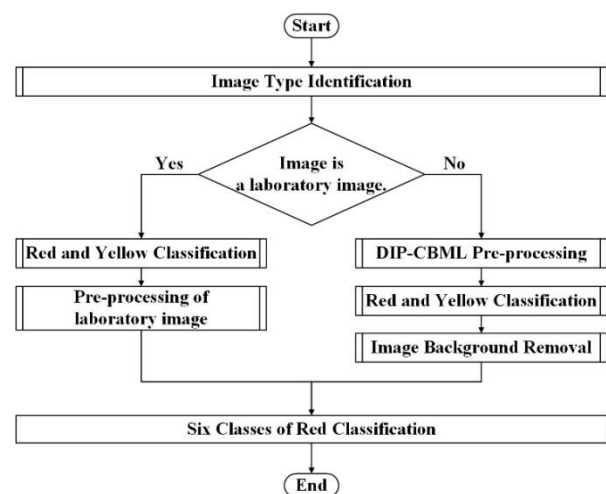


Fig. 1. The Steps of DIP-CBML method.

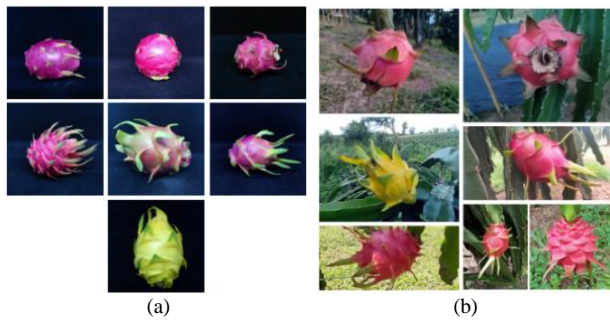


Fig. 2. Examples of two datasets as (a) laboratory images and (b) outdoor images.

B. Image Type Identification

This step is used to identify the type of images from either laboratory image or outdoor image because the image data pre-processing of the two types are different. The procedure is shown in algorithm 1.

Algorithm 1: Image Type Identification

```

Input: Original image with RGB color model.
Output: Type of image; laboratory or outdoor.
Resized Image = Resize the input image to not over 300 on each side.
R = R channel of Resized Image.
Gray = Gray scale of Resized Image.
Mean Threshold = (Sum of R value)/(image size)
MKR = The conversion result of R image to binary by Mean Threshold.
BG Pixel = The gray pixel at the same coordinate as a black pixel in
            the MKR.
If (BG Pixel != 0) then
    MP = Mean value of BG Pixel
    STD = Standard Deviation value of BG Pixel
    KS = Kurtosis value of BG pixel
    If (MP < 31.77) then
        | Output is a laboratory image type.
    else if (MP > 48.62) then
        | Output is an outdoor image type.
    else
        | If (STD < 15.27) then
        | | Output is a laboratory image type.
        | else if (STD > 20.52) then
        | | Output is an outdoor image type.
        | else
        | | If (KS >= 8.32 && KS <= 54.37) then
        | | | Output is a laboratory image type.
        | | else
        | | | Output is an outdoor image type.
        | | End
        | End
    End
End
else
    | Output is an outdoor image type.
End
    
```

From the characteristics of the laboratory images with a flat background, it is not as complex as the outdoor images. Therefore, the three statistical properties of the background pixels are used to identify the type of images. There are the mean, standard deviation, and kurtosis as shown in Fig. 3.

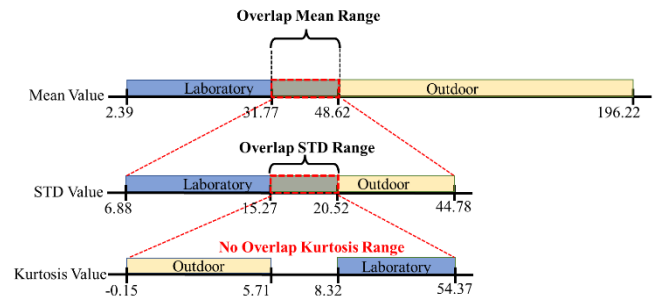


Fig. 3. The statistical properties of each type of image.

From the random 700 samples of each type of image, it was found that the laboratory images had an average of background pixels in a gray level ranging from 2.39-48.62 and outdoor images in ranging 31.77-196.22, because there is an overlap range. When considering the other statistics of the overlapping range, it was found that other statistics such as mode, median, standard deviation and skewness still overlap. Therefore, the statistics value that has the least overlap is the standard deviation. From the overlapping average range, it was found that the laboratory images had a standard deviation of background pixels in a gray level ranging from 6.88-20.52 and outdoor images from 15.27-44.78. Successively, at the overlapping standard deviation range, it was found that a kurtosis of background pixels in a gray level range is not overlapping. The laboratory images had a kurtosis of background pixels in a gray level ranging from -0.15-5.71 and outdoor images from 8.32-54.37.

Therefore, this step begins with the original image being reduced to a size of no more than 300x300 in proportion. Set the R image to represent the R channel of the RGB image and Gray to represent the grayscale image. The R image was used to create a segmentation mask, which is a binary image, using the mean threshold as the threshold value for the binary conversion as equation (1).

$$\text{Mean Threshold} = (\text{Sum of R value})/(\text{image size}) \quad (1)$$

If any pixel of the R image is greater than the mean threshold, this pixel will be set to white as the object, otherwise, this pixel will be set to a black background. The morphology function opening is used to decrease noises of the object, the Fill Hole from OpenCV is used to fill in any hole in the object, and the morphology function erosion is used to slightly decrease the edges of the image, respectively. The result is the MKR mask, a binary image with black pixels as the background (BG) as shown in Fig. 4 on the 2rd row.

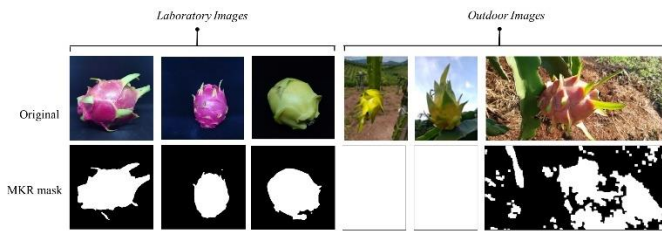


Fig. 4. Characteristics of Laboratory and Outdoor images after converting to binary mask by using the mean threshold.

For an image where background pixels are not found, it can be concluded that it is an outdoor image. On the other hand, calculate the mean, standard deviation and kurtosis of BG pixels which is a gray pixel at the same coordinate as a black pixel in the MKR and replace mean with MP, replace standard deviation with STD and replace kurtosis with KS.

As mentioned above, the mean of the background pixels of both images overlaps. Therefore, the type of image can be clearly identified. An image with an average less than 31.77 is a laboratory image. An image with an average greater than 48.62 is an outdoor image. If any image is within the overlapping average range of the background pixels which is from 31.77-48.62, consider a standard deviation of the background pixels instead. If a standard deviation of the background pixels less than 15.27, an image is a laboratory image. If a standard deviation of the background pixels greater than 20.52, an image is an outdoor image. As the same, any image is within the overlapping standard deviation range of the background pixels which is from 15.27-20.52, consider a kurtosis of the background pixels instead. If a kurtosis of the background pixels between 8.32 and 54.37, an image is a laboratory image. On the other hand, that image was an outdoor image.

C. DIP-CBML Pre-processing

As mentioned above, the image data pre-processing of the two types are different. The laboratory image can use the process of creating MKR mask as image pre-processing but not for an outdoor image. Therefore, the pre-processing of DIP-CBML was used to support an outdoor image especially. This process still aims to separate the background from the dragon fruit by creating a mask that can be used to divide into two parts. The steps as shown in algorithm 2 and Fig. 5, DIP-CBML uses the graph cut algorithm to create the segmentation mask. It is generally known that graph cut requires a position of interest object covered in a rectangle. Therefore, it needs to locate the dragon fruit before the graph cut algorithm was used to create the segmentation mask.

To locate the dragon fruit, the HSV color model was used to create a binary image that helps locate the fruit in the image by HSV ranging same as [8] which consists of the H range, S range, and V range in the OpenCV system. There are H ranging from 0-23 and 151-179 for a red and 23-37 for a yellow. For S and V ranging from 100-255. The result is a binary image that is created by any pixel in the HSV image within this range will be scaled as a white pixel represent for a fruit pixel. On the contrary, a black pixel is an out of range; represent for a background pixel. Then, bring the binary image

to the detect location of dragon fruit subprogram as shown in Fig. 5.

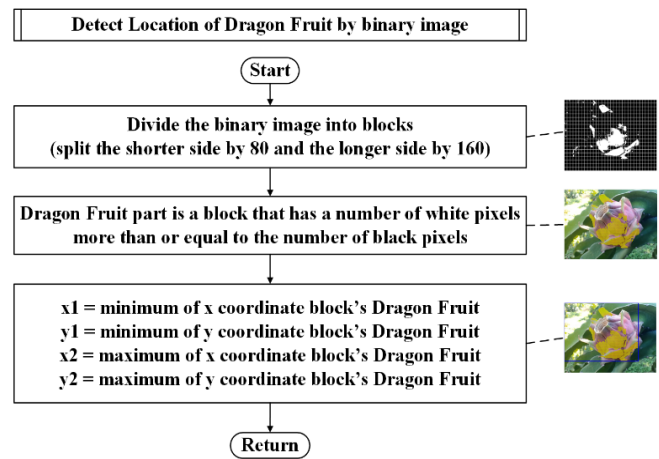


Fig. 5. Flowchart of detecting dragon fruit location.

In Fig. 5, the binary image is divided into grid blocks by that have no more than 160x80 blocks. The size of each block was calculated by dividing the shorter side by 80 and the longer side by 160. For example, the image size is 4,608x2,240 pixels, the longer side was divided, as $4,608/160 = 28.8$ approximated 29, and the shorter side was divided, as $2,240/80 = 28$. Therefore, each block size is equal to 29x28 pixels. Then, the binary image is segmented into many blocks with 29x28 pixels as the grid block size. From this block size, the number of blocks is equal to 158x80 blocks. The number of blocks is not over 160x80 blocks. Any block with the number of white pixels greater than or equal to the number of black pixels is defined as part of the dragon fruit. The position of all the blocks that are part of the dragon fruit is the location of the fruit. If all blocks are merged into one rectangle then let x1 equal the minimum value of the x-coordinate, y1 equal the minimum value of the y-coordinate, x2 equal the maximum value of the x-coordinate, and y2 equal the maximum value of the y-coordinate. The coordinate (x1,y1) is the northwest corner of the rectangle, and the coordinate (x2,y2) is the southeast corner of the rectangle. The coordinates (x1,y1,x2,y2) will be the boundary used to segment the image with the graph cut, which must not be equal to the border of the image. If the coordinates (x1,y1,x2,y2) is equal to the border of the image, the binary image was modified by the morphology function erosion with kernel size 5x5 and returned to the detect location of dragon fruit processes until the coordinates are not equal to the border of the image. Then, the coordinates (x1,y1,x2,y2) were set as the rectangle that will be used to create the mask by the graph cut algorithm that can separate the background from the dragon fruit.

To create the mask, DIP-CBML uses a graph cut algorithm with the coordinates which were modified to four directions, namely (x1,y1,x2,y2), (0,y1,x2,y2), (x1,0,x2,y2), and (0,0,x2,y2) because the background around the fruit was removed as shown in Fig. 6. The four results are RGB color images, converted them to a mask that is a binary image by setting the part of the dragon fruit to be a white pixel and the

background part to be black. Then we bring all four masks to the white pixels together with an intersection mask represented by the HSV1-Mask.

The HSV1-Mask can be used to separate the background from the dragon fruit where black pixels refer to the background and white pixels refer to dragon fruit. Any coordinate in RGB image that has the same coordinates as a background pixel are changed to 0. The result is RGB image with some or all of its background black, represented by the Image-HSV1. The illustration of DIP-CBML pre-processing as shown in Fig. 6 and the result of this step is shown in Fig. 7(b).

Algorithm 2: DIP-CBML pre-processing

```

Input: Original image with RGB color model.
Output: Image-HSV1, HSV1-Mask, and Coordinates (x1,y1,x2,y2).
hsv_img = Result of converting input image RGB to HSV color model.
binary_img = Result of converting hsv_image to binary by HSV ranges from [8]
(x1,y1,x2,y2) = Return values of Detecting Dragon Fruit Location by binary_img

While ((x1,y1,x2,y2) == Border of image) do
    Erosion binary_img with kernel 5x5
    (x1,y1,x2,y2) = Return values of Detecting Dragon Fruit Location by eroded binary_img
End

IMG1, IMG2, IMG3 and IMG4 = Return values of Grab Cut 4Directions by Coordinates (x1,y1,x2,y2).
M1, M2, M3 and M4 = Return values of Converting IMG1, IMG2, IMG3 and IMG4 to mask

HSV1-Mask = Result of Intersection all Masks (M1, M2, M3 and M4)
Image-HSV1 = Output of Removing Background by HSV1 Mask
    
```

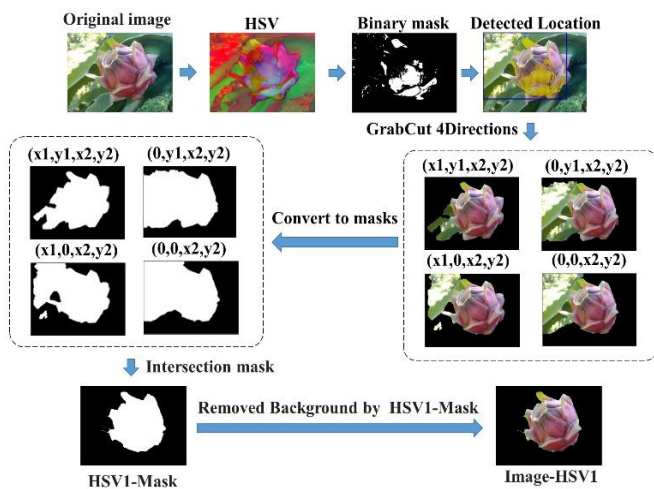


Fig. 6. Illustration of DIP-CBML pre-processing.

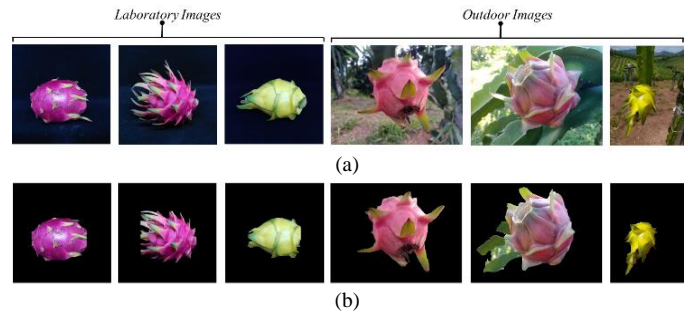


Fig. 7. Examples of output with DIP-CBML pre-processing (a) Original images (b) Image-HSV1.

D. Red and Yellow Classification

Red and yellow classification is the procedure to classify the dragon fruit group into two groups using the characteristics of its peel color, consisting of dragon fruit red peel, and yellow peel. This process has already been discussed in [8]. The laboratory images can use the original image for processing. The results of the laboratory images are highly satisfactory, but the results of outdoor images are not. Therefore, in this research, the Image-HSV1 was used as an input image to classify the dragon fruit groups based on peel color instead of the original image.

The process uses HSV color images to calculate the red ratio and yellow ratio by using the HSV range of red and yellow as the threshold value for counting the number of red pixels and the number of yellow pixels. There is an H value from 23-37 for yellow. The red is divided into two ranges: 0-23 and 151-179. The Saturation (S) and Value (V) values are set from 100-255. Then divide each value by the image size and multiply by 100 to calculate the percentage as Eq. (2) and (3). If any image has a yellow ratio greater than a red ratio, it is an image of yellow peel. The method can immediately be classifying the species of dragon fruit in the image because there is only one species of yellow peel in the dragon fruit.

$$Yellow\ ratio = YP / (image\ size) * 100 \quad (2)$$

$$Red\ ratio = RP / (image\ size) * 100 \quad (3)$$

where YP is the number of yellow pixels and RP is the number of red pixels.

This work has performed greatly for the results of outdoor images. For laboratory images, the results are still satisfactory. This step reduces the volume of the dataset because the remaining data are red peel groups and affects processing time. It is an advantage of adding this step into research operations.

E. Image Background Removal

Image background removal is a process in which only the background is removed from the image. From Fig. 7(b), the pre-process can remove the background of some images completely, especially the laboratory images. While some outdoor images still have backgrounds left. Therefore, DIP-CBML added this process to remove the remaining background, especially the outdoor image by following the steps in algorithm 3. The illustration of image background removal process is shown in Fig. 8.

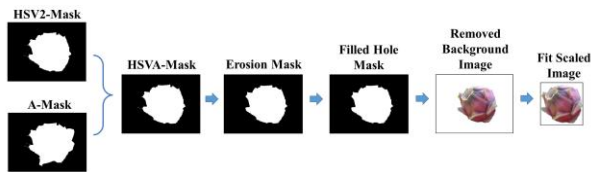


Fig. 8. Illustration of image background removal.

Algorithm 3: Image Background Removal

Input: Original image with RGB color model.

Output: Fit scaled image.

HSV2-Mask = Result of remaining background removal by HSV color model.

A-Mask = Result of background removal by Lab color model.

HSVA-Mask = Result of Intersection A-Mask and HSV2-Mask

Erosion Mask = Result of Erosion HSVA-Mask with kernel 5x5

Filled Hole Mask = Result of Fill Hole HSVA-Mask by OpenCV Library

Removed Background Image = Result of Removing Background in the input image by Filled Hole Mask

Fit Scaled image = Result of cropping proportion of fruit and fit scale its size not over 100 on each side

This process is designed with two background removals, first using an output of pre-process procedure as shown in algorithm 2; input to a subprogram of the remaining background removal by the HSV color model and the second using the original image input to subprogram of the background removal by lab color model. Both subprograms yield two masks named HSV2-Mask as Fig. 10(b) and named A-Mask as Fig. 10(c) respectively. After that take the two masks to the intersection represented by the HSVA-Mask as Fig. 10(d). Use the morphology function erosion to remove extraneous pixels in the HSVA-Mask with kernel size 5x5 and fill the hole with the OpenCV library. Then use the modified HSVA-Mask to remove the background from the image where black pixels refer to background pixels and white pixels refer to dragon fruit pixels. Any coordinate in the original RGB image with the same coordinate as the background pixel will be changed to 255. The result will be a dragon fruit image with a white background, as Fig. 10(e), and the final step is to fit scale the image of the dragon fruit proportion to 100x100 pixels, the result is Fig. 10(f).

1) *Subprogram of remaining background removal by HSV color model:* This subprogram is the remaining background removal process. The input data is the result of pre-processing as shown in algorithm 2 and Fig. 6. consisting of Image-HSV1, HSV1-Mask, and Coordinates (x1,y1,x2,y2). This data will be used as initial processing steps in the algorithm 4 which is processed similarly to pre-processing as mentioned in Section 3(C). The output of the pre-processing procedure was reprocessed again to remove any pixel that expected part of the background out of the image. The final output of this subprogram is a binary image named HSV2-Mask that can be used to split the background off.

As algorithm 4, starting from the processing of the check mask and image subprogram as shown in algorithm 5, the Image-HSV1 is recalculated for the yellow ratio and the HSV1-Mask is detected for the new coordinates, represented by coordinates (a1,b1,a2,b2) by the detect location of dragon fruit subprogram as Fig. 5 and take the coordinates (a1,b1,a2,b2) to remove the background from the image by 4 graph cut. The result is a binary image represented by the RM-Mask.

If the background has been completely removed, the yellow ratio of Image-HSV1 will be equal to 0 that means not a yellow pixel in the image already or the new coordinates (a1,b1,a2,b2) must be equal to the old coordinates (x1,y1,x2,y2) that means if continue to remove background again, the result is still the same, but if these conditions are not met, the RM-Mask will be used as a mask to remove the background from the original image again; where black pixels refer to background pixels and white pixels refer to dragon fruit pixels. Any coordinate in RGB image that has the same coordinates as a background pixel is changed to 0. The result is RGB image represented by Image-HSV2. The yellow ratio of Image-HSV2 is recomputed and increases the value of the NR variable by 1 to count the number of background removal attempts. This will not remove the background more than 3 times.

After that, if the yellow ratio of Image-HSV2 is equal to 0 or the coordinates (a1,b1,a2,b2) are equal to the original coordinates. (x1,y1,x2,y2) sets the HSV2-Mask value to be the same as the RM-Mask and terminates the subprogram immediately because the background is considered eliminated, but if the conditions are not met, it will continue to remove the background by using the RM-Mask as the initial data to remove the next background.

The process is restarted using the RM-Mask as the starting point, creating a new set of inputs: specifying new (x1,y1,x2,y2) coordinates with the detect location of dragon fruit subprogram, creating a new HSV1-Mask by 4 Graph Cut that used new (x1,y1,x2,y2) coordinates and reconstructing new Image-HSV1 with a new HSV1-Mask. After that, the new HSV1-Mask and new Image-HSV1 were processed with the check mask and image subprogram again to compute the yellow ratio, specify the coordinates (a1,b1,a2,b2), and finally create a new RM-Mask. This new RM-Mask will be used to reconstruct the Image- HSV2 and calculate the yellow ratio of the new Image-HSV2, with the NR variable increased by 1 as before. The image with the background removed will have a yellow ratio of 0 or coordinates (a1,b1,a2,b2) equal to coordinates (x1,y1,x2,y2). If this condition is met, the background removal will be stopped. Set the mask HSV2-Mask as same as RM-Mask. On the other hand, we will remove the background repeatedly, but not more than three times, because it may remove the background too much and cause the dragon fruit part to be removed as well. The results obtained from this step are shown in Fig. 10(b).

Algorithm 4: Remaining Background Removal by HSV Color Model

```

Input: Image-HSV1 , HSV1-Mask and (x1,y1,x2,y2).
Output: HSV2-Mask.
Yellow_Ratio, (a1,b1a2,b2) and RM-Mask = Return values of Check
Mask and Image by Image-HSV1 and HSV1-Mask.

NR = 0 /*stand for number of removing*/
If (Yellow_Ratio == 0) then
    | RM-Mask = HSV1-Mask
else
    | If ((a1,b1a2,b2)==(x1,y1,x2,y2)) then
        | | RM-Mask = HSV1-Mask
        | | Yellow_Ratio = 0
    | else
        | | Image-HSV2 = Remove Background by RM-Mask
        | | Yellow Ratio = Yellow Ratio of Image-HSV2
        | | NR++
    | End
End
While (Yellow_Ratio!=0 && (a1,b1a2,b2)!= (x1,y1,x2,y2)) do
    | If (NR<=3) then
        | | (x1,y1,x2,y2) = Detecting Dragon Fruit Location by RM-Mask
        | | While ((x1,y1,x2,y2) == Border of image) do
            | | | Erosion RM-Mask with kernel 5x5
            | | | (x1,y1,x2,y2) = Return values of Detecting Dragon Fruit
            | | | Location by eroded RM-Mask
        | | End
        | | HSV1-Mask = GrabCut 4Directions by (x1,y1,x2,y2)
        | | Image-HSV1 = Remove by HSV1-Mask
        | | RM-Mask = Return values of Check Mask and Image by
        | | Image-HSV1 and HSV1-Mask.
        | | Image-HSV2 = Remove background by RM-Mask
        | | Yellow_Ratio = Yellow Ratio of Image-HSV2
        | | NR++
    | else
        | | Yellow_Ratio = 0
    | End
End
HSV2-Mask =RM-Mask
    
```

Algorithm 5: Check Mask and Image Subprogram

```

Input: image and mask data.
Output: Yellow_Ratio of input image, Coordinates (a1,b1a2,b2) and
RM-Mask.
Yellow_Ratio = Yellow Ratio of input image.
(a1,b1,a2,b2) = Detect Location of Dragon Fruit by input mask.
RM-Mask = GrabCut 4Directions by (a1,b1,a2,b2)
    
```

2) *Subprogram of background removal by lab color model:* The subprogram of background removal by lab color model is a process that uses Lab color model's properties to remove background pixels as shown in the algorithm 6. The illustration of background removal by lab color model process

as shown in Fig. 9. First, the original image, which is RGB color model, is converted to a Lab color model. After that, a channel is split and converted to a binary image by Otsu' Threshold. Take the binary image into the process of the detect location of dragon fruit subprogram as shown in Fig. 5, which gives the coordinates (x1,y1,x2,y2) as the location of the dragon fruit.

As before, take the coordinates (x1,y1,x2,y2) as the rectangle that will be used to remove the background from the image by graph cut with four directions. If (x1,y1,x2,y2) is the same coordinate as the border of the image, Use the morphology function erosion with kernel size 5x5 to modify the binary image before reading the new position again until the coordinates (x1,y1,x2,y2) are not equal to the border of the image.

Take the results from graph cut with four directions and convert them to a mask. Make the dragon fruit part into white pixels. The background part is black. Bring all four masks to find the white pixels together by using the intersection area. The result is a binary image, represented by A-mask which can be used to remove the background from the image. The results obtained from this step are shown in Fig. 10(c).

Algorithm 6: Background Removal by Lab Color Model

```

Input: Original image with RGB color model.
Output: A-Mask.
lab_img = Result of converting input image RGB to Lab color model.
binary_img = Result of converting A channel of lab_img to binary
image by Otsu's Threshold
(x1,y1,x2,y2) = Return values of Detecting Dragon Fruit Location by
binary_img
While ((x1,y1,x2,y2) == Border of image) do
    | Erosion RM-Mask with kernel 5x5
    | (x1,y1,x2,y2) = Return values of Detecting Dragon Fruit
    | Location by eroded binary_img
End
IMG1, IMG2, IMG3 and IMG4 = Return values of Grab Cut
4Directions by Coordinates (x1,y1,x2,y2).
M1, M2, M3 and M4 = Return values of Converting IMG1, IMG2,
IMG3 and IMG4 to mask
A-Mask = Result of Intersection all Masks (M1, M2, M3 and M4)
    
```

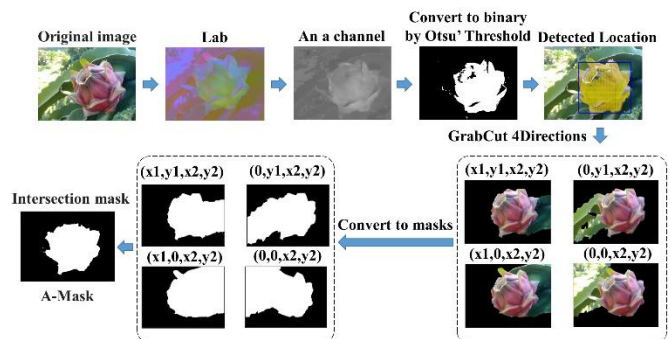


Fig. 9. Illustration of background removal by lab color model subprogram.

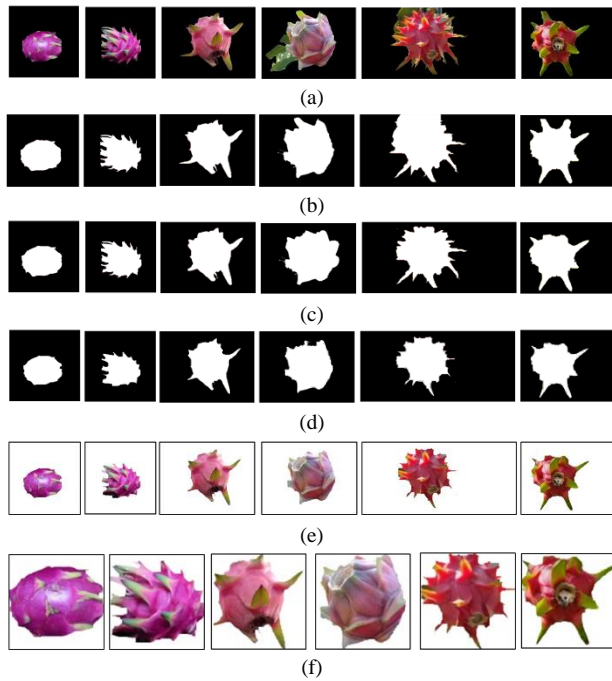


Fig. 10. Example Output of image background removal (a) HSV1-Image is an input image. (b) HSV2-Mask is an output from subprogram of remaining background removal by HSV color model. (c) A-Mask is an output from subprogram of background removal by Lab color model. (d) HSVA- Mask is an output from intersection A-Mask and HSV2-Mask process. (e) Output from remove background by HSVA-Mask process. and (f) Output from fit scale fruit to 100x100 process.

F. Six Classes of Red Classification

From the procedure in Fig. 1, this method classifies the dragon fruit into two groups from the peel color. Because there is only one species of yellow-skinned in the dataset. For red-skinned dragon fruit, the background in the image will be removed. Then, the dataset will leave only the image of six species of red peel. Therefore, at this stage, only the red-skinned dragon fruit species will be classified by using the content-based technique and deep learning.

Classification using the content-based technique in this research is divided into two parts: feature extraction and classification model. The feature extraction section consists of 24 color attributes, 3 texture attributes, and 2 attributes from edge and line feature. A total of 29 attributes are used as shown in Table I. In The classification model section used a machine learning method by support vector machine algorithm (SVM) with polynomial kernel (degree = 11).

The deep learning models such as DIPDEEP[8], VGG16[38], ResNet50[39], and MobileNetV2[40] were used to classify six species of red peel dragon fruit. All models start with an RGB image size of 100x100 pixels as an input layer and end with six output nodes. There is an optimizer using the Adam algorithm. The learning rate was set at 0.001. For the training process, the batch size and epochs were set at 100. The remaining parameters are not specified using all Keras default values.

For an experiment, DIP-CBML was compared with CBML[9] which is the model that uses content-based

techniques, and DIPDEEP[8], VGG16[38], ResNet50[39], and MobileNetV2[40] are the models that use deep learning techniques.

TABLE I. FEATURE EXTRACTION OF DIP-CBML METHOD

Extracted Features	Description	Feature Dimension
Colors	Statistical features (mean, standard deviation, skewness, kurtosis) extracted from color channel R,G,B of RGB color model H of HSV color model and a, b of Lab color model.	24
Texture	Properties features (dissimilarity, contrast and asm) extracted from GLCM of RGB only 0° direction.	3
Edge and Line	The ratio of edge pixels from Canny Edge algorithm and the number of lines from Hough Transform Standard algorithm	2

G. Feature Extraction of DIP-CBML

1) *Color feature*: Color features used in this research include statistical properties of the RGB, HSV, and Lab color models. All three models were split from three channels to one channel to get six image data: Red (R), Green (G), Blue (B), Hue (H), Red/Green Value (a), and Blue/Yellow Value (b). The pixel data of each image were calculated for the mean, standard deviation, skewness, and kurtosis as Eq. (4) to (7) [41]. The total of color features is 24 attributes.

$$Mean = \frac{1}{N} \sum_{k=0}^{N-1} P_k \quad (4)$$

$$Standard\ Deviation = \sqrt{\frac{1}{N} \sum_{k=0}^{N-1} (P_k - Mean)^2} \quad (5)$$

$$Skewness = \frac{\frac{1}{N} \sum_{k=0}^{N-1} (P_k - Mean)^3}{\left[\frac{1}{N} \sum_{k=0}^{N-1} (P_k - Mean)^2 \right]^{\frac{3}{2}}} \quad (6)$$

$$Kurtosis = \frac{\frac{1}{N} \sum_{k=0}^{N-1} (P_k - Mean)^4}{\left[\frac{1}{N} \sum_{k=0}^{N-1} (P_k - Mean)^2 \right]^2} - 3 \quad (7)$$

where P_k is the pixel value in order k of image pixel and N is the number of image pixels.

2) *Texture feature*: Texture features used in this research are the features from the gray-level co-occurrence matrix (GLCM) algorithm of RGB images. For feature extraction, importing RGB images into the GLCM algorithm with the skimage.feature library. Three features of GLCM have been extracted: dissimilarity (D), angular second moment (ASM), and contrast (Ct). Each feature uses horizontal direction information (0°). For a total of three features as Eq. (8) to (10) [42,43].

$$Dissimilarity = \sum_{i=0}^{n-1} \sum_{j=0}^{n-1} g(i,j) \cdot |i-j| \quad (8)$$

$$Angular\ Second\ Moment = \sum_{i=0}^{n-1} \sum_{j=0}^{n-1} (g(i,j))^2 \quad (9)$$

$$Contrast = \sum_{i=0}^{n-1} \sum_{j=0}^{n-1} (i-j)^2 \cdot g^2(i,j) \quad (10)$$

where n is the number of gray levels, $g(i,j)$ is the value of GLCM normalized where i and j are column and row numbers of GLCM normalized as a square matrix $n \times n$ in size. The values of i and j are between 0 and $n-1$.

3) *Edge and line features*: Edge and line features are representative of the density of the bracts surrounding the dragon fruit. If there are many bracts, the number of edges and lines will also be large. Each specie of dragon fruit has different a number of bracts. The edge of a fruit part and the direction of a line seem to be characteristics of dragon fruit. The edge and line may be a suitable feature for modeling the dragon fruit classification. Edge and line features are used in this research include the edge pixel ratio by processing with the canny edge algorithm[44,45] and the number of straight lines by processing the hough transform algorithm[46,47].

The canny edge algorithm [44,45] is a popular edge detection algorithm with multi-steps used to detect any pixel expected that is the edge of the object in the image. It consists of the noise removal with a 5x5 Gaussian filter, finding the intensity gradient of the image and direction, removing any unwanted pixels by a local maximum in its neighborhood in the direction of gradient and the last step is selecting whether the pixel expected is the edge or not by two threshold values, $minVal$ and $maxVal$. Any pixels with an intensity gradient more than $maxVal$ are sure to be edges and less than $minVal$ are sure to be non-edges. Any pixels with an intensity gradient between two thresholds are identified as edges or not by their connectivity. If they are connected to the sure-edge pixels, they are decided to be part of the edges. Otherwise, they will be rejected. It is very important to define two thresholds to get the correct result.

Therefore, to get an edge pixel ratio, this method uses the output image of the image background removal process which is the image that was scaled of the dragon fruit proportion to 100x100 pixels as shown in Fig. 10(f) and converted to a grayscale image. Then bring the grayscale image to frequency distribution by histogram. Set the data layer equal to 10. Use the lower boundary of the first layer and the last layer as lower threshold as $minVal$ and upper threshold as $maxVal$ respectively. The thresholds are processed to determine edge pixels using the canny edge algorithm through the $cv.Canny$ function of the OpenCV library[45]. The resulting image is a binary image with white pixels representing the edge pixels. So, the edge pixel ratio is equal to the number of white pixels divided by the image size and times 100, as shown in Eq. (11).

$$Ratio\ of\ Edge = (Edge\ pixels/image\ size)*100 \quad (11)$$

For the line features, the Hough transform algorithm[46,47] was used. Typically, it is a detection of the shape in the picture; that shape can be represented in a mathematical form such as lines, circles, ellipses, etc. It can detect the shape even if it is broken. This paper focuses on the straight line detection. The line equation in parametric form as shown in Eq. (12).

$$\gamma = x \cos\theta + y \sin\theta \quad (12)$$

where x,y is a pixel coordinate, γ (ρ) is the perpendicular distance from the origin to the line, and θ (θ) is the angle by

this perpendicular line and horizontal axis measured counter clockwise.

That means any pixels that are on the same line, have the same ρ and θ value. The first step of the algorithm is creating a 2D array as the accumulator, to collect the calculated values of each pair of ρ and θ for each pixel. The array initial with a zero value. Let rows equal to the ρ and columns equal to the θ . Any pixel was expected to be an edge of the object in the image, the ρ was computed by the pixel coordinate (x,y) and every possible θ . Then increment the values by 1 in the accumulator at the column and row that correspond to the ρ and θ value that is a result of computing. The number in each cell of the accumulator means the number of pixels that can be on the same line. In the last, this algorithm required minimum voting as a threshold to decide the group of pixels that can be the line. It may be the minimum length of the line that should be detected.

Therefore, to get the number of straight lines, this method takes the results of the canny edge algorithm to be processed, using the function $cv.HoughLines$ of the OpenCV library[47], setting ρ which is the distance resolution of the accumulator in pixels to 1, and θ which is the angle resolution of the accumulator in radians to $\pi/180$. An accumulator value was distributed to the histogram frequency, set the data layer equal to 11, take the data from layers two to six which are normal curve area, calculate the mean that rounded up to make an integer, and set it as the threshold as a minimum length of the line that should be detected. Finally, get the number of straight lines from the result of the $cv.HoughLines$ function. From the hypothesis, any dragon fruit with more bracts around the fruit will also have more straight lines.

4) *MinMaxScaler*: Because the result of the feature extraction mentioned above gives results in numbers with different scales. Therefore, this method adjusts the scale to the same scaling by $MinMaxScaler$ which will have a scale between 0 to 1 by using the formula as in Eq. (13).

$$MinMaxScaler\ Transform = (x - min) / (max - min) \quad (13)$$

where x is the data, min is the lowest value in the column, and max is the maximum value of the data in the column.

IV. EXPERIMENTAL RESULTS

The image dataset consists of 9,754 laboratory images and 9,067 outdoor images. Each dataset includes seven species of Thai Dragon Fruit. The laboratory images were divided into Jumbo White 1,172 images, Vietnamese White 1,190 images, Pink 1,309 images, Siam Red 1,869 images, Taiwan Red 1,184 images, Ruby Red 1,110 images, and Israel Yellow 1,920 images. The outdoor images were divided into Jumbo White 1,241 images, Vietnamese White 2,478 images, Pink 1,013 images, Siam Red 950 images, Taiwan Red 1,021 images, Ruby Red 871 images, and Israel Yellow 1,493 images.

The experiment was divided into three experiments. The first experiment is the image type identification. The second experiment is the red and yellow classification. The final experiment is the classification of six classes from the red peel group.

A. Experiment 1

The first experiment is the image type identification which is laboratory image or outdoor image. Before doing the experiment, images of two types were randomly selected 700 images per type (100 images per species) to study an average of background pixels in a gray level range. Test the range with all data. The experiment results are shown in Table II.

TABLE II. RESULTS OF IMAGE TYPE IDENTIFICATION

Types	Number of Samples	Accuracy (%)	Number of Samples	Accuracy(%)
Laboratory Image	700	100.00	9,754	100.00
Outdoor Image	700	100.00	9,067	100.00
Laboratory Image and Outdoor Image	1,400	100.00	18,821	100.00

B. Experiment 2

The Second experiment is the classification of the dragon fruit group from the peel color which is red or yellow. All images were divided into three methods. There are non-pre-processing, graph cut with [23] localization and pre-processing of DIP-CBML. The experiment results are shown in Table III.

TABLE III. CLASSIFICATION RESULTS BETWEEN RED AND YELLOW WITH THREE DIFFERENT METHODS

Types	Number of Samples	Accuracy(%)		
		Non-pre-processing	[23]+Graph Cut	Pre-processing of DIP-CBML
Laboratory Image	9,754	100.00	100.00	100.00
Outdoor Image	9,067	97.06	99.96	100.00
Laboratory Image and Outdoor Image	18,821	98.53	99.98	100.00

C. Experiment 3

The Third experiment is the classification of six classes from the red peel group by content-based and deep-learning models. The datasets used for this experiment are the results of the image background removal procedure, which is a dragon fruit image with a white background as Fig. 10(f). Before doing the experiment, the images were randomly selected at 1,000 per class. Any class with less number than 1,000 will be added to the image data by the augmentation technique. Here, this method uses only the horizontal flip image method because the required amount is only small. After that, create the dataset into four forms. The first form is only the 6,000 laboratory images in the dataset which were pre-processed by the creating MKR mask method, namely the Laboratory dataset. The second form is only the 6,000 outdoor images in the dataset which were pre-processed by the DIP-CBML method, namely the Outdoor dataset. The third form combined 12,000 images between the first form and the second form, namely the Mixdata1 dataset. The last form is combined images both the 6,000 laboratory images and the 6,000 outdoor images which are pre-processed by the DIP-CBML method, namely the Mixdata2 dataset. Each dataset was divided into 80%, 10%, and 10% for the training set, the validate set, and the test set, respectively. Using the 10-folds validation technique the DIP-

CBML was compared with CBML[9], DIPDEEP[8], VGG16[38], ResNet50[39], and MobileNetV2[40]. The experiment results are shown in Table IV.

V. DISCUSSION

This research presents the classification of Thai dragon fruit species from images that support two types of image datasets; laboratory and outdoor called DIP-CBML. The first experiment results showed that DIP-CBML can identify image types correctly with accuracy 100.00%. Therefore, the proposed method can support two types of images.

After identifying image types, the next process is the classification of the dragon fruit groups; red peel color and yellow peel color. The experiment results showed that the pre-processing of DIP-CBML was able to increase efficiency in classifying dragon fruit groups from peel color by 100% when compared to classifying by the original image. For graph cut with [23] localization, it was found that the dragon fruit group could be classified by the color of the peel with an accuracy of 99.98%. Therefore, the pre-processing of the DIP-CBML gives better results. The volume of the dataset was reduced because the process can stop when a yellow peel specie was founded, the remaining data are red peel groups which affect processing time.

Finally, dragon fruit images were changed the background to white and fit proportion of fruit size not over 100 on each side which were used to perform datasets for the classification of six classes from the red peel group. The experiment results showed that the DIP-CBML can get 100% accuracy for training set, but the other models do not. The DIP-CBML can classify six species of red peel group with 97.85%, 94.00%, 95.53% and 95.05% accuracy for Laboratory dataset, Outdoor dataset, Mixdata1 dataset and Mixdata2 dataset respectively. The confusion matrix of best accuracy which is Mixdata1 dataset can be shown in Fig. 11. and an example of the misclassified images is shown in Fig. 12.

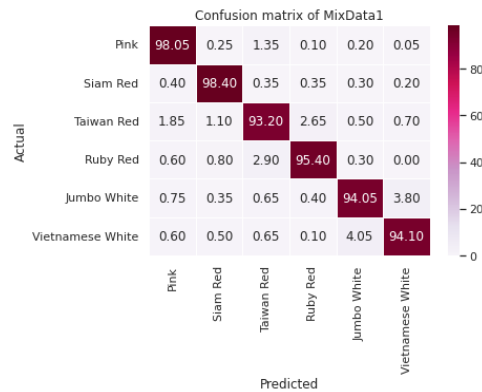


Fig. 11. Confusion matrix of DIP-CBML classification method with Mixdata1 dataset.



Fig. 12. Examples of the misclassified images.

TABLE IV. COMPARISON FOR ACCURACY OF DIFFERENT CLASSIFICATION METHODS AND DIFFERENT DATASETS FOR 6 SPECIES OF RED PEEL RESULTS BY 10-FOLD VALIDATION

Method	Mean (SD.)											
	Laboratory			Outdoor			Mixdata1			Mixdata2		
	Train	Valid	Test	Train	Valid	Test	Train	Valid	Test	Train	Valid	Test
CBML[9]	100.00 (0.00)	98.28 (0.42)	98.47 (0.62)	99.83 (0.03)	95.17 (1.09)	94.82 (1.24)	99.90 (0.01)	96.54 (0.45)	96.38 (0.68)	99.91 (0.01)	95.98 (0.91)	95.88 (0.56)
DIPDEEP[8]	100.00 (0.00)	98.45 (0.62)	98.80 (0.48)	99.80 (0.05)	94.42 (0.72)	94.18 (1.25)	99.68 (0.31)	95.02 (0.95)	94.96 (1.08)	99.66 (0.39)	94.18 (1.40)	94.34 (0.93)
VGG16[38]	100.00 (0.00)	98.80 (0.32)	98.70 (0.41)	99.81 (0.14)	93.55 (1.46)	93.33 (1.70)	99.78 (0.32)	95.32 (0.81)	95.35 (0.94)	99.69 (0.57)	94.16 (1.40)	94.47 (1.23)
ResNet50[39]	99.73 (0.85)	99.13 (1.64)	99.13 (1.65)	93.27 (18.60)	89.18 (18.15)	89.70 (18.00)	98.37 (3.20)	95.58 (3.55)	95.98 (3.74)	95.26 (9.80)	92.44 (9.97)	92.42 (10.58)
MobileNetV2[40]	86.56 (11.86)	85.43 (12.36)	86.05 (11.85)	73.56 (16.65)	71.35 (16.75)	71.27 (15.63)	90.95 (5.30)	88.53 (5.51)	88.98 (5.58)	70.44 (22.63)	68.88 (21.86)	68.63 (21.94)
DIP-CBML	100.00 (0.00)	97.58 (0.79)	97.85 (0.92)	100.00 (0.00)	94.27 (0.67)	94.00 (0.97)	100.00 (0.00)	95.32 (0.56)	95.53 (0.50)	100.00 (0.00)	95.00 (0.72)	95.05 (0.72)

VI. CONCLUSION

For this paper, the characteristics of laboratory and outdoor images were used to create the classification of Thai dragon fruit species from images that support two image datasets. The DIP-CBML method is used in the completed work. The channel R of RGB color model and gray image were used to identify the type of images between laboratory and outdoor images. The DIP-CBML can identify image type correctly with an accuracy of 100.00% with all datasets. The HSV color model and graph cut algorithm were used to pre-process the images which are able to increase efficiency in classification of dragon fruit groups by peel color with 100% accuracy for outdoor images. As a significant result, the method can classify image group of the laboratory type correctly with 100% accuracy same as other methods. Especially, non-pre-processed gives the same result. Therefore, if the laboratory type was detected, the method can use the original image of laboratory image to classify image groups. The HSV color model, channel of Lab color model and graph cut algorithm were used to remove the background of image which changed the background into white and fit scale on dragon fruit part to 100x100 pixels. The DIP-CBML used these images to classify the six species of Thai red dragon fruit by 29 features from color, texture, edge and line feature. The method gives 95.53% accuracy for both image types with a different pre-processed method. Finally, the entire research process was completed with all components. The precision of each step influences the others. The DIP-CBML may be developed again to increase the accuracy of the last step. The DIP-CBML was designed for the classification, especially Thai dragon fruit species. For other fruits, the DIP-CBML may work or not. This is a challenge for future research. Hopefully, the proposed model will be a guideline for developers to develop tools that can classify species of Thai dragon fruit from images that support pre- and post- harvesting image datasets. This research will add value to the yield of Thai dragon fruit cultivation and can be applied to industrial applications harvesting with robots.

VII. SUGGESTION

After a laboratory image was detected, the DIPDEEP[8] method may be used in the final step because it gives an accuracy of 98.80%. After an outdoor image was detected, the purpose method was used with an accuracy of 95.53%. The

combination of several methods in one application is a good approach that works.

REFERENCES

- [1] R. Goenaga, A. Marrero, and D. Perez, "Yield and Fruit Quality Traits of Dragon Fruit Cultivars Grown in Puerto Rico," Horttechnology. United States, vol. 30, no. 6, pp. 803-808, October 2020. <https://doi.org/10.21273/horttech04699-20>.
- [2] T. Perween, K. Mandal, and M. Hasan, "Dragon fruit: An exotic super future fruit of India," J. Pharmacogn Phytochem. India, vol. 7, no. 2, pp. 1022-1026, February 2018.
- [3] A. Trivellini, M. Lucchesini, A. Ferrante, D. Massa, M. Orlando, L. Incrocci, and A. Mensuali-Sodi, "Pitaya, an Attractive Alternative Crop for Mediterranean Region," Agronomy. Switzerland, vol. 10, no. 8, 1065, July 2020. <https://doi.org/10.3390/agronomy10081065>.
- [4] S. Wichienchot, M. Jatupornpipat, and R.A. Rastall, "Oligosaccharides of pitaya (dragon fruit) flesh and their prebiotic properties," Food Chem. United Kingdom, vol. 120, no. 3, pp. 850-857, November 2009. <https://doi.org/10.1016/j.foodchem.2009.11.026>.
- [5] S. Kosiyachinda, "Dragon Fruit," in Thai Youth Encyclopedia, vol. 38, THAI JUNIOR ENCYCLOPEDIA FOUNDATION by His Majesty King Bhumibol Adulyadej The Great. Bangkok: Thailand, 2013, pp. 106-139.
- [6] National Bureau of Agricultural Commodity and Food Standards, Ministry of Agriculture and Cooperatives. Thai agricultural standard: Dragon fruit. Available online: <https://www.acfs.go.th/standard/download/eng/DRAGON-FRUIT-ENG.pdf> (accessed on 9 March 2023).
- [7] Department of Agricultural Extension, Ministry of Agriculture and Cooperatives. Agricultural production information service system. Available online: <https://production.doae.go.th/service/site/login> (accessed on 9 March 2023).
- [8] N. Yusamran, and N. Hirasakolwong, "DIPDEEP: Classification for Thai dragon fruit," Eng. Appl. Sci. Res. Thailand, vol. 49, no. 4 pp. 521–530, Mar 2022.
- [9] N. Yusamran, and N. Hirasakolwong, "CBML: Classification Thai Red Dragon Fruit," ICIC Express Letters, Part B (ICIC-ELB). Japan, vol. 13, no. 11 pp. 1165-1175, November 2022. <https://doi.org/10.24507/icicelb.13.11.1165>.
- [10] S. Przybyłek, and C. Cena, "What is a Color Model? - Uses & Definition. Available online: <https://study.com/academy/lesson/what-is-a-color-model-uses-definition.html> (accessed on 9 March 2023).
- [11] R. Parekh, Fundamentals of image, audio, and video processing using Matlab®: with applications to pattern recognition, 1st ed. Boca Raton, FL: CRC Press (Taylor and Francis group), 2021.
- [12] W. Burger, and M. J. Burge, Principles of Digital Image Processing Fundamental Techniques. NY: Springer Undergraduate Topics in Computer Science – UtiCS, 2009.

- [13] Opencv Python Tutorials. Changing Colorspaces. Available online: https://opencv24-python-tutorials.readthedocs.io/en/latest/py_tutorials/py_imgproc/py_colorspaces/py_colorspaces.html (accessed on 9 March 2023).
- [14] M. Elgendy, *Deep Learning for Vision Systems*, 1st ed. Shelter Island, NY: Manning, 2020.
- [15] K. Hameed, D. Chai, and R. Alexander, "A comprehensive review of fruit and vegetable classification techniques," *Image Vis Comput. United Kingdom*, vol. 80, pp. 24-44, December 2018. <https://doi.org/10.1016/j.imavis.2018.09.016>.
- [16] S. Srisuk, *Advanced Image Processing*. Bangkok, TH: Mahanakorn University of Technology, 2013.
- [17] S. K. Abdulateef, and M. D. Salman, "A Comprehensive Review of Image Segmentation Techniques," *Iraqi Journal for Electrical and Electronic Engineering. Iraq*, vol. 17, no. 2, pp. 166-175, December 2021. <https://doi.org/10.37917/ijeee.17.2.18>.
- [18] O. Marques, *Practical image and video processing using MATLAB*. Hoboken, NJ: Wiley-IEEE Press, 2011.
- [19] N. T. Bani, and S. Fekri-Ershad, "Content-based image retrieval based on combination of texture and colour information extracted in spatial and frequency domains," *The Electron. Libr. United Kingdom*, vol. 37, no. 4, pp. 650-666, August 2019. <https://doi.org/10.1108/EL-03-2019-0067>.
- [20] S. Jana, S. Basak, and R. Parekh, "Automatic fruit recognition from natural images using color and texture features," In *Proc. the 2nd International Conference on 2017 Devices for Integrated Circuit, DevIC 2017*, pp. 620-624, March 2017. <https://doi.org/10.1109/DEVIC.2017.8074025>.
- [21] S. Arivazhagan, R. N. Shebiah, S. S. Nidhyandhan, and L. Ganesan, "Fruit Recognition using Color and Texture Features," *J. emerg. trends comput. inf. sci.*, vol. 1, no. 2, pp. 90-94, October 2010.
- [22] G. Muhammad, "Automatic date fruit classification by using local texture descriptors and shape-size features," In *Proc. the UKSim-AMSS 8th European Modelling Symposium on Computer Modelling and Simulation, EMS 2014*, pp. 174-179, October 2014. <https://doi.org/10.1109/ems.2014.63>.
- [23] L. Fu, J. Duan, X. Zou, G. Lin, S. Song, B. Ji, and Z. Yang, "Banana detection based on color and texture features in the natural environment," *Comput. Electron. Agric. Netherlands*, vol. 167, 105057, December 2019. <https://doi.org/10.1016/j.compag.2019.105057>.
- [24] J. F. Reyes, E. Contreras, C. Correa, and P. Melin, "Image analysis of real-time classification of cherry fruit from colour features," *J. Agric. Eng. Italy*, vol. 52, no. 4, pp. 1-6, December 2021. <https://doi.org/10.4081/jae.2021.1160>.
- [25] W. Samek, G. Montavon, S. Lapuschkin, C. J. Anders, and K. R. Müller, "Explaining Deep Neural Networks and Beyond: A Review of Methods and Applications," *Proc. IEEE*, vol. 109, no. 3, pp. 247 - 278, March 2021. <https://doi.org/10.1109/JPROC.2021.3060483>.
- [26] J. Schmidhuber, "Deep Learning in Neural Networks: An Overview," *Neural Networks. United Kingdom*, vol. 61, pp. 85-117, January 2015. <https://doi.org/10.1016/j.neunet.2014.09.003>.
- [27] S. L. Raja, N. Ambika, V. Divya, and T. Kowsalya, "Fruit Classification System Using Computer Vision: A Review," *Int. j. trend res. dev. India*, vol. 5, no. 1, pp. 22-26, February 2018. <https://doi.org/10.31219/osf.io/kt75d>.
- [28] H. Muresan, and M. Oltean, "Fruit recognition from images using deep learning," *Acta Univ. Sapientiae, Inform. Romania*, vol. 10, no. 1, pp. 26-42, August 2018. <https://doi.org/10.2478/ausi-2018-0002>.
- [29] R. E. Masithoh, H. Tampani, and L. Sutiarsro, "Detection of White Dragon Fruits (*Hylocereus Undatus*) in Outdoor Environment Using Image Processing Technique," *Aust. J. Basic & Appl. Sci. Jordan*, vol. 7, no. 9, pp. 254-260, July 2013.
- [30] M. Momeny, A. Jahanbakshi, K. Jafarnejad, and Y. D. Zhang, "Accurate classification of cherry fruit using deep CNN based on hybrid pooling approach," *Postharvest Biol. Technol. Netherlands*, vol. 166, 111204, August 2020. <https://doi.org/10.1016/j.postharvbio.2020.111204>.
- [31] Y. Osako, H. Yamane, S. Y. Lin, P. A. Chen, R. Tao, "Cultivar discrimination of litchi fruit images using deep learning," *Sci. Hortic. Technol. Netherlands*, vol. 269, 109360, July 2020. <https://doi.org/10.1016/j.scienta.2020.109360>.
- [32] H. Cecotti, A. Rivera, M. Farhadloo, and M. A. Pedroza, "Grape detection with convolutional neural networks," *Expert Syst. Appl. United Kingdom*, vol. 159, 113588, November 2020. <https://doi.org/10.1016/j.eswa.2020.113588>.
- [33] J. Liu, Z. Zhao, W. Jia, and Z. Ji, "DLNet: Accurate segmentation of green fruit in obscured environments," *J. King Saud Univ. - Comput. Inf. Sci. Saudi Arabia*, vol. 34, no. 9, pp. 7259-7270, October 2022. <https://doi.org/10.1016/j.jksuci.2021.09.023>.
- [34] Y. Wang, J. Lv, L. Xu, Y. Gu, L. Zou, Z. Ma, "A segmentation method for waxberry image under orchard environment," *Sci. Hortic. Netherlands*, vol. 266, 109309, May 2020. <https://doi.org/10.1016/j.scienta.2020.109309>.
- [35] H. S. Gill, O. I. Khalaf, Y. Alotaibi, S. Alghamdi, and F. Alassery, "Fruit Image Classification Using Deep Learning," *Comput. Mater. Contin. United States*, vol. 71, no. 1, pp. 5135-5150, January 2022. <https://doi.org/10.32604/cmc.2022.022809>.
- [36] R. Kirk, G. Cielniak, and M. Mangan, "L*a*b*Fruits: A Rapid and Robust Outdoor Fruit Detection System Combining Bio-Inspired Features with One-Stage Deep Learning Networks," *Sensors. Switzerland*, vol. 20, no. 1, 275, January 2020. <https://doi.org/10.3390/s20010275>.
- [37] Q. Sun, X. Chai, Z. Zeng, G. Zhou, and T. Sun, "Noise-tolerant RGB-D feature fusion network for outdoor fruit detection," *Comput. Electron. Agric. Netherlands*, vol. 198, 107034, July 2022. <https://doi.org/10.1016/j.compag.2022.107034>.
- [38] K. Simonyan, and A. Zisserman, "Very deep convolutional networks for large-scale image recognition," In *Proc. the 3rd International Conference on Learning Representations ICLR 2015*, pp. 398-406, May 2015.
- [39] K. He, X. Zhang, S. Ren, and J. Sun, "Deep residual learning for image recognition," In *Proc. IEEE Conference on Computer Vision and Pattern Recognition (CVPR) 2016*, pp. 770-778, June 2016.
- [40] M. Sandler, A. Howard, M. Zhu, A. Zhmoginov, and L. C. Chen, "MobileNetV2: inverted residuals and linear bottlenecks," In *Proc. IEEE Conference on Computer Vision and Pattern Recognition (CVPR) 2018*, pp. 4510-4520, June 2018.
- [41] P. Inkeaw, *Documents for teaching the course process 204123 Introduction to data science (Introduction to Data Science)*. Chiang Mai, TH: Document Printing Unit Education Services and Student Quality Development Faculty of Science Chiang Mai University, 2021.
- [42] R. M. Haralick, K. Shanmugam, and I. Dinstein, "Textural Features for Image Classification," *IEEE Trans. Syst. Man Cybern. United States*, vol. SMC-3, no. 6, pp. 610-621, November 1973. <https://doi.org/10.1109/TSMC.1973.4309314>.
- [43] Y. Park, and J. M. Guldmann, "Measuring continuous landscape patterns with Gray-Level Co-Occurrence Matrix (GLCM) indices: An alternative to patch metrics?," *Ecol. Indic. Netherlands*, vol. 109, 105802, February 2020. <https://doi.org/10.1016/j.ecolind.2019.105802>.
- [44] J. Canny, "A Computational Approach to Edge Detection," *IEEE Trans. Pattern Anal. Mach. Intell. United States*, vol. PAMI-8, no. 6, pp. 679-698, November 1986. <https://doi.org/10.1109/TPAMI.1986.4767851>.
- [45] Opencv Python Tutorials, Canny Edge Detection. Available online: https://opencv24-python-tutorials.readthedocs.io/en/latest/py_tutorial_s/py_imgproc/py_canny/py_canny.html (accessed on 9 March 2023).
- [46] P. Mukhopadhyay, and B. B. Chaudhuri, "A survey of Hough Transform," *Pattern Recognit. United Kingdom*, vol. 48, no. 3, pp. 993-1010, March 2015. <https://doi.org/10.1016/j.patcog.2014.08.027>.
- [47] Opencv Python Tutorials, Hough Line Transform. Available online: https://opencv24-python-tutorials.readthedocs.io/en/latest/py_tutorial_s/py_imgproc/py_houghlines/py_houghlines.html (accessed on 9 March 2023).

Math-VR: Mathematics Serious Game for Madrasah Students using Combination of Virtual Reality and Ambient Intelligence

Hani Nurhayati, Yunifa Miftachul Arif

Department of Informatics Engineering, Universitas Islam Negeri Maulana Malik Ibrahim, Malang, Indonesia

Abstract—The challenge to increasing understanding of mathematics lessons for students in madrasah schools makes the learning process require the support of adaptive alternative learning media. In this study, we propose a serious game-based learning media supported by virtual reality and ambient intelligence technology to equip students with adaptive responses to subject matter scenarios. Ambient intelligence works based on recommendations generated by the Multi-Criteria Recommender System (MCRS). In calculating a similarity between users and reference data, MCRS uses cosine-based similarity calculations, and average similarity is used for ranking. We developed this learning media experiment called Math-VR using the Unity game engine. The experimental test results show that MCRS-based ambient intelligence technology can provide an adaptive response to the choice of geometry subject matter recommendations for students according to their pre-test results. The analysis results show that the recommendation system as part of ambient intelligence has the highest accuracy rate of 0.92 when using 80 reference data.

Keywords—Mathematics; serious game; virtual reality; ambient intelligence; MCRS

I. INTRODUCTION

In Indonesian national education, madrasah is one of the education providers with Islamic overtones. Madrasah play an essential role in educating the nation's children through educational institutions with a combination of general subject matter and Islamic education [1]. Based on its level, madrasah consist of Madrasah Ibtidaiyah, which is equivalent to Elementary Schools; Madrasah Tsanawiyah, which is equivalent to Junior High Schools; and Madrasah Aliyah, which is equivalent to Senior High Schools. Of all these levels, the madrasah has its challenges and obstacles in the learning process for students, especially in mathematics. One indicator of problems in the learning process in madrasah is low student achievement. The leading indicator can be seen from the average National Examination scores for mathematics in madrasah students, which are lower than students from public schools [2] [3]. This problem could be born because more facilities, media, and learning methods still need to be used where it indirectly affects students' understanding of each learning material.

The madrasah curriculum combines general science and Islamic religious knowledge [4] [5]. The breadth of knowledge you want to transfer to students is a different obstacle for students to understand every material the teacher

presents. In addition, the level of intelligence and different backgrounds of students makes the level of understanding of students vary. Therefore, to increase madrasah students' understanding of mathematics subject matter, it is necessary to develop learning media that can provide knowledge through interactive visualization and simulation to students. The aim is to make it easier for students to understand compared to when using other conventional learning media such as books or student worksheets. Besides that, it is also necessary to develop learning media that can choose subject matter according to student's level of understanding. Learning media adaptively can provide material according to student's needs as a solution to variations in students' understanding that are different even in the same class.

To answer some of the problems regarding the need for instructional media for madrasah students, in this study, we propose using ambient intelligence-based serious games as an alternative to new interactive, adaptive, fun, and easy-to-understand learning media. Games with interesting interactive and visualization capabilities are needed in learning activities [6]. Serious games are currently being developed as alternative learning media that can provide knowledge to players through the educational, visualization, simulation, exploration, and training functions contained therein [7][8]. Using serious games in education allows players to understand knowledge content in more detail with interactive visualization images via mobile (smartphone) [9]. Furthermore, the addition of ambient intelligence technology in serious games is expected to increase the ability of the system to predict and provide recommendations for learning material choices effectively. That still needs to be better understood by students as game players based on their obtained scores, where scores are an essential part of computer games [10]. Subject matter wrapped in fun interactive games is expected to increase students' interest in and understanding of the subject matter [11].

Ambient intelligence is a technology that makes the virtual environment in the system sensitive, flexible, and adaptive to the presence of users [12]. In this study, we used a Virtual Reality (VR) framework to handle interactive visualizations for students. VR is a type of learning media that is gaining popularity in various fields of science, such as biology [13], tourism [14], digital engineering [15], english [16], and engineering controller [17]. VR-based learning media provides an exciting visualization through the virtual environment provided for players. Furthermore, we also

introduce the use of recommender system-based ambient intelligence to predict the level of student understanding so that the system can adaptively choose visualization of mathematics subject matter suitable for madrasah students. The combination of VR technology and ambient intelligence is our effort to increase learning enjoyment, understanding of mathematical content, and students' engagement with the proposed serious game, which we call Math-VR.

II. RELATED WORK

The implementation of serious games as learning media is an exciting field of research and presents a challenge. One of them is that conducted by Hamari et al., who shows that involvement in serious games has an apparent positive effect on the game's challenge and has a positive effect on learning both directly and through increased involvement. Becoming skilled at games does not directly affect learning but increases engagement in games. In the design of educational games, researchers suggest that game challenges must be able to keep up with the development of student's abilities and learning to support continuous learning in a game-based learning environment [18]. In another study, Mohammad Iqbal stated that there were seven steps in designing serious games as learning media. This method begins with analyzing the specification of the pedagogical goals to be achieved and then selecting the type of game model to be used. The third is the adjustment of pedagogical scenarios with fun game scenarios, and the next is the search for software components that can be used. The next step is the detailed description of scenarios and pedagogical quality control, and the final is determining subcontractors' specifications and game design tools [19]. Some of these studies are the primary references of this research proposal. To design serious games as interactive and adaptive learning media, we use the implementation of ambient intelligence supported by Virtual reality technology and a recommender system.

Furthermore, several studies have introduced games as learning media, especially in mathematics for example, M. Hartono et al. Authors use games developed in 2-dimensional visualization so that they are for students studying in elementary school. The experimental results show that students prefer learning mathematics through game media rather than conventional media. In addition, another advantage is that mathematics subject matter becomes more accessible for students to understand [20]. In another study, Sun et al. propose the use of game-based learning media also for mathematics lessons. In the experiment, the authors involving many students and teachers in collecting data through observation and interviews. This study's results indicate that using games as a medium for learning mathematics positively influences learning activities and understanding of mathematics [21]. Based on research by Sun et al. it is necessary to increase adaptive intelligence to the surrounding environment, according to Yunifa et al, one of the adaptive intelligence technologies is ambient intelligence which can be applied to serious games to arrange response scenarios for selecting tourist destinations [22]. In this study using ambient intelligence to set scenarios for selecting responses to games for selecting mathematics learning materials. Some studies that have been carried out use simple game media that still

have prospects for improving their abilities, for example, by utilizing game genres with better visualization and simulation capabilities. One of the game genres that can answer the ability challenges from several previous studies is the serious game. Therefore, this study proposes the implementation of serious games as a mathematics learning technology for students in madrasah schools.

Several studies have discussed the idea and design of game-based learning media for madrasah students. One of them is done by Melati et al. in 2022. In their research, authors use educational games as a medium for learning English for madrasah students. They take advantage of educational games that can be accessed online by students. The results of the study show that online game media can help the process of learning English for madrasah students [23]. In contrast to previous research, in this study, we propose using games as a medium for mathematics for madrasah students.

III. SYSTEM DESIGN

This study discusses the proposed serious game system as an interactive and adaptive mathematics learning media for madrasah students. Games are built with story scenarios that describe what is adapted to the subject matter that becomes game content. Therefore, for students who play to get an apparent experience of simulation and visualization of subject matter, we build and design virtual environments and objects that support the process of learning mathematics. Next, we use Unity 3D as the game engine that will be used to build scenarios, objects, characters, and 3-dimensional virtual environments in this serious game.

Fig. 1 shows the proposed mathematics learning system using a serious game. Where to produce interactive and adaptive mathematics learning media, we offer the implementation of ambient intelligence technology in serious games supported by virtual reality visualization and recommender systems. The virtual reality (VR) platform provides visualization and simulation of subject matter content so that it is easy for students to understand, which can be assisted with several types of markers for their interactions. Furthermore, we use the Multi-Criteria Recommender System (MCRS) to provide recommendations for selecting suitable material levels for students based on the scores they obtained through the pre-test.

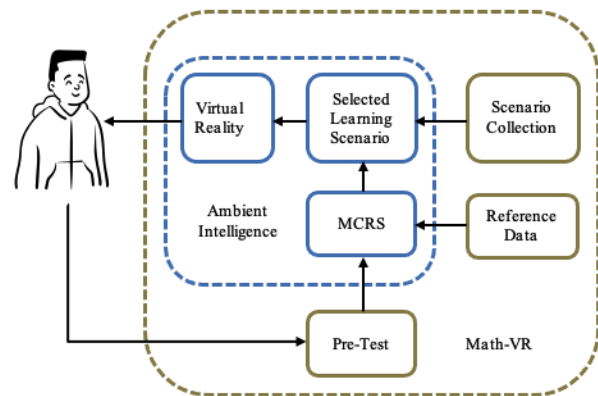


Fig. 1. Architecture of the proposed Math-VR system as mathematics learning media.

In this study, we chose one of the subject matters of mathematics as serious game content, which is about geometric shapes. A VR-based spatial learning game is a game that simulates the activities of students at school. The system starts the game scenario activity by displaying the main menu page, which consists of three options: starting the game, about the game, and exiting the game. After the player selects the start game option, the player will enter the school scene where several classes have different content, and there are material content and tests. When a player completes a test session and gets a score, the system will calculate the Score, so players can get recommendations for subjects that players still must study. Besides recommendations, players can also choose their desired class goals by pressing the destination button. The system will help with the direction of the goal with arrow direction indicators. Fig. 2 shows the rule of a serious game for mathematics educational media based on VR introduced in this study.

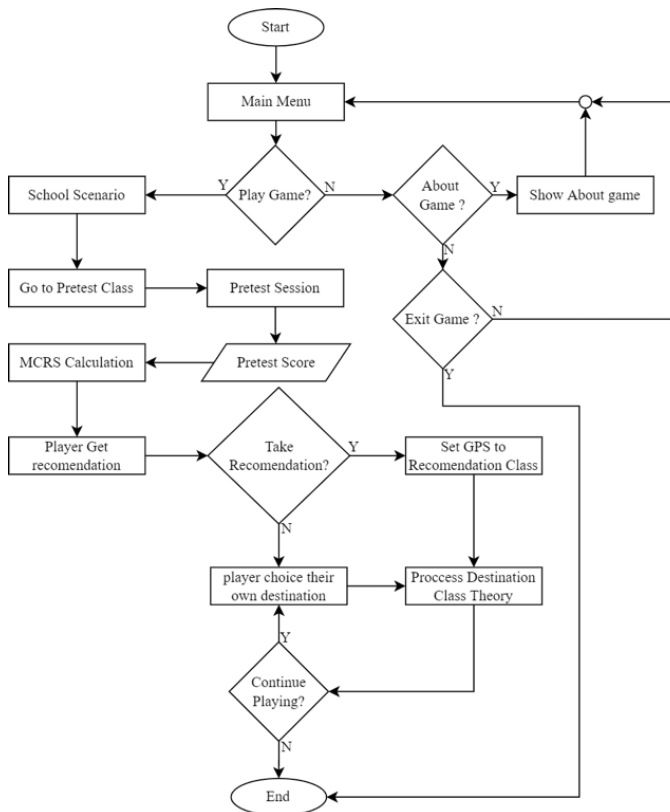


Fig. 2. The rule of proposed Math-VR.

A. Object, Character, and Environment Design

Developing game elements begins with creating assets consisting of the environment, user interface (UI), and characters. We design each asset using Blender software. The characters designed in this game function as non-playable characters (NPC), representing a teacher teaching in class. The process of making a character has a higher level of difficulty compared to making an environment. Character creation requires rigging and animation processes so that the character can move according to the running scenario. The following process is creating 2-dimensional assets in the form of illustrations and UI. Making these assets aims to help users

interact with the game. One example is the creation of button images that function as game navigation. As shown in Fig. 3, 4, and 5, we designed the environment and character using Blender software.



Fig. 3. Designing a school environment.



Fig. 4. Designing a class environment.



Fig. 5. Designing game character.

B. MCRS-Based Ambient Intelligence

This study utilized a multi-criteria-based recommender system to provide ambient intelligence capabilities in serious games. MCRS generates recommendations based on player pretest value data at an early stage when playing a spatial learning game. The value data includes the value of the answer score (R1) and the length of processing time (R2). The MCRS system performs calculations using a heuristic approach based on the multi-criteria recommender system (MCRS). Eq. (1) shows the calculation to get the value of R1 after the player completes the pretest session. Twenty questions will be randomized from the 64 questions available

in the game database. In the pretest session, besides being required to answer correctly, players must also answer questions as quickly as possible. The faster the player answers the questions, the bigger the Score they get.

$$R1 = \frac{(JS-SS) \times MS}{SF} \quad (1)$$

The calculation that occurs to get the value of R1 is shown through (1). First, the number of questions (JS) is reduced by the number of wrong questions (SS), then the multiplier is multiplied by the correct answers (MS). The purpose of multiplying by the multiplier is to get a score of 100/100 where this value will be displayed on the game interface. In this research, the multiplier value used is 5. Furthermore, the value is divided by the simplified value (SF) or simplified value. The reason is that R1 only has a value range of 0-10. The simplified value in this study is 10. After that, the value of R1 or the first criterion will be obtained.

$$R2 = \frac{\sum_{CT=n}^{JS} CT_n - TS}{JS} \quad (2)$$

In (2), the calculation of the long processing time criterion (R2) begins with the process of obtaining the current time (CT) and start time (TS) values. The following process calculates the time required by the value (CT) minus the value (TS). The process will repeat until all questions (JS) has been answered. In this study, there were five items in each type of question. For example, the cube problem has five questions, five blocks, five prisms, and five pyramids for 20 questions. After all the questions have been answered, all the reduction values will be added and divided by the number of available questions (JS).

R1 and R2 values are rating values used in MCRS calculations. In this study, we used the MCRS algorithm based on a heuristic approach with several steps to calculate the similarity of u' and u ratings. The first step is to calculate the similarity rating of the new player u' , and all the ratings of previous players u using the cosine-based similarity formula. At (3), $I(u, u')$ is an item rated by players u and u' . While $R(u, i)$ is the rating value, new players give to items [24] [25].

$$sim(\mu, \mu') = \frac{\sum_{i \in I(\mu, \mu')} R(u, i) R(\mu', i)}{\sqrt{\sum_{i \in I(\mu, \mu')} R(u, i)^2} \sqrt{\sum_{i \in I(\mu, \mu')} R(\mu', i)^2}} \quad (3)$$

After the results of the calculation of similarity between players are known, the second step is to calculate the individual similarity values using the average similarity formula $sim_{avg}(\mu, \mu')$ as in (4). This calculation aims to find out the player who has the highest overall Score with the highest level of similarity among all players. The value n indicates the number of criteria rated by the player, while $sim_c(\mu, \mu')$ is the similarity for each criterion between user u and the previous user u' [26] [27].

$$sim_{avg}(\mu, \mu') = \frac{1}{n+1} \sum_{c=0}^n sim_c(\mu, \mu') \quad (4)$$

IV. RESULT AND DISCUSSION

A. The User Interface and Environment Result of Math-VR

In this research, we developed game elements for Math-VR using the Unity 3D game engine. When players start the game for the first time, they will find three options on the main menu, namely "Mulai" to enter the game's gameplay, "Tentang" to find out information about the application, and "Keluar" to navigate out of the application as in Fig. 6. After starting the game, the player will immediately enter the school environment as in Fig. 7. Where at this stage, the system will show the first-person view of players who use VR devices and are synchronized with movements in the virtual game environment. Furthermore, players will be directed using arrows to go to class. Fig. 8 shows an example of visualizing a virtual classroom environment used in learning activities using Math-VR.



Fig. 6. Math-VR menu.

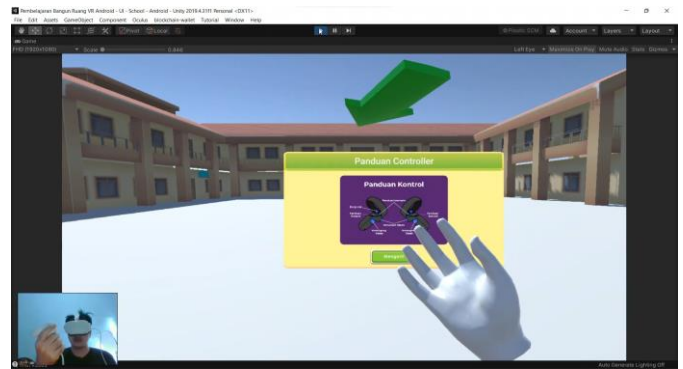


Fig. 7. School environment in the player view.



Fig. 8. Classroom environment in the player view.

When entering the classroom environment, the system provides pre-test questions to the player as the first step to obtaining the rating data needed by the recommendation system. In the pretest class, the Math-VR system guides players to pay attention to the questions on the blackboard and answer them by taking the alphabet according to the selected answer. After the player has answered all the questions, then the game displays the pretest results panel in the form of the Score obtained by the player, the number of questions answered correctly and incorrectly, as shown in Fig. 9. Players can press the "Lanjutkan" button to find out the results of the system evaluation regarding the recommended subjects to study. Fig. 10 shows the display of recommendations generated by the system using the MCRS method to implement ambient intelligence technology in Math-VR. In this session, players can choose one of three subjects that they want to study first. Fig. 11 shows example of the results of the visual display of the condition of the virtual environment when the player has entered one of the learning scenarios about geometric shapes.

B. MCRS-Based Ambient Intelligence Results

In this study, we tried implementing ambient intelligence technology into a serious game proposal using the multi-criteria-based recommender system method. The system uses the results of the recommendations as a reference in responding to players regarding the choice of lesson scenarios that are appropriate to their level of understanding. In the process of generating recommendations, MCRS requires initial data as a reference to predict the similarity of the new user ratings.



Fig. 11. Example of virtual environment visualization for geometry learning.

In this study, we obtained reference data through a direct test that 125 students attended. There are two assessment factors in the test: the correct or incorrect answer and how long it takes the participant to answer the question. The longer the time it takes, the smaller the Score the participant will get. We also carry out a selection process for each data based on variations in the criteria value. We do not use exact respondent rating data.

Meanwhile, we only use rating data very far from the average participant score. After the data selection process, we got 110 valid test data values divided into two, namely 100 reference data and 10 test data. This study uses five scenarios of experimental testing, namely with 40, 50, 60, 70, and 80 reference data. The aim is to see the relationship between accuracy and the amount of reference data used. At the same time, some of the variables resulting from the testing experiment are precision, recall, accuracy, and F1 Score. Table I shows the test results based on 40, 50, 60, 70, and 80 reference data. We also carry out tests for the results of the Top N recommendations 1, 2, and 3.

TABLE I. RECOMMENDATION SYSTEM TEST RESULTS FOR PRECISION, RECALL, ACCURACY, AND F1 SCORE

Top N	Result	Reference Data					
		40	50	60	70	80	Average
1	Precision	0,50	0,60	0,70	0,73	0,82	0,67
	Recall	0,56	0,55	0,64	0,73	0,90	0,67
	Accuracy	0,78	0,78	0,83	0,85	0,92	0,83
	F1 Score	0,53	0,57	0,67	0,73	0,86	0,67
2	Precision	0,61	0,67	0,68	0,75	0,85	0,71
	Recall	0,58	0,60	0,68	0,75	0,85	0,69
	Accuracy	0,63	0,65	0,70	0,75	0,85	0,72
	F1 Score	0,59	0,63	0,68	0,75	0,85	0,70
3	Precision	0,52	0,60	0,64	0,74	0,76	0,65
	Recall	0,60	0,68	0,70	0,77	0,90	0,73
	Accuracy	0,40	0,58	0,60	0,72	0,80	0,62
	F1 Score	0,56	0,64	0,67	0,76	0,83	0,69

Fig. 12, 13, and 14 show the test results in graphical form on the variables precision, recall, accuracy, and F1 Score for 40, 50, 60, 70, and 80 reference data. These results also show

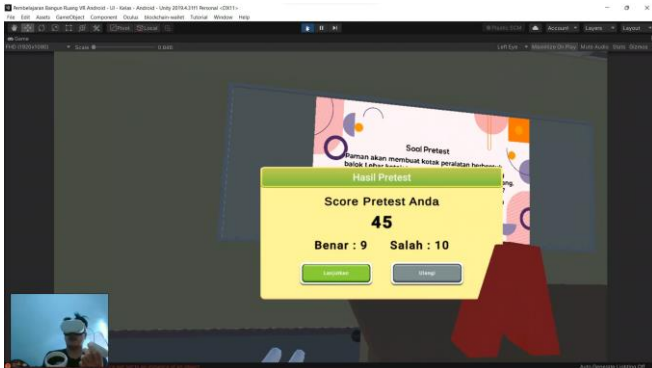


Fig. 9. Pre-test score result.



Fig. 10. Visualization of geometry learning material recommendation.

that the more test data used, the better the accuracy of the recommendations. The highest accuracy value is 0.92 when using 80 test data for Top 1 recommendation results. While the highest average accuracy value is 0.83 for Top 1 recommendation results, the highest average precision is 0.71 for Top 2 recommendation results, average -the highest average recall is 0.73 for Top 3 recommendation results, and the highest average F1 Score is 0.70 for Top 2 recommendation results.

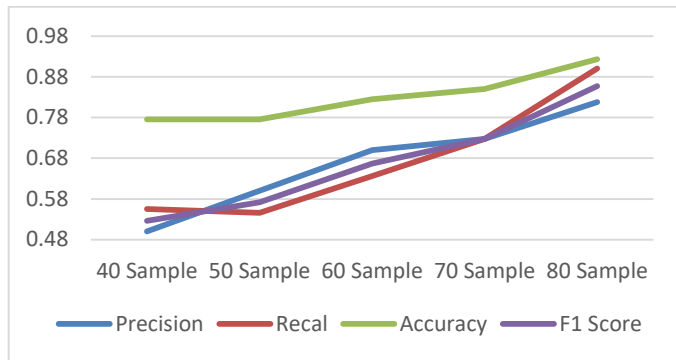


Fig. 12. The test results for Top 1 recommendation.

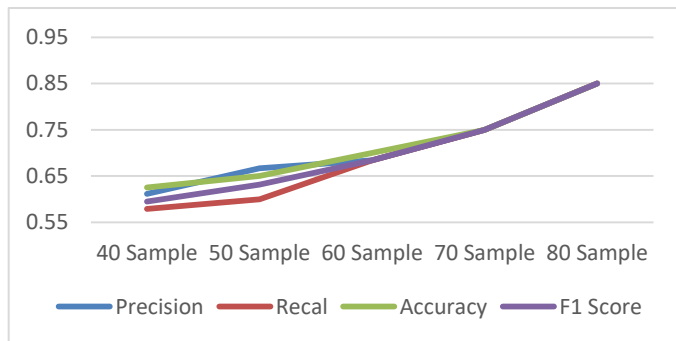


Fig. 13. The test results for Top 2 recommendation.

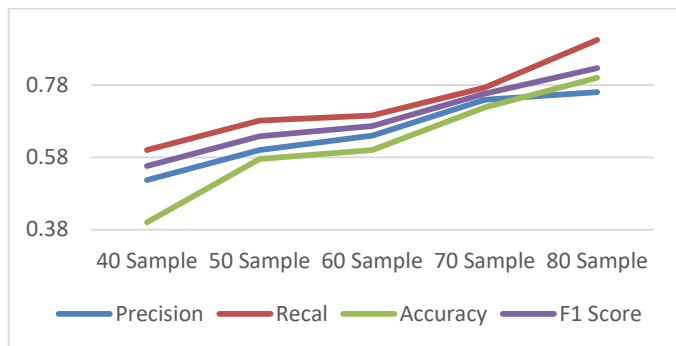


Fig. 14. The test results for Top 3 recommendation.

V. CONCLUSION

In this study, we propose a serious game-based mathematics learning media supported by virtual reality technology and ambient intelligence called Math-VR. This study utilizes a multi-criteria-based recommendation system to generate ambient intelligence system responses. The recommendations generated by MCRS respond to the choice of geometry learning scenarios following the results of the

pre-test player. In the MCRS system, the formula algorithm used to calculate similarity is cosine-based similarity, while calculating ranking uses average similarity. In this research, we developed Math-VR using the Unity game engine. Furthermore, the test results show that Math-VR can respond to the recommendation of subject matter scenarios that are adaptive to the results of the pre-test player. The highest accuracy value is 0.92 when using 80 test data for Top 1 recommendation results. While the highest average accuracy value is 0.83, precision is 0.71, recall is 0.73, and F1 Score is 0.70.

Several parts of this research have prospects for further development in future research plans. One of them is the recommendation system-based ambient intelligence section. We can also use machine learning methods to get better results. Besides that, in the following research, Serious games can be used in content other than learning mathematics. To make it more interesting, the VR-based serious game, the subject of this study, can be developed into a metaverse-based learning technology.

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REFERENCES

- [1] A. Syar'i and A. Akrim, "The Development of Madrasa Education in Indonesia," *Revista Argentina de Clínica Psicológica*, vol. XXIX, no. 4, pp. 513–523, 2020, doi: 10.24205/03276716.2020.858.
- [2] Kusaeri, "The Portrait of Madrasah Aliyah in Indonesia: A Critical Evaluation of the Mathematics Score in the National Examination," in *Journal of Physics: Conference Series*, Institute of Physics Publishing, Jun. 2018. doi: 10.1088/1742-6596/1028/1/012126.
- [3] A. Umar, Kusaeri, A. Ridho, A. Yusuf, and A. H. Asyhar, "Does opportunity to learn explain the math score gap between madrasah and non-madrasah students in Indonesia?," *Cakrawala Pendidikan*, vol. 41, no. 3, pp. 792–805, Oct. 2022, doi: 10.21831/cp.v41i3.40149.
- [4] M. Uin, S. Maulana, and H. Banten, "The Curriculum of Madrasah Aliyah in The National Education System in Indonesia: The Shift Analysis," in *6th International Conference on Community Development (ICCD 2019)*, 2019, pp. 345–349.
- [5] S. A. Husin, "An Overview of Madrasah Model of Education in Indonesian System of Education: Opportunity and Challenges," *Jurnal Pendidikan dan Pembelajaran Dasar*, vol. 10, no. 2, pp. 65–73, 2018.
- [6] A. S. Purba, A. Hufad, B. K. Amal, A. Ahyani, and N. Sutarni, "Development of Games Instruction Plant Growth Concept," *Journal of Engineering Science and Technology*, vol. AASEC2019, pp. 1–10, 2020.
- [7] Y. M. Arif, S. Harini, S. M. S. Nugroho, and M. Hariadi, "An Automatic Scenario Control in Serious Game to Visualize Tourism Destinations Recommendation," *IEEE Access*, vol. 9, pp. 89941–89957, 2021, doi: 10.1109/ACCESS.2021.3091425.
- [8] N. Ferreira, "Serious Games," *Universidade do Minho*, 2008.
- [9] A. M. Moosa, N. Al-Maadeed, M. Saleh, S. A. Al-Maadeed, and J. M. Aljaam, "Designing a Mobile Serious Game for Raising Awareness of Diabetic Children," *IEEE Access*, vol. 8, pp. 222876–222889, 2020, doi: 10.1109/ACCESS.2020.3043840.
- [10] Y. M. Arif, M. N. Firdaus, and H. Nurhayati, "A Scoring System For Multiplayer Game Base On Blockchain Technology," in *The 2021 IEEE Asia-Pacific Conference on Wireless and Mobile (APWiMob)*, 2021, pp. 199–204.
- [11] Y. M. Arif, R. P. Pradana, H. Nurhayati, S. M. S. Nugroho, and M. Hariadi, "A Blockchain-Based Multiplayer Transaction For Tourism

- Serious Game,” in International Conference on Computer Engineering, Network and Intelligent Multimedia (CENIM), 2020, pp. 138–143.
- [12] D. J. Cook, J. C. Augusto, and V. R. Jakkula, “Ambient intelligence: Technologies, applications, and opportunities,” *Pervasive Mob Comput*, vol. 5, no. 4, pp. 277–298, 2009, doi: 10.1016/j.pmcj.2009.04.001.
- [13] N. A. Nasharuddin, N. A. Khalid, and M. Hussin, “InCell VR: A Virtual Reality-based Application on Human Cell Division for Mobile Learning,” *International Journal of Interactive Mobile Technologies*, vol. 15, no. 2, pp. 55–71, 2021, doi: 10.3991/ijim.v15i02.18049.
- [14] I. Oncioiu and I. Priescu, “The Use of Virtual Reality in Tourism Destinations as a Tool to Develop Tourist Behavior Perspective,” *Sustainability (Switzerland)*, vol. 14, no. 7, Apr. 2022, doi: 10.3390/su14074191.
- [15] M. Khairudin, A. K. Triatmaja, W. J. Istanto, and M. N. A. Azman, “Mobile virtual reality to develop a virtual laboratorium for the subject of digital engineering,” *International Journal of Interactive Mobile Technologies*, vol. 13, no. 4, pp. 79–95, Jan. 2019, doi: 10.3991/ijim.v13i04.10522.
- [16] A. Y. Chandra, P. T. Prasetyaningrum, O. Suria, P. I. Santosa, and L. E. Nugroho, “Virtual Reality Mobile Application Development with Scrum Framework as a New Media in Learning English,” *International Journal of Interactive Mobile Technologies*, vol. 15, no. 8, pp. 31–49, 2021, doi: 10.3991/ijim.v15i08.19923.
- [17] I. Drofova, W. Guo, H. Wang, and M. Adamek, “Use of scanning devices for object 3D reconstruction by photogrammetry and visualization in virtual reality,” *Bulletin of Electrical Engineering and Informatics*, vol. 12, no. 2, pp. 868–881, Apr. 2023, doi: 10.11591/eei.v12i2.4584.
- [18] J. Hamari, D. J. Shernoff, E. Rowe, B. Coller, J. Asbell-Clarke, and T. Edwards, “Challenging games help students learn: An empirical study on engagement, flow and immersion in game-based learning,” *Comput Human Behav*, vol. 54, pp. 170–179, 2016, doi: 10.1016/j.chb.2015.07.045.
- [19] M. Iqbal, C. Machbub, and A. S. Prihatmanto, “Educational Game Design Using The 7 Steps for Designing Serious Games Method,” 2015 4th International Conference on Interactive Digital Media (ICIDM), no. Icidm, pp. 1–9, 2015.
- [20] M. Hartono, B. Yulianto, A. G. Santoso, and C. Lebu, “Educational Mathematics Game for Elementary Students,” in Proceedings of 2017 International Conference on Information Management and Technology (ICIMTech), 2017, pp. 156–159.
- [21] L. Sun, H. Ruokamo, P. Siklander, B. Li, and K. Devlin, “Primary school students’ perceptions of scaffolding in digital game-based learning in mathematics,” *Learn Cult Soc Interact*, vol. 28, Mar. 2021, doi: 10.1016/j.lcsi.2020.100457.
- [22] Y. M. Arif, D. D. Putra, D. Wardani, S. M. S. Nugroho, and M. Hariadi, “Decentralized recommender system for ambient intelligence of tourism destinations serious game using known and unknown rating approach,” *Heliyon*, vol. 9, no. 3, p. e14267, Mar. 2023, doi: 10.1016/j.heliyon.2023.e14267.
- [23] E. Melati, F. Malabar, A. Hardiansyah, N. Husen, and P. A. Cakranegara, “Identification Of Online Educational Game Applications In Teaching English For Madrasah Students,” *Jurnal Pendidikan Islam*, vol. 5, no. 3, pp. 994–1012, 2022, doi: 10.31538/nzh.v5i3.2502.
- [24] Y. M. Arif, H. Nurhayati, S. M. S. Nugroho, and M. Hariadi, “Destinations Ratings Based Multi-Criteria Recommender System for Indonesian Halal Tourism Game,” *International Journal of Intelligent Engineering and Systems*, vol. 15, no. 1, pp. 282–294, 2022, doi: 10.22266/IJIES2022.0228.26.
- [25] R. P. Pradana, M. Hariadi, Y. M. Arif, and R. F. Rachmadi, “A Multi-Criteria Recommender System For NFT Based IAP In RPG Game,” in International Seminar on Intelligent Technology and Its Applications (ISITIA), 2022, pp. 214–219. doi: 10.1109/ISITIA56226.2022.9855272.
- [26] Y. M. Arif and H. Nurhayati, “Learning Material Selection for Metaverse-Based Mathematics Pedagogy Media Using Multi-Criteria Recommender System,” *International Journal of Intelligent Engineering and Systems*, vol. 15, no. 6, pp. 541–551, 2022, doi: 10.22266/ijies2022.1231.48.
- [27] G. Adomavicius and Y. Kwon, “Multi-criteria recommender systems,” in *Recommender Systems Handbook, Second Edition*, Springer US, 2015, pp. 847–880. doi: 10.1007/978-1-4899-7637-6_25.

An Adaptive Channel Selection and Graph ResNet Based Algorithm for Motor Imagery Classification

Yongquan Xia, Jianhua Dong, Duan Li*, Keyun Li, Jiaofen Nan, Ruyun Xu
School of Computer and Communication Engineering, Zhengzhou University of Light Industry,
Zhengzhou, Henan, China

Abstract—In Brain-Computer interface (BCI) applications, achieving accurate control relies heavily on the classification accuracy and efficiency of motor imagery electroencephalogram (EEG) signals. However, factors such as mutual interference between multi-channel signals, inter-individual variability, and noise interference in the channels pose challenges to motor imagery EEG signal classification. To address these problems, this paper proposes an Adaptive Channel Selection algorithm aimed at optimizing classification accuracy and Information Translate Rate (ITR). First, C3, C4, and Cz are selected as key channels based on neurophysiological evidence and extensive experimental studies. Next, the channel selection is fine-tuned using spatial location and absolute Pearson correlation coefficients. By analyzing the relationship between EEG channels and key channels, the most relevant channel combination is determined for each subject, reducing confounding information and improving classification accuracy. To validate the method, the SHU Dataset and the PhysioNet Dataset are used in experiments. The Graph ResNet classification model is employed to extract features from the selected channel combinations using deep learning techniques. Experimental results show that the average classification accuracy is improved by 5.36% and 9.19%, and the Information Translate Rate is improved by 29.24% and 26.75%, respectively, compared to a single channel combination.

Keywords—Brain-Computer Interface; motor imagery; channel selection; deep learning; graph convolutional neural network

I. INTRODUCTION

Brain-Computer Interface (BCI) systems allow for direct communication with the outside world without relying on the brain's typical output pathways [1,2]. Within the field of BCI, motor imagery is one of the most commonly utilized paradigms. Motor imagery (MI) involves mentally simulating the movement of a limb without actually moving it [3]. BCI systems can capture EEG signals from the brain during these imagined movements through electrodes, and thereby enable control over external devices [4]. With their potential applications in fields such as rehabilitation and medical care, communication security, and environmental protection, BCI systems have a wide range of possible uses [5].

Deep learning [6] is a widely used approach in the field of BCI. Compared to shallow learning models like traditional machine learning, deep learning uses neural network architecture with multiple complex network layers that perform varying functions. This leads to a significant improvement in the quantity and quality of feature extraction and recognition. Many studies have applied deep learning methods such as convolutional neural networks (CNN), long short-term

memory (LSTM), and deep Boltzmann machine (DBM) for motor imagery classification, achieving good recognition results. However, these methods overlook the rich topological relationships between electrodes by treating EEG data as simple two-dimensional data. In contrast, the utilization of graph convolutional neural networks for EEG signal classification addresses this issue.

Different regions of the human brain have distinct functions. For instance, the motor cortex is responsible for motor functions, while the parietal lobe processes various sensory information like touch, smell, and taste. However, most current studies have used EEG data from all channels to extract features, which inevitably introduces redundancy. Additionally, the brain's electrical activity may vary among individuals. Therefore, selecting task-specific signal recording sites can reduce preparation time and improve user comfort in nonclinical BCI applications [7]. By choosing the optimal channel, the impact of noise interference can be minimized, and the computational costs of processing high-dimensional data can be reduced.

The objective of this study is to address the issue of individual variability and to decrease the computational complexity involved in processing high-dimensional EEG data. The main contributions of the paper are as follows:

- An Adaptive Channel Selection algorithm is proposed. For different individuals, the method selects all or partial channels as input to the BCI system by itself, and the partial channels are selected based on the correlation between channels and spatial location.
- A residual-based graph neural network is used to decode the MI signal.
- This method achieves good results on the SHU dataset and the PhysioNet dataset.

The main part of this paper consists of five sections. The first section is the introduction, which provides the background, significance, and methodology of the motor imagery study, as well as the reasons for conducting channel selection. The second section is the related work, where research related to feature extraction and classification algorithms of EEG signals is discussed. Section III presents the core part of the paper, introducing the channel selection algorithm and the Graph ResNet model. Section IV presents the experimental testing of the algorithms proposed in Section III, along with the corresponding results and analysis. Finally,

Section V concludes the research approach and provides future outlook.

II. RELATED WORKS

A. Feature Extraction

The method of feature extraction method has a significant impact on the performance of BCI systems. Popular methods include CNN and RNN [8-13]. In [11], a combination of convolutional and recurrent neural networks achieved an accuracy of 98.3% on the PhysioNet dataset. However, these methods only considered regular data in Euclidean space and did not take into account the topological relationships between electrodes. To address the issue of non-Euclidean space data being unable to be convolved, the first graph convolutional neural network (GCN) was proposed in [14] and applied to non-Euclidean space structured data. In [15] and [16], GCN was applied to MI decoding, achieving the highest accuracy of 93.056% and 98.08% on the PhysioNet dataset, respectively, demonstrating the superiority of GCN in processing EEG signals. However, in order to fully utilize the topological relationship between electrode channels, all channel data are typically used as network inputs, resulting in a large amount of redundant data [17].

B. Channel Selection

EEG signals are acquired using multi-channel electrodes, but using all channels as network input can consume more computational resources and degrade system performance due to noise in some channels. Therefore, channel selection is necessary [17]. One simple method is to select data from the three channels (C3, C4, and Cz) where potential changes during motor imagery are mainly concentrated [18]. Additionally, the StEEGCS algorithm, proposed in [19], utilizes EEG shapelet-transformed for EEG channel selection. It selects the top-k EEG channels by solving a logistic loss-embedded minimization problem while simultaneously learning EEG shapelets, hyperplanes, and channel weights. and in [20], a Spatiotemporal-Filtering-Based channel selection (STECS) method was introduced to extract discriminative information from EEG signals. The STECS method was able to achieve the same classification performance as the full channel by using only half of the number of channels. However, these methods lack a neurophysiological basis. In [21], it was assumed that the channels associated with MI should contain public information, and channels were selected based on inter-channel correlation. An iterative multi-objective optimization channel selection (IMOCS) algorithm was proposed in [7] that selects optimal channels using anatomical and functional correlations of EEG channels, but it does not consider the spatial distribution of electrodes.

Subject-independence can reduce the time of data preprocessing in BCI systems. However, the investigation results showed [22] that subject-specific classification accuracy is higher than that of subject-independent BCI systems. This suggests that the optimal channel varies across subjects.

In summary, the paper addresses the problems of data redundancy and individual variability faced by using deep neural networks for EEG signal classification. An adaptive Channel Selection is proposed, which considers both the

neurophysiological basis and the correlation between channels to select the optimal channel for each subject individually.

III. MATERIALS AND METHODS

A. Overview

The framework of this paper is shown in Fig. 1.

- 1) Computing the channel correlation and obtaining the graph Laplacian.
- 2) Selecting electrodes using an Adaptive Channel Selection algorithm.
- 3) Generating a graph representation of the channel correlation from the graph Laplacian.
- 4) Applying the residual graph neural network to decode EEG signals.
- 5) Determining the optimal channel selection scheme based on the test results.

The Adaptive Channel Selection algorithm automatically selects the combination of channels with a higher Information Transfer Rate (ITR) based on the ITR obtained after training data from both schemes. Fig. 2 illustrates the algorithm framework, which includes one scheme that uses all channels in the original data and another that uses proposed channel selection algorithm. Channel selection is based on the following two criteria.

B. Adaptive Channel Selection Algorithm

To minimize computational effort during graph pooling, the number of selected channels is chosen as integer powers of two since the number of channels is reduced by half each time.

1) *Neurophysiological basics and spatial location*: Motor imagery EEG refers to the spontaneous electrical activity of brain tissue that reflects the functional state of the brain. Different bands of EEG activity typically appear in different functional areas of the brain, and changes in their activity can reflect various brain states. Previous studies [23] have shown that during motor imagery, the phenomena of ERD and ERS in the mu (8-13 Hz) and beta (13-30 Hz) bands are concentrated in the C3 and C4 electrodes of the cerebral motor cortex. in addition to Cz, which also receives the influence of hand movements. Therefore, first selected the C3, C4, and Cz channels that are most relevant to motor imagery EEG activity. Next, selected another set of channels that are spatially closest to the selected channels, with the already selected channels being referred to as "Fixed Channels".

2) *Absolute pearson coefficient*: For the remaining channels, they needed to be closely related to EEG activity in the motor cortex of the brain, and considering the variability among individuals, this work selected a unique set of channels for each subject based on the absolute Pearson correlation coefficient. These channels were referred to as "Free Channels", and the three sets of channels were combined to form the input to the model. The composition of each part of the channel is shown in Fig. 3.

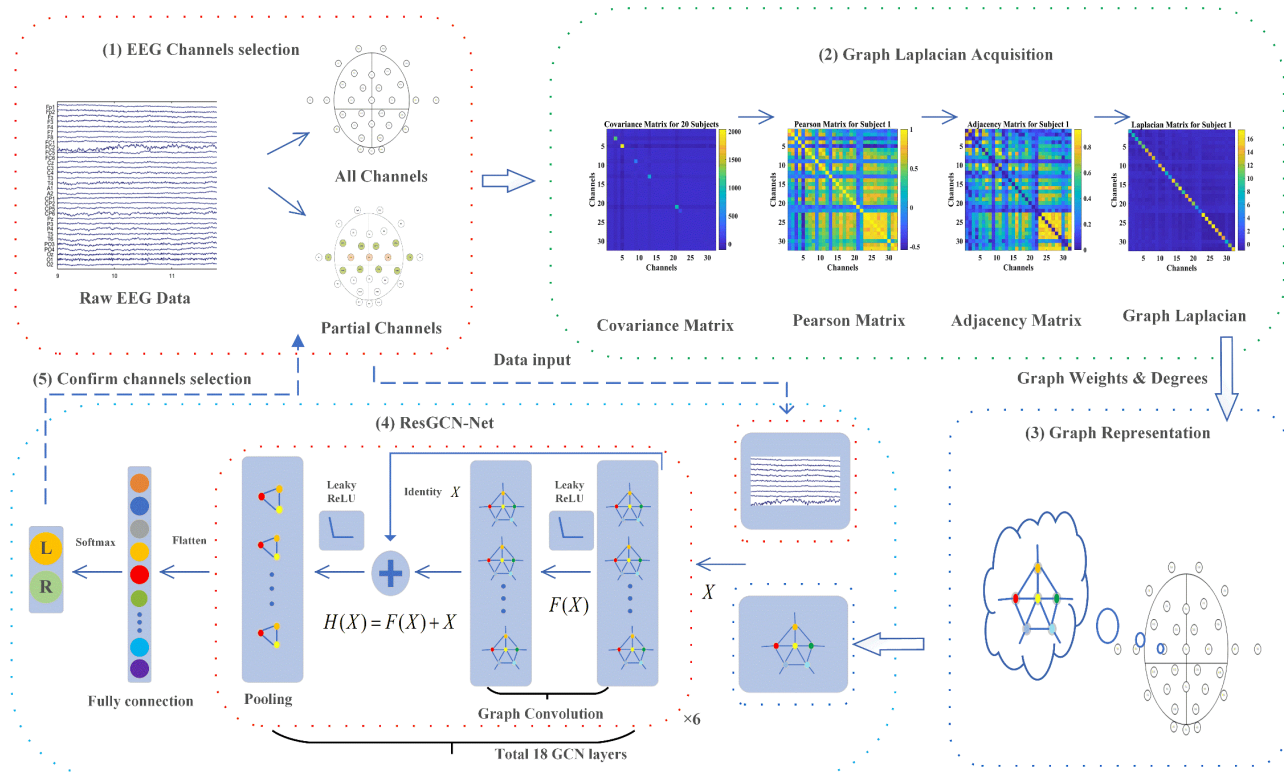


Fig. 1. Illustration of the proposed framework.

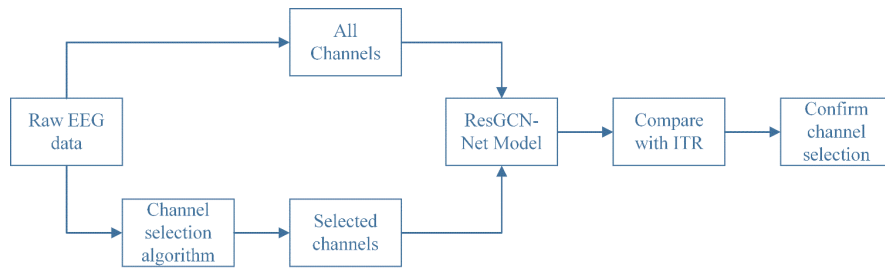


Fig. 2. Adaptive channel selection algorithm flowchart.

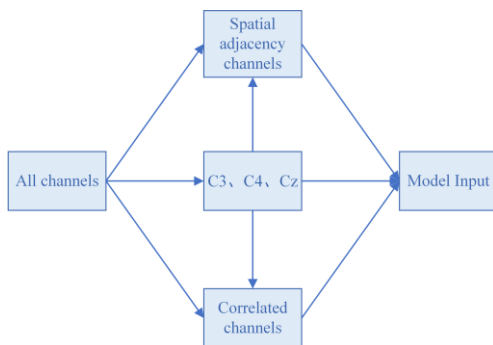


Fig. 3. Diagram of channel composition.

The absolute Pearson coefficient is a commonly used method for feature selection and extraction, as it measures the degree of correlation between two variables. In channel selection, this work aims to identify channels that are highly correlated with changes in motor cortex EEG signals. To achieve this, this work uses the absolute Pearson coefficient to evaluate the degree of correlation between each channel and

the motor functional areas of the brain, and select the channels with high correlation [21].

The Pearson correlation coefficient between two variables is calculated as the quotient of the covariance and the standard deviation between the two variables.

$$\rho_{X,Y} = \frac{\text{cov}(X,Y)}{\sigma_X \sigma_Y} \quad (1)$$

where $\rho_{X,Y}$ denotes the overall Pearson correlation coefficient of variables X and Y , $\text{cov}(X,Y)$ represents the covariance between variables X and Y , and $\sigma_X \sigma_Y$ represents the product of the standard deviations of variables X and Y . The estimation is based on the sample with respect to the variance and covariance.

$$\sigma_X^2 = \frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2 \quad (2)$$

$$\text{cov}(X,Y) = \frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y}) \quad (3)$$

Bring (2) and (3) into (1). The absolute Pearson coefficients of the samples are obtained as follows.

$$r = \left| \frac{\sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^n (X_i - \bar{X})^2} \sqrt{\sum_{i=1}^n (Y_i - \bar{Y})^2}} \right| \quad (4)$$

With the EEG channels considered as variables and their corresponding data as observations, the Pearson correlation coefficients were calculated for all channels and the three channels most closely associated with motor imagery, C3, C4, and Cz. To ensure that negative correlations between channels and changes in EEG signals in the motor cortex of the brain were not overlooked, the absolute values of the Pearson correlation coefficients were taken. The correlation degree between all channels and the three motor imagery-related channels was calculated, and the channels with the highest correlation were selected as “Free Channels” for model input. The number of “Fixed Channels” and “Free Channels” selected for different datasets are shown in Table I.

C. Graph ResNet

The graph convolution network can be divided into two categories: spectral graph convolution network and spatial graph convolution network [24]. The spectral method defines graph convolution in the spectral using the convolution theorem, while the spatial method aggregates the central node and its neighboring nodes by defining an aggregation function in the node domain. In this paper, the spectral graph convolution method is employed.

1) *Graph represents*: For an undirected graph, it can be represented as $G = \{V, E, A\}$, where $|V| = n$ denotes the number of nodes, E denotes the set of edges, and A denotes the adjacency matrix that defines the connectivity between nodes. The Laplacian matrix of the graph is denoted by $L = D - A$, where D is a diagonal matrix. The normalized Laplacian matrix [24] is defined as

$$L = I_n - D^{-\frac{1}{2}} A D^{-\frac{1}{2}} \quad (5)$$

and since L is a real symmetric matrix, an eigen-decomposition of L yields $L = U \Lambda U^T$, where U denotes the identity matrix of L , Λ is the diagonal array of eigenvalues. The correlation matrix, Pearson matrix, absolute Pearson coefficient matrix, adjacency matrix, degree matrix, and Laplace matrix of subject 1 in SHU-Dataset are given in in Fig. 4.

2) *Graph convolution*: In the spectral, the graph convolution of signals x_1, x_2 is defined as

$$x_1 *_g x_2 = U((U^T x_1) \odot (U^T x_2)) \quad (6)$$

where $*_g$ represents the graph convolution operator and \odot represents the Hadamard product. For an input signal x , the graph convolution operation through a convolution kernel filter $g \in \mathbb{R}^n$ is defined as

$$x *_g g = U(U^T x \odot U^T g) \quad (7)$$

Define g as $g_\theta = \text{diag}(U^T g)$, then the graph convolution operation for x can be simplified to

$$x *_g g_\theta = U g_\theta U^T x \quad (8)$$

To parameterize the convolution kernel g_θ , Chebyshev network (ChebyNet) [25] is used instead of the convolution kernel in the spectral. g_θ is defined as $g_\theta = \sum_{i=0}^K \theta_i T_i(\tilde{\Lambda})$, where $\tilde{\Lambda}$ can be represented as

$$\tilde{\Lambda} = \frac{2\Lambda}{\lambda_{max}} - I_n \quad (9)$$

TABLE I. DISTRIBUTION OF DIFFERENT CHANNEL TYPES

Dataset	Number of Channels	Fixed Channels	Free Channels
SHU Dataset	32		
	16	13	3
Physionet MI Dataset	64		
	32	21	11
	16	3	13

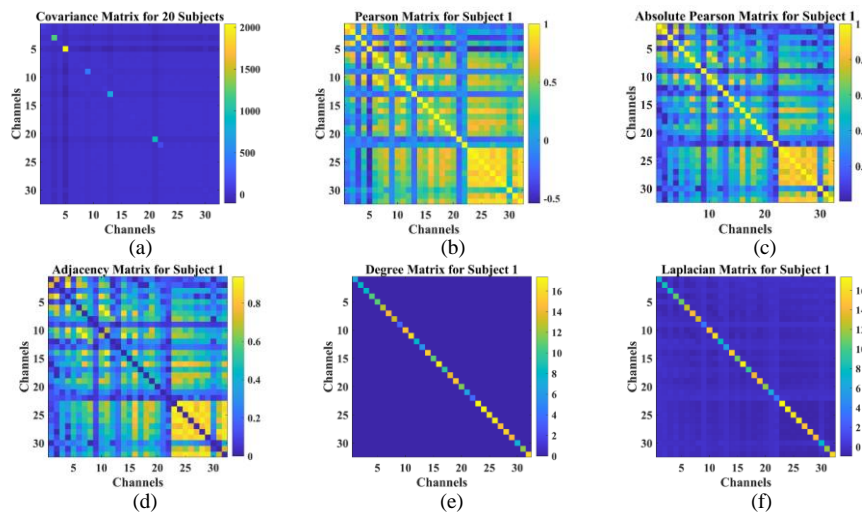


Fig. 4. The correlation matrix, Pearson matrix, absolute Pearson coefficient matrix, adjacency matrix, degree matrix, and Laplace matrix of subject 1 in SHU-dataset.

and the Chebyshev polynomial is defined as $T_i(x) = 2xT_{i-1}(x) - T_{i-2}(x)$, where $T_0(x) = 1$ and $T_1(x) = x$. Therefore, the ChebyNet graph convolution operation is

$$x *_G g_\theta = U(\sum_{i=0}^K \theta_i T_i(\tilde{\Lambda})) U^T x \quad (10)$$

Let $\tilde{L} = \frac{2L}{\lambda_{max}} - I_n$, then $T_i(\tilde{L}) = UT_i(\tilde{\Lambda})U^T$, and the ChebyNet graph convolution operation can be simplified as

$$x *_G g_\theta = \sum_{i=0}^K \theta_i T_i(\tilde{L}) x \quad (11)$$

ChebyNet convolution does not require feature decomposition of the Laplacian matrix, and the convolution kernel has only $K + 1$ trainable parameters [25]. Therefore, the parameter complexity is significantly reduced.

3) *Graph pooling*: ChebyNet implements pooling operation using a complete binary tree. In the coarsening phase based on the Graclus multi-level clustering algorithm [26], the input feature tensor is divided into blocks of equal

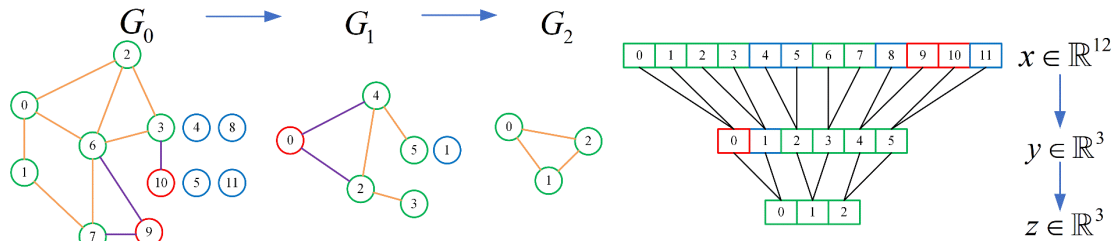


Fig. 5. ChebyNet implements pooling operators using complete binary trees[25].

IV. RESULTS AND DISCUSSION

A. Dataset Description

1) *SHU dataset*: This work utilized the SHU Dataset, a publicly available motor imagery dataset from Shanghai University in 2022[28]. The dataset includes 25 subjects who underwent a total of 5 sessions every 2-3 days. Each session included 100 trials, which were automatically labeled by using EEGLAB with amplitudes greater than $100 \mu V$. Experts then reviewed and eliminated any bad segments, resulting in a small number of missing trials in some sessions. The motor imagery tasks consisted of left-hand (L) and right-hand (R). EEG data were recorded using 32 electrodes based on the International 10-10 system with a 250 Hz sampling rate and a 4-second time window. Each subject had a total of 500 trials (5 sessions * 100 trials), and each trial included 1000 sampling points. The EEG data acquisition paradigm is shown in Fig. 6.

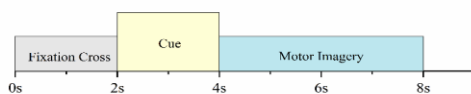


Fig. 6. Timing paradigm of SHU dataset.

2) *PhysioNet dataset*: The PhysioNet dataset included 109 subjects who performed motor imagery tasks using their left

hand (L), right hand (R), both fists (B), and both feet (F). EEG data was recorded from 64 electrodes based on the International 10-10 system, with a sampling rate of 160 Hz and a time window of 4 seconds. Each subject completed 84 trials (3 runs * 7 trials * 4 tasks), with each trial consisting of 640 sampling points.

4) *Residual learning*: Deep neural networks are known for their improved ability to fit nonlinear functions as the number of layers and neurons increases. However, simply stacking layers can lead to problems such as vanishing gradients, exploding gradients, and network degradation. To address these issues, Residual Learning proposed in [27]. This framework assumes that $H(X) = X$ represents the optimal solution mapping, and the general convolutional neural network is directly fitted with $H(X) = X$. In contrast, the residual network aims to fit the residual mapping, $F(X) = H(X) - X$. The optimal solution mapping is then given by $H(X) = F(X) + X$.

hand (L), right hand (R), both fists (B), and both feet (F). EEG data was recorded from 64 electrodes based on the International 10-10 system, with a sampling rate of 160 Hz and a time window of 4 seconds. Each subject completed 84 trials (3 runs * 7 trials * 4 tasks), with each trial consisting of 640 sampling points.

B. Channel Selection Results

1) *SHU dataset*: The original SHU-Dataset had 32 channels. Firstly, three channels C3, C4, and Cz -were selected, and then 10 additional channels were selected based on their spatial location: FC1, FC2, FC5, FC6, T3, T4, CP1, CP2, CP5, and CP6. In total, 13 channels were selected and has been marked in Fig. 7(a). Finally, three Free Channels are selected based on the absolute Pearson coefficients, and a total of 16 channels were used as input for the model.

Taking the first three subjects in the dataset as an example, computing the sum of the absolute Pearson coefficients for all channels and C3, C4, and Cz channels. The computation results are presented in Fig. 7(b), and the channels that were selected based on this result are listed in Table II.

2) *PhysioNet dataset*: The original dataset consists of 64 channels, which are reduced to 32 and 16 channels respectively. In both cases, three channels (C3, C4, Cz) were first selected from the source channels, and the remaining channels were selected using the following method:

- For the 32 EEG channels, 18 channels were initially selected based on their spatial location, resulting in a total of 21 Fixed Channel as shown in Fig. 8. Then, 11 Free Channels were selected based on the absolute Pearson coefficients.
- For the 16-channel subset, due to the densely arranged 64 channels based on the international 10-10 system and the need for fewer channels, the remaining 13 Free Channels were all selected based on the absolute Pearson coefficients.

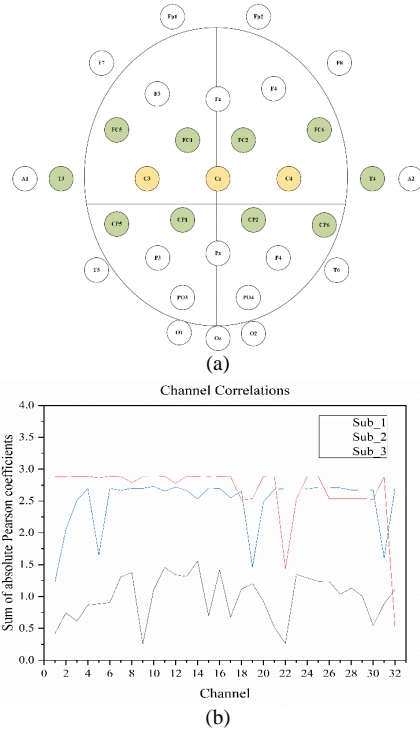


Fig. 7. (a) Shows schematic diagram of SHU Dataset Fixed Channels, (b) Shows the sum of the absolute Pearson coefficients between all channels and the C3, C4, and Cz channels for the first three subjects in the SHU-Dataset was calculated.

TABLE II. FREE CHANNELS SELECTED OF THE THREE SUBJECTS

Subject	Added channels label	Added channels
1	7、23、24	F8、Pz、P3
2	3、6、17	Fz、F7、A1
3	25、26、27	P4、T5、T6

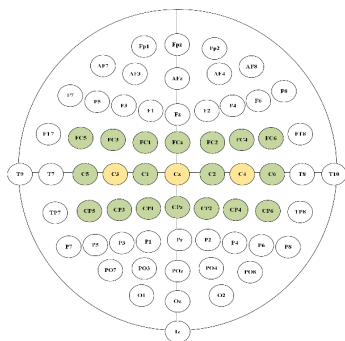


Fig. 8. Schematic diagram of physionet dataset fixed channels.

C. Evaluation Metrics

To evaluate this algorithm, this work introduces the Information Translate Rate (ITR) [29] as an additional evaluation metric, in addition to the traditional precision metric. ITR is a standard method for measuring communication systems, expressing the amount of information transmitted per unit time. The bit rate depends on both speed and accuracy. The formula for calculating ITR is as follows

$$ITR = 60 \cdot \frac{\log_2 M + P \log_2 P + (1-P) \log_2 \frac{1-P}{M-1}}{T_0} \quad (12)$$

Here, T_0 represents the prediction time of each sample in the model, M represents the number of categories, and P represents the classification accuracy. The unit of ITR is bits/min.

D. Equipments

This work utilized a remote server that runs on the Ubuntu 18.04 operating system to conduct experiments. The experiments were conducted in a Python 3.6 environment using the TensorFlow 1.15 deep learning framework. The models were trained and evaluated using 1 NVIDIA Tesla V100-PCIE-32GB GPU and 1 Intel Xeon Processor (Skylake) 2.4GHZ CPU. The system was equipped with 147GB RAM for system memory and had 6TB hard disk capacity.

E. Model Parameters

The network architecture consists of 12 convolutional layers, each connected to a pooling layer every two layers. The dataset is split into 90% training data and 10% test data. A training cycle of 100 batches is utilized and the performance of the trained model is evaluated on the test set after each cycle. Evaluation metrics including ITR and accuracy are calculated, and finally the average value of the successive ITR is taken to reduce randomness. The model hyperparameters are shown in Table III.

TABLE III. MODEL HYPERPARAMETERS

Hyperparameter	Value
Chebyshev Order	3
Activation Function	Leaky ReLu
Batch size	1024
Epoch	50
Optimization Algorithm	Adam
Learning Rate	0.001
Dropout	0.5

F. Experimental Results

1) *SHU dataset*: For this dataset, choosing to train the EEG dataset of the first 15 subjects separately, and the outcomes are presented in Fig. 9.

Table IV presents the results of motion imagery classification accuracy using all 32 channels, with an impressive accuracy of 83.98% reported in [16]. This outperforms the various benchmark classification methods used in [28], which achieved a maximum accuracy of 78.9%

on the cross-session task. After applying proposed method to halve the channels, the classification accuracy improved by 1.86%, the ITR improved by 14.4%, and the sample prediction time decreased by 22.7%. This result indicates that reducing the number of channels effectively reduces interference information, reduces data redundancy, and improves information transmission rate. In particular, some subjects who previously had poor classification accuracy and ITR, such as subjects 4, 5, 8, and 10, showed significant improvement after channel reduction. Using only half of the channel data, higher average classification accuracy and ITR were achieved compared to using all 32 channels. Furthermore, after applying the Adaptive Channel Selection algorithm, significant improvements were observed in classification accuracy and ITR compared to using all channels and only 16 channels. The classification accuracy improved by 5.36% and 3.5%, ITR improved by 29.24% and 12.97%, and single-sample prediction time was reduced by 12.56% and 13.13%, respectively.

2) *Physionet dataset*: For this dataset, training the EEG data of the first 20 subjects separately, and the experimental results were obtained by taking the mean values of the different subjects. These results are presented in Fig. 10.

Table V shows that with the input of all 64 channels data [16], the classification accuracy is improved by 1.26% and 8.21% compared to 32 and 16 channels, respectively, due to the availability of more extracted features. However, this leads to more data redundancy and the longest single-sample prediction time, resulting in a lower ITR compared to 32 channels. Although the ITR of 16 channels has only a 3.85% difference compared to 64 channels, the classification accuracy loss is higher due to less information available and less training

time. By using the proposed Adaptive Channel Selection algorithm, the classification accuracy is improved by 0.98%, 2.24%, and 9.19% compared to 64, 32, and 16 channels, respectively, and the ITR is improved by 26.75%, 7.66%, and 22.05%, respectively.

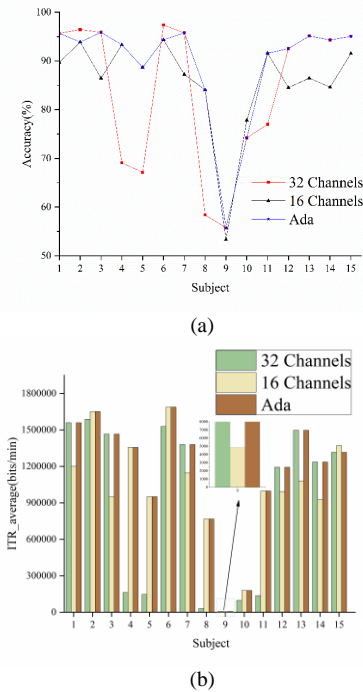


Fig. 9. (a) Shows the classification accuracy of the model under different channel strategies. (b) Shows the ITR of the BCI system under different channel strategies.

TABLE IV. SHU DATASET EXPERIMENTAL RESULT

Subject	Channels Strategies								
	32			16			Ada		
	ACC (%)	ITR (bits/min)	T_0 (μ s)	ACC (%)	ITR (bits/min)	T_0 (μ s)	ACC (%)	ITR (bits/min)	T_0 (μ s)
1	95.67	1558783	22	89.7	1201300	22	95.67	1558783	22
2	96.44	1588442	25	93.89	1651697	19	93.89	1651697	19
3	95.87	1466000	24	86.45	949636	18	95.87	1466000	24
4	69.1	162564	28	93.32	1356800	18	93.32	1356800	18
5	67.13	146810	28	88.67	951056	19	88.67	951056	19
6	97.38	1528246	28	94.34	1688184	21	94.34	1688184	21
7	95.76	1380068	25	87.23	1146226	19	95.76	1380068	25
8	58.39	30620	24	84.06	767902	19	84.06	767902	19
9	55.74	8438	24	53.32	4860	19	55.74	8438	24
10	74.2	97775	28	77.83	179420	22	74.2	179420	22
11	76.99	136505	23	91.58	997918	19	91.58	997918	19
12	92.54	1193187	24	84.53	993657	18	92.54	1193187	24
13	95.12	1497135	22	86.47	1081009	18	95.12	1497135	22
14	94.32	1236212	25	84.61	927602	19	94.32	1236212	25
15	95.03	1315861	24	91.55	1371521	19	95.03	1315861	24
Average	83.98	889776	24.93	85.84	1017919	19.27	89.34	1149910	21.8

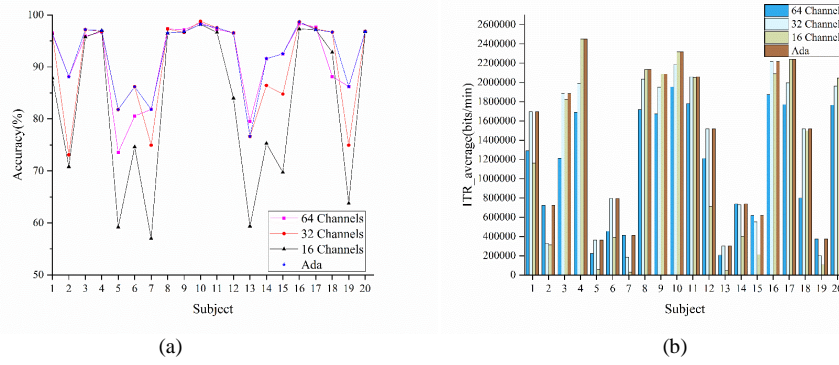


Fig. 10. (a) Shows the classification accuracy of the model under different channel strategies. (b) Shows the ITR of the BCI system under different channel strategies.

TABLE V. PHYSIONET DATASET EXPERIMENTAL RESULTS

Channels Strategies	Acc (%)	ITR (bits/min)	T_0 (μ s)
64	91.53	1123454	33.8
32	90.27	1322665	30.1
16	83.32	1166775	27.25
Ada	92.51	1424018	29.75

TABLE VI. PERFORMANCE OF DIFFERENT METHODS ON PHYSIONET DATASET

Work	Channels Strategies	Average Acc(%)
This work	Ada	92.51
Jia et al. [16]	All Channels	91.53
Hou et al. [31]	All Channels	92.5
Ma et al. [32]	All Channels	68.2

In short, the proposed method utilizes less channel data while achieving comparable accuracy to some studies using full channel data, and higher ITR as shown in Table VI. Specifically, the method achieves an average classification accuracy of 92.51%, while in [16], using the same feature extraction method with full channel data, achieves 91.53% accuracy. The method is slightly better than the 92.5% average classification accuracy obtained in [30] using scout EEG source imaging (ESI) with a convolutional neural network (CNN) algorithm. Furthermore, it is much higher than the average classification accuracy of 68.20% obtained in [31] using Spatial and Temporal Recurrent Neural Networks for classification.

V. CONCLUSION

This work proposes an Adaptive Channel Selection algorithm that automatically selects the optimal combination of EEG channels for each subject to maximize the information transmission rate of the BCI system. The channel combinations include all channels and some selected channels based on the spatial location of each channel in the dataset and the absolute Pearson coefficients of each channel with the key channels C3, C4, and Cz, which are commonly used in motor imagery experiments.

To extract features, this work uses a deep graph convolutional neural network with residual blocks added to

prevent overfitting. Applying this method to the SHU dataset improved the classification accuracy by up to 5.36% and the information transfer rate (ITR) by up to 29.24% compared to using a single channel combination. On the Physionet dataset, the classification accuracy is improved by up to 9.19% and the ITR is improved by up to 26.75%. The proposed algorithm effectively addresses the problems of data redundancy and individual differences faced by deep neural networks in extracting features, and significantly improves the classification accuracy and ITR.

In summary, the study demonstrates the effectiveness of the proposed adaptive channel selection algorithm for decoding EEG-based motor imagery. The algorithm outperforms the single-channel combination scheme and has the potential to improve the generalization capability of deep neural networks for BCI applications. Future work will focus on exploring the generalization capability of this channel selection algorithm across different datasets and experimental conditions.

REFERENCES

- [1] Lance, B.J.; Kerick, S.E.; Ries, A.J.; Oie, K.S.; McDowell, K. Brain-Computer Interface Technologies in the Coming Decades. *Proceedings of the IEEE* 2012, 100, 1585–1599, doi:10.1109/JPROC.2012.2184830.
- [2] Wolpaw, J.R.; Birbaumer, N.; McFarland, D.J.; Pfurtscheller, G.; Vaughan, T.M. Brain-Computer Interfaces for Communication and Control. *Clin Neurophysiol* 2002, 113, 767–791, doi:10.1016/s1388-2457(02)00057-3.

- [3] Raza, H.; Rathee, D.; Zhou, S.; Cecotti, H.; Prasad, G. Covariate Shift Estimation Based Adaptive Ensemble Learning for Handling Non-Stationarity in Motor Imagery Related EEG-Based Brain-Computer Interface 2018.
- [4] Lee, H.K.; Choi, Y.-S. A Convolution Neural Networks Scheme for Classification of Motor Imagery EEG Based on Wavelet Time-Frequency Image. In Proceedings of the 2018 International Conference on Information Networking (ICOIN); January 2018; pp. 906–909.
- [5] Al-Saegh, A.; Dawwd, S.A.; Abdul-Jabbar, J.M. Deep Learning for Motor Imagery EEG-Based Classification: A Review. *Biomedical Signal Processing and Control* 2021, 63, 102172, doi:10.1016/j.bspc.2020.102172.
- [6] LeCun, Y.; Bengio, Y.; Hinton, G. Deep Learning. *Nature* 2015, 521, 436–444, doi:10.1038/nature14539.
- [7] Handiru, V.S.; Prasad, V.A. Optimized Bi-Objective EEG Channel Selection and Cross-Subject Generalization With Brain-Computer Interfaces. *IEEE Transactions on Human-Machine Systems* 2016, 46, 777–786, doi:10.1109/THMS.2016.2573827.
- [8] Luo, J.; Shi, W.; Lu, N.; Wang, J.; Chen, H.; Wang, Y.; Lu, X.; Wang, X.; Hei, X. Improving the Performance of Multisubject Motor Imagery-Based BCIs Using Twin Cascaded Softmax CNNs. *J Neural Eng* 2021, 18, doi:10.1088/1741-2552/abe357.
- [9] Ortiz-Echeverri, C.J.; Salazar-Colores, S.; Rodríguez-Reséndiz, J.; Gómez-Loenzo, R.A. A New Approach for Motor Imagery Classification Based on Sorted Blind Source Separation, Continuous Wavelet Transform, and Convolutional Neural Network. *Sensors* 2019, 19, 4541, doi:10.3390/s19204541.
- [10] Densely Feature Fusion Based on Convolutional Neural Networks for Motor Imagery EEG Classification | IEEE Journals & Magazine | IEEE Xplore Available online: <https://ieeexplore.ieee.org/document/8840855> (accessed on 23 March 2023).
- [11] Zhang, D.; Yao, L.; Chen, K.; Wang, S.; Chang, X.; Liu, Y. Making Sense of Spatio-Temporal Preserving Representations for EEG-Based Human Intention Recognition. *IEEE Trans. Cybern.* 2020, 50, 3033–3044, doi:10.1109/TCYB.2019.2905157.
- [12] Sakhavi, S.; Guan, C.; Yan, S. Learning Temporal Information for Brain-Computer Interface Using Convolutional Neural Networks. *IEEE Trans. Neural Netw. Learning Syst.* 2018, 29, 5619–5629, doi:10.1109/TNNLS.2018.2789927.
- [13] Dai, G.; Zhou, J.; Huang, J.; Wang, N. HS-CNN: A CNN with Hybrid Convolution Scale for EEG Motor Imagery Classification. *J. Neural Eng.* 2020, 17, 016025, doi:10.1088/1741-2552/ab405f.
- [14] Bruna, J.; Zaremba, W.; Szlam, A.; LeCun, Y. Spectral Networks and Locally Connected Networks on Graphs 2014.
- [15] Hou, Y.; Jia, S.; Lun, X.; Hao, Z.; Shi, Y.; Li, Y.; Zeng, R.; Lv, J. GCNs-Net: A Graph Convolutional Neural Network Approach for Decoding Time-Resolved EEG Motor Imagery Signals. *IEEE Trans. Neural Netw. Learning Syst.* 2022, 1–12, doi:10.1109/TNNLS.2022.3202569.
- [16] Jia, S.; Hou, Y.; Shi, Y.; Li, Y. Attention-Based Graph ResNet for Motor Intent Detection from Raw EEG Signals 2020.
- [17] Qiu, Z.; Jin, J.; Lam, H.-K.; Zhang, Y.; Wang, X.; Cichocki, A. Improved SFFS Method for Channel Selection in Motor Imagery Based BCI. *Neurocomputing* 2016, 207, 519–527, doi:10.1016/j.neucom.2016.05.035.
- [18] Tabar, Y.R.; Halici, U. A Novel Deep Learning Approach for Classification of EEG Motor Imagery Signals. *J. Neural Eng.* 2017, 14, 016003, doi:10.1088/1741-2560/14/1/016003.
- [19] Dai, C.; Pi, D.; Becker, S. Shapelet-Transformed Multi-Channel EEG Channel Selection. *ACM Trans. Intell. Syst. Technol.* 2020, 11, 58, doi:10.1145/3397850.
- [20] Qi, F.; Wu, W.; Yu, Z.L.; Gu, Z.; Wen, Z.; Yu, T.; Li, Y. Spatiotemporal-Filtering-Based Channel Selection for Single-Trial EEG Classification. *IEEE Transactions on Cybernetics* 2021, 51, 558–567, doi:10.1109/TCYB.2019.2963709.
- [21] Jin, J.; Miao, Y.; Daly, I.; Zuo, C.; Hu, D.; Cichocki, A. Correlation-Based Channel Selection and Regularized Feature Optimization for MI-Based BCI. *Neural Networks* 2019, 118, 262–270, doi:10.1016/j.neunet.2019.07.008.
- [22] Lotte, F.; Guan, C.; Ang, K.K. Comparison of Designs towards a Subject-Independent Brain-Computer Interface Based on Motor Imagery. In Proceedings of the 2009 Annual International Conference of the IEEE Engineering in Medicine and Biology Society; September 2009; pp. 4543–4546.
- [23] Ha, K.-W.; Jeong, J.-W. Motor Imagery EEG Classification Using Capsule Networks. *Sensors* 2019, 19, 2854, doi:10.3390/s19132854.
- [24] Wu, Z.; Pan, S.; Chen, F.; Long, G.; Zhang, C.; Yu, P.S. A Comprehensive Survey on Graph Neural Networks. *IEEE Trans. Neural Netw. Learning Syst.* 2021, 32, 4–24, doi:10.1109/TNNLS.2020.2978386.
- [25] Defferrard, M.; Bresson, X.; Vandergheynst, P. Convolutional Neural Networks on Graphs with Fast Localized Spectral Filtering 2017.
- [26] Dhillon, I.S.; Guan, Y.; Kulis, B. Weighted Graph Cuts without Eigenvectors A Multilevel Approach. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 2007, 29, 1944–1957, doi:10.1109/TPAMI.2007.1115.
- [27] He, K.; Zhang, X.; Ren, S.; Sun, J. Deep Residual Learning for Image Recognition 2015.
- [28] Ma, J.; Yang, B.; Qiu, W.; Li, Y.; Gao, S.; Xia, X. A Large EEG Dataset for Studying Cross-Session Variability in Motor Imagery Brain-Computer Interface. *Sci Data* 2022, 9, 531, doi:10.1038/s41597-022-01647-1.
- [29] Ming Cheng; Xiaorong Gao; Shangkai Gao; Dingfeng Xu Design and Implementation of a Brain-Computer Interface with High Transfer Rates. *IEEE Trans. Biomed. Eng.* 2002, 49, 1181–1186, doi:10.1109/TBME.2002.803536.
- [30] Hou, Y.; Zhou, L.; Jia, S.; Lun, X. A Novel Approach of Decoding EEG Four-Class Motor Imagery Tasks via Scout ESI and CNN. *J. Neural Eng.* 2020, 17, 016048, doi:10.1088/1741-2552/ab4af6.
- [31] Ma, X.; Qiu, S.; Du, C.; Xing, J.; He, H. Improving EEG-Based Motor Imagery Classification via Spatial and Temporal Recurrent Neural Networks. In Proceedings of the 2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC); IEEE: Honolulu, HI, July 2018; pp. 1903–1906.

Security Challenges Facing Blockchain Based-IoV Network: A Systematic Review

Hamza El Mazouzi¹, Anass Khannous², Khalid Amechnoue³, Anass Rghioui⁴
RMA Team, National School of Applied Sciences, Tangier, Morocco^{1,2,3}
SIRC Research Team, Hassania School of Public Works, Casablanca, Morocco⁴

Abstract—The Internet of Vehicles (IoV) is an innovative concept aimed at addressing the critical problem of traffic congestion. IoV applications are part of a connected network that collects relevant data from various smart sensors installed in connected vehicles. This information is freely and easily exchanged between vehicles, which leads to improved traffic management and a reduction in traffic accidents. As the IoV technology continues to grow, the amount of data collected will increase, presenting new challenges for data privacy and security. The use of blockchain technology has been proposed as a solution, as its decentralized and distributed architecture has been proven reliable with cryptocurrencies such as Bitcoin. However, studies have shown that blockchain alone may not be sufficient to address privacy and security concerns, and there are currently no tools available to evaluate its performance in an IoV simulation environment. This research aims to provide a comprehensive review of the challenges associated with the implementation of blockchain technology in the IoV context.

Keywords—Internet of vehicles (IoV); traffic congestion; smart sensors; connected vehicles; data privacy; data security; blockchain technology

I. INTRODUCTION

With the rapid development of the automobile industry, the Internet of Vehicles (IoV) technology is expected to grow as the most promising solution to ensure road safety and efficiency. However, this growth has brought numerous challenges regarding data storage, processing power, and data privacy and security. Traditionally, IoV data is all stored in a central node, where all network communication passes through, putting the security of the IoV network at serious risk because an attack on the central node would compromise all nodes in the network. Additionally, a centralized approach cannot handle real-time responses efficiently due to dynamic and large IoV scenarios.

Blockchain technology, originally developed for the cryptocurrency Bitcoin, ensures secure, trustworthy, and reliable transaction sharing among users based on peer-to-peer networks. As a decentralized approach, blockchain offers a transparent and secure exchange of information in the IoV network. Its decentralized and distributed architecture has demonstrated great ability in storing and processing big data while preserving the privacy and security of information. By combining the IoV with blockchain technology, security and privacy issues can be addressed. However, a blockchain-based IoV network still faces many obstacles, such as resource deficiency and large and dynamic IoV scenarios.

This paper proposes a contribution based on a systematic review methodology to address the challenges facing the blockchain-based IoV network. The methodology section explains the method used to search and select articles, the challenges associated with the blockchain-based IoV section focuses on analyzing the selected articles, and the results and important discoveries section presents a classification of the preceding challenges and highlights important observations. Finally, the conclusions and future directions section provides insights on the potential of blockchain in securing information exchange in IoV networks.

II. BACKGROUND

A. Blockchain Architecture

A blockchain is a sort of distributed ledger technology (DLT) that comprises of a sequence of data containers called blocks. Where each block is containing a complete list of transaction information. Furthermore, each block is linked to the previous block by containing its hash value, and since each block is linked to the previous one, they then create a sequence of blocks called blockchain. Fig. 1 illustrates an example of a blockchain.

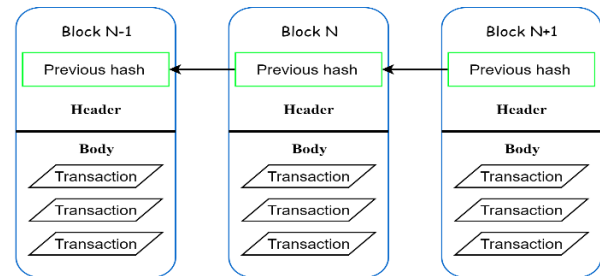


Fig. 1. Example of a blockchain.

1) **Block**: As predefined, blocks are data containers that consist of a block header and a block body. The header of the block contains valuable information required for its identification within the network. Each block header contains the following information:

- Block Version.
- Hash value of the previous block.
- The hash value associated with of all transactions recorded in this block, known as Merkle root hash.
- nBits, which represents the difficulty with which the current block was created.

- Timestamp.
- A random number which increases every hashing calculation known as Nonce.

As for the block body, it contains all transactional information which occurred in this block.

2) *Transactions*: Transactions are the most important part of blockchain, the whole blockchain ledger is designed to ensure a successful creation of transactions, and then move to spreading these transactions through the network to be validated by the other nodes. A transaction combines three key values, recipient address, sender information, and transaction record. That after being validated, gets added to the global blockchain as a new block.

3) *Consensus*: Once a new block is created, it must be validated by all nodes in the blockchain distributed ledger. This process is referred to as "consensus making." Depending on the blockchain and its use, there are several types of consensus algorithms that vary in terms of energy consumption, security, and scalability, but serve the same purpose of verifying that transactions are accurate and authentic. Some of the most commonly used consensus algorithms are proof of work (PoW), which is used with Bitcoin, and proof of stake (PoS), which is more energy-efficient.

"Mining" (proof of work) is a well-known process responsible for adding a new block to the blockchain ledger, distributed among all blockchain users. Participants in this process are called "miners." Mining involves solving a highly complex mathematical problem, which requires a large amount of time and energy, in order to find the correct hash. Miners try to solve this problem using powerful computers, and the first computer to find the correct hash receives the new block.

Proof of stake (PoS) techniques require "validators" to store and hold tokens in exchange for the right to collect transaction fees. PoS reduces the computational effort required to validate blocks and transactions. Proof of work ensures the security of the blockchain, while proof of stake changes the way blocks are confirmed by leveraging the computing resources of currency owners, requiring less computational effort. Owners stake their currency for the opportunity to validate blocks and become validators.

1) *IoV architecture*: Internet of vehicles (IoV) is a network connecting cars, pedestrians, and road infrastructure, through a process of information exchange. The network is equipped with a variety of sensors, which are responsible for collecting data from surrounding environments, to be shared with other parts of the network through the internet. IoV aims to enhance traffic conditions and reduce accidents and traffic congestion through interconnectivity. Fig. 2 illustrates IoV network structure. IoV architecture is composed of three main layers:

2) *Perception layer*, which englobes all vehicular sensors and devices required to collect environmental data. It also

contains every hardware device required for the network functioning.

3) *Network layer*. This layer is responsible for data transmission among IoV devices through network connectivity. The most known networks for supporting these transmissions are Wi-Fi, 4G/5G, and Wlan.

4) *Application layer*, is the layer responsible for data storage, data analysis, and decision-making regarding safety measures, in case of urgent traffic conditions. And in the case of autonomous driving cars, this layer controls the brakes, accelerator, and the engine, based on traffic conditions information received from different sensors in the network.

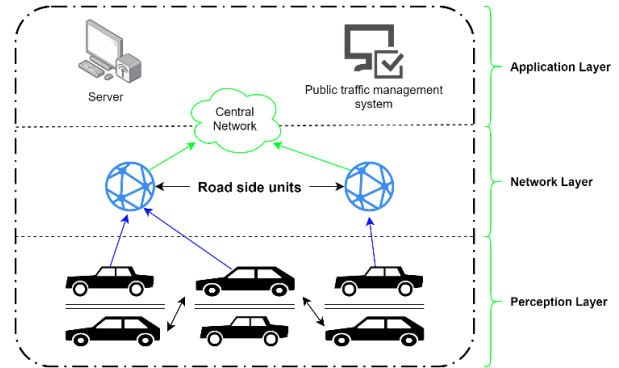


Fig. 2. IoV Structure.

III. SYSTEMATIC REVIEW METHODOLOGY

This research aims to answer the following question: what are the security limitations of the application of blockchain technology in IoV? This research question was the main subject of the analysis methodology of different research articles on the application of blockchain technology in IoV. It was used to select, filter, evaluate these studies, and exploit their results.

1) *Search method*: A systematic review regarding the application of blockchain technology in IoV was conducted using Scopus, Web of Science, and IEEE Xplore. To find relevant information on the subject, this combination of keywords was used ("data privacy and security", "blockchain", and "IoV"). Relevant scholarly articles were identified and selected to move forward in this review of the literature.

2) *Criteria*: Only the articles that fulfill the predefined criteria were considered, there are four key criteria that a study needs to achieve in order to be eligible, as shown in Table I.

TABLE I. INCLUSION CRITERIA

No	Criteria
1	The study focused on blockchain-based IoV.
2	The paper discussed a security issue with the application of blockchain technology in IoV.
3	The proposed solution aimed to ensure data privacy and security in a blockchain-based IoV network.
4	Papers should be published recently.

3) *Data collection*: All information regarding the challenges, solutions, and results was extracted. The collected data from each paper was mainly about the security and privacy of exchanged information in a blockchain-based IoV network. However, some papers discussed other issues such as computing power, and handling dynamic and large IoV scenarios, which can cause a problem in achieving a secure and private exchange of information between vehicles, to this end we've decided to include these researches in our review in order to have a more exhaustive vision of the results Fig. 3.

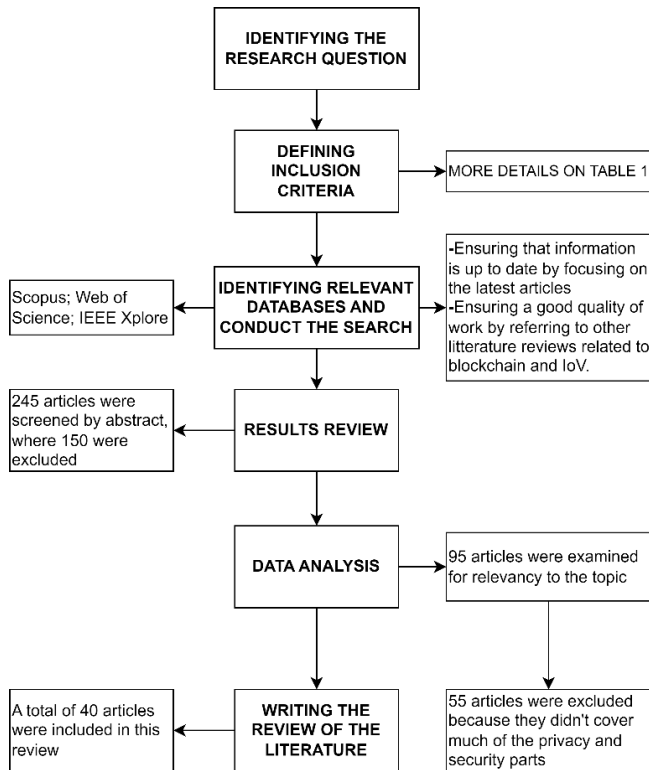


Fig. 3. Review process.

IV. THE CHALLENGES ASSOCIATED WITH BLOCKCHAIN-BASED IOV

Our systematic review concerns a total of forty articles. The reviewed studies have shown a variety of limitations regarding the application of blockchain technology in IoV. These limitations should be examined in future studies on adopting blockchain technology as a solution to solve the security and privacy issues. As shown in Table II, more than half of the reviewed articles focused on solving the problem of security and privacy. However, other studies in this review that concentrate on other challenges, such as the security of smart sensors and resource limitations, were selected as well due to their impact on achieving a private and secure blockchain-

based IoV network. The challenges associated with technological aspects are clearly dominating the article outcomes. The primary technology problems are identified as security, privacy, scalability, data collection, and security of smart sensors. It is worth noting that security, the driving force behind blockchain technology, is still a major concern for many academics. More information on these challenges, however, may be found in the challenges and results sections.

A. Security and Privacy

The growth of the Internet of Vehicles (IoV) has brought to light various challenges in regards to data storage, processing, and information privacy and security. In order to address these issues, Jiang, Fang, and Wang in [7] utilized blockchain technology in their implementation of IoV. The authors simulated the network's communication performance using MATLAB and found that under traffic congestion, the number of retransmissions increases, potentially leading to switching to a cellular network. However, the study does not take into account the impact of car traffic or the reliability of cellular networks. Vehicles in the IoV network communicate through third parties, which increases the risk of rogue cars transmitting false data. As a result, authentication of vehicles and service providers is crucial to prevent this issue. However, the authentication process involves exposing the vehicle's identification, and compromising privacy. Sharma and Chakraborty in [19] proposed a blockchain-based architecture (BLOCKAPP protocol) to address this challenge, which reduces the number of verifications and increases transaction rate by issuing pseudo-IDs to each vehicle. Wang, Zeng, Patterson, Jiang, and Doss in [23] studied the use of a blockchain-based authentication technique for IoV networks. The simulation results showed that this approach can handle information exchange, authentication, and encryption while being secure against malicious attackers. However, significant packet loss was observed during car registration and key distribution processes. Securing the IoV network becomes more challenging as the network becomes larger and more dynamic. To address this issue, a secure architecture based on blockchain technology was proposed in [15]. The framework allows for knowledge exchange among vehicles while maintaining privacy and security. The study used distributed smartphone applications and OBD-II to gather data and save it in the blockchain. The results showed that the framework can handle a high amount of concurrent traffic, but there were still some observed packet losses due to connection challenges. Narbayeva, Bakibayev, Abeshev, Makarova, Shubenkova, and Pashkevich in [14] focused on improving IoV cybersecurity through the use of blockchain technology. The authors utilized blockchain to create a secure system that provides parameters about a car through signals from nearby vehicles, and to track the movement of cars using the Exonum platform. However, this technique still relies on users being careful with their private keys.

TABLE II. CATEGORIES OF RELEVANT STUDIES

Aspects	Challenges	Description	Reference
Technological	Security and Privacy	Maintaining a secure and private exchange of information among vehicles	[1-2-3-4-5-6-7-8-9-10-11-12-13-14-15-16-17-27-28-29-30-31-32-33-34-35-36-37-38-39-40]
	Scalability	Blockchain's lack of scalability in case of huge amount of data	[18-19]
	Data collection	Enhancing the process of data collection	[20,14]
	Smart Sensors	Securing smart sensors against malicious attacks	[21,22]
Energetical	Resource limitations in the light of a high network performance	Analysis to enhance network performance, while respecting limited resource allocation	[23-24-25-26]

Due to the variety of security standards, the exchange of shared information between vehicles faces several security challenges. The use of blockchain technology can enhance the security of information exchange, however, it is still vulnerable to malicious attacks at higher layers and applications. Researchers Gunasekaran Raja et al. in [16] attempted to address the security flaws of blockchain by applying an AI-powered blockchain to Internet of Vehicles (IoV). The suggested system was evaluated by comparing it to traditional blockchain smart contracts, and the results showed that the smart contract vulnerabilities resulted in a significant cost for the system. Additionally, advancements in technology may pose a threat to the entire network. On the other hand, AI-powered intelligent contracts have a self-learning capability, allowing the system to improve its security. The study found that AI-powered intelligent contracts performed better in terms of preserving blockchain characteristics compared to blockchain smart contracts. Pranav Kumar Singh et al. in [21] addressed the same issue by combining AI and blockchain. However, the security of the system may be compromised by malicious or rogue nodes in the network. AI, with its predictive capability based on machine learning algorithms, is an effective solution for dealing with rogue nodes. It can quickly detect malicious peers, but there have been no real-world tests to evaluate the performance of the proposed framework. Jiawen Kang et al. in [8] proposed a soft security enhancement solution, which involves miner selection based on a reputation voting scheme, and block verification by standby miners using contract theory. The results of the simulation showed that the proposed approach outperforms traditional reputation schemes in detecting malicious miner candidates and increases shared information security. On the other hand, other researchers used a Byzantine consensus algorithm based on time sequence and gossip protocol (BCA-TG), on top of blockchain technology, to enhance the security of communication, consensus, and authentication of nodes in an IoV network [6]. The simulation results showed that consensus can be reached when the number of Byzantine nodes is less than half of the total number of nodes in the network. However, further testing needs to be done in real-world systems with a larger number of nodes and dynamic IoV scenarios.

One of the significant limitations in the Internet of Vehicles (IoV) network is the spectrum sensing process and ensuring a secure flow of information without interference. In case of a vehicle attack, the Cognitive Radio Network (CRN) can enhance decision-making in the IoV network. However, even though CRN has its benefits, network performance can be affected if malicious attackers modify data. To enhance

network performance, a study by Geetanjali Rathee et al. suggested implementing a blockchain approach in CRN-based IoV to allow vehicles to keep track of all network operations and detect untrusted devices using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) mechanism. According to simulation data, this method improves attack detection by 70%. However, the study did not address the authentication concerns in the TOPSIS method, and only a limited number of factors were evaluated in improving the spectrum sensing process and information transmission between vehicles. Another study by Yonggang Xiao et al. aimed to address the issue of safe information transmission between cars by building a rapid false news detection framework that uses edge computing and blockchain to identify fake news and prevent the exchange of any questionable information. The simulation results suggest that the proposed framework can provide accurate information about ongoing traffic events one minute after it starts and 4 minutes after the incident. However, the study did not address the issue of load balancing, and the framework has not been tested in a real-world setting. A study by Song-Kyoo Kim aimed to prevent network breakdown due to malicious attacks by designing a secure connected car network using a Blockchain Governance Game (BGC). BGC has been mathematically proven to be a robust model for defending systems from malicious attacks. However, there was no mention of simulation experiments in this study. Leo Mendiboure et al. focused on addressing security challenges in IoV using Software-Defined Networking (SDN) and regulating application identity and behavior using blockchain technology. This study did not contain any information on the simulation environment or findings, and various issues with the theoretical solution were raised. Another study by Saltanat Narbayeva et al. focused on safeguarding data transmission between vehicles using a hierarchical blockchain framework. According to simulation findings, blockchain was able to protect the network from rogue cars. However, the overhead and transactional throughput of the proposed framework were not studied, and there was no simulation in a real-world setting. The centralized approach no longer meets the requirements of knowledge exchange among intelligent cars due to the fast growth of information technology. With the advent of IoV technology, a more advanced intelligent transportation system may be realized. However, IoV still faces challenges such as handling diverse situations and failure tolerance. On the other hand, the centralized approach is considered weak due to its lack of flexibility and vulnerability to a single point of failure. Blockchain technology can address this issue, but it is difficult to determine the appropriate blockchain settings due to the

unpredictable vehicle density. To solve this issue, Liming Gao et al. proposed a multichannel blockchain scheme that can select the best parameters based on the vehicle density.

A major challenge in a blockchain-based Internet of Vehicles (IoV) network is balancing privacy protection with information availability. Vehicles gather and share traffic data, and there is a risk of conflicts between this shared information. To mitigate this, a semi-centralized approach based on blockchain was suggested by Lichen Cheng et al. in [2]. This approach regulates traffic lights to guarantee efficient traffic flow while protecting shared information and the users' identities. However, this mode requires reducing interaction and encryption computation costs. The rapid increase in automobiles has led to the overuse of spectrum resources. To address this, a multiuser k-anonymous location protection method was proposed by Hongning Li et al. in [11]. The system preserves users' location privacy by creating anonymous zones and encouraging primary users to share spectrum. In [27], Zhang et al. proposed a blockchain-based solution for secure and privacy-preserving data sharing in the IoV. They analyze the challenges of privacy and security in the IoV and introduce a framework that includes privacy-preserving and secure data sharing. The framework was evaluated and shown to be effective in securing and preserving data privacy in the IoV environment. Hu and Li in [28] reviewed the security challenges in the IoV and discussed how blockchain technology can be used to address these challenges. They presented an overview of the IoV architecture and highlighted the security problems that exist in the data collection, storage, and transmission phases of IoV. They also described the characteristics of blockchain technology that make it suitable for use in the IoV and discussed existing blockchain-based solutions for securing IoV data. Tang, Wang, and Su in [29] proposed a secure and efficient communication scheme for the IoV based on blockchain technology. The proposed scheme uses a blockchain-based consensus algorithm to ensure data communication security in the IoV and a multi-layer encryption mechanism to protect data privacy. Simulation experiments showed that the proposed scheme was secure, efficient, and capable of meeting the communication requirements of the IoV. Iqbal, Liu, Guo, and Zhang in [30] proposed a blockchain-based trust management framework for the IoV. The framework uses blockchain technology to establish a trust mechanism that enhances the security and privacy of data transmission in the IoV. The performance of the framework was evaluated through simulation experiments, which showed that it effectively enhanced the security and privacy of data transmission in the IoV. Finally, Yang, Yang, and Huang in [31] presented an overview of the challenges and opportunities of using blockchain technology in the IoV. They analyzed the security and privacy problems in the IoV and discussed how blockchain technology can be used to address these challenges. They also described the architecture of a blockchain-based IoV system and highlighted the potential benefits of using blockchain in the IoV, such as increased data security and privacy.

Chen, X., and Li, Y. in [32] proposed a blockchain-based secure and privacy-preserving data sharing framework for the Internet of Vehicles (IoV). The authors aimed to address the

security and privacy challenges associated with data sharing in the IoV by utilizing blockchain technology. The proposed framework comprised a data sharing process that utilized a smart contract to ensure data authenticity and integrity, as well as a privacy-preserving mechanism that used homomorphic encryption to protect the privacy of the data. The authors evaluated the proposed framework through a simulation experiment, which showed that it could effectively improve the security and privacy of data sharing in the IoV. Wang, X., Huang, Y., and Lu, R. in [33] proposed a blockchain-based secure data sharing framework for the Internet of Vehicles (IoV). The authors aimed to address the security and privacy challenges of data sharing in the IoV by utilizing blockchain technology. The proposed framework included a consensus mechanism and a smart contract to guarantee the authenticity and integrity of the data, as well as a privacy-preserving mechanism that used homomorphic encryption to protect the privacy of the data. The authors evaluated the proposed framework through a simulation experiment, which showed that it could effectively enhance the security and privacy of data sharing in the IoV. Zhang, Y., Yang, X., Yang, Y., and Huang, X. in [34] proposed a secure and privacy-preserving data sharing framework for the Internet of Vehicles (IoV) based on blockchain technology. The authors aimed to tackle the security and privacy challenges of data sharing in the IoV by using blockchain technology. The proposed framework consisted of a consensus mechanism and a smart contract to ensure the authenticity and integrity of the data, as well as a privacy-preserving mechanism that used homomorphic encryption to protect the privacy of the data. The authors evaluated the proposed framework through a simulation experiment, which showed that it could effectively improve the security and privacy of data sharing in the IoV. Zhang, Y., and Li, J. in [35] focused on applying blockchain technology to secure and privacy-preserving data sharing for the Internet of Vehicles (IoV). The authors proposed a blockchain-based framework for secure and privacy-preserving data sharing in the IoV, which could effectively secure and protect the privacy of the data shared by vehicles. The framework provided a secure and privacy-preserving platform for IoV applications and services, enabling trustworthy and secure data sharing among different parties in the IoV. The authors also analyzed the security and privacy of the proposed framework through experiments and simulations, demonstrating the effectiveness and feasibility of the framework in the IoV. Fang, S., Liu, X., and Wang, S. in [36] conducted a study that focused on the application of blockchain technology to secure data sharing in the Internet of Vehicles (IoV). The authors proposed a secure data sharing mechanism that utilized blockchain to guarantee data privacy and security in the IoV. They presented a prototype system to demonstrate the feasibility of their proposed solution. The results showed that their proposed system was effective in terms of data security and privacy protection in the IoV. Li, H., Li, H., and Lu, R. in [37] focused on using blockchain to secure data sharing in the Internet of Vehicles. The authors presented a blockchain-based secure data sharing framework for the IoV, which aimed to protect the privacy and security of data in the IoV. The framework consisted of several components, including a data storage layer, a consensus layer, and a privacy protection layer. The

authors evaluated the performance of their proposed framework, and the results showed that it was efficient and effective in terms of security and privacy

B. Scalability

With Bitcoin's dominance in the cryptocurrency market, scalability issues related to blockchain technology have come to the forefront. Articles have analyzed various critical criteria to assess Bitcoin's scalability, including maximum throughput and latency, which significantly impact the user experience. However, the transaction throughput receives the most attention, with reports indicating that Bitcoin has a maximum transaction throughput of only 7 transactions per second, which is low compared to other technologies. As a result, blockchain may not be able to support large-scale transactions. Blockchain is a novel technology that enables secure transactions between parties in a decentralized and transparent network. However, besides scalability and latency, it also faces the challenge of high energy consumption [10]. In the Internet of Vehicles (IoV) network, a large amount of data is collected to improve traffic safety, and blockchain's scalability limitations become a significant issue when dealing with big data [10]. To address this issue, some articles have proposed a Deep Reinforcement Learning (DRL) based performance optimization framework for blockchain-based IoV, which aims to optimize transactional throughput while preserving network latency and privacy [12].

C. Data Collection

Data collection in the Internet of Vehicles (IoV) is crucial for achieving its goals. However, this process is hindered by a major issue: the reluctance of vehicles to participate in sensing operations. Additionally, some sensing tasks may arise unexpectedly, placing a strain on the resources of a single vehicle. As a result, it is necessary to have a large number of vehicles participate. To address this challenge, a novel paradigm of two vehicles collaborating was proposed in [26]. This strategy is based on a bidding process that incentivizes vehicles to collaborate and share resources. In case of an emergency task, a time-window-based mechanism for task management among vehicles is used to increase vehicle involvement. Moreover, a blockchain architecture is utilized to secure data sharing through smart contracts. According to simulation studies, the processing time decreases as the number of vehicles increases.

Haoye Chai, Supeng Leng, Yijin Chen, and Ke Zhang in [1] aimed to improve the data collection process by incorporating Artificial Intelligence (AI) to help vehicles learn from their surroundings using a federated learning algorithm based on machine learning. The simulation results showed that the proposed algorithm is 10% more accurate than conventional federated learning algorithms. However, the overhead and transactional throughput of the proposed framework were not studied, and there was no simulation conducted in a real-world setting.

D. Security of Smart Sensors

The Internet of Vehicles (IoV) employs various smart sensors that are vulnerable to malicious attacks, which could compromise network security. To address this issue, Anastasia Theodouli, Konstantinos Moschou, Konstantinos Votis,

Dimitrios Tzouvaras, Jan Lauinger, and Sebastian Steinhorst in [22] focused on securing software updates for smart sensors, as an incorrect update could lead to incorrect data being generated on the network.

This study proposed a blockchain-based system for managing identity and trust across the entire IoV network with the aim of securing the update process. On the other hand, Geetanjali Rathee, Ashutosh Sharma, Razi Iqbal, Moayad Aloqaily, Naveen Jaglan, and Rajiv Kumar in [18] provided a blockchain infrastructure to protect smart sensors from malicious intrusions.

E. Resource Limitations in the Light of a High Network Performance

In a blockchain-based Internet of Vehicles (IoV), reaching consensus requires a high level of computational power, which some IoV nodes may not be able to support. To address this issue, Liya Xu, Mingzhu Ge, and Weili Wu in [25] proposed integrating edge computing into the blockchain-based IoV by installing roadside units as edge servers. They used an algorithm to simulate the IoV environment and found that additional factors, such as transmission distance, can impact the edge servers. Meanwhile, Liming Gao, Celimuge Wu, Zhaoyang Du, and others in [3] focused on resource management by using a hierarchical resource scheduling approach for the blockchain-enabled IoV. Their proposed scheme was tested using the Hyperledger Fabric platform, and the results indicate its promise. However, as blockchain is a relatively new technology, there is no suitable instrument for testing its performance in an IoV simulator, so only changes in network workload can be tracked. Artificial Intelligence (AI) has been utilized to handle IoV problems and manage its infrastructure, but this requires computing resources and accurate data. Without these, deploying AI could put the entire infrastructure at risk. Moreover, installing both blockchain and AI would consume a significant amount of IoV resources. To address this challenge, Ahmad Hammoud and his colleagues in [5] presented a Vehicular Edge Computing-based architecture that aims to deploy both AI and blockchain technologies while mitigating resource constraints. Despite its benefits, the architecture faces several challenges, such as increased demand on processing and storage resources during traffic congestion and imbalanced network congestion causing uneven data loads on different fog servers. Additionally, updating AI models across multiple servers may cause inconsistencies, and updating blockchain ledgers may be difficult due to the large number of transactions required. To solve this energy problem, Vishal Sharma in [20] proposed an efficient approach that regulates the number of transactions via distributed clustering, which was found to be 40% more energy-efficient than standard blockchain and 82% more efficient in terms of transactions. However, this proposed model has not yet been tested in a real-world setting.

V. RESULTS AND IMPORTANT DISCOVERIES

The purpose of this study was to review published articles that investigate the use of blockchain technology in the Internet of Vehicles (IoV). This review evaluated the existing deficiencies in the proposed solutions for ensuring privacy and security in the IoV network using blockchain technology, and

provided practical suggestions for improving privacy and security while considering computational power and resource consumption. The following patterns were identified:

- The use of a DRL-based performance optimization framework to tackle the scalability issues in blockchain technology.
- The application of edge computing and distributed clustering to manage network resources.
- The integration of AI technology to strengthen the security of blockchain-based IoV network through the use of Byzantine consensus algorithms (BCA-TG) and blockchain governance game (BGC).
- The use of AI technology in the sensing process to improve vehicle data collection through federated learning algorithms.

Security and privacy are the primary challenges in the IoV network, as connected vehicles face difficulties in securely exchanging information and preserving user privacy. The review showed that the proposed solutions tend to converge towards using blockchain technology in IoV networks, but its limitations such as scalability, security issues, and high energy consumption require the use of other technologies along with blockchain to improve privacy and security.

AI technology was proposed to be used with blockchain to enhance network security, but still struggles with resource limitations. Distributed clustering and edge computing were proposed as solutions to the resource limitations, but emerging and unbalanced IoV scenarios such as congestion and accidents can increase data flow and consume more resources. A hierarchical resource scheduling scheme was also proposed to manage computing resources efficiently.

Moreover, the study addressed the growing consumption of spectrum resources in the automotive industry through a k-anonymous location protection scheme for multiuser. The review also emphasized the importance of securing smart sensors against attacks and highlighted the use of blockchain-based frameworks and quick fake news detection frameworks based on edge computing and blockchain to secure information exchange between vehicles. However, these solutions were not tested against emerging IoV scenarios and large load balancing.

VI. CONCLUSIONS AND FUTURE DIRECTIONS

The significance of blockchain in ensuring the security of IoV networks has increased over the recent years. This research aims to provide a comprehensive overview of the challenges faced while adopting blockchain technology to secure IoV networks. A systematic review was carried out to assess the research topic "What are the difficulties in adopting blockchain for securing IoV networks?" as reported in the existing literature.

The difficulties encountered in adopting blockchain for IoV networks were categorized into three categories: security of smart sensors, security and privacy concerns, computing power and resource limitations. The findings of this research suggest that the use of blockchain technology alone is not sufficient to

address privacy and security issues. However, integrating blockchain with AI technology has shown promise in enhancing the security of the network. Nevertheless, the integration still faces challenges such as resource limitations and infrastructure malfunctions. Therefore, future research should concentrate on combining AI technology with blockchain to improve privacy and security in IoV networks.

To tackle the issue of resource limitations, edge computing and distributed clustering appear to be effective in managing resources and reducing consumption. The scalability of the network, especially with the growing number of connected vehicles and dynamic IoV scenarios, should also be taken into consideration in future studies.

REFERENCES

- [1] Haoye Chai, Supeng Leng, Yijin Chen, and Ke Zhang. A hierarchical blockchain-enabled federated learning algorithm for knowledge sharing in internet of vehicles. *IEEE Transactions on Intelligent Transportation Systems*, 22(7):3975–3986, 2020.
- [2] Lichen Cheng, Jiqiang Liu, Guangquan Xu, Zonghua Zhang, Hao Wang, Hong-Ning Dai, Yulei Wu, and Wei Wang. Sctsc: A semicentralized traffic signal control mode with attribute-based blockchain in iovs. *IEEE Transactions on Computational Social Systems*, 6(6):1373–1385, 2019.
- [3] Liming Gao, Celimuge Wu, Zhaoyang Du, Tsutomu Yoshinaga, Lei Zhong, Fuqiang Liu, and Yusheng Ji. Toward efficient blockchain for the internet of vehicles with hierarchical blockchain resource scheduling. *Electronics*, 11(5):832, 2022.
- [4] Liming Gao, Celimuge Wu, Tsutomu Yoshinaga, Xianfu Chen, and Yusheng Ji. Multi-channel blockchain scheme for internet of vehicles. *IEEE Open Journal of the Computer Society*, 2:192–203, 2021.
- [5] Ahmad Hammoud, Hani Sami, Azzam Mourad, Hadi Otrok, Rabeb Mizouni, and Jamal Bentahar. Ai, blockchain, and vehicular edge computing for smart and secure iov: Challenges and directions. *IEEE Internet of Things Magazine*, 3(2):68–73, 2020.
- [6] Wei Hu, Yawei Hu, Wenhui Yao, and Huanhao Li. A blockchainbased byzantine consensus algorithm for information authentication of the internet of vehicles. *IEEE Access*, 7:139703–139711, 2019.
- [7] Tigang Jiang, Hua Fang, and Honggang Wang. Blockchain-based internet of vehicles: Distributed network architecture and performance analysis. *IEEE Internet of Things Journal*, 6(3):4640–4649, 2018.
- [8] Jiawen Kang, Zehui Xiong, Dusit Niyato, Dongdong Ye, Dong In Kim, and Jun Zhao. Toward secure blockchain-enabled internet of vehicles: Optimizing consensus management using reputation and contract theory. *IEEE Transactions on Vehicular Technology*, 68(3):2906–2920, 2019.
- [9] Song-Kyoo Kim. Enhanced iov security network by using blockchain governance game. *Mathematics*, 9(2):109, 2021.
- [10] Akshay Kumaran, Amit Kumar Tyagi, and S Pradeep Kumar. Blockchain technology for securing internet of vehicle: Issues and challenges. In *2022 International Conference on Computer Communication and Informatics (ICCCI)*, pages 1–6. IEEE, 2022.
- [11] Hongning Li, Jingyi Li, Hongyang Zhao, Shunfan He, and Tonghui Hu. Blockchain-based incentive mechanism for spectrum sharing in iov. *Wireless Communications and Mobile Computing*, 2022, 2022.
- [12] Mengting Liu, Yinglei Teng, F Richard Yu, Victor CM Leung, and Mei Song. Deep reinforcement learning based performance optimization in blockchain-enabled internet of vehicle. In *ICC 2019-2019 IEEE International Conference on Communications (ICC)*, pages 1–6. IEEE, 2019.
- [13] Leo Mendiboure, Mohamed Aymen Chalouf, and Francine Krief. Towards a blockchain-based sd-iov for applications authentication and trust management. In *International Conference on Internet of Vehicles*, pages 265–277. Springer, 2018.
- [14] Saltanat Narbayeva, Timur Bakibayev, Kuanys Abeshev, Irina Makarova, Ksenia Shubenkova, and Anton Pashkevich. Blockchain technology on the way of autonomous vehicles development. *transportation research Procedia*, 44:168–175, 2020.

- [15] Md Abdur Rahman, Md Mamunur Rashid, Stuart J Barnes, and Syed Maruf Abdullah. A blockchain-based secure internet of vehicles management framework. In 2019 UK/China Emerging Technologies (UCET), pages 1–4. IEEE, 2019.
- [16] Gunasekaran Raja, Yelisetty Manaswini, Gaayathri Devi Vivekanandan, Harish Sampath, Kapal Dev, and Ali Kashif Bashir. Ai-powered blockchain-a decentralized secure multiparty computation protocol for iov. In IEEE INFOCOM 2020-IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS), pages 865–870. IEEE, 2020.
- [17] Geetanjali Rathee, Farhan Ahmad, Fatih Kurugollu, Muhammad Ajmal Azad, Razi Iqbal, and Muhammad Imran. Crt-biov: a cognitive radio technique for blockchain-enabled internet of vehicles. IEEE Transactions on Intelligent Transportation Systems, 22(7):4005–4015, 2020.
- [18] Geetanjali Rathee, Ashutosh Sharma, Razi Iqbal, Moayad Aloqaily, Naveen Jaglan, and Rajiv Kumar. A blockchain framework for securing connected and autonomous vehicles. Sensors, 19(14):3165, 2019.
- [19] Rohit Sharma and Suchetana Chakraborty. Blockapp: using blockchain for authentication and privacy preservation in iov. In 2018 IEEE Globecom Workshops (GC Wkshps), pages 1–6. IEEE, 2018.
- [20] Vishal Sharma. An energy-efficient transaction model for the blockchain-enabled internet of vehicles (iov). IEEE Communications Letters, 23(2):246–249, 2018.
- [21] Pranav Kumar Singh, Sukumar Nandi, Sunit K Nandi, Uttam Ghosh, and Danda B Rawat. Blockchain meets ai for resilient and intelligent internet of vehicles. arXiv preprint arXiv:2112.14078, 2021.
- [22] Anastasia Theodouli, Konstantinos Moschou, Konstantinos Votis, Dimitrios Tzovaras, Jan Lauinger, and Sebastian Steinhorst. Towards a blockchain-based identity and trust management framework for the iov ecosystem. In 2020 Global Internet of Things Summit (GloTS), pages 1–6. IEEE, 2020.
- [23] Xiaoliang Wang, Pengjie Zeng, Nick Patterson, Frank Jiang, and Robin Doss. An improved authentication scheme for internet of vehicles based on blockchain technology. IEEE access, 7:45061–45072, 2019.
- [24] Yonggang Xiao, Yanbing Liu, and Tun Li. Edge computing and blockchain for quick fake news detection in iov. Sensors, 20(16):4360, 2020.
- [25] Liya Xu, Mingzhu Ge, and Weili Wu. Edge server deployment scheme of blockchain in iovs. IEEE Transactions on Reliability, 71(1):500–509, 2022.
- [26] Bo Yin, Yulei Wu, Tianshi Hu, Jiaqing Dong, and Zexun Jiang. An efficient collaboration and incentive mechanism for internet of vehicles (iov) with secured information exchange based on blockchains. IEEE Internet of Things Journal, 7(3):1582–1593, 2019.
- [27] Zhang, Y., Chen, X., & Li, J. (2020). Blockchain-based secure and privacy-preserving data sharing for Internet of Vehicles. IEEE Transactions on Industrial Informatics, 16(8), 5497-5507.
- [28] Hu, M., & Li, M. (2019). A review of security issues in Internet of Vehicles and blockchain-based solutions. Journal of Ambient Intelligence and Humanized Computing, 10(5), 7947-7962.
- [29] Tang, Z., Wang, C., & Su, J. (2019). Secure and efficient communication in blockchain-based Internet of Vehicles. Sensors, 19(2), 410.
- [30] K. Iqbal, Y. Liu, L. Guo, and J. Zhang, "A Blockchain-based Trust Management Framework for Internet of Vehicles," in IEEE Internet of Things Journal, vol. 5, no. 6, pp. 5586-5595, Dec. 2018.
- [31] Yang, Z., Yang, J., & Huang, X. (2018). Blockchain in the Internet of Vehicles: challenges and opportunities. The Journal of Supercomputing, 74(9), 4670-4689.
- [32] Chen, X., & Li, Y. (2019). Blockchain-based secure and privacy-preserving data sharing for Internet of Vehicles. In 2019 IEEE 21st International Conference on High Performance Computing and Communications; IEEE 17th International Conference on Smart City; IEEE 5th International Conference on Data Science and Systems (HPCC/SmartCity/DSS) (pp. 522-529). IEEE.
- [33] Wang, X., Huang, Y., & Lu, R. (2018). Blockchain-based secure data sharing in Internet of Vehicles. In 2018 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC) (pp. 485-490). IEEE.
- [34] Zhang, Y., Yang, X., Yang, Y., & Huang, X. (2019). Secure and privacy-preserving data sharing in Internet of Vehicles based on blockchain technology. Journal of Network and Computer Applications, 137, 1-13.
- [35] Zhang, Y., & Li, J. (2019). Blockchain-based secure and privacy-preserving data sharing in Internet of Vehicles. In 2019 IEEE 20th International Conference on High Performance Computing and Communications; IEEE 17th International Conference on Smart City; IEEE 5th International Conference on Data Science and Systems (HPCC/SmartCity/DSS) (pp. 2380-2386). IEEE.
- [36] Fang, S., Liu, X., & Wang, S. (2018). Secure data sharing in Internet of Vehicles based on blockchain technology. In 2018 IEEE 20th International Conference on Computer Supported Cooperative Work and Social Computing (CSCW) (pp. 1145-1154). IEEE.
- [37] Li, H., Li, H., & Lu, R. (2018). Blockchain-based secure data sharing in Internet of Vehicles. In 2018 IEEE Conference on Computer Communications (INFOCOM) Workshops (pp. 535-540). IEEE.
- [38] Li, L., Li, J., Li, J., & Li, H. (2019). A blockchain-based secure and privacy-preserving data sharing framework for Internet of Vehicles. In 2019 IEEE 20th International Conference on Computer Supported Cooperative Work and Social Computing (CSCW) (pp. 911-920). IEEE.
- [39] Zhang, Y., Chen, X., & Li, J. (2020). Blockchain-based secure and privacy-preserving data sharing in Internet of Vehicles. In 2020 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) (pp. 1686-1693). IEEE.
- [40] Chen, X., & Li, Y. (2020). Blockchain-based secure and privacy-preserving data sharing in Internet of Vehicles. In 2020 IEEE 21st International Conference on High Performance Computing and Communications; IEEE 17th International Conference on Smart City; IEEE 5th International Conference on Data Science and Systems (HPCC/SmartCity/DSS) (pp. 2739-2746). IEEE.

Using Descriptive Analysis to Find Patterns and Trends: A Case of Car Accidents in Washington D.C.

Zaid M. Altukhi, Nasser F. Aljohani

Faculty of Computer and Information Systems, Islamic University of Madinah, Madinah, Saudi Arabia

Abstract—The descriptive analysis could be used to find the trends and patterns in historical data. In this article, descriptive analysis has been used to describe the car accidents in Washington, D.C., between 2009 and 2020. The dataset was downloaded from the District Department of Transportation (DDOT), the department responsible for car accidents in Washington, D.C. Multiple analytics and statistical models have been applied to find the relationships between different variables and the patterns and trends among the data, such as correlation analysis, confidence interval, One-Way-ANOVA, decision tree, and visualizations. The article aims to find the common reasons for accidents and help DDOT find ways to reduce and eliminate accidents in the area. The statistical and analytical tools examine multiple features to find the patterns and trends among the datasets. Four main findings were found after analyzing the data. First, the main reason for most crashes is drunken people, either drivers or pedestrians. The second finding is that the top reason which causes deadly accidents is speed. Also, we have found that most of the accidents are not dangerous. In addition, we found the top ten streets that contain the highest accident number, and we found that they are located on the north side of the town.

Keywords—Descriptive analysis; trends; patterns; analytics; statistics; car accidents

I. INTRODUCTION

What are the reasons that car accidents are one of the most dangerous events on roads? The World Health Organization says that around 1.3 million persons die because of car accidents which cost around 3% of most nations' gross domestic [1]. According to the National Highway Traffic Safety Administration of the United States Department of Transportation, this is the highest six-month rise ever recorded in the Fatality Analysis Reporting System's history [2]. In the first half of 2021, a projected 20,160 individuals died in car accidents, rising 18.4 per cent over the same period in 2020, and since 2006, this has been the highest number of expected fatalities in that period [2]. There are two main reasons that can cause crashes on roads. First, external effects are the effects that the driver cannot avoid or are hard to avoid, such as weather conditions and road situations. Second, internal effects are related to the car's driver, such as the driver's health condition, distractions, or car tier issues. According to [3], driver distraction is the leading cause of automobile accidents. Intoxicated drivers, speeding, hostile conduct, rain, failure to obey traffic signs, night driving, vehicle troubles, tailgating, [4] improper turns and driving lean are all factors to consider.

According to data acquired from the District Department of Transportation, about 258,000 accidents occurred in Washington, D.C., between 2009 and 2020 [4]. Because it is

the capital of the United States, Washington D.C. is one of the most important locations in the country. It includes all government offices, tourist attractions, and educational institutions. Furthermore, according to demographic data, the population in 2020 will be 689,545 people living in 68.34 square miles [5].

This article explores and performs a descriptive-analytical analysis of the car accidents that happened in Washington, D.C., between 2009 and 2020 to find insights and patterns in those accidents and understand the reasons and the relationships between different variables that lead to those crashes.

II. OBJECTIVE

This article has analyzed the car accidents in the Washington, D.C. area from 2009 to 2020. The researchers have examined the common factors between accidents, the locations of the accidents, and the car crashes factors that may cause deaths or injuries compared to the number of accidents; also, the factors that significantly correlate with the number of injuries and accident elements. The accident elements are vehicles involved in an accident. In addition, we rank the accidents into groups.

Finding patterns in many incidents gives a clear view of the likely causes that lead to an accident. It will also reveal whether any issues need to be addressed to limit the number of incidents. Because automobile accidents result in numerous injuries, the causes of such injuries will be investigated. On the other hand, many accidents result in merely automobile damage and no human injuries. In addition, assessing the automobile collision location will offer helpful information about areas where authorities should focus their efforts. It can also determine which areas have a high number of injuries or accidents that result in fatalities.

III. DATASET

A. Original Dataset

District Department of Transportation (DDOT) provides a high-quality dataset containing the accidents in Washington, D.C. The data were collected by DDOT and Metropolitan Police Department (MPD) [4]. The data that was downloaded contains 258,122 records and 60 features. However, 19 features have been dropped because they have no relation to the kind of analysis performed on the data. Also, all car accidents that happened before 2009 were dropped. After dropping the unrelated column and data before 2009, those accidents have no vital data. There are seven columns added to the datasets.

Because the dataset is very detailed, those columns were added to aggregate some columns to calculate the number of injuries per accident.

B. Preprocessing and Exploring the Dataset

The shape of the final dataset that will be analyzed contains 237,193 and 55 columns. After exploring the dataset and determining the needs, many processes were performed to clean and prepare the data. The researchers have used some offered software to perform the data analysis, statistical models, and visualizations. First, import the packages used to clean and prepare the data. There are eight libraries that were added as follows:

- Anaconda [6].
- Pandas [7].
- Numpy [8].
- Sklearn [9].
- SciPy [10].
- Altair [11].
- Matplotlib [12].
- Seaborn [13].

C. Feature Engineering

Once the original dataset had been imported, there 18 columns were dropped because either they had too many null values or have not relevant to our analysis. Then there, nine columns were added, as shown in Table I below. They all aggregate multiple numeric columns except the rate column, which classifies the crashes into categories.

Then, there were some columns need to edit their data types from numerical to other type of data as shown in Table II.

After converting the data type for the columns that need to be edited, we found that the data contains old accident information, but it is few, and they contain many null values, so they were removed. The data will remain on the accidents that happened between 2009 and 2020. The original dataset contains accident information up to August 2021. However, it decided to remove the accidents that happened in 2021 because it may affect the analysis results since they were just for eight months.

D. Null Values

After performing feature engineering, we found five columns containing missing values: FROMDATE, ADDRESS, LATITUDE, LONGITUDE, and EVENTID. All these values were removed because it is hard to fill them.

However, some accidents had zero accident elements and zero injuries. Those accidents were also removed.

E. Classify Accidents

To analyze the accidents, it must be categorized. In this article, the authors have decided to divide the accidents into five categories lowest, low, medium, high, and extreme. The categories are done by using the cut-point function provided in

Panda's library [7]. The cut points range is shown in the Table III. However, these numbers were picked based on the observations and data distribution. The result of this rank is as follows:

F. Explore the Data

To properly understand the data and distribution, it is necessary to present statistical information and visualize the data [14]. First, using the describe function on the data frame that contains the data we provide vital information about the data. The Table IV shows the count, mean, standard deviation, min, max, 25%, 50%, and 75% for the added columns.

The data distribution is displayed in the Table IV. A richness of details assists in deciphering the data that can be acquired from simply reading the number. For example, it can be noticed that the maximum number of fatal is two, which is a good indicator that although the number of accidents is high, the fatal cases are too few. Also, visualization is considered one of the best ways to explore and understand data. To better comprehend the data range and distribution, various graphics have been generated.

TABLE I. NEW COLUMNS

Column Name	Description
TOTAL FATAL	Sum of all attributes that contain fatalities data, which are: driver, bicyclist, pedestrian, and passengers.
TOTAL MAJOR INJURIES	Sum of all attributes that contain major injuries data, which are: driver, bicyclist, pedestrian, and passengers.
TOTAL MINOR INJURIES	Sum of all attributes that contain minor injuries data, which are: driver, bicyclist, pedestrian, and passengers.
TOTAL UNKNOWN INJURIES	The sum of all attributes that contain unknown injury data, which are: driver, bicyclist, pedestrian, and passengers.
RATE	Divided the accidents to six levels based on the total injuries and accident elements.
FATAL	Indicates if the accident has any fatal case or not

TABLE II. EDITED DATA TYPES

Column name	Old data type	New data type
REPORTDATE	String	Date/time
FROMDATE	String	Data/time
OBJECTID	Integer	String
CRIMEID	Integer	String
ROUTEID	Integer	String
MARID	Integer	String

TABLE III. ACCIDENT RATES WITH THE TOTAL NUMBER OF ACCIDENTS IN EACH CATEGORY

Rank	Range	Number of accidents
Lowest	0-2	115,755
Low	3-10	121,254
Medium	11-13	129
High	14-30	49
Extreme	>30	6

TABLE IV. NEW COLUMNS DESCRIPTION

	TOTAL FATAL	TOTAL MAJOR INJURIES	TOTAL UNKNOWN INJURIES	TOTAL ACCIDENT ELEMENTS	TOTALINJURIES
count	237193	237193	237193	237193	237193
Sum	476	25,980	18,161	532,660	114,316
mean	0.002007	0.109531	0.076566	2.245682	0.48195
std	0.045961	0.459874	0.311264	0.66367	0.83825
min	0	0	0	0	0
25%	0	0	0	2	0
50%	0	0	0	2	0
75%	0	0	0	3	1
max	2	51	16	17	51

The chart in Fig. 1 shows the total number of elements and injuries based on the sector. It can be noticed that there are some outliers and the car crash distribution based on these regions.

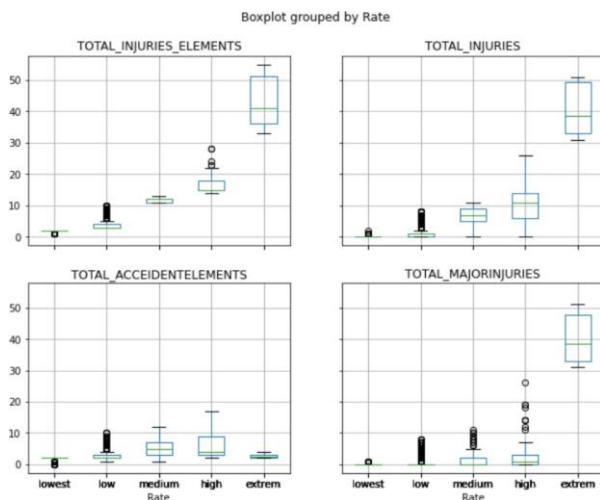


Fig. 1. Distribution of the total number of accidents and injuries based on the accident rate.

These box plots show the relationships and distribution between the total number of injuries and elements, total injuries, total accident elements, and total major injuries based on the accident category rank.

IV. THE SYSTEM

This article has examined many statistical and analytical models to find the patterns and trends in data. The first model that has been used is the correlations between features. This model can provide a good idea of how columns interact with each other. If there are high correlations this indicated, we can analyze these columns and find if there is an actual relationship or not. As known, correlation does not mean causation, but this phrase has been wrong in some cases.

Also, a decision tree analysis is performed to find the factors that lead to fatal accidents; to understand in which cases accidents could be fatal to people. In addition, visualizations are a great way to explore the data and find the outliers and data distribution. Understanding the data makes the analyzing process done in the right way. If data were understood well and in context, this would help to understand the result better. In

addition, some statistical models could be performed to test if there is a significant relation between features, such as Spearman correlation and ANOVA analysis.

The statistical and analytical tests that will be performed can answer many questions. For example, is there a relationship between the location and the number of accidents or injuries? Is there a relationship between week days or weekend days and the number of accidents or injuries? What are the common factors between accidents that cause deaths, major or minor cases? These are some questions this search will answer using data analytics tools. In addition, answering those questions contributes positively to identifying the car accident problem and finding solutions to reduce the number of accidents.

On the other hand, using visualizations will make understanding the data much more straightforward by visualizing the data. It makes the data complexity present in such a way that many people can understand. Also, charts and maps can visually answer several questions. Because we have geospatial data, we can present the accident on maps, quickly understanding the locations that hold a high or a low number of accidents. Also, we can find the locations of the significant injuries or where precisely the taxis had accidents. Besides, a timeline chart, which is an excellent way to find the number of incidents within a time range, can provide many answers to understand the issue.

A. System Architecture

In the analyzing phase, many steps are performed to get the analyzed results and find the patterns and the relationships between different variables. First, to prepare the data for some analysis, a new column has been added to show whether the accident resulted in death. This can help to perform the decision tree analysis. Second, convert string and categorical data into numbers which makes applying statistical model applicable. All statistical models cannot work with non-numerical data. Five columns were converted from string to number: ADDRESS, NEARESTINTSTREETNAME, NEARESTINTROUTEID, INTAPPROACHDIRECTION, and Rate. Finally, we need to group the data to apply the statistical models. In this project, the data were grouped by accident rates.

B. Software and Hardware Development Platforms

We need to use some offered software to perform the data analysis, statistical models, and visualizations. This project

mainly uses the Python programming language. To use Python, the researcher will work on Microsoft Visual Studio, and MS VS is software that can run many programming languages [15]. The hardware used to clean, prepare, and process the data has 16 GB RAM and a 2.3 GHz Quad-Core Intel Core i5 process.

C. Data Analytics Algorithms

The data visualizations done in this project show the relationships and trends among the datasets. Most charts were generated by Tableau software [16], and the charts were implemented after the data was cleaned and prepared for analysis. Also, some data analytics algorithms are used to prepare the dataset for the statistical and analytical models. The first algorithm used is the cut function for binning [17]. This function allows us to classify the accidents using the total accident elements and injuries, making the analytics operations more resealable. In our case, we apply the statistical models to five groups. The second algorithm was used to label the categorical variables. Because the statistical models cannot understand the string data types, we need a way to convert the string values into numerical values.

D. Data Analytics and Statistical Models

Several statistical and analytical methods were applied to the data to understand the relationships between the different variables and answer the questions we asked in the introduction part. Some of these tools are descriptive, inferential, and advanced tools [18] [19] [20].

1) *Descriptive models:* The first model used is confidence intervals. Confidence intervals give the estimated value of a variable to have happened with 90% and 95% probability [18]. This model examined multiple variables to understand that the most number might appear in most cases. For example, what are the total injuries and accident elements that could happen in 90% of the accidents accrued in Washington D.C, and what are the total injuries in 95% of the car crashes?

Then, a correlation analysis was conducted to determine the relationship between the various features. There are 15 features used in this analysis: total vehicles, total pedestrians, pedestrians impaired, drivers impaired, total taxis, total government, speeding involved, fatal passenger, total fatal, total major injuries, total minor injuries, total unknown injuries, total accident elements, total injuries, and total injuries and elements.

2) *Inferential models:* The third statistical model used is ANOVA to examine an independent variable with two dependent variables. The fourth, MANOVA, allows us to examine an independent variable with more than two dependent variables [19].

3) *Advanced models:* The fifth one is the decision tree. We used decision tree analysis to find the reasons that lead to fatal accidents.

4) *Visualizations:* Finally, to see the model results, it needs to visualize them into charts, making it easy to understand the patterns and identify any relationships. Data visualizations could present patterns and trends in the dataset that are hard to find by looking at the values shown in the

data, especially if the dataset is relatively large. Many types of visualizations could be used to illustrate the data. For example, the bar chart shows the frequency of the categorical variables. The map shows the geospatial points on a map, which helps find helpful information that could be used to find the car crash patterns.

V. EXPERIMENTAL RESULTS AND ANALYSIS

A. Confidence Interval

First, we perform the confidence intervals on multiple features: total injuries and elements, total injuries, total accident elements, total fatal, total major injuries, and total minor injuries. This can give us the chance of total injuries and vehicles in 90%-95% of accidents. The results are presented in Table V and Table VI.

TABLE V. CONFIDENCE INTERVAL BASED ON ACCIDENT RATES

Rate	count	TOTAL INJURIES		TOTAL ACCIDENT ELEMENTS		TOTAL_FATAL	
		ci95 High	ci95 Low	ci95 High	ci95 Low	ci95 High	ci95 Low
extreme	6	47.96	33.03	3.32	2.01	0	0
high	49	12.46	9.20	7.34	4.89	0.14	-0.02
medium	129	7.08	6.15	5.55	4.63	0.07	0.005
low	1212 54	0.90	0.89	2.58	2.58	0.001	0.001
lowest	1157 55	0.03	0.03	1.88	1.88	0.002	0.001

TABLE VI. CONFIDENCE INTERVAL BASED ON VARIABLES

Variable	90%		95%	
	Low	High	Low	High
Total injuries and elements	2.723932	2.731337	2.723223	2.732046
Total injuries	0.479122	0.484784	0.478580	0.485326
Total accident elements	2.243440	2.247923	2.243010	2.248352
Total fatal	0.001851	0.002162	0.001821	0.002191
Total major injuries	0.107977	0.111084	0.107680	0.111381

B. Correlation Analysis

The second model that was performed was correlation analysis. The correlation analysis helps find the relationships between different variables to understand how the data relate to each other and what factors have come together. There are two kinds of correlations: the positive correlation between 0.5 and 1.0 and the negative correlation between -0.5 and -1.0. The more significant number indicates high correlations, while the smaller number indicates weak correlations [19].

The 20 highest correlations between the variables are displayed in Table VII. The correlation between 0.5 and 1.0 indicates a high positive correlation. On the contrary, the correlation between -0.5 to -1.0 indicates a high negative correlation. The table gives vital information about how the features relate to each other. However, if we ignore similar

features, such as the total vehicles and total taxis, because all of them are cars, it is normal to see a high correlation between these columns. The exciting result could be seen from the columns that have no relationships. For example, the total injuries and taxis have 0.88, indicating a highly positive correlation. We can say that the number of taxis accident accrue affects the number of injuries positively. In other words, taxi accidents cause more injuries than other vehicles involved in an accident. Nonetheless, we can conclude from this table that there are highly significant relationships between the different variables as follow.

TABLE VII. THE TOP 20 HIGHEST CORRELATIONS

Variable 1	Variable 2	Correlation
Total Fatal	Total Minor Injuries	0.996284
Total Injuries Elements	Total Injuries	0.993960
Total Accident Elements	Total Vehicles	0.992893
Total Pedestrians	Total Minor Injuries	0.991245
Total Minor Injuries	Total Accident Elements	0.990081
Total Pedestrians	Total Fatal	0.988103
Total Injuries	Total Major Injuries	0.983547
Total Accident Elements	Total Fatal	0.978477
Total Vehicles	Total Minor Injuries	0.977746
Speeding Involved	Total Injuries Elements	0.974481
Total Vehicles	Total Unknown Injuries	0.974045
Total Fatal	Total Vehicles	0.971432
Total Pedestrians	Total Accident Elements	0.966891
Total Major Injuries	Total Injuries Elements	0.957828
Total Unknown Injuries	Total Accident Elements	0.954655
Speeding Involved	Total Injuries	0.945711
Total Pedestrians	Total Vehicles	0.941978
Total Unknown Injuries	Total Minor Injuries	0.938114
Total Fatal	Total Unknown Injuries	0.936562
Total Government	Total Pedestrians	0.931648

There are many significant relations between different variables; here are the most notable ones:

- The total number of injuries and accident elements with taxis.
- The total number of injuries and speed and taxis.
- the speed and
 - total accident and injuries total injuries
 - total major injuries
 - total taxes
- major injuries with taxis
- Total number of accident elements with
 - fatal passenger
 - minor injuries
 - total fatal
 - pedestrians
 - government
 - driver impaired

- Total number of vehicles involved in the accidents with:
 - Fatal passenger
 - minor injuries
 - total fatal

C. One-Way-ANOVA

The third statistical model that was applied is the One-Way-ANOVA algorithm tests the differences between one independent variable and two dependent variables. This can help find if the data are random or if there is a significant relationship between the independent and dependent variables. Here are the results that we found:

TABLE VIII. ONE-WAY-ANOVA RESULTS

Independent Variable	Dependent variable 1	Dependent variable 2	p-value
Total Injuries Elements	Drivers impaired	Speeding Involved	0.03978
Total Injuries Elements	Total Fatal	Speeding Involved	0.03974
Total Accident elements	Drivers Impaired	Pedestrians Impaired	0.000154
Total Fatal	Total Taxis	Drivers Impaired	0.01528
Total Fatal	Total Government	Drivers Impaired	0.05858
Total Fatal	Total Taxis	Speeding Involved	0.04698
Total Fatal	Total Government	Speeding Involved	0.11406
Fatal passenger	Total Taxis	Speeding Involved	0.03778
Total Major injuries	Pedestrians Impaired	Speeding Involved	0.28874

The Table VIII shows significant relationships between the independent and dependent variables where the p-value is less than 0.05 [21]. It can be seen that the total injuries and elements have a significant relationship between impaired drivers and speed. Also, total injuries have a significant relationship with total fatalities and speed. However, the total accident elements variable has a significant relationship with drivers impaired and pedestrians impaired. In addition, it can be noticed that the total fatal has significant relationships between multiple dependent variables: total taxis & drivers impaired, total taxis & speed. Nevertheless, there is no significant relationship between total government and drivers impaired and total government and speed.

D. MANOVA

The MANOVA model is similar to the ANOVA. Nevertheless, the difference is examining more than one dependent variable to fit MANOVA, which is in our project's RATE column because it contains five groups [19]. We examine four statistical tests that use in MANOVA, which are Wilk's lambda, Pillai's trace, Hotelling-Lawley trace, and Roy's greatest root. The number of degrees of freedom (DF) is five, and the denominator degrees of freedom (Den DF) is 237183. Where the probability of obtaining an F-ratio is zero in all tests. The Table IX shows the results for the different variables examined.

TABLE IX. FIRST MANOVA ANALYSIS RESULTS FOR WILK'S LAMBDA, PILLAI'S TRACE

Variable	Wilks' lambda		Pillai's trace	
	Value	F Value	Value	F Value
Total Injuries Elements	0.8365	9270.002	0.1635	9270.002
Total Accident Elements	0.9948	247.9693	0.0052	247.9693
Total Injuries Elements	0.8365	9270.002	0.1635	9270.002
Total Minor Injuries	0.9884	554.5788	0.0116	554.5788
Total Fatal	0.9992	37.7784	0.0008	37.7784

TABLE X. FIRST MANOVA ANALYSIS RESULTS FOR HOTELLING-LAWLEY TRACE, AND ROY'S GREATEST ROOT

Variable	Hotelling-Lawley trace		Roy's greatest root	
	Value	F Value	Value	F Value
Total Injuries Elements	0.1954	9270.002	0.1954	9270.002
Total Accident Elements	0.0052	247.9693	0.0052	247.9693
Total Injuries Elements	0.1954	9270.002	0.1954	9270.002
Total Minor Injuries	0.0117	554.5788	0.0117	554.5788
Total Fatal	0.0008	37.7784	0.0008	37.7784

- The above Table X shows Rate column with:
 - TOTAL_INJURIES_ELEMENTS
 - TOTAL_ACCIDENTELEMENTS
 - TOTAL_MAJORINJURIES
 - TOTAL_MINORINJURIES
 - TOTAL_FATAL

TABLE XI. SECOND MANOVA ANALYSIS RESULTS FOR WILK'S LAMBDA, PILLAI'S TRACE

Variable	Wilks' lambda		Pillai's trace	
	Value	F Value	Value	F Value
Drivers impaired	0.9999	7.3326	0.0001	7.3326
Speeding Involved	0.9989	64.4123	0.0011	64.4123
Total Fatal	0.9993	40.5339	0.0007	40.5339
Total Taxis	0.9993	5833.992	0.0896	5838.244
Total Government	0.9058	6163.467	0.0942	6166.538

TABLE XII. SECOND MANOVA ANALYSIS RESULTS FOR HOTELLING-LAWLEY TRACE, AND ROY'S GREATEST ROOT

Variable	Hotelling-Lawley trace		Roy's greatest root	
	Value	F Value	Value	F Value
Drivers impaired	0.0001	7.3326	0.0001	7.3326
Speeding Involved	0.0011	64.4123	0.0011	64.4123
Total Fatal	0.0007	40.5339	0.0007	40.5233
Total Taxis	0.0983	5830.1229	0.0977	5790.4932
Total Government	0.1039	6160.6854	0.1034	6133.7925

- The second Table XI and Table XII show the results of MANOVA of the Rate column with:
 - DRIVERS IMPAIRED
 - SPEEDING INVOLVED
 - TOTAL FATAL
 - TOTAL TAXIS
 - TOTAL GOVERNMENT

E. Decision Tree

The sixth model used is a kind of machine learning model, a decision tree algorithm. The decision tree can help find the factors that lead to a specific event [14]. In this project, we use a decision tree to find the factors that lead to fatal accidents, which could help us understand the causes that might lead to deadly accidents.

The decision tree in Fig. 2 shows that speed is a significant cause of deadly accidents. This chart shows four-level depth, which gives a scenario if the accident has a speeding case, the total injuries and accident elements are less than 6.5, and there are government cars involved. The chance of an accident having a fatal case is high. The model accuracy is 99.8% which is high accuracy.

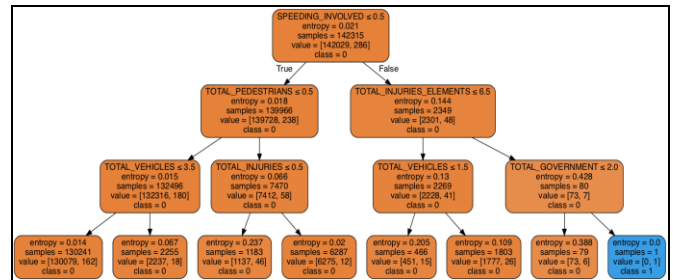


Fig. 2. Decision tree.

F. Data Visualization

Data visualization is a critical tool for evaluating and learning from enormous datasets. They are especially helpful in spotting patterns, trends, and linkages that may not be visible from raw data. In the context of data analysis, visualizations can provide a more natural and accessible approach for stakeholders to communicate complicated information.

The visualizations in this scenario were created with Tableau software [16]. This section's four charts give a detailed overview of the data distribution, allowing the viewer to discover trends and other significant insights immediately.

Fig. 3 depicts the pattern of automobile accidents over time, giving a clear picture of how the frequency of accidents has evolved over time. Fig. 4 shows crashes across time but removes the lowest and lowest, allowing the viewer to focus on the most relevant trends. Fig. 5 is a bar chart displaying the top 20 streets with the most accidents, offering a more thorough look at the data and aiding in the identification of places that may require more attention. Finally, Fig. 6 depicts a map of the District of Columbia with the top ten streets and all accidents depicted as dots, allowing for a visual depiction of the geographical distribution of accidents.

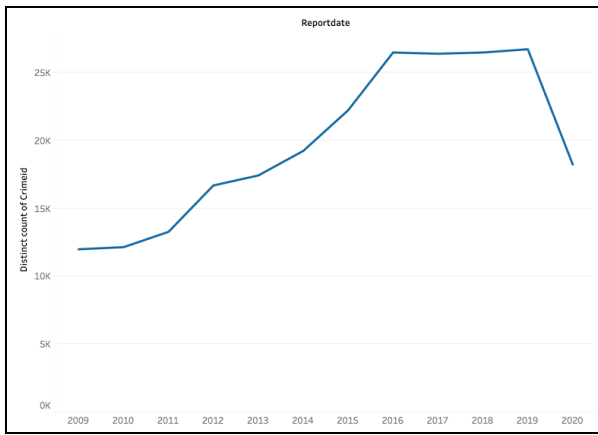


Fig. 3. Total number of accidents over time (2009-2020).

This chart shows the accident number from 2009 to 2020. It can be seen that the number of accidents rose from 2009 to 2016 from 11,982 to 26,470, respectively. After that, the numbers changed slightly from 2016 until 2019. However, the accident number hit its peak in 2019 with 26,711 accidents. In contrast, car crashes dropped significantly in 2020, with 18,230 accidents. The reason for that drop is the Covid-19 lockdown.

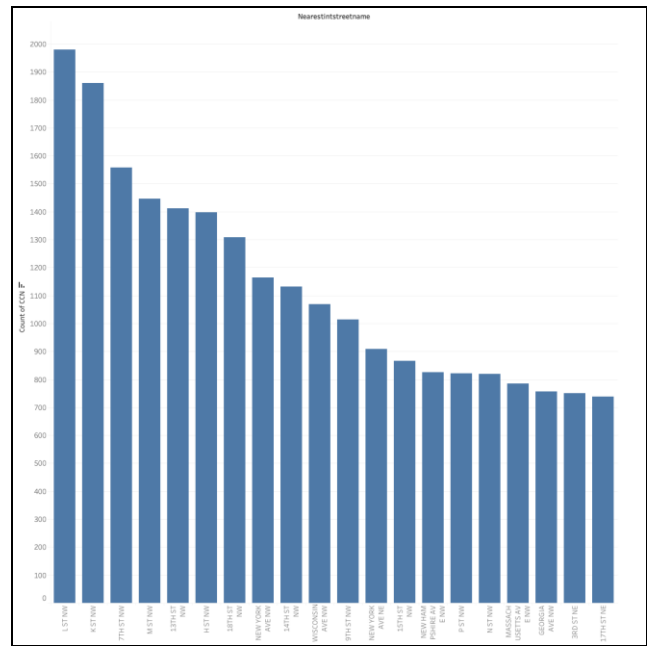


Fig. 5. Top 20 streets with the number of accidents.

The map (Fig. 5) below depicts the top ten streets in the District of Columbia where accidents happened between 2009 and 2020. By mapping the geographic distribution of incidents, this visualization can assist in identifying patterns and trends that may not be immediately obvious from raw data alone. Closer examination reveals that most incidents happened in the city center and on routes going out of town from the northeast. This shows that certain issues, such as heavy traffic, bad road conditions, or insufficient signs, may contribute to the high incidence of accidents in these regions.

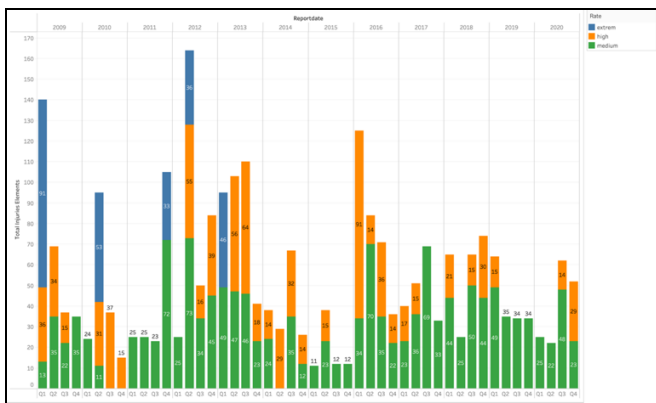


Fig. 4. Number of extreme, high, and medium accidents.

The above chart shows the number of extreme, high, and medium accidents from 2009 to 2020 divided by quarters of each year. The number shown in the bars represents the total number of injuries and the number of vehicles involved in those accidents. It can be seen that the extreme accidents stopped in 2013. The number of accidents reached its highest point in 2012, with approximately 163 accidents resulting in 144 injuries and damage to vehicles in the second quarter. Furthermore, the first quarter of 2009 saw the highest number of severe accidents, with a total of 90. This chart provides insight into the distribution of accidents over time and helps to understand the correlation between the type of accident and the year it occurred.

This bar graph represents the top 20 streets with the number of accidents in those streets sorted ascending. It can be noticed that most accidents happen in the northwest regions. From this chart, we can conclude that the streets located in the northwest have the highest chance of having accidents more than the other regions in Washington, D.C.

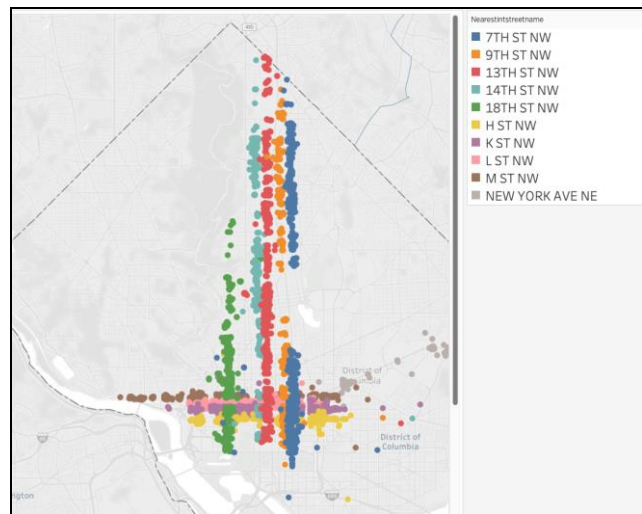


Fig. 6. Map of the top 10 streets that contained accidents.

It is also worth mentioning that while there were some incidents on the city's northeast and southwest sides, the number of accidents on the northwest side was substantially lower. This might imply that characteristics peculiar to the northwest side contribute to the high incidence of accidents in that area. Overall, this visualization might be useful for

identifying the streets with the most accidents and researching the causes to design remedies. Policymakers and city planners may strive to improve road conditions, change traffic patterns, and take other steps to minimize the frequency of accidents and enhance overall safety for cars, cyclists, and pedestrians alike by identifying high-accident zones.

VI. CONCLUSION

In conclusion, this paper studies the dataset related to car accidents in Washington, D.C., between 2009 and 2020. The data has multiple processes to be ready for analytical models. First, we cleaned the data by dropping the unrelated columns and null values that the known ways could not fill. Then the data were explored to understand the data distribution and find the columns that may benefit this analysis. After that, the data was prepared to be ready for the analytical and statistical models. The preparation processes include classifying the accidents into five groups (lowest, low, medium, high, and extreme) and creating a separate dataset that contains the categorical data mapped the string values into numbers. Then we applied correlation analysis, ANOVA, confidence interval, decision tree model, and visualizations. These models were used to find the trend and patterns among the data and find any significant relationships between different variables. This project aims to help the authorities to understand car accidents within the area so they can find the proper solutions to reduce the number of accidents and fix any issues that can be fixed. We have found that most crashes in the area are caused by impaired persons, while deadly accidents happen if one of the accident cars is driving fast or a government car is involved in the accidents. Also, we have found a significant relationship between the number of fatal and the number of taxis involved in the accidents. In addition, most roads that hold accidents are located in the northern area of the district.

On the other hand, we believe that this project could be enhanced by analyzing the crash address and zip codes. There are some issues in the address feature that need to be handled. For instance, some addresses are not complete, and others contain missing numbers or street names to name a few. Also, we found that there was no information about impaired people before 2015. This issue needs to be found the proper way to solve. If these problems are fixed, we think the results could be better.

REFERENCES

- [1] W. H. Organization, "Road traffic injuries," World Health Organization, 21 June 2021. [Online]. Available: <https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries>. [Accessed March 2022].
- [2] N. H. T. S. A. o. t. U. S. D. o. Transportation, "NHTSA," October 2021. [Online]. Available: <https://www.nhtsa.gov/press-releases/usdot-releases-new-data-showing-road-fatalities-spiked-first-half-2021>. [Accessed March 2022].
- [3] T. S. H. Heinrich and Russell, LLP, "Amarillo Car Accident Lawyers | 200+ Years of Combined Experience," 9 December 2022. [Online]. Available: <https://www.templetonsmith.com/personal-injury/car-accidents/>. [Accessed January 2022].
- [4] D. D. o. Transportation, "Crashes in DC [These data represent the crash locations associated along the DDOT centerline network within the District of Columbia," 2021. [Online]. Available:

- <https://opendata.dc.gov/datasets/DCGIS::crashes-in-dc/about>. [Accessed January 2022].
- [5] D. Commons, "Washington, D.C. Demographics - Place Explorer - Data Commons," [Online]. Available: <https://datacommons.org/place/geoId/11001/?category=Demographics>. [Accessed 18 November 2022].
- [6] A. S. Distribution, "Anaconda Documentation," Anaconda Inc, 2022. [Online]. Available: <https://docs.anaconda.com/>. [Accessed January 2022].
- [7] T. p. d. team, "pandas-dev/pandas," Pandas (3.8.8) [Python library]. Zenodo, 2020. [Online]. Available: <https://doi.org/10.5281/zenodo.3509134>. [Accessed January 2022].
- [8] C. R. Harris, K. J. Millman, S. J. Van Der Walt, R. Gommers, P. Virtanen, D. Cournapeau and T. E. Oliphant, "Array programming with NumPy," *Nature*, vol. 585, no. 7825, pp. 357-362, 2022.
- [9] G. Varoquaux, L. Buitinck, G. Louppe, O. Grisel, F. Pedregosa and A. Mueller, "Scikit-learn," *GetMobile: Mobile Computing and Communications*, vol. 19, no. 1, pp. 29-33, 2015.
- [10] P. Virtanen, R. Gommers, T. Oliphant, M. Haberland, T. Reddy, D. Cournapeau, E. Burovski, P. Peterson, W. Weckesser, J. Bright, S. J. van der Walt, M. Brett, J. Wilson, K. J. Millman, N. Mayorov, A. R. J. Nelson, E. Jones, R. Kern and Lars, "SciPy 1.0: fundamental algorithms for scientific computing in Python," *Nature Methods*, vol. 17, no. 3, pp. 261-272, 2020.
- [11] J. VanderPlas, B. Granger, J. Heer, D. Moritz, K. Wongsuphasawat, A. Satyanarayan, E. Lees, I. Timofeev, B. Welsh and S. Sievert, "Altair: Interactive Statistical Visualizations for Python," *Journal of Open Source Software*, vol. 3, no. 32, p. 1057, 2018.
- [12] J. D. Hunter, "Matplotlib: A 2D graphics environment," *Computing in Science Engineering*, vol. 9, no. 3, pp. 90-95, 2007.
- [13] M. Waskom, O. Botvinnik, D. O'Kane, P. Hobson, S. Lukauskas, D. C. Gemperline, T. Augspurger, Y. Halchenko, J. B. Cole, H. Warmenhoven, J. Ruitter, C. Pye, S. Hoyer, J. Vanderplas, S. Villalba, G. Kunter, E. Quintero, P. Bachant and Martin, "mwaskom/seaborn: v0.8.1." 3 September 2017. [Online]. Available: <https://zenodo.org/record/883859#.ZGLQIC8RqDU>. [Accessed March 2022].
- [14] Y. Wang, Z. Sun, H. Zhang, W. Cui, K. Xu, X. Ma and D. Zhang, "Datashot: Automatic generation of fact sheets from tabular data," *IEEE transactions on visualization and computer graphics*, vol. 26, no. 1, pp. 895-905, 2019.
- [15] "Visual Studio Code (1.61.0)," Microsoft, 2019. [Online]. Available: <https://code.visualstudio.com>. [Accessed November 2021].
- [16] C. Chabot, A. Beers and P. Hanrahan, "Tableau (2021.3.3) [Computer software]," Tableau, 2021. [Online]. Available: <https://www.tableau.com>. [Accessed March 2022].
- [17] A. Jain, "Pandas In Python | Data Manipulation With Pandas," Analytics Vidhya, 26 June 2020. [Online]. Available: <https://www.analyticsvidhya.com/blog/2016/01/12-pandas-techniques-python-data-manipulation>. [Accessed 30 November 2021].
- [18] M. Wood, "Bootstrapped confidence intervals as an approach to statistical inference," *Organizational Research Methods*, vol. 8, no. 4, pp. 454-470, 2005.
- [19] Y. Xia, J. Sun and D. G. Chen, "Statistical analysis of microbiome data with R," *Singapore: Springer*, vol. 847, 2018.
- [20] Q. Zhang, H. Abel, A. Wells, P. Lenzini, F. Gomez, M. A. Province and I. B. Borecki, "Selection of models for the analysis of risk-factor trees: leveraging biological knowledge to mine large sets of risk factors with application to microbiome data," *Bioinformatics*, vol. 31, no. 10, pp. 1607-1613, 2018.
- [21] S. Mcleod, "P-Value And Statistical Significance: What It Is & Why It Matters," *SimplyPsychology*, 15 May 2023. [Online]. Available: <https://www.simplypsychology.org/p-value.html#:~:text=A%20p%20%2Dvalue%20less%20than,and%20accept%20the%20alternative%20hypothesis..>

Towards an Adaptive e-Learning System Based on Deep Learner Profile, Machine Learning Approach, and Reinforcement Learning

Riad Mustapha, Gouraguine Soukaina, Qbadou Mohammed, Aoula Es-Sâadia
Mathematics and Computer Science Department, ENSET of Mohammedia, Mohammedia, MOROCCO

Abstract—Now-a-days, the great challenge of adaptive e-learning systems is to recommend an individualized learning scenario according to the specific needs of learners. Therefore, the perfect adaptive e-learning system is the one that is based on a deep learner profile to recommend the most appropriate learning objects for that learner. Yet, the majority of existing adaptive e-learning systems do not give high importance to the adequacy of the real learner profile and its update with the one taken into account in the learning path recommendation. In this paper, we proposed an intelligent adaptive e-learning system, based on machine learning and reinforcement learning. The objectives of this system are the creation of a deep profile of a given learner, via the implementation of K-means and linear regression, and the recommendation of adaptive learning paths according to this deep profile, by implementing the Q-learning algorithm. The proposed system is decomposed into three principal modules, data preprocessing module, learner deep profile creation module, and learning path recommendation module. These three modules interact with each other to provide a personalized adaptation according to the learner's deep profile. The results obtained indicate that taking into account the learner's deep profile improves the quality of learning for learners.

Keywords—Adaptive e-learning system; deep learner profile; reinforcement learning; Q-learning; k-means; linear regression; learning path recommendation; learning object

I. INTRODUCTION

In traditional learning systems ("all to all" system), the learning content was determined without taking into consideration the specific needs and characteristics of the learners. As a result, all learners were learning the same learning content, which did not ensure the effectiveness of the learning activity. In the last decade, due to technological developments, various approaches to teaching and learning have come onto the scene, accelerated by e-learning in particular during the covid19 pandemic. However, finding the appropriate learning path and content for a given learner is a very interesting question for achieving learning goals, especially in today's education and teaching systems. It is in this context that intelligent tutoring systems are developed to enable learners to locate educational resources that meet their needs and concerns [1].

Adaptive learning presents a new approach to teaching and learning compared to traditional learning. This new approach allows learners to learn at any time and any place, taking into

account the needs and characteristics of learners who are usually heterogeneous to achieve a specific skill within a certain time [2], [3]. In fact, learners have different learning profiles in terms of learning speed, knowledge, preferences, intellectual abilities, learning styles, etc., therefore, have different learning paths [4], [5], [6]. In this perspective, many studies have been realized during the last decade on the personalization of learning with the help of e-learning systems. However, most of these systems do not have methods to perfectly represent the learner's profile (deep profile), on which the system can propose and intelligently adapt the learning path that corresponds to this learner at the time of the execution of a learning activity.

In this paper, on the one hand, we focus on the creation of the deep learner profile from raw datasets on this learner, by combining two machine-learning algorithms: K-means classification and linear regression after executing the data preprocessing technique. On the other hand, the researchers focused on the adaptation and recommendation of learning paths to the learner according to their created deep profile. Next step is the implementation of the developed algorithm Q-learning of the reinforcement learning approach at the time of the execution of a learning activity, Fig. 6, and this via an intelligent and automatic choice of the most appropriate learning objects.

The plan followed in this paper includes, in the second section, a literature review is conducted on adaptive e-learning systems. Then, in the third section, the researchers described the architecture of the proposed approach, while defining the main concepts of the algorithms used to create the deep profile of the learner and to generate the learning path most adapted to this type of profile. The fourth section presents an example of the implementation and results of the application of the algorithms. Finally, the fifth section concludes the present paper and proposes suggestions and perspectives for future work.

II. RELATED WORK

In this section, we have briefly reviewed work related to adaptive systems in e-learning environments and the machine-learning approaches that are used to identify and adapt learning objects to learners.

Recently, adaptive e-learning systems have been frequently developed and used to identify the most appropriate learning objects for learners' profiles. [7-9]. The vast volume of these

learning objects presents different opportunities, though, presents constraints for learners to locate the most adequate learning objects for their profiles [2]. The majority of these systems use techniques just based on the learner's learning style and knowledge level to generate a personalized learning context [10]. These techniques are generally underpinned by the Felder-Silverman model [11] to determine this learning style and knowledge level. A few of these systems are discussed in the next paragraph.

Nafea et al. [12] proposed a novel and effective recommender algorithm that recommends personalized learning objects, this algorithm based on the student learning styles. In this system, various similarity metrics are considered in an experimental study to investigate the best similarity metrics to use in a recommender system for learning objects. Vedavathi et al. [13] created a hybrid system that generally uses the learning styles, and knowledge level of the learners to select the relevant learning objects. This system uses a two-step process to generate adaptation via the recommendation of the most appropriate learning objects. First, it categorizes learners based on their learning style, and knowledge level. Then, it looks for learning objects that match his request and that are of interest to similar learners. In the same context, P. Dwivedi et al. [14] and Alshammari et al. [15] have built a similar hybrid adaptation system that clusters learners based on their similarities and proposed the most appropriate learning objects to them. This system is based on learners' history activity, learning styles, and knowledge levels to create learner profiles. Then, it groups learners by using the Nearest Neighbor algorithm (KNN). Consequently, it provides adaptations according to the profile of the group of learners obtained, rather than to individuals.

M. Boussakssou et al. [16] presented an adaptation model based on reinforcement learning. This system takes merely the learning style to adapt and suggest the learning path to the learners' needs. Similarly, H. El Fazazi et al. [17] proposed an adaptive e-learning system design based on the multi-agent system approach and reinforcement learning to recommend an adaptive learning path for a learner with the following profile: intermediate knowledge level, verbal learning style, and hearing impairment. This system tries to recommend a list of learning objects appropriate for this learner profile.

Moreover, W. Intayoad et al. [18] proposed a method based on reinforcement learning, more precisely the State-Action-Reward-State-Action algorithm (SARSA). This method is able to explore the environment to obtain information and exploit it to recommend appropriate learning objects to learners in an e-learning system.

Based on previous studies, it was observed that the proposed learning systems do not have powerful techniques in terms of the quality of learner classification (deep profile creation), which allow to significantly represent the learner and provide the learning system with pertinent information to adapt the learning to the learner's profile. Generally, these systems just consider the learning style and knowledge level of the learner to generate the adaptation.

Therefore, the researchers proposed this system to create a personalized learning experience. That is, it can analyze the

learner's learning style, preferences, and abilities, etc. to establish a customized learning path for them. As a result, it can adjust the difficulty level of the content, provide feedback, and offer additional resources based on the learner's performance.

In this study, this system takes into account not only learning style and knowledge level but also other types of profiles (preference profile, knowledge profile, feature profile, etc.), as well as the learner's learning objectives, via the application of machine learning algorithms. This deep profile created will be used to adapt the learning to the specific needs and characteristics of the learner in question, using reinforcement-learning approach. This system will be able to search and select the most appropriate learning objects for this depth profile, thus providing each learner with a learning path that is the most advantageous and adequate.

III. METHODOLOGY

The approach proposed in this paper takes into account the deep learner's profile by using two approaches; namely machine learning and reinforcement learning to intelligently adapt the content of the learning activity to the individual needs of the learners. This latter is done by the recommendation of the most appropriate list of learning objects according to the learner's deep profile. At first, after the preprocessing phase, we used the K-means algorithm and linear regression on the resulting datasets to identify the deep profile of a given learner were used. Then the Q-learning algorithm was applied to generate the learning path of each learner according to his or her deep profile. Our system is composed of three principal modules; data pre-processing module, learner deep profile creation module, and learning path recommendation module. These three modules interact with each other to provide a personalized adaptation according to the learner's deep profile.

A. Overall Process

In this section, the general process of the study was presented in Fig. 1. The important step at the beginning of the pipeline is to initiate the data preprocessing process.

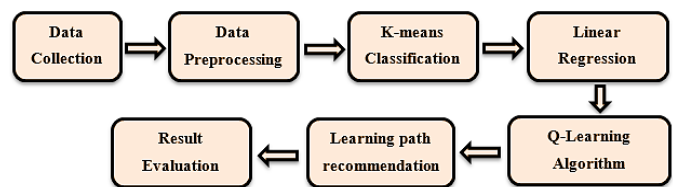


Fig. 1. The overall process for learning path recommendation.

- Data collection: A collection of learner information and characteristics to build a raw dataset containing a volume of pertinent learner information of learners.
- Data preprocessing: This technique consists of removing all redundant, non-pertinent, or less important attributes, extracting the information, and transforming the raw datasets into a useful and efficient format, which allows us to proceed to the next step. The extracted information is relevant and truly represents the learner's deep profile in terms of personal data,

learning style, and prerequisites, etc., and help in their classification. Feature extraction is a difficult and usually time-consuming process.

- K-means classification: Once the datasets are well defined, K-means is used for the classification and generation of homogeneous (similar) learner clusters.
- Linear regression: Once the clusters are generated by K-means, the linear regression algorithm is used to distinguish the different data that generate the same cluster i.e. help K-means to represent the data correctly in each cluster.
- Q-learning algorithm: Once the classification of the learners is completed by using K-means and linear regression, the Q-learning algorithm is used to search and determine the optimal learning path taken by the learner according to his or her deepened profile.
- Learning path recommendation: This step consists of recommending the most appropriate learning objects in real time to the learner based on their deepened profile.
- Result evaluation: The proposed system provides excellent results in terms of precision and quality obtained.

B. Description of the Learning Path Recommendation Process

In examining previous studies on the topic of adaptive e-learning systems development, it has been observed that they are generally based on the Felder-Silverman model (FSLSM) technique [19], to identify the learning style and knowledge level, as the learner profile. However, these types of profiles do not always represent the real learner in terms of specific learner needs and characteristics. To address this need, an intelligent mechanism based on artificial intelligence (AI) was proposed in this study to create the deep profile of a given learner from raw datasets on this learner, by applying in cascade the two machine learning algorithms: K-means and linear regression. Finally, recommending the most appropriate learning objects in real-time to this learner as the most beneficial adaptive learning path to this deep profile via the application of the Q-learning algorithm. The figure below Fig. 2, describes the developed system:

The figure describes the proposed system that integrates Artificial Intelligence (AI) for the creation of the deep profile of the learner connected to the system and for the adaptation of learning paths to the needs and characteristics of learners. In fact, the creation of the deep profile is a very interesting step in the context of recommending adequate learning objects to the learner, because if the created profile does not represent correctly the learner, then the proposed learning path will not be well adapted to him.

In this system, the key modules used are: **1)** the data preprocessing module, which consists of reducing the dimension of the datasets vectors, using techniques associated with dimension reduction, **2)** the module for creating the learner's deep profile from a volume of raw data on the learner in question, and **3)** the learning path recommendation module.

These three modules interact with each other to provide personalized adaptation based on the deep profile created in the Module 2 phase. This system will try to find the appropriate learning objects for this deepened profile.

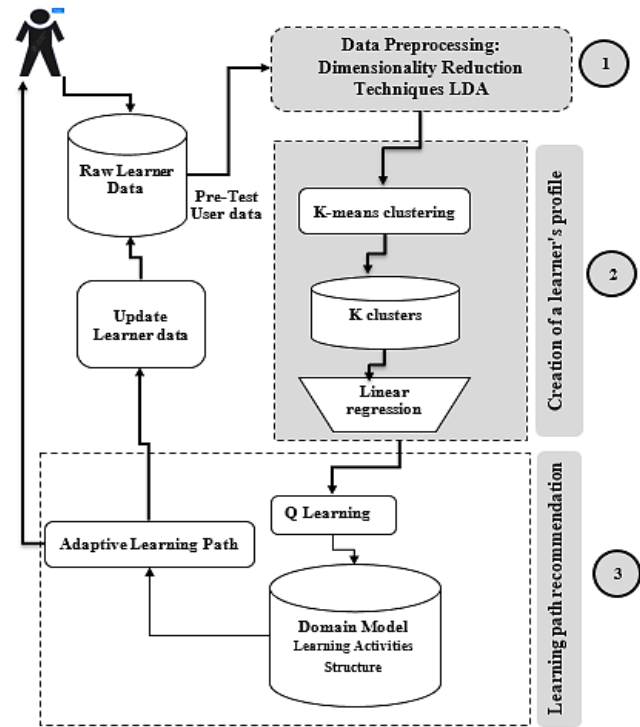


Fig. 2. The process of constructing the adaptive learning path developed.

A. Data Preprocessing

In a datasets, not all attributes are necessarily important. Some may be redundant, others may be not pertinent, etc. Ignoring or removing these non-pertinent or less important attributes reduces the load on the machine learning algorithms and improves the quality of the results obtained. In this context, the technique of dimension reduction plays a very interesting role, in reducing the dimension of high-dimensional datasets vectors [20]. Among these techniques, the best known according to the literature is Linear Discriminant Analysis (LDA), as a supervised algorithm. The aim is to project the features of a higher-dimensional space into a lower-dimensional space. This technique is based on two criteria to create another axis on which to project:

- 1) Maximize the distance between the means of the two classes;
- 2) Minimize the variation within each class;

Assuming two classes and d-dimensional elements such as x_1, x_2, \dots, x_n , where: n_1 is an individual from class C_1 and n_2 from class C_2 . If x_i is the data point, then its projection on the line represented by the unit vector v can be written as $v^T x_i$:

$$\tilde{u}_1 = \frac{1}{n_1} \sum_{x_i \in C_1} v^T x_i = v^T u_1 \quad (1)$$

The same goes for \tilde{u}_2 ,

$$\check{u}_2 = v^T u_2 \quad (2)$$

Then the dispersion for the elements of C1 is:

$$\check{s}_1^2 = \sum_{y_i \in C_1} (y_i - u_1)^2 \quad (3)$$

The same goes for \check{s}_2^2 ,

$$\check{s}_2^2 = \sum_{y_i \in C_2} (y_i - u_2)^2 \quad (4)$$

B. Creating the Deep Learner Profile

The adaptive e-learning system has been developed to provide a personalized learning path in the experience of executing a pedagogical activity. However, this adaptation must be based on the learner's deep profile that is created when the learner as soon as it is connected to the system, and that will be updated over time by the learner's feedback with the system. The use of deep profiles in Computer Environments for Human Learning (CEHL), and especially in distance learning platforms, is one of the most important ways to adapt learning to the specificities of learners. It plays a very interesting role in the individualization of learning paths. In fact, it focuses on learners' preferences, such as a learner's preference for video over text, or his or her preference for teaching to begin with an example and not a theoretical introduction. But also the features of the learners which contain important information allowing to describe the learner not only from the point of view of his demographic features such as age or gender but also from the point of view of his possible disabilities (e.g. hearing 85%; sight 30%, etc.), preferred time for learning, preferred language, culture, country, hobbies, preferred type of media, prerequisites, the learner's learning objectives, etc. which can be described finely.

The module in charge of creating the learner's deep profile within the system is decomposed into two sub-modules:

- The K-means classification algorithm;
- The Linear regression algorithm.

1) *K-means classification algorithm*: In the literature, there are many classification algorithms including K-means, KNN, SVM, etc. In this paper, the K-means Algorithm, which is one of the most popular algorithms due to its simplicity and intuitive interpretation [21] was adopted. It can be defined as the process of organizing objects in a dataset into clusters, such that objects in the same cluster have a high degree of similarity, while those belonging to different groups have a high degree of dissimilarity.

The key step for any unsupervised algorithm is to identify the optimal number of clusters (optimal K) into which the data can be grouped. The Elbow method [22], is one of the most popular methods for identifying this optimal value of K. i.e. the optimal k is the point after which the distortion/inertia starts to decrease linearly, where distortion is computed as the average of the squared distances of the cluster centers of the sample and inertia is the sum of the squared distances of the elements to their nearest center of gravity. It consists in calculating the variance of the different cluster volumes considered, and then placing the variances obtained on a graph:

intra – Cluster Variance

$$= \sum \sum Distance(x, centroid)^2 \quad (5)$$

After calculating the optimal value of k, by the formula (5), we proceed to the running of the K-means algorithm, explained by the mathematical formula below:

$$\arg \min_c \sum_{i=1}^k \sum_{x \in C_i} ||x - \mu_i||^2 = \arg \min_c \sum_{i=1}^k |C_i| \text{Var } C_i$$

Where μ_i is the average of the points in C_i . For its implementation, in the system, the following steps are respected:

- Step 0: Select optimal K calculated by the formula (5);
- Step 1: Select K random points in datasets as initial group centers;
- Step 2: Create K Clusters by associating each data point with its nearest center, according to the Euclidean distance defined by the formula:

$$d(x, y) = \sum_{i=1}^n (x_i - y_i)^2 \quad (7)$$

- Step 3: Recalculate the center of gravity of each cluster, as the average of all data points in that cluster;
- Step 4: Repeat steps 2 and 3 until the centers of gravity no longer change;

By examining the results of previous studies on the subject of data classification, the researchers find that after the execution of the K-means algorithm on the datasets, there is a problem in the distributions of the vectors of each cluster, i.e. different data can be represented by similar clusters, which results in a false classification of the data. In this paper and to overcome this problem, the researchers suggest to add another criterion to distinguish the different data that give the same cluster, by using in cascade the linear regression algorithm on each cluster obtained by K-means, to approximate the data and characteristics that make up the learner's deep profile, to improve the quality of classification, precision and error reduction.

2) *Linear regression algorithm*: In the literature, linear regression is classified among the multivariate analysis methods that deal with quantitative data, with the objective to find a linear relationship between a quantitative variable Y and one or more also quantitative variables X, i.e. to find the line that passes "as close as possible" to all the points of the cloud. This relationship can be expressed mathematically by the formula below:

$$y_i = \beta_0 + \beta_1 x_{i1} + \dots + \beta_p x_{ip} + \epsilon_i \\ = X_i^T \beta + \epsilon_i \quad (8)$$

Where T denotes the transposition, so that $X_i^T \beta$ is the internal product between the vectors X_i and β .

C. Learning Path Recommendation

1) *Domain model of the proposed approach:* In the adaptive e-learning system, the pedagogical content is divided into many pedagogical activities, each of which is composed of several chapters. A concept tree represents each chapter. The concept tree contains a list of learning objects (LOs) that represent external representations, such as images, videos, examples, exercises, etc. This learning content is generally stocked in a database as a tree of 4 levels called the domain model. The figure below Fig. 3, describes the overall domain model structure of our system:

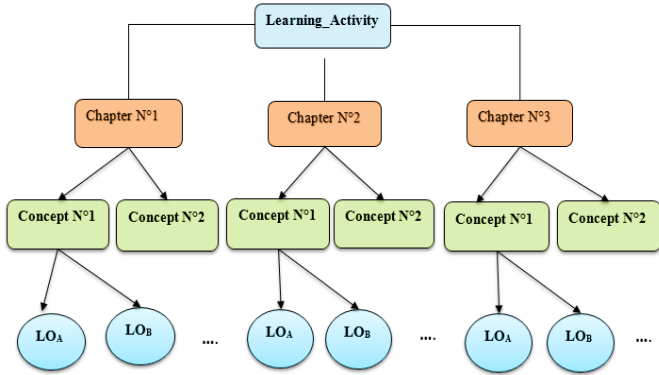


Fig. 3. Learning activity organization of the proposed approach.

The learning activity organization of the proposed approach is mapped into four hierarchical levels:

- Level 1: represents the root of the domain model structure, which presents the learning activity to be taught.
- Level 2: represents learning activity chapters, which particularly address a learning activity element to be taught.
- Level 3: represents the concepts of each chapter of the learning activity taught and is generally identified by a level: advanced, intermediate, or beginner.
- Level 4: represents the different types of learning objects (LOs) that represent external representations, such as images, videos, examples, exercises, etc. Each LO is characterized by several properties such as autonomy; adaptation; indexing; accessibility; durability, and reusability as the most important property. Each LO must be provided with a description, usually called a metadata file, allowing it to be easily found. This file uses emerging technologies associated with the development of learning objects, such as the semantic web and ontologies.

The figure below Fig. 4, describes the metadata file of each domain model level of the proposed system, based on the ontology technology:

In a traditional learning system, learners use a linear path of learning objects $\{LO_A, LO_B, LO_C, \dots, LO_z\}$ regardless of their preferences, knowledge level, etc. The figure below Fig. 5,

shows an example of the sequence of learning objects as a learning path for five learners $\{L_1, L_2, L_3, L_4, L_5\}$ when executing a learning activity in this system.

However, in a personalized adaptive e-learning system, learners use a non-linear learning path to build the optimal sequence of learning objects according to their needs and characteristics. The figure below Fig. 6, shows the adaptive learning path for the same learners $\{L_1, L_2, L_3, L_4, L_5\}$ when running the same pelagic activity.

In this learning path, the system can ignore some learning objects like $LO_E, LO_F, LO_G,$ and $LO_H,$ since they do not correspond to any profile of the five learners in question.

2) *Adaptation and recommendation of learning paths:* Many algorithms are available for Reinforcement Learning (RL), which uses Q-function as a learning strategy like Opponent Modeling, Q-learning, and Ascending Gradient. In this paper, the Q-learning algorithm was adopted to recommend the most appropriate learning path for a given learner. It is more efficient than other algorithms in terms of precision and quality of results. Thus, it converges towards an optimal strategy, i.e. it leads to maximizing the total reward of the successive steps. The figure below Fig. 7, presents the overall process of reinforcement learning.

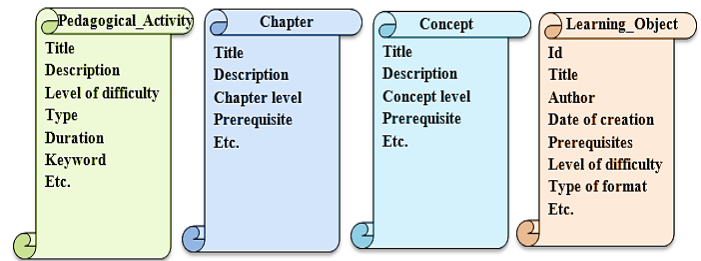


Fig. 4. Metadata file of the domain model levels.

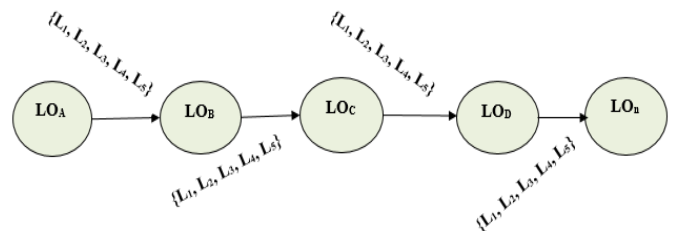


Fig. 5. Learning path in a traditional system.

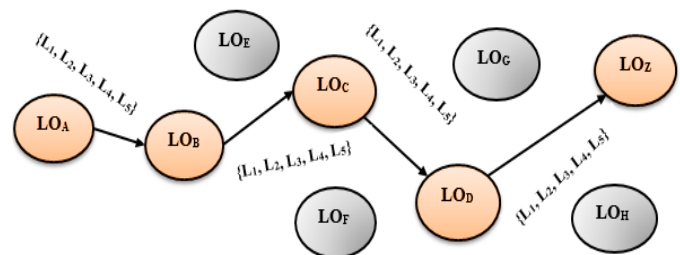


Fig. 6. Learning paths in an adaptive e-learning system.

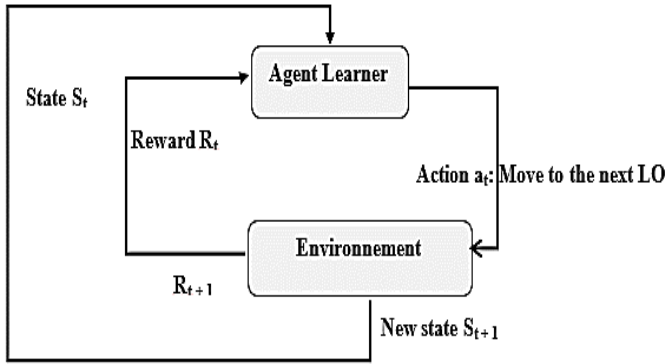


Fig. 7. The overall process of reinforcement learning.

In the proposed system, the high number of users will allow us to consider each learner as an agent. The agent can move from one state S (LO_A) to another S_{t+1} (LO_B) by choosing an action A . This transition gives the agent a reward/sanction on which we calculate the total gain to define its optimal adaptive learning path. This gain is estimated and calculated by a Q-Value () which evaluates the quality of the combination of each state-action pair $Q(s, a)$ over the long term and updates its table. Mathematically the Q-Value() function is expressed as follows.

$$V(S) = [R_{t+1} + \gamma R_{t+2} + \gamma^2 R_{t+3} + \dots] \left[\sum_{k=0}^{\infty} \gamma^k R_{t+k+1} | S_t = s \right]$$

Where the parameter γ is the discount rate between 0 and 1, k is the number of states, and R is the rewards. The agent learns from experience due to exploration, often called an episode [23]. The figure below Fig. 8, presents the overall process of learning by the Q-learning algorithm developed:

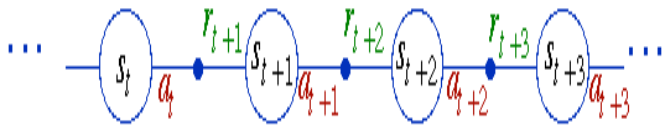


Fig. 8. Overall process of learning by the Q-learning algorithm.

The general algorithmic structure of this algorithm is detailed in Fig. 9.

Where α is the learning rate between 0 and 1. It determines how well the new calculated information will overcome the old, If $\alpha = 0$, the agent (learner) learns nothing, but if $\alpha = 1$, the agent still ignores everything it has learned so far and will only take into account the last information. In a deterministic environment, the learning speed $\alpha_t(s,a) = 1$ is optimal; γ is the discount factor between 0 and 1. It determines the importance of future rewards. A factor $\gamma = 0$ would make the agent (learner) myopic by considering only current rewards, but a factor γ near 1 would also include more distant rewards and the value of Q can diverge; s' is the new state; s is the previous state; a is the chosen action and R is the reward received by the agent (learner), and $Q [v_1, v_2, \dots, v_p]$ is Q-table.

Algorithm 1: Heading

```

Input
    α ;
    γ ;
Output
    Q [v1, v2, ..., vp];
Initialize
    Q [s, a] for any non-terminal state s, any action a arbitrarily;
    Q [terminal state, a] = 0;
Repeat
    // start of an episode
    s := terminal state
    Repeat
    // for each episode
    Choose an action a from s using the policy specified by Q;
    Execute the action a;
    Observe the reward r and the new state s';
    Update the values of Q
    | Q(s,a) = α * (r + γ * maxQ(s') - Q(s,a))
    | Define the next state as the current
    Until s is the terminal state
    End
End
    
```

Fig. 9. Q-function pseudo-code for e-learning adaptation and recommendation system.

IV. RESULTS AND DISCUSSION

A. Implementation Example

In this part, the researchers start with a data preprocessing module to prepare datasets which will be used to create a deep profile of the learner connected to the system. By doing this, the deep profile is processed by using the developed Q-learning algorithm to find the ideal learning path for this learner. The experiments are conducted on a Dell computer with a CORE i5 processor using the Collaboratory platform and Python for result generation.

1) *Data preprocessing:* The datasets used in the experiments contain different raw information about 100 learners $\{L_0, L_1, \dots, L_{99}\}$, with 23 characteristics {Age, Gender, Handicap, Country, Language, Learning style; Knowledge level; etc.} numbered from 0 to 22. The specifications of the datasets are summarized in the figure below, Fig. 10.

In the first experiment, the researchers start to reduce the dimension of the vectors of the datasets, by ignoring the less important or unimportant attributes to improve the quality of the results obtained, by applying the LDA technique, while focusing on the criteria of "Minimizing the variation" within each cluster. Firstly, the variance of all the attributes of the datasets is calculated using the following formula:

$$V = \frac{1}{n} \sum_i^n (x - \bar{x})^2 \tag{9}$$

	Age	Gender	Handicap	Culture	...	Obj2N	Obj3	Obj3F	Obj3N
0	18	1	1	2	...	2	8	5	3
1	19	1	1	3	...	17	8	5	2
2	22	2	0	1	...	5	8	3	9
3	20	1	1	2	...	14	7	2	14
4	22	2	1	1	...	7	7	3	17
5	19	1	1	1	...	0	9	1	11
6	22	1	0	2	...	2	8	3	11
7	16	1	0	4	...	16	9	3	3
8	17	1	0	2	...	10	7	4	2
9	22	1	1	1	...	7	9	3	0
10	18	1	0	2	...	6	8	3	17
11	18	1	0	3	...	8	7	1	6
12	21	1	1	1	...	17	7	3	8
13	18	2	1	2	...	14	9	4	0
14	19	1	1	3	...	16	9	3	18
15	19	2	1	3	...	6	9	5	15
16	22	1	0	4	...	12	8	5	7
17	22	1	1	3	...	10	9	1	16
18	21	1	1	2	...	0	8	5	5
19	19	2	1	1	...	10	9	5	14
20	18	1	1	2	...	0	7	5	13
21	18	2	1	1	...	4	7	3	10
22	18	1	0	1	...	8	7	4	8
23	17	1	1	3	...	14	9	5	2
24	21	2	0	3	...	20	9	1	16
25	20	2	1	1	...	20	9	4	19
26	22	2	0	3	...	9	7	1	5
27	21	2	0	3	...	7	8	5	20
28	19	1	0	4	...	5	8	4	10
29	20	1	1	4	...	1	8	2	15
...
70	21	1	0	1	...	10	7	5	12
71	17	2	0	2	...	10	9	3	6
72	22	2	1	3	...	15	7	4	10
73	19	2	0	3	...	2	7	4	11
--	--	--	--	--	--	--	--	--	--

Fig. 10. Raw Datasets of learners.

Then, the researchers try to find the attribute whose variance is the smallest compared to the others (the less significant attribute). The figure below, Fig. 11, shows the result of calculating the variance of all the attributes of the datasets:

```
[ 3.83545455 0.24434343 0.25242424 1.3069697 11.92515152 0.67232323
 4.91909091 0.25090909 0.25 0.25090909 0.25090909 0.64
 2.19555556 2.01373737 0.79707071 1.87585859 31.29292929 0.64
 1.92515152 33.90494949 0.64434343 2.22222222 43.73848485]
```

Fig. 11. Result of variance calculation.

By examining the figure above, the researchers notice that the minimum variance is 0.24434343. This variance corresponds to the 2nd attribute of the datasets whose index is 1 (gender). In fact, it was imperative to delete this attribute because it is not significant in terms of importance. To evaluate the performance of the approach, the datasets must be divided into two sections: the training set (80%) and the test set (20%)

B. Creating a Learner Deep Profile

1) *Application of K-means Algorithm:* In the second experiment, and once the data preprocessing step is over, the researchers try to classify all learners into homogeneous (similar) groups. Initially, a sample of 100 learners {L₀, L₁,..., L₉₉} was used. In this case, the system categorized the learners into three clusters (0, 1, and 2). The figure below, Fig. 12, shows the list of learners in each Cluster.

```
Console 15/A
Learners liste of cluster 0 :
[1, 3, 6, 7, 11, 12, 16, 19, 21, 22, 23, 29, 30, 31, 32, 36, 37, 50, 53, 56, 57, 60, 65, 74, 78, 84, 89, 95, 96]
Learners liste of cluster 1 :
[2, 8, 9, 10, 13, 14, 17, 24, 27, 33, 34, 35, 39, 40, 41, 42, 44, 48, 54, 59, 61, 63, 66, 67, 69, 72, 76, 77, 87, 88, 90, 93, 94]
Learners liste of cluster 2 :
[4, 5, 15, 18, 20, 25, 26, 28, 38, 43, 45, 46, 47, 49, 51, 52, 55, 58, 62, 64, 68, 70, 71, 73, 75, 79, 80, 81, 82, 83, 85, 86, 91, 92, 97, 98, 99, 100]
```

Fig. 12. Lists of learners in each group.

The results in the form of a 2D histogram graph are presented in the figure below, Fig. 13 as follows: we have 33 learners in Cluster 0 and 38 learners in Cluster 1, and 29 learners in Cluster 2:

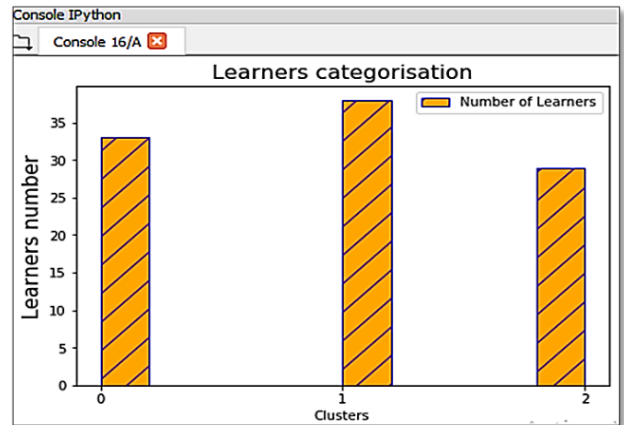


Fig. 13. Classification of learners into cluster.

The results in the form of a 3D sector graph are presented in the figure below, Fig. 14 and as follows: we have 33% learners in Cluster 0 and 38% learners in Cluster 1 and, 29% learners in Cluster 2.

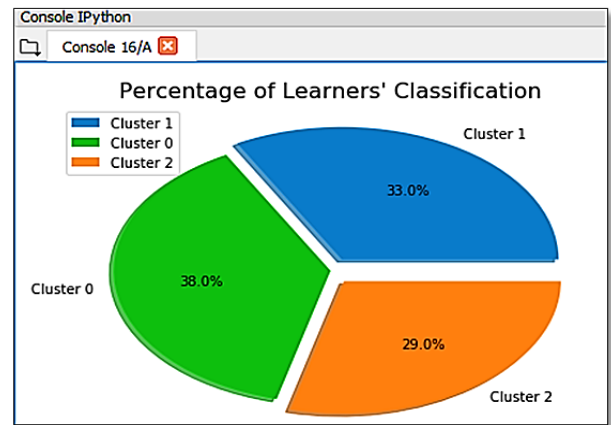


Fig. 14. Classification of learners into clusters.

In the third experiment, the results of classifying learners concerning the two attributes age and motivation for each cluster are presented in the figure below, Fig. 15:

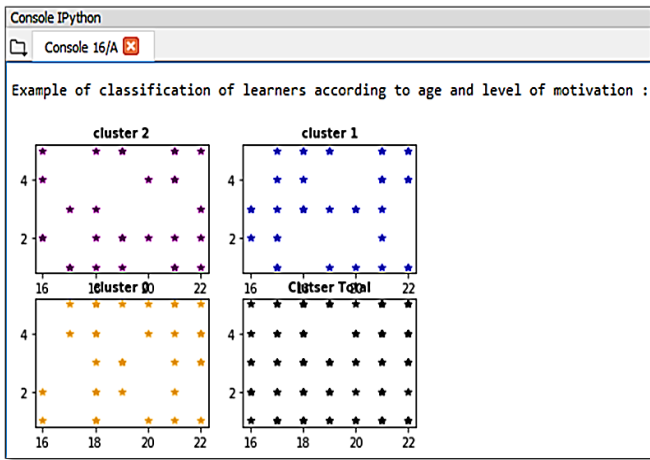


Fig. 15. Classification of learners according to age and motivation level.

The results above show the distribution of learners in the three clusters (Cluster 0, Cluster 1, and Cluster 2) according to age and the degree of motivation among learners. While in the cluster, whose name is “All_Cluster” presents the union of the three clusters. To identify the learners in each cluster to reduce the error, the researchers propose to run the linear regression algorithm in cascade on the clusters generated by the K-mean classification algorithm.

2) *Application of the linear regression algorithm:* By examining the results obtained previously on the classification of the learners according to their age and their degree of motivation, via the application of the K-means algorithm, and to improve the quality of classification, the performance of calculations, the precision, and the reduction of the error, the researchers propose to apply in cascade the linear regression algorithm on each cluster to identify it well to distinguish it compared to the other clusters. First, the researchers start to calculate the slope and the intercept of each cluster. The results are presented in the figure below, Fig. 16.

These values allow us to draw linear regression lines for each cluster. This method allows us to identify the learners of each cluster and to build homogeneous clusters in terms of the classification quality of the learners according to their deep profiles. The figure below, Fig. 17, graphically presents a comparison of the linear regression of the three clusters:

The results in the Fig. 17 show that there is a relationship between the “age” and the “degree of motivation” of learners during the execution of an educational activity. Where the researchers notice that the degree of motivation of the learners is remarkable when the age ≥ 15 the level of motivation of the learners equals 2.5 for cluster 0 and cluster 2, on the other hand, the level of motivation of the learners equals 3 for cluster 1. Moreover, when the age = 25, the motivation among the learners reaches the peak: 4 for Cluster 1 and 3.8 for Group 0, and 2.8 for Cluster 2.

C. Learning Path Recommendation

In this example, the researchers show in the form of a graph Fig. 18 how to define an adaptive e-learning activity for a

given learner, using "Bloom's taxonomy" [16], [24], [25] the researchers give a list of states (LOs) that describe the learning activity: Introduction; Chapter N° 1; Examples, Exercises, and Exam. Bloom's taxonomy" helps us to give each transition a reward (at the basis of a scale from 0 to 10) according to its difficulty level, where each level depends on the previous one:

Stay = + 00; Next_level = + 0,5; High_level = + 0,5; Exercising = + 0,4; Look_Examples = + 0,2; Previous = + 0,1 and Passing_Quiz = + 0,3.

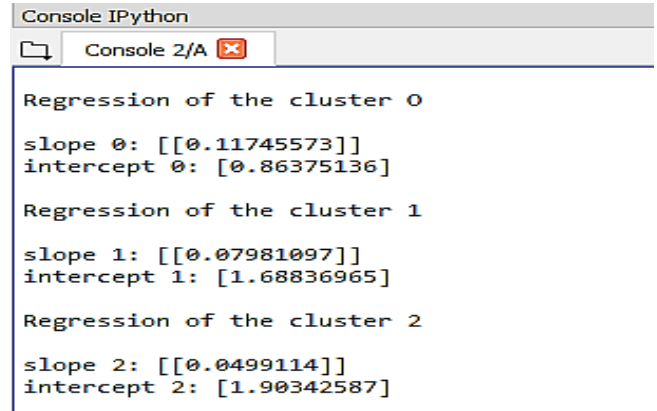


Fig. 16. Slope calculation and cluster interception.

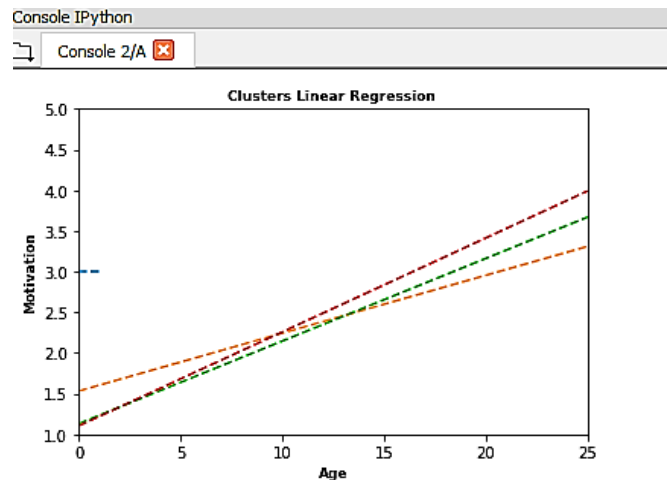


Fig. 17. Cluster linear regression.

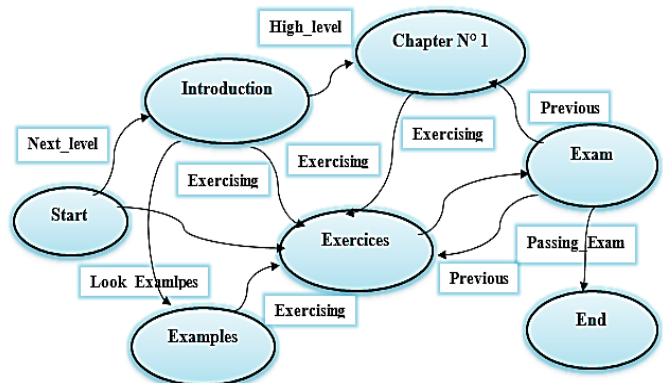


Fig. 18. Example of a state-action combination graph for the execution of an educational activity.

Applying "Bloom's taxonomy" to our example above, the researchers deduce the reward matrix of state-action pairs on the set of related (directly connected) states:

$$M_{ij} \begin{pmatrix} +00 & +0,5 & +00 & +00 & +0,4 & +00 \\ +00 & +00 & +0,5 & +0,2 & +0,4 & +00 \\ +00 & +00 & +00 & +00 & +0,4 & +00 \\ +00 & +00 & +00 & +00 & +0,4 & +00 \\ +00 & +00 & +00 & +00 & +00 & +0,3 \\ +00 & +00 & +0,1 & +00 & +0,1 & +00 \end{pmatrix}$$

Reward matrix of state-action pairs

Where, the rows i of the matrix M_{ij} represent the states, while the columns j of the matrix M_{ij} represent the actions. To determine the optimal adaptive learning path to be taken by the learner for this learning activity cited in Fig. 17, based on their deep profile, the researchers must first generate the Q-value of the Q-learning algorithm as follows:

1	[0 ; 1,157229998544553 ; 0 ; 0 ; 0,0999999999991 ; 0]
2	[0 ; 0,0,98899999588963 ; 0,6699999971061 ; 0,6999999955544 ; 0,2999999997890]
3	[0 ; 0 ; 0 ; 0,626999999999999 ; 0 ; 0,299999999999999]
4	[0 ; 0 ; 0 ; 0 ; 0,699999999999999 ; 0]
5	[0 ; 0 ; 0 ; 0 ; 0 ; 0,299999999999999]
6	[0 ; 0 ; 0 ; 0 ; 0 ; 0]

Fig. 19. Q-table matrix of the Q-value function for the action-state.

The matrix above presents the results obtained by running the Q-learning algorithm on our system, where rows i of the Q-table represent states, while columns j represent actions. They show how the Q-learning algorithm proposes the most optimal learning path for a given learner. The learner can choose to start with any learning object at the time of the learning activity, after which the system will recommend the best learning path, by choosing and organizing the sequence of learning objects appropriate in real time to their deeper profile.

If the agent (the learner) were to use the policy described in the Q-table above to find the most appropriate learning path for her deep profile, then:

- From state zero (Start), the action with the maximum value is Next_level, so that's what he will do, achieving state one (learning object Introduction).
- From state one (Introduction), the action with the maximum value is High_level, This leads the learner to state two (learning object Chapter N°1).
- From state two (Chapter N°1), the action with the maximum value is High_level, This leads the learner to state four (learning object Exercises).
- From state four (Exercises), the action with the maximum value is Passing_Exam, This leads the learner to state five (learning object Exam).

Based on these transitions, we can deduce the adaptive learning path for this learner:

Start → Introduction → Chapter N° 1 → Exercises → Exam → End.

V. CONCLUSION

Deep learner profiles are very interesting objects that can contribute to the success of adaptive e-learning systems. These deep profiles must be able to contain different types of information and characteristics about the learner, to take into account the different facets of their learning. Therefore, generic models are needed to properly represent learners. To address this need, the researchers have presented in this paper a new intelligent approach based on K-means, linear regression, and algorithms Q-learning. The system is designed to create the most detailed and best structured in-depth profile for a given learner, and then recommend the most appropriate learning path for that learner. The proposed system ensures that it can be used by various learning management systems (LMS) in these various contexts.

As a perspective, on the one hand, the researchers plan to propose a technique for the choice of optimal k in the learner classification phase and on the other hand to experiment with the approach while adding as many states and actions as possible for each state (learning object) to allow the discovery of the optimal action for each learner. This can of course lead to complexity and convergence constraints, especially if the system is to be put online. For this, the use of deep reinforcement learning (Deep Q-learning) will be a good idea for issues of complexity and optimization of the system.

This study has potential limitations, since Reinforcement learning has various drawbacks while appearing to be a very potent and useful technique, it needs to store values for each state; it frequently uses too much RAM. That is, it might become a memory-intensive process. Moreover, due to the small sample size, the results may not be representative of the entire population. Therefore, it may limit the validity and generalizability of the findings. A larger sample size would be needed to increase the statistical power and improve the representativeness of the sample since there would be the chance of having different deep profiles

REFERENCES

- [1] M. Laaziri, S. Khouliji, K. Benmoussa, and K. M. Larbi, "Outlining an Intelligent Tutoring System for a University Cooperation Information System," Engineering, Technology & Applied Science Research, vol. 8, no. 5, pp. 3427–3431, Oct. 2018, <https://doi.org/10.48084/etasr.2158>.
- [2] Manal Abdullah, Reem M. Bashmail, Wafaa H. Daffa, Mona Alzahrani and Malak Sadik, The Impact of Learning Styles on Learner's Performance in E-Learning Environment. (IJACSA) International Journal of Advanced Computer Science and Applications, Vol. 6, No. 9, 2015.
- [3] H.M. Truong, : Integrating learning styles and adaptive e-learning system: current developments, problems and opportunities, Comput. Hum. Behav., vol. 55, pp. 1193 (2016).
- [4] Hoang Tieu Binh and Bui The Duy.: Predicting Students' performance based on Learning Style by using Artificial Neural Networks. IEEE International Conference on Knowledge and Systems Engineering(KSE) (2017).
- [5] H. Imran, M. Belghis-Zadeh, T. Chang, T.S Graf. PLORS: a personalized learning object recommender system. Vietnam J.Comput. Sci. vol. 3, no. 1, pp. 3–13, 2016, doi: 10.1007/s40595-015-0049-6.
- [6] Manal Abdulaziz Abdullah.: Learning style classification based on student's behavior in moodle learning management system. Transactions on Machine Learning and Artificial Intelligence, 3(1):28 (2015) 045815.
- [7] Madani, Y., Bengourram, J., Erritali, M., Hssina, B., & Birjali, M. (2017). Adaptive e-learning using genetic algorithm and sentiments

- analysis in a big data system. *International Journal of Advanced Computer Science And Applications*, 8(8), 394403.
- [8] Rajesh C. Panicker, Akash Kumar, Dipti Srinivasan and Deepu John. Adaptive Learning and Analytics in Engineering Education; 2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE). 978-1-5386-6522-0/18/\$31.00 ©2018 IEEE 4-7 December 2018, Wollongong, NSW, Australia.
- [9] Outmane Bourkoukou, and Essaid El Bachari . A Big-Data Oriented Recommendation Method in E-Learning Environment. Article in *International Journal of Emerging Technologies in Learning (IJET)* · June 2022 . doi: 10.3991/ijet.v17i10.27861.
- [10] M. T. Alshammari and A. Qtaish, "Effective Adaptive E-Learning Systems According to Learning Style and Knowledge Level," *Journal of Information Technology Education: Research*, vol. 18, pp. 529–547, Nov. 2019.
- [11] Ikawati, Y., Al Rasyid, M. U. H., & Winarno, I. (2020, September). Student behavior analysis to detect learning styles in Moodle learning management system. In *2020 International Electronics Symposium (IES)* (pp. 501-506). IEEE. doi: 10.1109/IES50839.2020.9231567.
- [12] Nafea, S. M., Siewe, F., & He, Y. (2019, February). A novel algorithm for course learning object recommendation based on student learning styles. In *2019 International Conference on Innovative Trends in Computer Engineering (ITCE)* (pp. 192-201). IEEE. doi: 10.1109/ITCE.2019.8646355.
- [13] N. Vedavathi, K.M. Anil. An efficient e-learning recommendation system for user preferences using hybrid optimization algorithm. *Soft Comput*, 25, 9377–9388, 2021, doi: 10.1007/s00500-021-05753-x.
- [14] Dwivedi, P., Kant, V., & Bharadwaj, K. K. (2018). Learning path recommendation based on modified variable length genetic algorithm. *Education and information technologies*, 23, 819-836.
- [15] M. T. Alshammari and A. Qtaish, "Effective Adaptive E-Learning Systems According to Learning Style and Knowledge Level," *Journal of Information Technology Education: Research*, vol. 18, pp. 529–547, Nov. 2019.
- [16] M. Boussakssou, B. Hssina, and M. Erittali, "Towards an Adaptive Elearning System Based on Q-Learning Algorithm," *Procedia Computer Science*, vol. 170, pp. 1198–1203, Jan. 2020, <https://doi.org/10.1016/j.procs.2020.03.028>.
- [17] H. El Fazazi, M. Elgarej, M. Qbadou, and K. Mansouri, "Design of an Adaptive e-Learning System based on Multi-Agent Approach and Reinforcement Learning", *Engineering, Technology & Applied Science Research (Eng. Technol. Appl. Sci. Res.)*, vol. 11, no. 1, pp. 6637–6644, Feb. 2021.
- [18] W. Intayoad, C. Kamyod, and P. Temdee, "Reinforcement Learning for Online Learning Recommendation System," in *2018 Global Wireless Summit (GWS)*, Chiang Rai, Thailand, Nov. 2018, pp. 167–170, <https://doi.org/10.1109/GWS.2018.8686513>.
- [19] Graf, S., Viola, S. R., & Kinshuk, T. L. (2006, December). Representative characteristics of felder-silverman learning styles: An empirical model. In *Proceedings of the IADIS International Conference on Cognition and Exploratory Learning in Digital Age (CELDA 2006)*, Barcelona, Spain (pp. 235-242).
- [20] G. Thippa Reddy M. ; Praveen Kumar Reddy; Kuruva Lakshmana; Rajesh Kaluri; Dharmendra Singh Rajput; Gautam Srivastava; Thar Baker "Analysis of Dimensionality Reduction Techniques on Big Data". IEEE, 16 March 2020, doi: 10.1109/ACCESS.2020.2980942.
- [21] B. K. Ponukumati, P. Sinha, M. K. Maharana, A. V. P. Kumar, and A. Karthik, "An Intelligent Fault Detection and Classification Scheme for Distribution Lines Using Machine Learning", *Eng. Technol. Appl. Sci. Res.*, vol. 12, no. 4, pp. 8972–8977, Aug. 2022.
- [22] Cui, M. (2020). Introduction to the k-means clustering algorithm based on the elbow method. *Accounting, Auditing and Finance*, 1(1), 5-8. doi: 10.23977/accaf.2020.010102.
- [23] Sutton, R. S., & Barto, A. G. (1998). *Introduction to reinforcement learning* (Vol. 2, No. 4). Cambridge: MIT press.
- [24] Krathwohl, D. R. (2002). A revision of Bloom's taxonomy: An overview. *Theory into practice*, 41(4), 212-218. Doi:10.1207/s15430421tip4104_2.
- [25] Anderson, L. W., & Krathwohl, D. R. (2021). A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives. Longman.

Industrial Practitioner Perspective of Mobile Applications Programming Languages and Systems

Amira T. Mahmoud^{1*}, Ahmad A. Muhammad², Ahmed H. Yousef³, Hala H.Zayed⁴, Walaa Medhat⁵, Sahar Selim⁶
School of Information Technology and Computer Science, Nile University, Giza, Egypt^{1,2,4,5,6}
Center for Informatics Science, Nile University, Giza, Egypt^{1,6}
Faculty of Engineering, Egypt University of Informatics, Cairo, Egypt³
Faculty of Engineering, Ain Shams University, Cairo, Egypt³
Faculty of Computers and AI, Benha University, Benha, Egypt^{4,5}

Abstract—The growth of mobile application development industry made it crucial for researchers to study the industry practices of choosing mobile applications programming languages, systems, and tools. With the increased attention of cross-platform mobile applications development from both researchers and industry, this paper aims at answering the question of whether most of the industries are using cross-platform development or native development. The paper collects feedback about industry's most used mobile development systems. In addition, it provides a map of the different technologies used by mobile applications development companies according to some of the demographics like company size and location. An online questionnaire is carried out to collect the data. The survey targeted both amateur and professional mobile developers. A total of 85 participants participated in answering the survey. Qualitative analysis using descriptive statistics is done on the results of the survey. Although the results show that there is an industrial trend towards using the cross-platform languages, native development is still used by the well-established companies. More than 50% of the participants are found to be aware of the performance issues of the cross-platform development languages and frameworks. Comparison with findings of related work is discussed which raises more research questions and draws out future research in this field.

Keywords—Android; cross-platform; development; iOS; mobile applications, questionnaire

I. INTRODUCTION

Mobile applications are becoming essential in human lives. During the corona pandemic, many countries had totally shut down to protect their people from the crisis. Mobile applications played a very important role in providing people the ability to do all their daily tasks through their mobiles. Health organizations and governments have developed numerous mobile applications for managing the pandemic [1]. Hundreds of applications emerged to aid people in their work, education, shopping, entertainment, and more. In fact, the second quarter of 2020 became the largest for mobile app usage, with new downloads reaching billions. Mobile applications are found in two main stores: Apple store for iOS platform and Google play store for Android platform. Recently, Huawei released a new platform called Harmony OS for Huawei mobile phones and devices. This release was a response for the Huawei ban which happened in May 2019 [2].

Development of mobile applications for the different platforms is done in one of two ways: either the applications are developed natively for each platform, or the application is developed once on a cross-platform framework. Native development means to develop the application in java or Kotlin for Android and in swift or objective C for iOS. However, for the past few years, swift is being used more than objective C and is considered the official language for iOS platform. Regarding Android in 2018, Google announced that they support Kotlin for Android [3]. Native development might take much time, money, and effort from mobile application vendors. However, native development provides the flexibility for developers to handle platform-specific functionalities [4] like push notifications, camera access, and GPS.

On the other hand, Cross-platform development is a way adopted by several frameworks that depend on variant methodologies to save the time and effort of developing the application specifically for each platform. Cross-platform frameworks have their own challenges and limitations. One of the most important challenges is the dependency of these frameworks on languages that are different from the native languages. This implies developers to learn these new languages and frameworks. Many researchers evaluated these frameworks and compared them to each other and to the native development [5]–[10]. Most of this research figured out that cross-platform development has limitations regarding the performance of the product applications. These limitations include memory, speed, user experience, and security. However, the inventors of these frameworks are enhancing and improving their tools every day. Many libraries are emerging to aid developers and increase the flexibility of developing the applications.

Researchers are continuing to introduce new cross-platform techniques. They depend on the research findings that the existing cross-platform frameworks are not closing the gap between developers and end-users' needs regarding applications' development and performance. Therefore, it is essential to make studies that aim at investigating the industry and practitioners' feedback on using cross-platform frameworks. In addition, researchers also need to know how industry practitioners use Kotlin, compared to Java, after six years of 2017 announcement of Google. On the other hand, there is a need to investigate whether there are developers for the new platform released by Huawei company, or the platform

is not being used yet. This feedback will lead researchers to industrial needs regarding the cross-platform and native development techniques and their practical usage.

The aim of this empirical study is to answer three research questions that are believed will aid researchers in this field. The questions are presented in section three. These questions are answered by conducting an online questionnaire among junior and professional mobile applications practitioners. Analysis of the survey results will be used to draw a conclusion on the practitioners' perspective regarding mobile application development techniques, which is the most used, and what are the most performance issues they face. It will also guard practitioners and researchers to decrease the gap between them and use the implications presented in this article in their future work.

The rest of this paper is organized as follows: Section two will present the literature of mobile applications development. Section three will present the research questions and our methodology for creating the questionnaire to answer these questions. In addition, the methodology of analyzing the data is explained. In the fourth Section, the results of the conducted questionnaire are presented in the form of descriptive statistics and graphs. Section five includes discussion of the results and implications for practitioners and researchers. Section six then compares our findings to the related work findings. Finally, a conclusion that summarizes the results and analysis is presented in Section seven.

II. RELATED WORK

The related work and literature of this topic are summarized in two main subsections. Subsection one will highlight the existing tools and approaches. Subsection two will present the survey papers that are done on this topic while subsection three will summarize the practitioner studies done. These studies are the most related to our work.

A. Approaches and Tools

Originally, mobile application development was done using the native development language for each platform. The mobile application was developed once for each platform. Languages used for the native development are java or Kotlin for Android and Objective C or swift for iOS. Some years ago, new approaches appeared to develop the application once for multiple platforms. These approaches are called cross-platform development approaches. These approaches are categorized into: 1. Web-based, 2. Hybrid, 3. Interpreted, 4. Compiled approach, 5. Model driven [11][12].

The web-based approach simply relies on the web languages that are already supported by all platforms. The Hybrid approach hybrids web and native code to reach the native UI of mobile applications. Continuous communication between the web view and native components represents the overhead of this approach. The interpreted approach depends on having a layer that interprets the JavaScript code and bridges the JavaScript engine with the native engine to be able to render the native components. This bridging also represents an overhead for the applications developed by this approach. Compiled approach depends on compiling the source code of an application to another code. Flutter which is considered the

most used cross-platform framework nowadays uses the compiler-based approach. One subcategory lies under the compilation approach is called trans-compilation. Trans-compilation involves compiling source code from one high-level language to another high-level language [13]. Tools introduced in [14]–[19] used this approach to translate source code of mobile applications from java for Android to swift for iOS and vice versa. The limitation of these tools lies in their dependence on having corresponding code for each functionality used in the mobile application. This mapping concept might be successful for small applications, but it is not tested yet on conversion of real or complicated applications. The model driven Development (MDD) approach depend on generation of user interface code and business logic from models and templates of the application [20]. This approach is limited by the features and abilities provided by the models used and the experience of developers in using the models. MD2 is one of the tools which depend on the concept of model driven development [21].

Each of the mentioned approaches has its own advantages and its limitations and drawbacks. It is now totally dependent on the applications features and requirements to select the suitable development approach. However, it is not common to see a developer or even a team of developers work with a different approach for every project depending on its requirements. This raised our research questions about the most used tools and techniques, whether more than one approach is used by the same vendor, and whether developers are aware of the performance issues of the used frameworks.

B. Literature Studies

This section summarizes literature studies related to our work, identifying similarities and differences between our work and each study. A systematic study was conducted to create a classification scheme for existing research in cross-platform mobile app development. The study aimed to identify research gaps and challenges in the field by mapping 30 studies. The primary research question focused on identifying the contributions of each of the 30 included studies [22]. Most of our literature is included in that study.

Bjorn-Hansen et al. [23], conducted an empirical study using an online questionnaire to survey 101 industry practitioners. Their study aimed to identify the most used cross-platform frameworks by developers and the issues they face. Their findings revealed that PhoneGap, Ionic, and React Native were the most used frameworks, but cross-platform solutions still faced performance and user experience issues compared to native solutions. While some of our survey questions overlapped with theirs, the main difference is that our study targets both developers and management and provides more detailed respondent demographics through in-depth questions on job position and experience. Our study thus extends some of the limitations of their work.

Ahmed [24] conducted a qualitative study by using two-phased research approach. The first phase is using systematic literature review to identify nine challenges that are found in literature. Then in the second phase, they interviewed 34 participants from industry to validate the literature by identifying 13 challenges and issues of web, native and hybrid

mobile development with nine of them already extracted from the Systematic Literature Review (SLR). The main difference with our study is that this study used an interview to gather qualitative data regarding issues facing mobile application development while our research, an online survey is used to gather quantitative data on both cross-platform and native mobile development.

Francese et al. used a qualitative study [25] in 2017 to gather qualitative data related to mobile application development and management. They invited four mobile application managers to discuss differences between mobile applications and web applications. The interview outcome was used to plan and create the survey questionnaire. The online survey was sent to 510 developers using their LinkedIn profile, but only 82% responded. The results showed that junior developers are the ones that mainly develop applications and there is a huge issue regarding testing mobile applications.

Puvvala [26], conducted a survey to investigate mobile development, and used a Delphi study with 11 senior developers to identify the top four factors influencing platform choice: development costs, ease of coding, support, and expected return. They then used these factors to create a survey on their impact on developers' platform choices, finding that availability of SDKs was the most significant factor. However, their study differs from ours in that it focused specifically on the factors influencing platform choice for application development.

Biørn-Hansen et al. investigated the approaches of Android mobile applications development through exploring applications on Google Play Store. A dataset called Androzo[27] that has 661,705 apps was used to detect the framework used for developing each of these applications. The investigation aimed to answer three research questions about the distribution, usage of cross-platform development frameworks on the Google Play Store and how the usage of deployed apps changed within the last decade. The findings showed that only 15% of the total dataset were cross platform applications and Cordova was the most used cross-platform framework.

Previous studies have not kept up with the fast-paced advancements in the mobile application development industry, as they only focused on either cross-platform frameworks or native development and did not consider both. Additionally, they lacked information on respondent demographics and did not provide in-depth questions for developers. This paper aims to address these gaps by exploring the relationship between respondent demographics and their responses. Our survey methodology, including the questions, target audience, and response validation process, will be detailed in the following section. The results of our study can also be compared to previous surveys in this field.

III. METHODOLOGY

This study used the empirical research specific steps that were stated in [28] as a reference to formulate the literature review, research questions, survey questions and analysis method. Both the survey guidelines in the review done by JS Molleri et al. [29] and the check list provided in [30] are used

to help us in evaluating our survey questions and methodology. The research questions are formulated after reviewing previous work and figuring the limitations of previous empirical studies on mobile applications development in order to ensure that answering these research questions will decrease the gap between researchers and practitioners. An online questionnaire using Pollfish website [31] is used for gathering the data. The questionnaire is shared with LinkedIn users who are working in the field of mobile application development. The next subsections will present our research questions, the survey questions, and how the survey questions are answering the research questions. Afterwards, the methodology of publishing our survey and how we selected the participants is discussed. Finally, the statistical methodologies that we used to analyze the results are explained.

A. Research Questions

RQ1: Which mobile applications development techniques do practitioners use and which platform they are developing for?

Researchers need to know the percentage of cross-platform users among mobile applications vendors and developers. Are the majority using cross-platform development? or the majority are using native development? And why? It is also important to know whether most companies are developing applications for more than one platform, or the majority is developing for only one platform. Does Huawei new platform have companies and/or developers?

RQ1.1: Which native languages are used the most?

For years, java for Android has been the most used language for developing Android applications. A few years ago, Kotlin language started to be used for Android development. Google announced in 2017 that Kotlin will be the official language for Android. We need to know the impact on practitioners and how much did they switch to Kotlin language after this announcement. A similar story happened between Objective-C language and swift for iOS development. We need to know if swift has taken over objective-C or if there are still some developers using Objective-C language.

RQ1.2: Which Cross-platform framework is used the most?

Former surveys and research were done to answer the question of the most popular and most used cross-platform framework. However, this information is changing rapidly due to the continuous evolution of existing frameworks. In addition, new frameworks are appearing, and researchers may not even be aware of their existence. Therefore, it is very important to investigate which frameworks are being used by developers and which are the most used.

RQ2: Are practitioners realizing that cross-platform development is not closing the gap with native development in terms of performance?

In the research field of mobile applications development, it is well known for researchers that cross-platform tools available do not provide the same performance and user experience as natively developed applications. Research comparing the cross-platform frameworks is done on certain applications and case studies. However, we need the

practitioners' point of view regarding this matter. This question is to investigate the performance and the issues of the cross-platform frameworks that face the practitioners and whether native development is the best way to get a high-performing application.

RQ3: Do developers know about trans-compiler-based solutions? Are developers interested in having a trans-compiler-based conversion tool?

Trans-compiler-based solutions for cross-platform development have been recently introduced by researchers [14]–[19]. These solutions are using compilers to translate the source code of mobile applications from one language to another to be available for more than one platform at a time. Researchers need to know practitioners' feedback about these solutions and whether they are a point of interest or not.

B. Questionnaire Design

In this study, questionnaires are considered because they are the fastest and easiest way to gather information for our research purpose. With wide use of professional social media like Linked in, it is easy to spread an online questionnaire among developers across the globe to obtain very useful qualitative data and analyze this data. However, this research is limited by the questionnaire drawbacks that does not allow us of know why or on what basis each participant chose a certain answer. This work can be extended later by making Interviews to focus on that point.

The questionnaire is created by Pollfish website [32] which was chosen over survey monkey and google forms to overcome the limitations regarding the number of participants and the limitations of forcing users to have a google account which may prevent some participants from taking the survey. While formulating our survey questions, we have considered making the questions clear and unbiased. We have also focused on designing questions that would answer the research questions stated previously.

The survey starts by five demographic questions that ask about age, gender, job status, job position and nationality. All these questions are predefined by Pollfish website except the job position (SQ1) and nationality (Q1) questions; we had to add them manually. The job position question was defined as a screening question since it is used to form the logic of the rest of the survey questions.

Then the following four questions (Q2,Q3,Q6,Q7) or (Q4,Q5,Q6,Q7) are profession questions that would help us draw a more rigid conclusion and deeper analysis of the results and exclude any non-valid responses. It will also help us identify correlations or dependencies between variables. Depending on the role of the participant defined in SQ1, the questions flow will differ as shown in Fig. 1. For managers and developers, we ask about the company they are working for and its location (Q2,Q3). For students, we ask about the university/college they are from and its location (Q4,Q5) while freelancers are directly navigated to Q6. The years of experience are also identified in the profession part for all participants and the number of mobile applications developed by the participant (Q6,Q7).

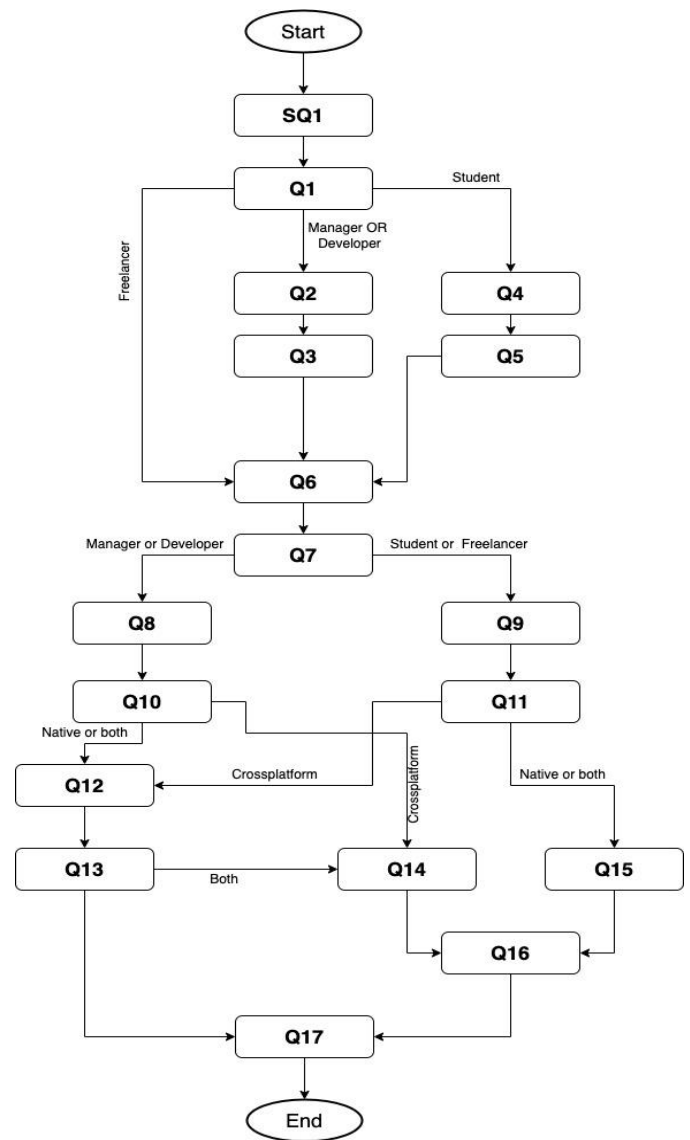


Fig. 1. Survey questions logical flow.

The personal information part is followed by technical questions. The technical questions also have two paths according to the role of the participant. In case the respondent is a student or freelancer, then the question is asked in a personal way “do you use”. If the participant is a manager or developer, then the question is asked targeting the company he/she is working for, like “does your company use”. First technical question (Q8 or Q9) is asking about the target platform whether it is Android, iOS, both platforms, or other platform. The participant can write an alternative. Then a direct question targets the approach used whether it native or cross-platform development (Q10 or Q11). For the native development, another question is asked targeting the language used in developing (Q12,Q13). Choices will be Kotlin or java for Android and swift or objective C for iOS. Then (Q14 and Q15) are targeting the most used cross-platform framework between developers and within companies. The choices of frameworks are added according to monitoring and collecting the most popular frameworks from related work and Statista

website [33]. Some frameworks have been well known for years, and others emerged recently. These two questions use Likert scale from 1 to 5, 1 corresponds for always using the framework and 5 corresponds to never. The question about the framework is followed by a question about the performance issue experienced while using the cross-platform framework (Q16). Finally, a question (Q17) about the familiarity with the Trans-compiler-based approaches is asked with a Likert scale answer between extremely familiar to not familiar at all.

C. Publishing the Questionnaire

Before publishing the questionnaire, we conducted a pilot test to check the availability of the website, the time taken and how clear the questions are. The pilot test was made among five participants of different experiences. The questionnaire took two minutes on average. The questions were clear and understandable. However, some questions needed proper branching. For example, the cross-platform frameworks question should appear only to the participants who chose cross-platform development and should not appear to the participants who chose native development. Similarly, the questions about the native language should not appear to those who chose cross-platform only. The pilot test helped us modify the logic of the questions and branching them correctly. Fig. 1 shows the flow of the questions and the different paths according to the selected answers.

We have created two different links for the survey, one for the Facebook community and the other one for LinkedIn. After publishing on Facebook communities and mobile applications development pages, we got only six participants. On the other hand, the link shared on LinkedIn showed 85 participants. Therefore, we decided to depend on LinkedIn participants. It proved to be a more professional social media through which we can communicate with real practitioners and get accurate answers to our questionnaire. The six responses we got from Facebook were excluded as we couldn't guarantee the level of professionalism the respondents had.

We used the search engine LinkedIn to search for people working in mobile applications development. We used the keywords "mobile application" with applying no filters first. Then, we applied different filters with it. For example, we used "manager" and "senior" keywords in the job title filter. We also used the location filter to reach developers in different countries like USA, Canada, England, India, Pakistan, Germany, Saudi Arabia, Emirates, and many other countries. We applied the filter of each country separately so we can send the survey to multiple people in each country. We have sent the survey link to more than 350 people through LinkedIn.

D. Analysis Methodology

The first step before conducting the analysis is filtering the responses and excluding any responses that were not valid. Two of the responses had answers that showed the participants were not answering the survey correctly. For example, one of the respondents chose all cross-platform frameworks as always used and in the native language question chose other and wrote the name of a cross-platform framework. This showed that either the participant was not reading the survey questions or had very little experience. Therefore, we excluded such

responses to guarantee that the answers and analysis are correct.

Since most of our questions were close ended, we have used descriptive statistics for qualitative analysis to report the survey results. Any provided open-ended text by the participants was used to draw more intuitions and verify the implications of the study. This will be mentioned in discussion sections.

We used a filter to categorize the participants into two main categories according to their role in the mobile applications development industry: Managers or developers and freelancers or students. For some questions, we used this filter to know the results of each category separately.

A filter by the company name was used to identify which method each company uses in developing mobile applications. Companies' names are not revealed in the results to keep the confidentiality and privacy of the respondents' answers. Companies' names were only used to retrieve the company size information from LinkedIn and validate the location information too which is already provided by the participant. Thus, we could categorize for different company sizes and locations whether they are using cross-platform or native development or both, which cross-platform is used by each company category, and which native language is used. There is a difference between the number of managers and developers and number of companies for two main reasons: 1) Not all employed participants provided their company name 2) Some participants were unemployed at the time they answered the survey; therefore, they didn't provide a company name.

Another important filter we used was the cross-platform framework filter. We filtered the answers to frameworks issues question for every framework separately. Thus, for each framework, we could know the most reported issues from its users. All the used filters and the resulting statistics according to each filter used are analyzed and presented by graphs and charts in the results section.

IV. RESULTS

From the results of the survey, we can infer much different information. Before presenting the results and the different filters applied, a general analysis is done on the demographics of the participants like their age, nationality, gender, and years of experience. The general analysis is followed by subsections presenting the results of each question with applying different filters on the results. The technical analysis is presented in three subsections. Each section represents the answer of one of the research questions.

A. Demographics Analysis

A total of 85 participants answered the survey. Most of the participants' nationality is Egyptian with some Indians, Pakistanis, and Belgians. However, they are working in different countries: Egypt, USA, Saudi Arabia, India, Netherlands, Romania, and Germany. The number of participants employed for companies is 71. We had nine participants who didn't provide their company name. However, some of them provided the company location without the

name. Therefore, the companies' location statistics are done for 62 companies as shown in Fig. 2.

Among the 62 companies, 10 of them have unknown names, thus their size is categorized as unknown. The size of the companies was retrieved from Linked in website. Therefore, the size categories are like the categorization in Linked in as shown in Fig. 3. The company size is represented by the number of employees. Most of the companies' sizes are small to moderate sized companies, 27 companies are of size 50 and below. The rest of the 52 companies are almost normally distributed among the rest of the size categories. We have nine companies from 51 to 200 employees. Another nine are from 201 to 1000 employees, and ten companies are of size 1000+.

Among the participants 91% are males the remaining are females. 32% of the participants' age ranges are between 18 to 24, 62% ranges between 25 to 34 and around 5% are above 35. These percentages were also reflected in the years of experience question. Most participants have 2-5 years of experience in the field. Regarding the employment status of the participants, 62% are employed for wages, while the rest are self-employed or out of work currently or students or working in military.

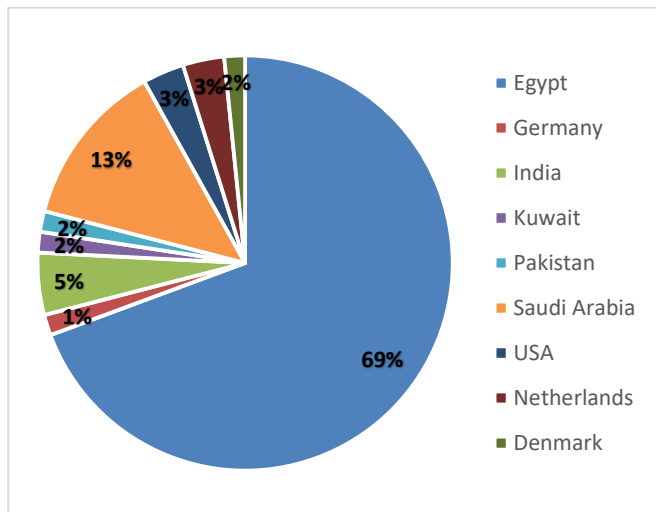


Fig. 2. Participants' companies' locations.

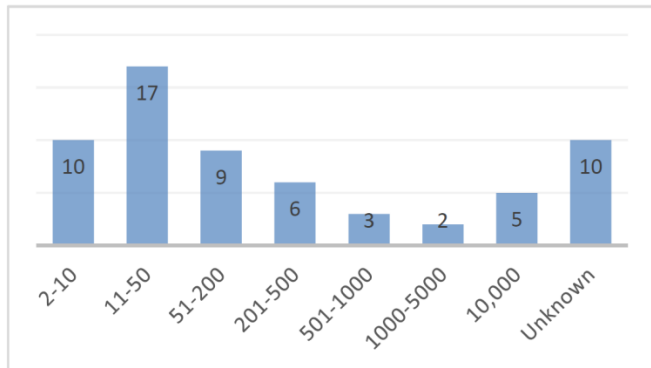


Fig. 3. Companies' size vs number of participants from each category.

We categorized the participants according to their job position into two main categories: Managers or developers who are considered and freelancers or students. This categorization differentiates between participants whose answers represent the companies they are working for and participants who are self-employed. Around 85% of the participants work as managers and developers in the field of mobile applications. 15% are freelancers and students. In the following subsection, we will present statistics answering our research questions. In the statistics of most of the questions, we will use the filter of job position to differentiate between both categories

B. Technical Questions Analysis

The technical questions' part is represented by six questions in the survey for each participant. The analysis of the answers to these questions will answer our previously mentioned research questions. Results of analyzing the participants' answers are presented as follows:

RQ1: Which mobile applications development techniques do practitioners use and which platform they are developing for?

One of the main research questions that we were eager to answer was whether the industry now is going towards cross-platform development or returning to the native development. In the questionnaire, we provided three options for this question: cross-platform, Native or both. The results revealed that most of the participants chose the "both" option. Cross-platform development came in the next level then the native development. Fig. 4 shows the statistics of the approach used by both participants' categories. The statistics showed that most of the freelancers and students are using both approaches together. However, if we observe the companies' representative participants alone, we could notice that companies are either depending on cross-platform frameworks alone or on both cross-platform and native together. Few companies are using the native approach alone. This made us use the company size filter to analyze which companies are using which approach. Table I shows the company size vs. the used approach. From examining the data in the table, we can infer that 38.7% are using cross-platform development alone, 38.7% are using both native and cross-platform development, while 22.58% are using native development alone. Since Egyptian companies have a big share among the companies, we applied the same analysis but with excluding the Egyptian companies. We got nearly the same statistics for the non-Egyptian companies.

The second part of the first RQ asks about the platform which the respondent develops applications for. "Android", "iOS", "both platforms", or "other" are the four options for the platform question in the survey. The results in showed that 73% of participants are developing for both platforms Android and iOS. However, if we examined the freelancer's percentage separately, we could notice that the majority develop applications for Android platform. No participants chose the "other" option which shows that windows phone is obsolete now and that new platforms, like Harmony OS by Huawei, are still not very popular.

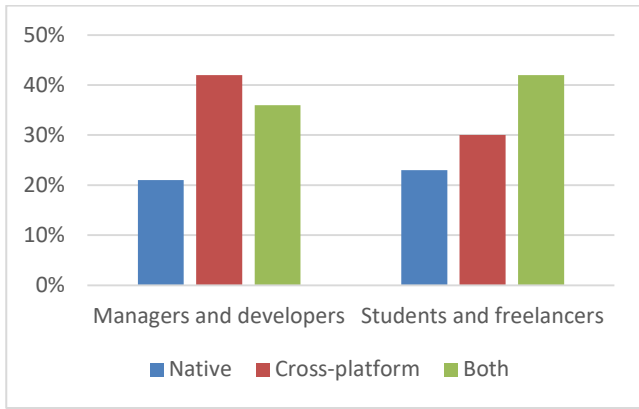


Fig. 4. Percentage of participants using native, Cross-platform or both approaches according to their category.

TABLE I. COMPANY SIZE VS DEVELOPMENT APPROACH

Company size vs used approach	Both	Cross-platform	Native
10,000+	5		
1000-5000	1		1
501-1000	1	1	1
201-500		2	4
51-200	4	5	
11-50	5	6	6
2-10	3	6	1
Unknown	5	4	1
Grand Total	24	24	14

RQ1.1: Which native languages are used the most?

For native development, Java and Kotlin are the languages used to develop Android applications. Swift and Objective C are used for iOS applications. Our aim is to know if there is any language that is preferred among developers over the other. The results showed that 47% of participants chose Kotlin for Android while 39% chose java and the rest use both. On the other hand, 92% chose swift for iOS. When we applied the companies filter, Java and Kotlin for Android are considered evenly used among practitioners. However, swift is used much more than Objective C. only one company is using Objective-C. This company is a very large sized and old governmental company. When we removed Egyptian companies from the analysis, we got the same statistics for both Android and iOS languages. Fig. 5 shows the company size vs. the used native language for 37 companies. These 37 companies are either using native development alone or native development with cross-platform development. The small-sized companies are using Kotlin and java evenly. The medium-sized companies are using Kotlin more than java, while the big companies are using java more than Kotlin.

RQ1.2: Which Cross-platform framework is used the most?

For the cross-platform development selectors, they were asked about the framework they are using. The options of this question included ten different frameworks. The most used framework according to the results is flutter, followed by React

Native, then comes Xamarin, Ionic, JQuery mobile, NativeScript, and Swiftic frameworks. The previous studies showed that React Native was on top [23], [34]. However, now flutter took the first place, and it seems to be very popular among both freelancing developers and companies. Fig. 6 shows the pie chart for seven frameworks. By applying analysis on the companies using cross-platform frameworks, we got similar ranking for the frameworks. When we tried to filter and exclude the small-sized companies then the large-sized companies alone, we got the same result. In addition, excluding Egyptian companies also resulted in the same statistics.

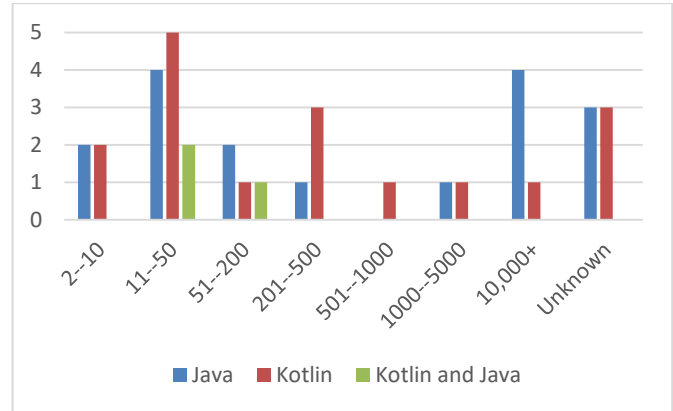


Fig. 5. Company size vs. number of companies using different native languages for android development.

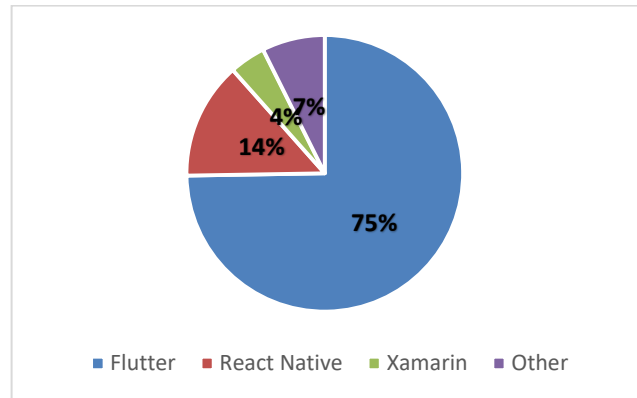


Fig. 6. Statistics of the most used cross-platform frameworks.

RQ2: Are practitioners realizing that cross-platform development is not closing the gap with native development in terms of performance?

To investigate the issues facing the developers using cross-platform frameworks, we asked the developers who are using cross-platform frameworks about the issues they face. This question allowed the participants to choose more than one answer among six different issues: Memory, speed, development effort, security, user experience and testability. An “other” option is also provided to let participants provide any other issues they see. In general, the most reported issue is Memory then comes the Speed and development effort then user experience and security, the least reported issue is testability. By filtering the results on each cross-platform

framework separately, we could see the issues related to each framework. For example, for flutter, the same order of issues is noticed, and this is normal since flutter is the most used framework. For React Native users, security then speed, and development effort were the most reported issues. However, for jQuery and Xamarin, memory, speed and security were the most reported in addition to user experience for Xamarin framework. Fig. 7 shows the statistics of the issues for the four most used frameworks according to the survey results. On the other hand, 12.5% of the participants chose the “other” option only without providing any extra issue. Few of them wrote and they cannot see any issues while using the cross-platform frameworks.

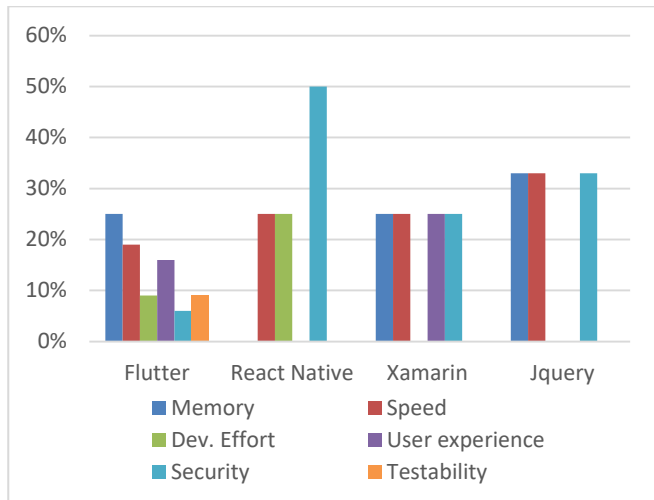


Fig. 7. Reported performance issues by each cross-platform framework.

RQ3: Do developers know about trans-compiler-based solutions? Are developers interested in having a trans-compiler-based conversion tool?

The final question of the survey asked how familiar participants are with the trans-compiler-based cross-platform solutions. 58% of the participants are not familiar with these solutions and 14% are moderately familiar, while 18% are extremely familiar. This shows that the trans-compiler-based solutions are never really tested by practitioners, and they are still under the research umbrella only.

V. DISCUSSION

The most important findings from our survey are discussed as follows: Most companies and practitioners are developing for both Android and iOS platforms. Very few participants chose only one platform. This shows that although developing the applications for more than one platform is a tedious task, and although iOS users are much less than Android users, mobile application vendors are developing applications for both platforms either natively or using cross-platform frameworks. No participant wrote other platform which shows that windows phones are now obsolete and new Operating systems like Harmony OS by Huawei are not very popular.

Only 25% chose native development solely. This means that the industry now is using a mix of cross-platform development and native development together. Almost 75% of

the survey participants are equally split between the “both” option and cross-platform when they were asked about the technology used in development. These statistics are almost similar regardless of the role of participants and regardless of the company size or location for professional participants. This shows that cross-platform frameworks proved to be a good solution but sometimes they are not enough for implementation of sophisticated functionalities on the different platforms. One of the survey participants who was using flutter framework wrote a comment stating that some functionalities must be written using native code then connected to flutter. In addition, cross-platform frameworks have performance issues regarding memory, speed, security, and user experience.

Our study also shows that Flutter is the most used right now. The numbers show that Flutter is becoming very popular among both freelancers and developers working in companies. However, the participants are aware that flutter has its own issues. The most reported issues by Flutter users were memory and speed.

Kotlin language is competing now with java for Android development. More than half of the Android developers who participated in the survey chose Kotlin as the native language they use for development. This was predicted as an impact to the announcement made by Google stating that they will use Kotlin as the official language for Android [35]. We encourage future researchers to investigate more the capabilities of Kotlin language and to support Kotlin language in their proposed development tools for mobile applications. On the other hand, swift language proved to be the most dominant for iOS development, only one participant chose objective C language. The participant who chose objective C is working for a very big and old company which means that objective C might still be used in old companies that do not want to change their structure of operation.

Regarding the familiarity of practitioners with the trans-compiler-based solutions, the results showed that practitioners are almost unaware of these solutions. They are dealing with the current cross-platform frameworks now as their current solution. However, the shift that has occurred from React Native, Phone gap, Ionic and Xamarin to flutter over the recent few years shows that whenever a better solution appears for developers and practitioners, they will easily move to it. These findings also encourage researchers to test their solutions by real practitioners and spread them to industry. This will help them introduce new solutions and tools that might close the gap between current solutions and performance issues.

VI. COMPARISON WITH RELATED WORK

To compare our work with the related works mentioned in the introduction, we focused on five main points based on our findings compared to their findings. These five main points are: What mobile platform do practitioners like to develop applications using? What development approach do practitioners prefer to use, native or cross-platform? Which cross-platform framework is the most used in the industry? What native language do practitioners use the most? What are the performance issues that are facing cross-platform mobile frameworks?

Puvalla et al. [36] discussed the factors that affect developers in choosing a development platform. They concluded that although Android has more apps than iOS, developers are switching from Android apps to iOS due to the monetization potential of the iOS apps. Therefore, iOS developers are paid more than Android developers. The findings of the survey show that the factor that affects the developer's choice of the platform the most is the availability of SDKs to support the platform. But our results show that most practitioners and companies prefer to build applications for both platforms rather than one specific platform. Our results are synonymous with the prediction made by Francesca et al.[37] in 2017, which asked a futuristic question, "In the next 5 years, on which native platform will your company actively develop?". They stated that regardless of what platform the respondents were using at that time, the target platform in the next five years would be both Android and iOS.

Regarding the question of whether practitioners prefer native or cross-platform development approaches. In 2017, Ahmed et al. findings show that most of their participants prefer using native development over cross-platform development. This is different to our findings as our result shows that only 25% are using native development alone while 37.5% are cross-platform and the remaining 37.5% chose both technologies. These differences are related to technological enhancements to the cross-platforms over the years. Besides the technical improvement, cross-platform frameworks are easier to use by developers since development community are getting bigger and giving more support to developers [23].

Bjorn-Hansen et al. [23] conducted an empirical study by targeting 101 industry practitioners. The reason is to find out which cross-platform frameworks are used the most by developers as a hobby and professionally, and what issues are facing cross-platform frameworks. Their findings show that PhoneGap, React-native, and Ionic are the most used apps both as a hobby and professionally. The findings of their research are similar to the findings of Francesca [38], which shows that PhoneGap is the most used. But the result differs from ours because in our study we found that flutter is the most used cross-platform development framework both in companies and by practitioners. This is due to the time that their survey was conducted in 2018 [23], so new technology now dominates the market. The same research group in 2022 [39] investigated approaches to Android mobile application development through applications on the Google Play store. The findings also show that Cordova is the most popular cross-platform framework. Their findings also contradict our findings. However, only 15% of their total dataset are cross-platform applications and the rest of the 85% are native applications, and the applications that are mentioned in the dataset are not recent, which is why they are not developed using flutter, one of the most recent frameworks.

In terms of the native language that the developers are using, Bjorn-Hansen et al. [23] predicted that Kotlin is the most used android development nowadays, not Java. This prediction is proven in our survey, as seen in the results section, that Kotlin is the most used android language by practitioners and companies. On the other hand, Swift is the dominating iOS programming language.

Lastly, regarding the issues that are facing cross-platform mobile frameworks, Bjorn-Hansen et al. [23] state that cross-platform solutions are still facing performance and user experience issues when compared to native solutions. Our findings suggest that memory and speed are the issues that affect Cross-platform frame works, most specifically flutter, which is the most dominant cross-platform framework in our survey.

VII. CONCLUSION AND FUTURE WORK

This paper investigates the most used development technique in the industry and to gather feedback on mobile application development. It seeks to answer the question of whether most industries use cross-platform mobile development or native mobile development. Furthermore, it investigates whether developers and industry have a perspective that is consistent with academic research by collecting data through an online questionnaire. The survey was aimed at both novice and experienced mobile developers. A total of 85 people responded to the survey, which enables us to get perspectives from the industry.

The implications that can be drawn from our findings are stated as follows: (1) Most companies and practitioners develop for both Android and iOS platform with only few choosing one platform. (2) Developers are moving towards cross-platform development. However, they are still using native development besides the cross-platform frameworks. This is due to the flaws and issues that still exist in these frameworks despite the noticeable technological enhancements. (3) Flutter is now the most used framework in the industry and the most reported issues by Flutter users were memory and speed. (4) In terms of which native language is used in the industry the most, Kotlin language currently leads the android development. However, Swift is still the main iOS programming language. (5) Most of the people in the industry are unaware of trans-compiler-based solution.

The findings presented and discussed in this article may all be significant and extensive topics for future research, both individually and collectively. This future work encourages researchers to: (1) Focus on expanding and generalizing the survey so that it will reach a large scale of people by covering more locations and adding interviews. (2) Investigate more the capabilities of Kotlin language and to support Kotlin language in their future work (3) to test their solutions by real practitioners and spread them to industry especially the Trans-compiler-based solutions. (4) To introduce a new way to decrease the issues and flaws facing cross-platform solutions.

REFERENCES

- [1] Z. A.-I. J. of A. T. and and undefined 2021, "A review of mobile applications developed by academics for COVID-19," researchgate.net, 2021, doi: 10.19101/IJATEE.2021.874058.
- [2] J. Lee and G. Gereffi, "Innovation, upgrading, and governance in cross-sectoral global value chains: The case of smartphones," *Industrial and Corporate Change*, vol. 30, no. 1, 2021, doi: 10.1093/icc/dtaa062.
- [3] B. P. D. Putranto, R. Saptoto, O. C. Jakaria, and W. Andriyani, "A Comparative Study of Java and Kotlin for Android Mobile Application Development," in 2020 3rd International Seminar on Research of Information Technology and Intelligent Systems, ISRITI 2020, 2020. doi: 10.1109/ISRITI51436.2020.9315483.

- [4] M. Latif, Y. Lakhri, E. H. Nfaoui, and N. Es-Sbai, "Cross platform approach for mobile application development: A survey," in 2016 International Conference on Information Technology for Organizations Development (IT4OD), IEEE, Mar. 2016, pp. 1–5. doi: 10.1109/IT4OD.2016.7479278.
- [5] D. You, M. H.-Wellington, and N. Zealand, "A Comparative Study of Cross-platform Mobile Application Development," citrenz.ac.nz.
- [6] P. Nawrocki, K. Wrona, M. Marczak, and B. Sniezynski, "A Comparison of Native and Cross-Platform Frameworks for Mobile Applications," *Computer (Long Beach Calif)*, vol. 54, no. 3, pp. 18–27, Mar. 2021, doi: 10.1109/MC.2020.2983893.
- [7] L. P. Barros, F. Medeiros, E. Moraes, and A. Feitosa Júnior, "Analyzing the Performance of Apps Developed by using Cross-Platform and Native Technologies," doi: 10.18293/SEKE2020-122.
- [8] M. Caulo, R. Francese, G. S.-C. on P., and undefined 2021, "Implications on the Migration from Ionic to Android," Springer, vol. 13126 LNCS, pp. 3–19, 2021, doi: 10.1007/978-3-030-91452-3_1.
- [9] M. Isitan and M. Koklu, "Comparison and Evaluation of Cross Platform Mobile Application Development Tools," *International Journal of Applied Mathematics, Electronics and Computers*, vol. 8, no. 4, pp. 273–281, 2020, doi: 10.18100/ijamec.832673.
- [10] Bjørn-Hansen, C. Rieger, T.-M. Grønli, T. A. Majchrzak, and G. Ghinea, "An empirical investigation of performance overhead in cross-platform mobile development frameworks," *Empirical Software Engineering* 2020 25:4, vol. 25, no. 4, pp. 2997–3040, Jun. 2020, doi: 10.1007/S10664-020-09827-6.
- [11] Bjørn-Hansen, T. M. Grønli, and G. Ghinea, "A survey and taxonomy of core concepts and research challenges in cross-platform mobile development," *ACM Comput Surv*, vol. 51, no. 5, Jan. 2019, doi: 10.1145/3241739.
- [12] W. S. El-Kassas, B. A. Abdullah, A. H. Yousef, and A. M. Wahba, "Taxonomy of Cross-Platform Mobile Applications Development Approaches," *Ain Shams Engineering Journal*, vol. 8, no. 2, pp. 163–190, Jun. 2017, doi: 10.1016/J.ASEJ.2015.08.004.
- [13] Korchi, M. K. Khachouch, Y. Lakhri, and A. Moumen, "Classification of existing mobile cross-platform approaches," 2nd International Conference on Electrical, Communication and Computer Engineering, ICECCE 2020, Jun. 2020, doi: 10.1109/ICECCE49384.2020.9179222.
- [14] R. B. Hamza, D. I. Salama, M. I. Kamel, and A. H. Yousef, "TCAIOSC: Application Code Conversion," in NILES 2019 - Novel Intelligent and Leading Emerging Sciences Conference, Institute of Electrical and Electronics Engineers Inc., Oct. 2019, pp. 230–234. doi: 10.1109/NILES.2019.8909207.
- [15] D. I. Salama, R. B. Hamza, M. I. Kamel, A. A. Muhammad, and A. H. Yousef, "TCAIOSC: Trans-Compiler Based Android to iOS Converter," *Advances in Intelligent Systems and Computing*, vol. 1058, pp. 842–851, 2020, doi: 10.1007/978-3-030-31129-2_77/TABLES/5.
- [16] A. Muhammad, A. T. Mahmoud, S. S. Elkalyouby, R. B. Hamza, and A. H. Yousef, "Trans-Compiler based Mobile Applications code converter: swift to java," in 2020 2nd Novel Intelligent and Leading Emerging Sciences Conference (NILES), IEEE, Oct. 2020, pp. 247–252. doi: 10.1109/NILES50944.2020.9257928.
- [17] A. Muhammad, A. M. Soliman, S. Selim, and A. H. Yousef, "Generic Library Mapping Approach for Trans-Compilation," pp. 62–68, Jun. 2021, doi: 10.1109/MIUCC52538.2021.9447641.
- [18] S. S. El-Kaliouby, S. Selim, and A. H. Yousef, "Native Mobile Applications UI Code Conversion," *Proceedings - 2021 16th International Conference on Computer Engineering and Systems, ICCES 2021*, 2021, doi: 10.1109/ICCES54031.2021.9686093.
- [19] R. Barakat, M. B. A. Radwan, W. M. Medhat, and A. H. Yousef, "Trans-Compiler-Based Database Code Conversion Model for Native Platforms and Languages," *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 13761 LNAI, pp. 162–175, 2023, doi: 10.1007/978-3-031-21595-7_12/TABLES/7.
- [20] M. Usman, M. Z. Iqbal, and M. U. Khan, "A product-line model-driven engineering approach for generating feature-based mobile applications," *Journal of Systems and Software*, vol. 123, pp. 1–32, Jan. 2017, doi: 10.1016/J.JSS.2016.09.049.
- [21] H. Heitkötter, T. A. Majchrzak, and H. Kuchen, "Cross-platform model-driven development of mobile applications with MD 2," in *Proceedings of the ACM Symposium on Applied Computing*, New York, New York, USA: ACM Press, 2013, pp. 526–533. doi: 10.1145/2480362.2480464.
- [22] T. Zohud and S. Zein, "A systematic mapping study of cross-platform mobile apps," *Journal of Computer Science*, vol. 15, no. 4. Science Publications, pp. 519–536, 2019. doi: 10.3844/jcsp.2019.519.536.
- [23] Bjørn-Hansen, T. M. Grønli, G. Ghinea, and S. Alounh, "An Empirical Study of Cross-Platform Mobile Development in Industry," *Wirel Commun Mob Comput*, vol. 2019, 2019, doi: 10.1155/2019/5743892.
- [24] Ahmad, K. Li, C. Feng, S. M. Asim, A. Yousif, and S. Ge, "An Empirical Study of Investigating Mobile Applications Development Challenges," *IEEE Access*, vol. 6, pp. 17711–17728, 2018, doi: 10.1109/ACCESS.2018.2818724.
- [25] R. Francese, C. Gravino, M. Risi, G. Scanniello, and G. Tortora, "Mobile App Development and Management: Results from a Qualitative Investigation," *Proceedings - 2017 IEEE/ACM 4th International Conference on Mobile Software Engineering and Systems, MOBILESoft 2017*, pp. 133–143, 2017, doi: 10.1109/MOBILESoft.2017.33.
- [26] Puvvala, A. Dutta, R. Roy, and P. Seetharaman, "Mobile application developers' platform choice model," *Proceedings of the Annual Hawaii International Conference on System Sciences*, vol. 2016-March, pp. 5721–5730, 2016, doi: 10.1109/HICSS.2016.707.
- [27] "AndroZoo: Collecting Millions of Android Apps for the Research Community | IEEE Conference Publication | IEEE Xplore." <https://ieeexplore.ieee.org/document/7832927> (accessed Oct. 11, 2022).
- [28] R. Malhotra, "Empirical research in software engineering: concepts, analysis, and applications," p. 472.
- [29] J. S. Molléri, K. Petersen, and E. Mendes, "Survey Guidelines in Software Engineering: An Annotated Review," *International Symposium on Empirical Software Engineering and Measurement*, vol. 08-09-September-2016, Sep. 2016, doi: 10.1145/2961111.2962619.
- [30] W. Hui, S. M. Lui, and W. K. Lau, "A reporting guideline for IS survey research," *Decis Support Syst*, vol. 126, p. 113136, Nov. 2019, doi: 10.1016/J.DSS.2019.113136.
- [31] "About Pollfish." <https://www.pollfish.com/about/> (accessed Feb. 02, 2022).
- [32] "Real Consumer Insights | Pollfish Survey Tools." https://www.pollfish.com/?utm_source=google&utm_medium=cpc&utm_campaign=gsem_Brand_sc-Ret&utm_adgroup1=pollfish&utm_term=pollfish_survey&utm_sitelink=%7Bstielink%7D&utm_device=c&utm_create=449133244745&gclid=Cj0KCQjw4PKTBhD8ARIsAHChzRjL1d2Jxcx71KUx8T2ogaHzKiMchLP7Ei-1gClI4Jy85MTS-oy_v1YaAnF5EALw_wcB (accessed May 12, 2022).
- [33] "Cross-platform mobile frameworks used by global developers 2021 | Statista." <https://www.statista.com/statistics/869224/worldwide-software-developer-working-hours/> (accessed May 12, 2022).
- [34] Ahmad, K. Li, C. Feng, S. M. Asim, A. Yousif, and S. Ge, "An Empirical Study of Investigating Mobile Applications Development Challenges," *IEEE Access*, vol. 6, pp. 17711–17728, Mar. 2018, doi: 10.1109/ACCESS.2018.2818724.
- [35] Mazuera-Rozo et al., "Taxonomy of security weaknesses in Java and Kotlin Android apps," *Journal of Systems and Software*, vol. 187, p. 111233, 2022, doi: 10.1016/j.jss.2022.111233.
- [36] Puvvala, A. Dutta, R. Roy, and P. Seetharaman, "Mobile application developers' platform choice model," *Proceedings of the Annual Hawaii International Conference on System Sciences*, vol. 2016-March, pp. 5721–5730, 2016, doi: 10.1109/HICSS.2016.707.
- [37] R. Francese, C. Gravino, M. Risi, G. Scanniello, and G. Tortora, "Mobile App Development and Management: Results from a Qualitative Investigation," *Proceedings - 2017 IEEE/ACM 4th International Conference on Mobile Software Engineering and Systems, MOBILESoft 2017*, pp. 133–143, 2017, doi: 10.1109/MOBILESoft.2017.33.

- [38] R. Francese, C. Gravino, M. Risi, G. Scanniello, and G. Tortora, "Mobile App Development and Management: Results from a Qualitative Investigation," Proceedings - 2017 IEEE/ACM 4th International Conference on Mobile Software Engineering and Systems, MOBILESoft 2017, pp. 133–143, 2017, doi: 10.1109/MOBILESoft.2017.33.
- [39] Biørn-Hansen, T.-M. Grønli, T. A. Majchrzak, H. Kaindl, and G. Ghinea, "The Use of Cross-Platform Frameworks for Google Play Store Apps," Proceedings of the 55th Hawaii International Conference on System Sciences, Jan. 2022, doi: 10.24251/HICSS.2022.934.

Feature Selection using Particle Swarm Optimization for Sentiment Analysis of Drug Reviews

Afifah Mohd Asri¹, Siti Rohaidah Ahmad², Nurhafizah Moziyana Mohd Yusop³

Department of Computer Science-Faculty of Defence, Science and Technology,
Universiti Pertahanan Nasional Malaysia, Sungai Besi, Kuala Lumpur, Malaysia

Abstract—Feature selection (FS) is an essential classification pre-processing task that eliminates irrelevant, redundant, and noisy features. The primary benefits of performing this task include enhanced model performance, reduced computational expense, and modified “curse of dimensionality”. The goal of performing FS is to find the best feature group that can be used to build an effective pattern recognition model. Drug reviews play a significant role in delivering valuable medical care information, such as the efficacy, side effects, and symptoms of drug use, facilities, drug pricing, and personal drug usage experience to healthcare providers and patients. FS can be used to obtain relevant and valuable information that can produce an optimal subset of features to help obtain accurate results in the classification of drug reviews. The FS approach reduces the number of input variables by eliminating redundant or irrelevant features and narrowing the collection of features to those most significant to the machine learning model. However, the high dimensionality of the feature vector is a major issue that reduces the accuracy of sentiment classification, making it challenging to find the best feature subset. Thus, this article presents a perceptive method to perform FS by gathering information from the potential solutions generated by a particle swarm optimization (PSO) algorithm. This research aimed to apply this algorithm to identify the optimal feature subset of drug reviews to improve the classification accuracy of sentiment analysis. The experimental results showed that PSO provided a better classification performance than a genetic algorithm (GA) and ant colony optimization (ACO) in most datasets. The results showed that PSO demonstrated the highest levels of performance, with an average of 49.3% for precision, 73.6% for recall, 59% for F-score, and 57.2% for accuracy.

Keywords—Sentiment analysis; feature selection; particle swarm optimization; drug reviews

I. INTRODUCTION

As the world becomes increasingly digitised, there is a growing need for the automation of various processes. One area that has experienced significant expansion is sentiment analysis, which is a crucial component of natural language processing. Sentiment analysis involves identifying the emotional responses elicited by a given text. One area where sentiment analysis has proven useful is in the analysis of drug reviews [1]. Sentiment analysis can identify the overall sentiment of a drug review, which can help healthcare providers understand the effectiveness and side effects of a given drug. However, a significant challenge in sentiment analysis is figuring out which features, or aspects of a text are essential in determining the sentiment. Feature selection (FS) involves identifying a relevant subset of features from a larger

set of potential features [2], [3]. By decreasing the number of features, FS can enhance the accuracy and efficiency of a sentiment analysis model [4], [5].

Particle Swarm Optimization (PSO) is a well-known optimization algorithm commonly used in FS due to its ability to simulate the behaviour of a swarm of particles. Each particle represents a possible solution to an optimization problem, and they interact with each other as they move through a solution space in search of the optimal solution [6], [7]. PSO is a suitable method for feature selection in sentiment analysis, as it can determine the optimal feature subset to maximise the model’s accuracy [8]. The features to be selected must be encoded as binary values, with 1 indicating their inclusion in the subset and 0 indicating their exclusion.

The PSO algorithm commences the optimization process by randomly assigning a set of particles to represent feasible feature subsets to form a swarm. The fitness value of each particle is then calculated by evaluating the accuracy of the sentiment analysis model with its corresponding feature set. Subsequently, the particles navigate through the solution space, influenced by their individual best position (pbest) and the best position of the swarm (gbest). This iterative process persists until a pre-defined termination criterion is reached, such as reaching a maximum number of iterations, or a specific level of accuracy [6], [9]. Once the PSO algorithm has identified the optimal subset of features, the sentiment analysis model can be trained using only these features, which would result in a more efficient and accurate model. Thus, utilising PSO for FS in a sentiment analysis of drug reviews can enhance the accuracy and efficiency of the model, ultimately leading to a more comprehensive understanding of the effectiveness and side effects of reviewed drugs.

This study aimed to utilise PSO as part of a feature selection method to identify an optimal set of features in drug review datasets that can enhance the classification accuracy. The use of PSO for FS has been demonstrated to be effective in identifying relevant and non-redundant subsets of features that can enhance the performance of machine learning algorithms [10], [11]. The results of these studies showed that PSO outperformed two algorithms by demonstrating the highest level of performance. The application of PSO in drug review datasets can uncover feature subsets that can enhance the accuracy of sentiment analysis models. This achievement can ultimately lead to a deeper comprehension of the efficacy and adverse reactions of various drugs. The experimental results indicated that PSO possessed the capability to produce high-

quality feature subsets, which increased the classification accuracy of the sentiment analysis model.

This article begins with an introduction to the background of this study, leading to a clear overview of the conducted experiments. The main body of this article is divided into several sections, with each section focusing on a specific topic, such as literature reviews, related works, brief explanation on PSO, research methodology, experimental setup, and analysis of results. Within each section, subtopics are introduced to offer explanations, support evidence, examples, and analysis. The conclusion section summarises the main points, restates the experiments, and ends with a concluding statement or call to action. The reference section is included to list the sources used in this article.

II. LITERATURE WORK

A. Sentiment Analysis

Sentiments can be defined as an individual’s attitude or belief that are often influenced by emotions rather than logical reasoning. Therefore, the process of analysing opinions is also commonly known as sentiment analysis, which aims to extract subjective information from various sources, such as speech, text, tweets, and databases [12]. Sentiment analysis involves using Natural Language Processing (NLP) techniques to automatically detect emotions, perspectives, opinions, and attitudes that are expressed in texts and to categorise them either as neutral, positive, or negative [13]. According to [14], sentiment analysis can be applied to social media and medical records to acquire information on the effectiveness of medical treatments or medications. By analysing public archives and social media posts, specific adverse effects of drugs can be identified more efficiently, leading to potential benefits for the pharmaceutical industry in terms of pharmacovigilance [15]. Thus, sentiment analysis can be used to extract information that can assist in making accurate judgments regarding public health and substance safety. Machine Learning and Lexicon-based approaches are commonly used in sentiment analysis.

Lexicon-based methods primarily depend on a sentiment vocabulary, or a set of well-known and precompiled emotional

words, sentences, and idioms, which is created for conventional communication categories [16]. The Machine Learning (ML) approach relies on the quantity of labelled data marked by specialists to train a classification [2]. ML can be divided into two categories, namely, supervised and unsupervised methods. An appropriate collection of features must be selected and retrieved to identify sentiments in order to improve the performance of these approaches [17]. The analysis of sentiments using machine learning was the focus of this study.

B. Drug Reviews

In recent years, there has been a significant surge in the number of social networks dedicated to discussing health-related matters. This has led to a substantial increase in the availability of healthcare information in the form of drug reviews on the Internet [18]. According to [15], Drugs.com is the biggest and most viewed medicinal information website that serves customers among the public and healthcare experts. According to [18], a substantial number of drug reviews has been created and published through various healthcare and drug-related online platforms, including AskaPatient and Drugratingz, where users express their first-hand experiences and reactions to various medications.

Drug reviews are written evaluations of numerous drugs by users based on their personal experiences and preferences [19]. Drug reviews can also be described as an individual’s impressions regarding several drug-related fields, such as efficacy, adverse effects, convenience, and value [14]. These reviews offer abundant data that can be utilised to make informed decisions concerning public health and medication safety [20].

III. RELATED WORKS

This section presents related studies on sentiment analysis of drug reviews. Table I shows an extended summary of related studies based on the techniques used in the sentiment analysis of drug reviews [20].

TABLE I. RELATED STUDIES ON TECHNIQUES USED IN SENTIMENT ANALYSIS OF DRUG REVIEWS

Author	Feature Extraction
[45]	n-gram, word cloud
[44]	Count Vectorizer, Term frequency-inverse document frequency (TF-IDF)
[43]	Bag of words (BoWs), Term frequency-inverse document frequency (TF-IDF)
[42]	Word position encoding and embedding in vector representation
[19]	Not stated in paper.
[41]	Not stated in paper.
[40]	Yes, but did not state the specific type of feature
[39]	Not stated in paper.
[38]	Not stated in paper.
[37]	Bags of words (BoW), or term frequency-inverse document frequency (TF-IDF)
[36]	Part of speech tagging, n-gram, content words, function words
[35]	Bag of Word (BOW), Part of Speech (POS) tagging, Semantic group and descriptive words.
[34]	Not stated in paper

Feature Selection	Classification Technique	Evaluation
Not stated in paper.	LightGBM, XGBoost, and the CatBoost	Precision, recall, F1-score and support
Not stated in paper.	Artificial Neural Networks (ANN), Recurrent Neural Networks with Long Short-Term Memory (LSTM) and Gated Recurrent Units (GRU), Support Vector Machines (SVM), Logistic Regression (LR) and also Random Forests (RF)	Precision, Accuracy, Recall and F1-score
Glowworm Swarm Optimization + ML	Naive Bayes (NB), K-Nearest Neighbour (KNN) and Support Vector Machine (SVM)	Precision, Accuracy, Recall and F1_Score
Not stated in paper.	SVM, RF, Naive Bayes, and RBFN	Recall, Precision, and F-Score
Not stated in paper.	CNN-NB, 3CRNN-NB, and GRU-NB, 3W3DT-DT, 3W3DT-NB, 3W3DT-KNN, and 3W3DT-RF	Recall, Precision, and F-Score
Not stated in paper.	Convolutional neural network (CNN), Weakly supervised model (WSM) and bidirectional long short-term memory (Bi-LSTM)	Precision, Accuracy, and F1-Score
Not stated in paper.	Probabilistic aspect mining model (PAMM)	Accuracy and Mean Pointwise Mutual Information (PMI)
Not stated in paper.	Radial basis function neural networks (RFN) Probabilistic neural network (PNN)	Recall, Precision, and F-Score
Not stated in paper.	Rule-based Linguistic	Precision, Accuracy, Recall and F1_Score
Fuzzy-Rough Quick Reduction (FRQR).	Random forest, Ripper, Decision tree and Naive Bayes	Accuracy, Performance of running independent hold-out test, time required to develop the model.
Pethe nguin Search Optimization (PESOA)	Naive Bayes (NB), K-Nearest Neighbour (KNN), support vector machine (SVM)	Precision, Accuracy, Recall and F1_Measure
Related Words (RW) Vector	Bidirectional Encoder Representation from Transformer (BERT)	Recall, Precision, and F-Measure
Not stated in paper	Bidirectional Encoder Representation from Transformer (BERT) with Long Short-Term Memory (LSTM)	Accuracy and F1_Score

IV. PARTICLE SWARM OPTIMIZATION

The study [21] first proposed Particle Swarm Optimization (PSO) in 1995. It is a stochastic optimization method for a population that takes its cue from the cooperative nature of flocking birds [22]. As stated by [6], PSO is an algorithm for population-based optimization that simulates the social interaction and communication among groups of animals, such as flocks of birds or schools of fish [39].

In PSO, each particle represents a candidate solution to the optimization problem. This set of particles will move through a search space in search of the optimal solution. Each particle has a position and a velocity, and the goal is to find the optimal position in the search space that minimises or maximises an objective function [23].

At each iteration of the algorithm, the particles will adjust their position and velocity based on their own best-known position (i.e., the best solution they have found so far) and the best-known position of the entire swarm (i.e., the best solution found by any particle in the swarm). This is done using a set of mathematical equations that determine each particle's new position and velocity. This process will continue until a stopping criterion is met, such as the maximum number of iterations or a satisfactory level of convergence. The final position of the particles represents the optimal solution to the optimization problem [23].

The PSO version employed in this study is represented by the equation in Fig. 1. Learning rates c_1 and c_2 are positive constants, r_1 and r_2 are random numbers in the range of 0 to 1, and P_i , X_i , and V_i represent the swarm's best previous location, the particle's current position, and the rate of change of position (velocity), respectively, for a D-dimensional

problem space at iteration t . Additionally, w indicates the inertia weight, g represents the best particle among all particles in the population, and V_{max} is the maximum velocity for the particles in each dimension. V_{max} is applied, if the total number of elements on the right side of the equation exceeds a predetermined fixed value.

$$V_i(t+1) = w_i V_j(t) + c_1 \cdot r_1(t) \cdot |P_i(t) - X_i(t)| + c_2 \cdot r_2(t) \cdot |g - X_i(t)|$$

$$X_i(t+1) = X_i(t) + V_i(t+1)$$

Fig. 1. Particle swarm optimization equation.

V. METHODOLOGY

This section presents a summary of the methodology used to conduct sentiment analysis of drug reviews using PSO for feature selection, as illustrated in Fig. 2.

A. Data Cleaning and Pre-processing

Prior to analysing the collected text data, data cleaning and text pre-processing steps were implemented to obtain satisfactory results. Data pre-processing involved the removal of words that did not help convey the meaning of the text, or were deemed unnecessary, thereby, enhancing the efficacy of

the search for valuable words in each sentence [4]. To create a standardised dataset, several pre-processing techniques were applied, including correcting misspelled words, tokenisation, removing stop words, segmentation, and part-of-speech tagging.

Datasets to be analysed need to undergo pre-processing because reviews are typically written by non-experts in the field of language and could contain various errors, such as spelling mistakes, incorrect use of capital letters, punctuation errors, and grammatical errors. These errors can negatively impact the accuracy and effectiveness of sentiment analysis models, which rely on clean and standardised datasets. By applying pre-processing techniques, the datasets can be cleaned and standardised to make them more suitable for sentiment analysis [4], [24].

In this study, drug review datasets were cleaned and pre-processed by excluding all blank reviews, HTML tags, and spacing. Capitalisation of words and punctuations were verified, words were checked for errors, such as grammar and spelling, and paragraphs were segmented into sentences. This process was performed using Microsoft Word and Microsoft Excel software. Fig. 3 shows an example of the reviews before and after undergoing the cleaning and pre-processing process.

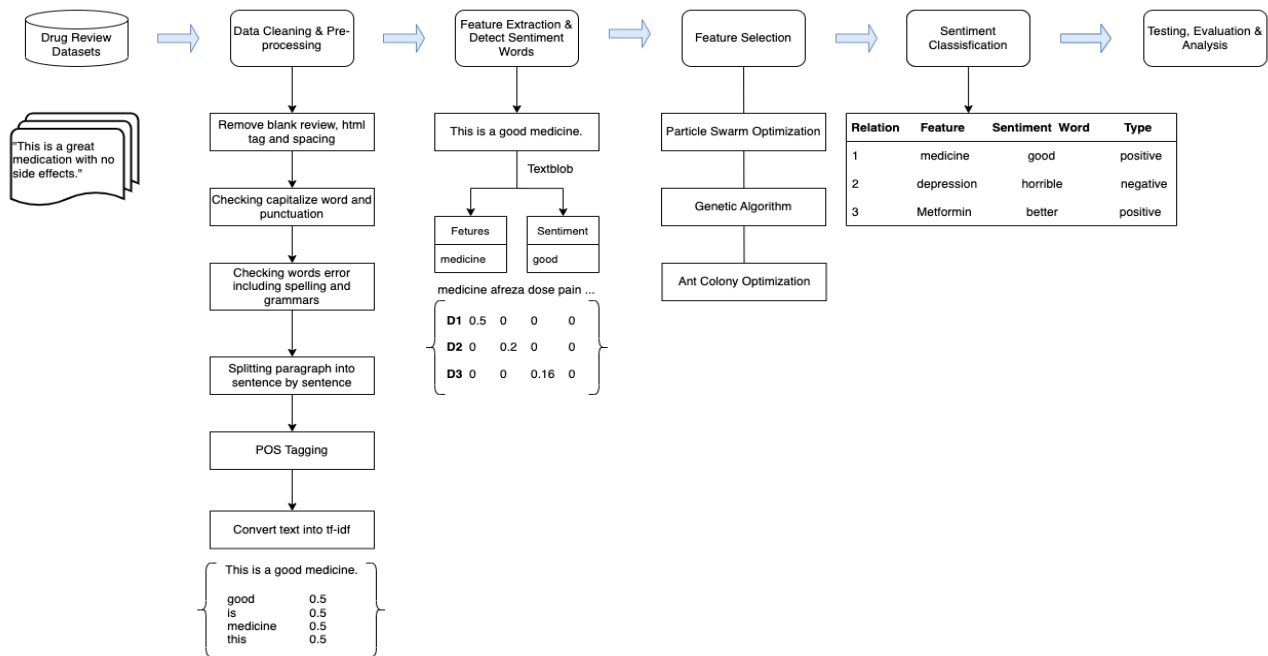


Fig. 2. The methodology of the study.

Sentence before preprocessing:
 “I’ve experienced NO Side Effects.”
Sentence after preprocessing:
 “I have experienced no side effect.”

Fig. 3. An example of a cleaned and pre-processed review.

The figure shows a sentence that contains HTML code syntax “',” which represents the apostrophe symbol. This syntax was removed and replaced with the full-form word. There were also capitalisation errors, such as “NO” and “Side Effect,” as well as a spelling error in the word “Effect,” with an extra “f”. After completing the cleaning process, part-of-speech tagging was conducted on each sentence to identify the features and sentiment words in the text.

B. Feature Extraction and Sentiment Word Identification

The identification of pertinent information from textual data through feature extraction is of utmost importance in sentiment classification, as it can inevitably affect the model’s performance [25]. The extraction of important terms from a dataset is known as feature extraction [24]. This approach seeks to select significant data that encompass the most important features of the text [25]. This study employed the TextBlob library, which is a Python-based tool that utilises the Natural Language Toolkit (NLTK) to conduct Natural Language Processing (NLP) tasks and to evaluate sentiment polarity. The library’s noun phrase extraction capabilities and sentiment analyser were used to extract all feature and sentiment words from the datasets.

C. Feature Selection

The first step in constructing a classification model is to detect relevant features within the dataset [2], [21]–[23]. The extracted features would then undergo data transformation from text data into feature vectors. Sentiment analysis is utilised for its emphasis on text documents, since a classifier cannot understand or interpret a text directly.

Consequently, it is necessary to transform textual documents into a format recognisable by a computer, with the Vector Space Model being the preferred technique to accomplish this. Term frequency-inverse document frequency (TF-IDF) was used in this study, as it is one of the most basic methods of conveying features through term count [26]. This model employed a vector space representation of the documents in the dataset, wherein the dimensions of the vector corresponded to the features selected from the dataset [27]. The data objects can be expressed as feature vectors in the feature space. Feature selection will then identify and remove non-essential features from a set of features to improve the classification accuracy, while reducing the feature space dimensionality [28]. In this study, PSO was chosen as a feature selection method to obtain the optimum subset of features.

D. Sentiment Classification

Sentiment classification is a crucial subfield of sentiment analysis, which entails the identification and categorisation of emotions conveyed in a textual data, including reviews and tweets. The primary objective of sentiment classification is to classify texts into various categories based on their subjective information, which typically include positive and negative sentiments [29]. In this study, feature and sentiment words were obtained feature extraction and sentiment word identification section. They underwent manual reviews in conjunction with the datasets to ascertain their conformity with the contextual information presented in the data collection.

E. Testing and Evaluation

The testing and evaluation procedure involved measuring how well the feature and sentiment words were related to one another. This procedure was performed to evaluate the ability of the proposed algorithm to detect and acquire dependable features along with correct sentiments. The efficacy of the proposed method is evaluated based on the following four metrics: precision, recall, F1-score, and accuracy using the measures shown in Table II:

- True Positive (TP) denotes correctly identified positive reviews.
- True Negative (TN) denotes correctly identified negative reviews.
- False Positive (FP) denotes positive reviews incorrectly identified as negative.
- False Negative (FN) denotes negative reviews incorrectly identified as positive.

TABLE II. CONFUSION MATRIX

	Predicted Positive	Predicted Negative
Actual Positive	TP	FN
Actual Negative	FP	TN

$$\text{Precision} = \text{TP} \div (\text{TP} + \text{FP}) \quad (1)$$

$$\text{Recall} = \text{TP} \div (\text{TP} + \text{FN}) \quad (2)$$

$$\text{F1} = (2 \times \text{Precision} \times \text{Recall}) \div (\text{Precision} + \text{Recall}) \quad (3)$$

$$\text{Accuracy} = (\text{TP} + \text{TN}) \div (\text{TP} + \text{TN} + \text{FP} + \text{FN}) \quad (4)$$

VI. EXPERIMENTS

This section summarises the drug review datasets obtained from the University of California Irvine (UCI) machine learning repository, along with the methodology employed for feature selection. Specifically, this study has introduced PSO as the primary feature selection technique, with Ant Colony Optimization (ACO) and Genetic Algorithm (GA) as the benchmarks.

A. Datasets

In this study, 1,229 drug reviews from druglib.com were analysed for several conditions, such as diabetes, high blood pressure, heart attack, etc. The datasets contained patient feedback on medications, information on associated conditions, and a patient rating of 10 stars, which reflected the overall patient happiness. Data were gathered by crawling the pharmaceutical review website, Drugs.com. The datasets utilised in this study were stratified into two distinct polarity levels based on review ratings, namely, positive (class 1, rating ≥ 5) and negative (class -1, rating ≤ 5), as previously defined in [30]. These datasets comprised a total of 719 positive reviews and 509 negative reviews, representing a valuable resource for training and evaluating sentiment classification models. These datasets were then divided into 10 sets. The first set includes 10% of the overall features, while the second set contains 20% and so on, as shown in Table III. Using a stratified random

sampling method, 70% and 30% of the datasets were put aside for training and testing.

The distribution of the two classes is illustrated in Fig. 4, with approximately 41% of the reviews having a negative polarity (class -1) and 59% having a positive polarity (class 1).

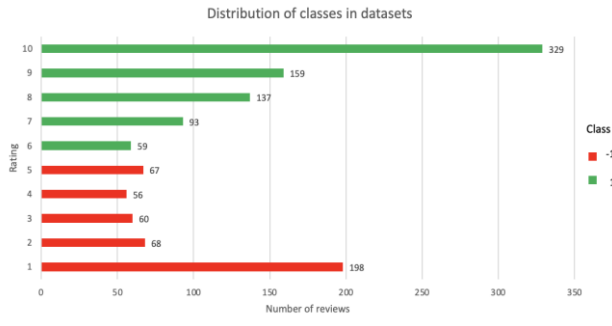


Fig. 4. Class distribution of drug review datasets.

B. Baseline Algorithms

Due to their proven effectiveness in improving the performance of sentiment analysis [31]–[33], the ACO and GA were chosen as the baseline algorithms for the PSO algorithm in this study. The aim was to compare the performance of PSO against these algorithms in identifying an optimal feature subset for the sentiment analysis of drug reviews.

TABLE III. SUMMARY OF TOTAL FEATURES AND REVIEWED SENTENCES IN EACH DRUG REVIEW DATASET

Dataset	Total Features	Total of Reviewed Sentences
Set 1	83	398
Set 2	167	583
Set 3	250	762
Set 4	334	923
Set 5	417	1030
Set 6	501	1135
Set 7	584	1231
Set 8	668	1329
Set 9	751	1417
Set 10	835	1506

C. Experimental Setups

The aim of the present study was to evaluate the efficacy of the proposed algorithm through a series of experiments designed to compare its performance with existing algorithms in the field. The experiments were conducted on a computer system equipped with an Apple M2 processor and 16 GB of RAM, which provided sufficient computational power and memory capacity to perform the required tasks. The high processing power and ample memory capacity of this machine facilitated the efficient execution of experiments and reliable collection of data. The proposed PSO algorithm was implemented using Python and was run on the Jupyter Notebook, while the ACO and GA algorithms were executed using an established algorithm in WEKA on the same machine.

TABLE IV. PSO PARAMETER SETTING

Parameter	Value
Acceleration Coefficients, c_1 & c_2	2
Inertial weight, w	1
Population Size	20
Iteration	20
Fitness	1

Table IV lists the PSO parameters that have been employed to identify the optimal parameter configuration that would yield a sentiment analysis model with superior performance based on the test set. The testing was performed to evaluate the ability of the PSO algorithm to produce a feature subset that was both significant and non-redundant, aiming to determine the most optimal feature set. The effectiveness of the proposed algorithm was measured using several performance metrics, namely, precision, recall, accuracy, and F-score, as elaborated in testing and evaluation section.

VII. ANALYSIS OF RESULTS

This section presents the outcomes of utilising the PSO algorithm for feature selection of a drug review dataset. Its performance was compared with the performance of the ACO and GA. The purpose of this research was to evaluate the effectiveness of PSO in identifying a relevant and non-redundant feature subset that could improve the performance of the sentiment analysis model. To achieve this objective, accuracy, precision, recall, and F-score were used as performance metrics to assess the quality of the outputs generated by each algorithm.

Table V presents the experimental outcomes of the proposed PSO algorithm, along with the compared algorithms (ACO and GA) based on the performance metrics (precision, recall, F-score, and accuracy). These results indicated that PSO outperformed ACO and GA in most of the datasets, with an average of 49.3% for precision, 73.6% for recall, 59% for F-score, and 57.2% for accuracy.

Fig. 5 to Fig. 9 show the performance evaluation of PSO compared to ACO and GA for feature selection in sentiment analysis based on precision, recall, F-score, and accuracy. The results showed that PSO outperformed both ACO and GA in terms of the average precision, recall, F-score, and accuracy. The average precision of PSO was 49.3%, which was higher than ACO with 46.4% and GA with 46.2%. Similarly, the average recall of PSO was 73.6%, which was higher than ACO with 71.5% and GA with 70.5%.

The experimental results listed in Table VI show that PSO has selected a higher number of features on average (197) compared to ACO (111) and GA (112). The table also shows that PSO was more efficient in selecting relevant features, as evidenced by its superior performance in terms of precision, recall, F-score, and accuracy. Therefore, the higher number of selected features by PSO can be attributed to its ability to identify and retain more relevant features, which ultimately improved its classification performance.

TABLE V. THE RESULTS OF ACO, GA, AND PSO BASED ON PERFORMANCE METRICS (PRECISION, RECALL, F-SCORE, AND ACCURACY) ON DRUG REVIEW DATASETS

Dataset	Precision			Recall			F-Score			Accuracy		
	ACO	GA	PSO	ACO	GA	PSO	ACO	GA	PSO	ACO	GA	PSO
Set 1	42.9	46.7	49.4	60.0	68.3	71.7	50.0	55.4	58.5	53.8	53.6	55.8
Set 2	48.7	43.6	45.3	75.3	64.1	73.8	59.2	51.9	56.1	57.9	51.6	53.4
Set 3	49.2	43.8	47.1	75.3	68.4	70.2	59.5	53.4	56.4	58.4	51.2	57.2
Set 4	44.5	49.2	51.2	70.1	71.3	75.7	54.4	58.2	61.1	53.4	54.9	56.9
Set 5	48.4	44.5	48.9	74.8	72.0	72.5	58.7	55.0	58.4	54.2	50.8	56.8
Set 6	44.5	46.2	49.8	72.6	72.2	75.6	55.2	56.3	60.1	52.4	52.7	57.7
Set 7	50.2	51.8	51.7	71.6	73.7	74.1	59.1	60.8	60.9	56.8	58.9	58.9
Set 8	45.1	43.2	52.4	72.4	68.3	73.1	55.5	52.9	61.0	54.0	51.9	58.9
Set 9	43.3	45.5	48.2	70.9	73.6	74.9	53.8	56.2	58.7	51.3	55.2	57.6
Set 10	47.5	47.4	49.0	72.4	72.9	74.8	57.3	57.5	59.2	54.4	54.9	59.1
Average	46.4	46.2	49.3	71.5	70.5	73.6	56.3	55.8	59.0	54.7	53.6	57.2

TABLE VI. AVERAGE PERFORMANCE AND SELECTED FEATURES FOR ACO, GA, AND PSO ON DRUG REVIEW DATASETS

Dataset	Precision			Recall			F-Score			Accuracy			Number of features		
	ACO	GA	PSO	ACO	GA	PSO	ACO	GA	PSO	ACO	GA	PSO	ACO	GA	PSO
Set 1	42.9	46.7	49.4	60.0	68.3	71.7	50.0	55.4	58.5	53.8	53.6	55.8	8	9	26
Set 2	48.7	43.6	45.3	75.3	64.1	73.8	59.2	51.9	56.1	57.9	51.6	53.4	30	38	56
Set 3	49.2	43.8	47.1	75.3	68.4	70.2	59.5	53.4	56.4	58.4	51.2	57.2	29	38	97
Set 4	44.5	49.2	51.2	70.1	71.3	75.7	54.4	58.2	61.1	53.4	54.9	56.9	73	83	135
Set 5	48.4	44.5	48.9	74.8	72.0	72.5	58.7	55.0	58.4	54.2	50.8	56.8	86	94	201
Set 6	44.5	46.2	49.8	72.6	72.2	75.6	55.2	56.3	60.1	52.4	52.7	57.7	99	98	244
Set 7	50.2	51.8	51.7	71.6	73.7	74.1	59.1	60.8	60.9	56.8	58.9	58.9	147	169	249
Set 8	45.1	43.2	52.4	72.4	68.3	73.1	55.5	52.9	61.0	54.0	51.9	58.9	228	183	322
Set 9	43.3	45.5	48.2	70.9	73.6	74.9	53.8	56.2	58.7	51.3	55.2	57.6	175	165	343
Set 10	47.5	47.4	49.0	72.4	72.9	74.8	57.3	57.5	59.2	54.4	54.9	59.1	239	246	302
Average	46.4	46.2	49.3	71.5	70.5	73.6	56.3	55.8	59.0	54.7	53.6	57.2	111	112	197

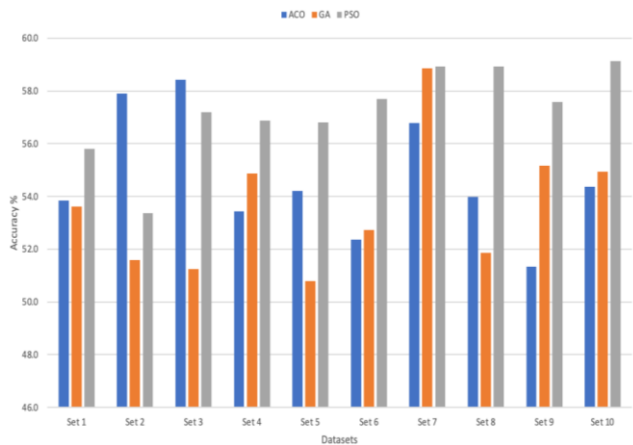


Fig. 5. Precision results for ACO, GA, and PSO on drug review datasets.

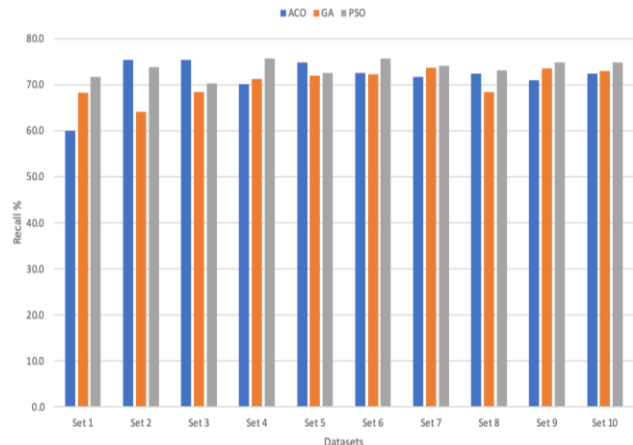


Fig. 6. Recall results for ACO, GA, and PSO on drug review datasets.

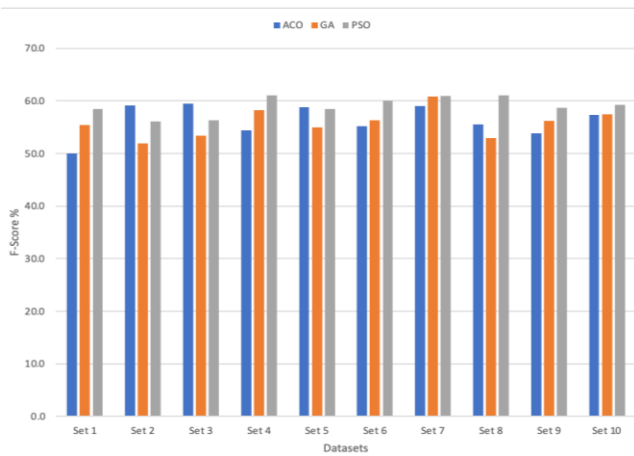


Fig. 7. F-score results for ACO, GA, and PSO on drug review datasets.

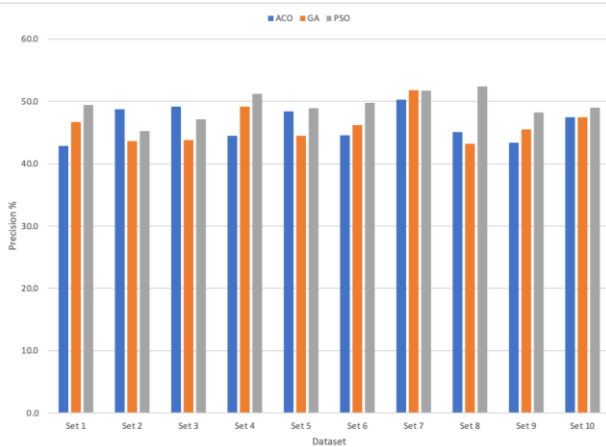


Fig. 8. Accuracy results for ACO, GA, and PSO on drug review datasets.

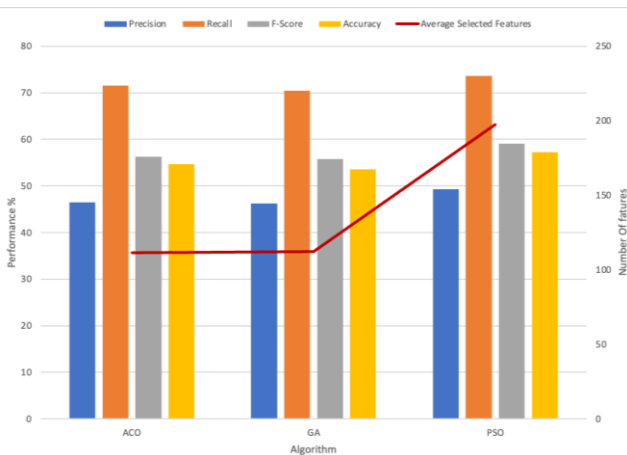


Fig. 9. Average performance and selected features of ACO, GA, and PSO on drug review datasets.

This study has shown that PSO was a highly effective algorithm for feature selection in sentiment analysis. The results showed that PSO outperformed the other two algorithms, demonstrating the highest level of performance. In these experiments, the parameters were set up appropriately to ensure the validity of the results. However, these experiments were not intended to determine the optimality of the selected

parameter values for PSO in the feature selection process of sentiment analysis. Consequently, further research is needed to investigate the optimal parameter values for PSO in this specific application domain. Additional experiments are also required to obtain accurate parameter settings for PSO in feature selection for sentiment analysis to enhance its performance and accuracy in this context.

The experimental results indicated that PSO possessed the capability to produce high-quality feature subsets, which increased the classification accuracy of the sentiment analysis model. This algorithm explored the vast search space of possible feature subsets to identify the most relevant and discriminative features, while discarding redundant or irrelevant ones. The global optimization capabilities of PSO ensured that the algorithm was able to converge the optimal solution, which further enhanced the quality of the selected feature subset. Therefore, the empirical evidence has shown that PSO was a highly effective method for feature selection, since it was capable of producing feature subsets that could improve the classification accuracy of a variety of applications.

VIII. CONCLUSION

This paper presents a novel approach that utilised the PSO algorithm for feature selection in drug reviews, with the objective of improving the performance of the sentiment analysis model. To verify the efficacy of the proposed approach, three feature selection methods were employed to compare the results obtained from drug review datasets. The results showed that PSO provided a better classification performance than GA and ACO in most datasets. PSO was both simple to use and well-known for accelerating convergence, since all particles learned from the global best, which was the current best value achieved by any particle in its neighbourhood. The results have also indicated that these techniques could yield favourable outcomes in acquiring the optimal feature subset. However, in a complex optimization, PSO could suffer from premature convergence. There is a scope for further research into the use of PSO for sentiment analysis in other domains, such as social media and customer reviews. Additionally, the combination of PSO with other optimization techniques, such as genetic algorithms or k-nearest neighbour algorithms could further improve the accuracy of sentiment analysis algorithms.

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REFERENCES

- [1] S. Noforesti and M. Shamsfard, "Resource construction and evaluation for indirect opinion mining of drug reviews," *PLoS One*, vol. 10, no. 5, pp. 1–25, 2015, doi: 10.1371/journal.pone.0124993.
- [2] G. H. John, R. Kohavi, and K. Ppeger, "Irrelevant Features and the Subset Selection Problem," *Machine Learning: Proceedings Of The Eleventh International Conference*, pp. 121–129, 1994.
- [3] A. Dasgupta, A. Banerjee, A. G. Dastidar, A. Barman, and S. Chakraborty, "A Study and Analysis of a Feature Subset Selection

- Technique Using Penguin Search Optimization Algorithm,” in *Data Science*, CRC Press, 2019, pp. 51–68. doi: 10.1201/9780429263798-3.
- [4] M. R. Y. 3 Siti Rohaidah Ahmad 1,* , Azuraliza Abu Bakar 2 and 1, “A review of feature selection techniques in sentiment analysis,” *Intelligent Data Analysis*, pp. 159–189, 2019.
- [5] S. R. Ahmad, A. A. Bakar, and M. R. Yaakub, “Metaheuristic algorithms for feature selection in sentiment analysis,” in *Proceedings of the 2015 Science and Information Conference, SAI 2015*, Institute of Electrical and Electronics Engineers Inc., Sep. 2015, pp. 222–226. doi: 10.1109/SAI.2015.7237148.
- [6] J. Kennedy and R. Eberhart, “Particle swarm optimization,” in *Proceedings of ICNN’95 - International Conference on Neural Networks*, IEEE, pp. 1942–1948. doi: 10.1109/ICNN.1995.488968.
- [7] D. Yazdani, B. Nasiri, A. Sepas-Moghaddam, and M. R. Meybodi, “A novel multi-swarm algorithm for optimization in dynamic environments based on particle swarm optimization,” *Applied Soft Computing Journal*, vol. 13, no. 4, pp. 2144–2158, 2013, doi: 10.1016/j.asoc.2012.12.020.
- [8] M. Ghosh, R. Guha, I. Alam, P. Lohariwal, D. Jalan, and R. Sarkar, “Binary genetic swarm optimization: A combination of ga and pso for feature selection,” *Journal of Intelligent Systems*, vol. 29, no. 1, pp. 1598–1610, Jan. 2020, doi: 10.1515/jisys-2019-0062.
- [9] A. de Campos, A. T. R. Pozo, and E. P. Duarte, “Parallel multi-swarm PSO strategies for solving many objective optimization problems,” *J Parallel Distrib Comput*, vol. 126, pp. 13–33, Apr. 2019, doi: 10.1016/j.jpdc.2018.11.008.
- [10] H. M. Harb and A. S. Desuky, “Feature Selection on Classification of Medical Datasets based on Particle Swarm Optimization,” *Int J Comput Appl*, vol. 104, no. 5, pp. 14–17, 2014, doi: 10.5120/18197-9118.
- [11] L. Shang, Z. Zhou, and X. Liu, “Particle swarm optimization-based feature selection in sentiment classification,” *Soft comput*, vol. 20, no. 10, pp. 3821–3834, 2016, doi: 10.1007/s00500-016-2093-2.
- [12] P. Moorthi, “Hybrid optimization for feature selection in opinion mining,” 2018. [Online]. Available: www.sciencepubco.com/index.php/IJET.
- [13] V. A. Kharde and S. S. Sonawane, “Sentiment Analysis of Twitter Data: A Survey of Techniques,” 2016. [Online]. Available: <http://ai.stanford>.
- [14] K. Denecke and Y. Deng, “Sentiment analysis in medical settings: New opportunities and challenges,” *Artif Intell Med*, vol. 64, no. 1, pp. 17–27, May 2015, doi: 10.1016/j.artmed.2015.03.006.
- [15] D. Cavalcanti and R. Prudêncio, “Aspect-based opinion mining in drug reviews,” *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 10423 LNAI, no. August, pp. 815–827, 2017, doi: 10.1007/978-3-319-65340-2_66.
- [16] J. Serrano-Guerrero, J. A. Olivas, F. P. Romero, and E. Herrera-Viedma, “Sentiment analysis: A review and comparative analysis of web services,” *Inf Sci (N Y)*, vol. 311, pp. 18–38, Aug. 2015, doi: 10.1016/j.ins.2015.03.040.
- [17] P. H. Prastyo, I. Ardiyanto, and R. Hidayat, “A Review of Feature Selection Techniques in Sentiment Analysis Using Filter, Wrapper, or Hybrid Methods,” in *Proceedings - 2020 6th International Conference on Science and Technology, ICST 2020*, Institute of Electrical and Electronics Engineers Inc., 2020. doi: 10.1109/ICST50505.2020.9732885.
- [18] J. Zheng, P. Wen, X. Ji, X. Lyu, and Y. Yang, “Helpfulness Prediction of Online Drug Reviews,” in *2021 IEEE International Conference on Consumer Electronics and Computer Engineering, ICCECE 2021*, Institute of Electrical and Electronics Engineers Inc., Jan. 2021, pp. 528–537. doi: 10.1109/ICCECE51280.2021.9342308.
- [19] M. E. Basiri, M. Abdar, M. A. Cifci, S. Nemati, and U. R. Acharya, “A novel method for sentiment classification of drug reviews using fusion of deep and machine learning techniques,” *Knowl Based Syst*, vol. 198, Jun. 2020, doi: 10.1016/j.knsys.2020.105949.
- [20] S. Rohaidah Ahmad, N. Moziyana Mohd Yusop, A. Mohd Asri, M. Fahmi Muhamad Amran, U. Pertahanan Nasional Malaysia, and S. Besi Kuala Lumpur, “A Review of Feature Selection Algorithms in Sentiment Analysis for Drug Reviews,” 2021. [Online]. Available: www.askapatient.com.
- [21] R. Eberhart and J. Kennedy, “A New Optimizer Using Particle Swarm Theory.”
- [22] M. Ghosh, R. Guha, I. Alam, P. Lohariwal, D. Jalan, and R. Sarkar, “Binary genetic swarm optimization: A combination of ga and pso for feature selection,” *Journal of Intelligent Systems*, vol. 29, no. 1, pp. 1598–1610, Jan. 2020, doi: 10.1515/jisys-2019-0062.
- [23] Chenye Qiu, *A Multi-swarm Particle Swarm Optimization with an Adaptive Regrouping Strategy for Feature Selection*.
- [24] S. R. Priya and M. Devapriya, “Twitter Sentiment Analysis with Diabetic Drugs Using Machine Learning Techniques with Glowworm Swarm Optimization Algorithm.” [Online]. Available: www.ijert.org.
- [25] M. Wankhade, A. C. S. Rao, and C. Kulkarni, “A survey on sentiment analysis methods, applications, and challenges,” *Artif Intell Rev*, 2022, doi: 10.1007/s10462-022-10144-1.
- [26] A. Sharma, J. Lyons, A. Dehzeni, and K. K. Paliwal, “A feature extraction technique using bi-gram probabilities of position specific scoring matrix for protein fold recognition,” *J Theor Biol*, vol. 320, pp. 41–46, Mar. 2013, doi: 10.1016/j.jtbi.2012.12.008.
- [27] S. R. Ahmad, A. Abu Bakar, and M. R. Yaakub, “A review of feature selection techniques in sentiment analysis.”
- [28] A. Kumar, R. Khorwal, and S. Chaudhary, “A survey on sentiment analysis using swarm intelligence,” *Indian J Sci Technol*, vol. 9, no. 39, 2016, doi: 10.17485/ijst/2016/v9i39/100766.
- [29] B. Liu, *Sentiment Analysis and Opinion Mining*, Morgan & Claypool Publishers, 2012.
- [30] F. Gräßer, H. Malberg, S. Kallumadi, and S. Zaunseder, “Aspect-Based sentiment analysis of drug reviews applying cross-Domain and cross-Data learning,” *ACM International Conference Proceeding Series*, vol. 2018-April, pp. 121–125, 2018, doi: 10.1145/3194658.3194677.
- [31] R. Katarya and A. Yadav, “A comparative study of genetic algorithm in sentiment analysis,” in *Proceedings of the 2nd International Conference on Inventive Systems and Control, ICISC 2018*, Institute of Electrical and Electronics Engineers Inc., Jun. 2018, pp. 136–141. doi: 10.1109/ICISC.2018.8399051.
- [32] S. R. Ahmad, A. A. Bakar, and M. R. Yaakub, “Ant colony optimization for text feature selection in sentiment analysis,” *Intelligent Data Analysis*, vol. 23, no. 1, pp. 133–158, 2019, doi: 10.3233/IDA-173740.
- [33] D. Eleyan, “Ant Colony Optimization Based Feature Selection in Rough Set Theory Customer Satisfaction and Awareness, A case study of South African Commercial vs Islamic Banks View project Software engineering View project,” 2016. [Online]. Available: <https://www.researchgate.net/publication/260986337>.
- [34] G. Abuka, J. Ranganathan, Z. Dong, and Y. Gu, “Text Summarization and Sentiment Analysis of Drug Reviews: A Transfer Learning Approach,” 2023.
- [35] M. Imani and S. Noferesti, “Aspect extraction and classification for sentiment analysis in drug reviews,” *J Intell Inf Syst*, vol. 59, no. 3, pp. 613–633, Dec. 2022, doi: 10.1007/s10844-022-00712-w.
- [36] T. Anuprathibha and C. S. Kanimozhiselvi, “Penguin search optimization based feature selection for automated opinion mining,” *International Journal of Recent Technology and Engineering*, vol. 8, no. 3, pp. 648–653, 2019, doi: 10.35940/ijrte.B2629.098319.
- [37] T. Chen, P. Su, C. Shang, R. Hill, H. Zhang, and Q. Shen, “Sentiment Classification of Drug Reviews Using Fuzzy-rough Feature Selection,” *IEEE International Conference on Fuzzy Systems*, vol. 2019-June, pp. 1–6, 2019, doi: 10.1109/FUZZ-IEEE.2019.8858916.
- [38] J. C. Na, W. Y. M. Kyaing, C. S. G. Khoo, S. Foo, Y. K. Chang, and Y. L. Theng, “Sentiment classification of drug reviews using a rule-based linguistic approach,” *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 7634 LNCS, pp. 189–198, 2012, doi: 10.1007/978-3-642-34752-8_25.
- [39] V. Gopalakrishnan and C. Ramaswamy, “Patient opinion mining to analyze drugs satisfaction using supervised learning,” *Journal of Applied Research and Technology*, vol. 15, no. 4, pp. 311–319, 2017, doi: 10.1016/j.jart.2017.02.005.
- [40] P. Gawande and S. Gore, “Extraction of Aspects from Drug Reviews Using Probabilistic Aspect Mining Model,” *International Journal of*

- Science and Research (IJSR)*, vol. 4, no. 11, pp. 4–7, 2015, doi: 10.21275/v4i11.nov151059.
- [41] Z. Min, “Drugs Reviews Sentiment Analysis using Weakly Supervised Model,” *Proceedings of 2019 IEEE International Conference on Artificial Intelligence and Computer Applications, ICAICA 2019*, pp. 332–336, 2019, doi: 10.1109/ICAICA.2019.8873466.
- [42] S. Liu and I. Lee, “Extracting features with medical sentiment lexicon and position encoding for drug reviews,” *Health Inf Sci Syst*, vol. 7, no. 1, 2019, doi: 10.1007/s13755-019-0072-6.
- [43] S. R. Priya, “Twitter Sentiment Analysis with Diabetic Drugs Using Machine Learning Techniques with Glowworm Swarm Optimization Algorithm,” vol. 9, no. 07, pp. 62–68, 2020.
- [44] S. Vijayaraghavan and D. Basu, “Sentiment Analysis in Drug Reviews using Supervised Machine Learning Algorithms,” *ArXiv*, 2020.
- [45] Sumit Mishra, “Drug Review Sentiment Analysis using Boosting Algorithm,” *International Journal of Trend in Scientific Research and Development (IJTSRD)*, vol. Volume 5, no. Issue 4, May-June 2021, 2021.

A Comparative Study of Machine Learning Techniques to Predict Types of Breast Cancer Recurrence

Meryem Chakkouch¹, Merouane Ertel², Aziz Mengad³, Said Amali⁴

Informatics and Applications Laboratory (IA)-Faculty of Sciences, Moulay Ismail University Meknes, Morocco^{1,2}
Centre for Doctoral Studies "Life and Health Sciences"-Drug Sciences Formation, Laboratory of Pharmacology and Toxicology (LPTR), Faculty of Medicine and Pharmacy of Rabat (FMPH), Impasse Souissi Rabat, Morocco³
Informatics and Applications Laboratory (IA), FSJES Moulay Ismail University, Meknes, Morocco⁴

Abstract—The prediction of breast cancer recurrence is a crucial problem in cancer research that requires accurate and efficient prediction models. This study aims to compare the performance of different machine learning techniques in predicting types of breast cancer recurrence. In this study, the performance of logistic regression, decision tree, K-Nearest Neighbors, and artificial neural network algorithms was compared on a breast cancer recurrence dataset. The results show that the artificial neural network algorithm outperformed the other algorithms with 91% accuracy, followed by the decision tree (DT) algorithm and K-Nearest Neighbors (kNN) also performed well with accuracies of 90.10% and 88.20%, respectively, while the logistic regression algorithm had the lowest accuracy of 84.60%. The results of this study provide insight into the effectiveness of different machine learning techniques in predicting types of breast cancer recurrence and could guide the development of more accurate prediction models.

Keywords—Breast cancer; machine learning; recurrence prediction; classification multi-classes; logistic regression; decision tree; K-Nearest Neighbors; artificial neural network

I. INTRODUCTION

Breast cancer is one of the most common types of cancer in women worldwide, with approximately 2.3 million new cases diagnosed in 2020 alone [1]. Although treatment options for breast cancer have advanced significantly in recent years, thanks to improved surgical techniques, chemotherapy and radiation therapy, the risk of recurrence remains a significant concern for patients and their clinicians.

Recurrence of breast cancer can occur in a variety of forms, including local, regional and distant recurrence. Local recurrence is when the cancer recurs in the same area where it was initially treated, while regional recurrence is when the cancer recurs in the lymph nodes of the axillary or supraclavicular region [2]. Distant metastases are when the cancer spreads to distant organs such as the lungs, liver, or bone. Each type of recurrence has its own clinical characteristics and treatment considerations, which makes customization of treatment particularly important for each patient.

In recent years, there has been increasing interest in developing predictive models that can accurately identify the likelihood of different types of breast cancer recurrence, allowing for more personalized treatment plans and better patient outcomes [3]–[9]. Predictive models are based on a variety of factors, such as the characteristics of the initial cancer, the patient's age, the stage of the cancer and the type of treatment received. Tools such as the Online Recurrence Score (Oncotype DX) [10], Metastatic DNA Prognosis Score (MammaPrint) [11], and Molecular Profiling Signature Score (EndoPredict) are available to help clinicians assess the risk of recurrence in patients with breast cancer [12]. These predictive models can help clinicians decide whether a patient requires adjuvant chemotherapy, radiation therapy, or hormone therapy, or whether she should simply be monitored closely. This can help avoid unnecessary treatment and reduce potentially harmful side effects of treatment.

In this paper, a multi-classification model is proposed, with the aim of producing predictions about the types of recurrence in breast cancer patients. This model is based on several important parameters, such as initial TNM status of the tumor, estrogen and progesterone receptors (ER, PR), HER2 expression levels, and previous treatments received by the patients. Additionally, new variables such as physical activity, diet type, and post-treatment psychology are incorporated to improve risk assessment and patient management. Indeed, previous research has demonstrated the importance of considering psychological and behavioral aspects of patients to better predict the risk of recurrence.

In the second section of this article, the predictive variables included in the model will be presented. A description of various data coding techniques such as data collection, preprocessing, cleaning, and transformation of the pathological, biological, and clinical dataset will be provided in the third section. The fourth section will explain the proposed multi-classification technique, including Logistic Regression (LR), K-Nearest Neighbors (kNN), Decision Tree (DT), and Neural Network (NN). Finally, the performance of the proposed model in predicting recurrence types for breast cancer patients will be evaluated.

II. MATERIALS AND METHODS

A. Data Collection

Clinical and pathological data were collected from electronic medical records of patients treated for breast cancer between 2015 and 2022 at a single center in the Meknes, Morocco. The dataset included 1189 patients who underwent surgery, radiation therapy, and/or chemotherapy - the follow-up of at least 60 months.

The dataset included 19 features, including tumor size, age, hormone receptor status, histological grade, lymph node status, human epidermal growth factor receptor 2 (HER2) status, progesterone receptor (PR) status, estrogen receptor (ER) status, chemotherapy, Targeted therapies, radiation therapy, hormone therapy, healthy eating, physical activity, type of psychosocial stress and type of recurrence. The important factors of our study are outlined in Table I.

B. Data Preprocessing

In this study, the data set was preprocessed to handle missing values, categorical variables, and feature selection. The Python programming language and the Pandas library were used to preprocess the data, as well as to analyze the medical records of cancer patients to identify factors associated with cancer recurrence. Several preprocessing techniques were used to prepare the data for machine learning, as shown in Fig. 1. First, missing or invalid values were verified and replaced where appropriate. Second, the categorical variables were recoded such as 'POSTMENOPAUSAL' and 'CHEMOTHERAPY (ANTHRACYCLINES / TAXANE)', 'TYPE OF PSYCHOSOCIAL STRESS' into numeric variables for easy analysis. The 'LYMPH_NODES' variable was also transformed into an ordinal variable, assigning values from 0 to 3 to represent the different levels of lymph node involvement. Additionally, variables such as AGE_DIAGNOSIS, TUMOR_SIZE, and KI67 were scaled into a common range to avoid bias in the analysis. Then, one-hot encoding was employed to convert categorical variables such as 'HER2,' 'ER,' 'PR,' 'SURGERY_TYPE,' 'TARGETED THERAPIES,' 'RADIOTHERAPY,' 'HEALTHY EATING,' and 'PHYSICAL ACTIVITY' into binary variables to enhance model accuracy. Fourth, a new target ordinal variable representing types of breast cancer recurrence (No, local, regional, or distant) was created, as shown in Table I.

Finally, feature screening was performed to identify the most important variables in predicting types of breast cancer recurrence. This reduced the dimensionality of the data improved the efficiency of the analysis.

TABLE I. CODE AND VALUE OF THE VARIABLES USED IN THIS STUDY

Variable_Name	Code or Value
AGE_DIAGNOSIS	≤ 25; 25 to 35; 36-45; 46 ≥ years old
POSTMENOPAUSAL	0 < 49 ; 1 ≥ 50)
TUMOR_SIZE	≤2 ; 3-4 ; ≥5
LYMPH_NODES	0 = "No" ; 1 = "1-3" ; 2 = "4-9" ; 3 = "0>9"
TUMOUR_GRADE	1 ; 2 or 3
HER2	0 ; 1
ER	0 ; 1

PR	0 ; 1
KI67	≤ 20; 21 to 40; 41-60; 61 ≥
SURGERY_TYPE	0= "lumpectomy"; 1= "mastectomy"
CHIMIOThERAPY	ANTHRACYCLINES 0="No" ; 1="EC 50"; 2="FEC 100";3= "AC60"
	TAXANE 0="No" ; 1=" PACLITAXEL "; 2=" DOCETAXEL "
TARGETED THERAPIES	0= "No"; 1= " TRASTUZUMAB "
RADIOTHERAPY	0= "No"; 1= " RADIOTHERAPY "
HORMONOTHERAPY	0= "No"; 1= " Tamoxifen "; 2="Aromatase inhibitors"; 3="Tamoxifene + Aromatase Inhibitors" ;4="Aromatase Inhibitors + Tamoxifene".
HEALTHY EATING	0= "No"; 1= " Yes "
PHYSICAL ACTIVITY	0= "No"; 1= " Yes "
TYPE OF PSYCHOSOCIAL STRESS	0="No"; 1= "Cognitive stress"; 2="Familial stress"; 3="Work-related stress"; 4="Environmental stress"; 5="Event-related stress".
TYPE OF RECURRENCE	No="0000" ; Local="0100"; Regional="0010" or Distant="0001")

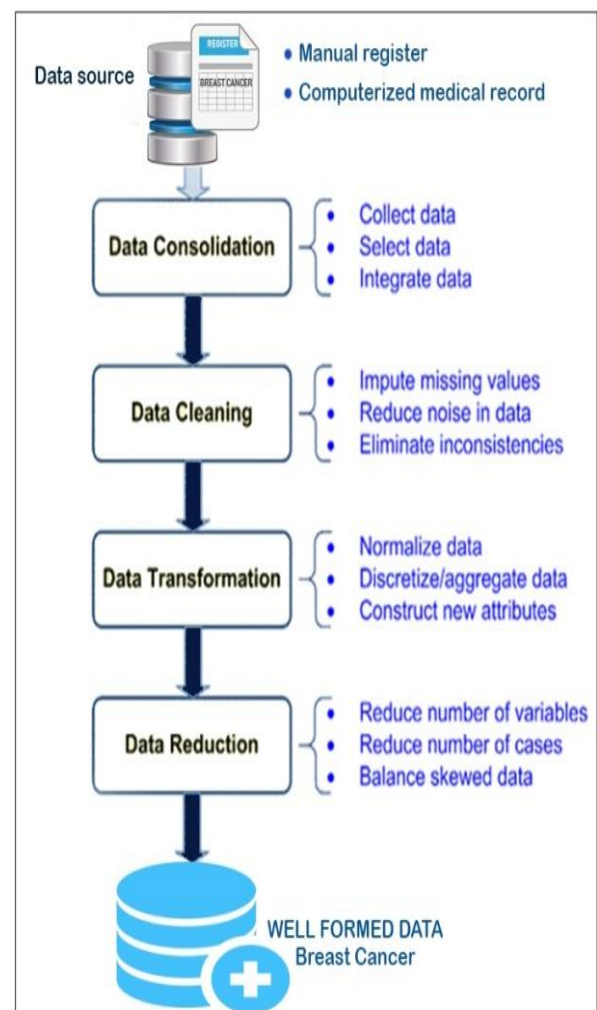


Fig. 1. The typical data mining procedure used in this study.

C. Machine Learning Models

The forms of recurrence in breast cancer patients were categorized into classes in this study using classification models based on demographic, biopsychological, and clinical traits. Fig. 2 depicts the complete experimentation procedure.

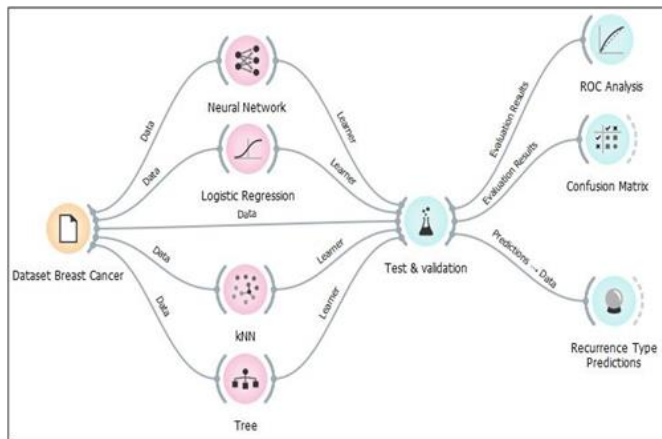


Fig. 2. Model machine learning use.

In this paper, the performance of four machine learning techniques was compared: logistic regression, decision tree, K-Nearest Neighbors, and artificial neural network. The Python programming language and the Scikit-learn library were used to implement the models. The models were trained and tested using a 10-fold cross-validation method [13].

1) *Artificial neural networks*: Artificial neural networks are a machine learning technique based on the architecture of interconnected neurons inspired by the functioning of the human brain [14]. They are very useful in multi-class classification, where several categories are to be predicted. In the case of recurrence in breast cancer patients, neural networks can be used to predict whether a patient is likely to experience a recurrence of the disease.

Once the data is prepared, the neural network model is constructed. It can consist of several layers of neurons, each with a specific number of neurons. The input layer is the one that receives the input data, while the output layer is the one that gives the classification results [15]. The intermediate layers are called hidden layers and are responsible for learning the relationships between the input features and the output classes.

The learning process is done using a gradient back-propagation algorithm, which calculates the gradients of the loss function with respect to the model weights and adjusts the weights to minimize the loss function [16]. The loss function can be a cross-entropy, which measures the distance between the model predictions and the actual classes.

2) *Logistic regression*: Logistic regression is a statistical technique commonly used in modeling binary data, where the dependent variable can take only two possible values[17]. However, it is possible to apply logistic regression to multi-class classification problems, such as the classification of recurrence types in breast cancer patients.

To use logistic regression in this context, there are several approaches. One is to apply multinomial logistic regression, which models the probability of each class of recurrence. In this case, the model will produce several equations for each class that describe the relationships between the input variables and the probabilities of each class.

Another approach was used, binary logistic regression for each recidivism class, treating each class as a separate binary variable. In this case, several logistic regression models must be fitted for each recurrence class, and the final class for each patient is determined based on the probabilities predicted by each model.

3) *K-Nearest Neighbors (K-NN)*: K-Nearest Neighbors (K-NN) is a classification algorithm used to predict the category of a new sample based on the training data samples closest to that sample[18]. In the case of multi-class classification of recurrence types in breast cancer patients, the K-NN algorithm can be used to predict whether a given patient is likely to experience local recurrence, distant recurrence, simultaneous local and distant recurrence, or no recurrence. The above steps can be applied after preprocessing the data as follows:

Distance definition: the distance can be calculated using Euclidean distance or other distance measures appropriate for the types of variables used.

Determining the K number: the K value can be chosen by cross-validation using different values for K and choosing the one that gives the best performance.

Category prediction: once the closest data samples have been identified, the majority of their categories can be used to predict the most likely recurrence category for the patient.

4) *Decision tree*: A decision tree can be an effective tool for multiclass classification of recurrence types in breast cancer patients[19]. The decision tree is a machine learning model that progressively divides a dataset into smaller subsets based on specific criteria, until each subset can no longer be divided. Each division of the dataset is based on a specific variable, which can be a continuous or categorical variable. At the end of the process, the decision tree provides a set of decision rules that can be used to predict the target classes.

D. Performance Indicators

In this study, the performance of each model was evaluated using the confusion matrix to calculate the following metrics: precision, sensitivity, specificity, and AUC-ROC.

1) *Confusion matrix*: A multiclass confusion matrix is used to evaluate the performance of a classification model that predicts classes belonging to more than two categories. In this case, assuming that the four classes are: "No recurrence," "Local recurrence," "Loco-regional recurrence," and "Remote recurrence," the confusion matrix will look like this, as shown in Table II.

TABLE II. CONFUSION MATRIX FOR MULTI-CLASS CLASSIFICATION OF RECURRENCE TYPE

Actual class / Predicted class	No recurrence	Local recurrence	Locoregional recurrence	Distant recurrence
No recurrence	True Positives	False Negatives	False Negatives	False Negatives
Local recurrence	False Positives	True Positives	False Negatives	False Negatives
Locoregional recurrence	False Positives	False Positives	True Positives	False Negatives
Distant recurrence	False Positives	False Positives	False Positives	True Positives

In this confusion matrix, TP stands for True Positives, TN stands for True Negatives, FP stands for False Positives and FN stands for False Negatives [20].

- True Positives (TP): The model correctly predicted the recurrence class for breast cancer patients who actually had a recurrence of that type.
- True Negatives (TN): The model correctly predicted the "No Recurrence" class for breast cancer patients who did not experience a recurrence.
- False Positives (FP): The model incorrectly predicted that a patient had a recurrence, when in fact there was no recurrence.
- False Negatives (FN): The model incorrectly predicted that there was no recurrence for a patient who actually had a recurrence.

The Sum of each row and column gives us useful statistics to evaluate the performance of the model, including:

Accuracy (1) is the proportion of the total number of correct predictions made by the model divided by the total number of predictions made by the model. It is typically represented as a percentage and is one of the most commonly used performance metrics for classification models [21]. The formula for accuracy is:

$$Overall\ Accuracy = \frac{\sum_{i=1}^N c_{i,i}}{\sum_{i=1}^N \sum_{j=1}^N c_{i,j}} \quad (1)$$

Sensitivity (or recall) (2) for each class, which measures the proportion of true positives among all true positive cases of this class.

$$Recall_{class} = \frac{TP_{class}}{TP_{class} + FN_{class}} \quad (2)$$

Specificity (3) for each class, which measures the proportion of true negatives among all the true negative cases in that class is given as,

$$Specificity_{class} = \frac{TN_{class}}{FP_{class} + TN_{class}} \quad (3)$$

Precision(4) for each class, which measures the proportion of true positives among all predicted positive cases in that class is given as,

$$Precision_{class} = \frac{TP_{class}}{TP_{class} + FP_{class}} \quad (4)$$

F1-Score (5) for each class, which is a measure of the combined accuracy and sensitivity is measured as,

$$F1 - Score = \frac{2 * TP_{class}}{2 * TP_{class} + FN_{class} + FP_{class}} \quad (5)$$

2) *The Roc and AUC curve:* Receiver Operating Characteristic (ROC) and Area Under the Curve (AUC) curves are commonly used evaluation tools in binary classification to assess the performance of classification models [22].

In the case of four-class classification of recurrence types in breast cancer patients, these curves can be used to evaluate the ability of a classification model to distinguish between different types of recurrence.

The ROC curve plots the true-positive rate (sensitivity) against the false-positive rate (1 - specificity) for different classification cut-off values. The AUC represents the area under the ROC curve and measures the overall ability of the model to discriminate between classes. The closer the AUC is to 1, the better the performance of the classification model.

In the case of four-class classification, several ROC curves can be plotted for each class. The overall performance of the model can be evaluated by calculating a weighted average of the AUC for each class.

Using these curves, physicians and researchers can evaluate the performance of classification models and select the best model for predicting recurrence types in breast cancer patients.

III. RESULTS

A. Analysis of Result

The study evaluated the performance of four classification algorithms - Neural Network, Decision Tree, kNN, and Logistic Regression - in predicting the type of recurrence in breast cancer. The evaluation metrics used to assess the performance of these algorithms were AUC, CA (Classification Accuracy), F1 score, Precision, Recall, and Specificity. The variables used to predict the type of recurrence were age at diagnosis of breast cancer, primary tumor size (TS), postmenopausal status, number of involved axillary lymph nodes, histological grade of the tumor, type of surgery, cellular marker of proliferation (Ki67), PR status, ER status, HER2 status, healthy eating, physical activity, type of psychosocial stress. Including these variables improved the performance of the classification algorithms. The study used 10-fold cross-validation to ensure that the results were representative and not overfit to the data, see Table III.

Table III provides the results of four different classification algorithms (A, B, C and D) for four classes (0000, 0100, 0010 and 0001). The columns represent the predictions of the algorithms and the rows represent the actual classes. The values in the cells indicate the number of times each class was predicted for each actual class.

For Algorithm A (neural network), it correctly predicted class 0000 for 904 times, class 0100 for 105 times, class 0010 for 24 times and class 0001 for 49 times. There are 107 incorrect predictions in total for algorithm A.

For Algorithm B (decision tree), it correctly predicted class 0000 for 904 times, class 0100 for 99 times, class 0010 for 27 times and class 0001 for 41 times. There are 118 incorrect predictions in total for algorithm B.

For Algorithm C (kNN), it correctly predicted class 0000 for 900 times, class 0100 for 110 times, class 0010 for 17 times and class 0001 for 22 times. There are 140 incorrect predictions in total for algorithm C.

For Algorithm D (logistic regression), it correctly predicted class 0000 for 903 times, class 0100 for 63 times, class 0010 for 8 times and class 0001 for 32 times. There are 183 incorrect predictions in total for algorithm D.

Looking at the overall results, it is evident that Algorithm A gave the best result with the least number of incorrect predictions, while Algorithm D gave the worst result with the highest number of incorrect predictions. The other algorithms (B and C) gave intermediate results. However, further analysis of the data, including measures of precision, recall, and F1-score for each class, would be required to provide a more complete and accurate assessment of the performance of the algorithms.

TABLE III. MULTI-CLASS CONFUSION MATRIX OF THE APPLICABLE CLASSIFICATION MODELS

A : Neural Network - Classifier						
		Predicted				
		0000	0100	0010	0001	Σ
Current	0000	904	7	10	8	929
	0100	7	105	1	11	124
	0010	23	1	24	7	55
	0001	6	21	5	49	81
Σ		940	134	40	75	1189

B : Decision Tree – Classifier						
		Predicted				
		0000	0100	0010	0001	Σ
Current	0000	904	7	7	11	929
	0100	3	99	0	22	124
	0010	22	0	27	6	55
	0001	19	18	3	41	81
Σ		948	124	37	80	1189

C : kNN – Classifier						
		Predicted				
		0000	0100	0010	0001	Σ
Current	0000	900	19	2	8	929
	0100	2	110	0	12	124
	0010	36	0	17	2	55
	0001	34	25	0	22	81
Σ		972	154	19	44	1189

D : Logistic Regression –Classifier						
		Predicted				
		0000	0100	0010	0001	Σ
Current	0000	903	12	2	12	929
	0100	44	63	2	15	124
	0010	40	7	8	0	55
	0001	30	15	4	32	81
Σ		1017	97	16	59	1189

B. Performance Evaluation

The four algorithms' performances were compared using classification metrics; see Table IV for details.

TABLE IV. PERFORMANCE METRICS OF MACHINE LEARNING MODELS

Model	AUC	CA	F1	Precision	Recall	Specificity
Neural Network	0.976	0.910	0.907	0.905	0.910	0.887
Decision Tree	0.899	0.901	0.898	0.897	0.901	0.863
kNN	0.934	0.882	0.868	0.873	0.882	0.778
Logistic Regression	0.941	0.846	0.826	0.822	0.846	0.652

Based on the table, we can see that the neural network model has the highest AUC (0.976) and the highest classification accuracy (0.910). It also has high precision (0.905), high recall (0.910), and high specificity (0.887), indicating that it performs well in both detecting positive instances and avoiding false positives and false negatives.

The decision tree model has a lower AUC (0.899) and classification accuracy (0.901) than the neural network, but still performs relatively well. It has a similar F1 score (0.898) and precision (0.897) to the neural network, but slightly lower recall (0.901) and specificity (0.863).

The kNN model has a lower AUC (0.934) and classification accuracy (0.882) than both the neural network and decision tree models. It has a lower F1 score (0.868) and precision (0.873) than the other two models, but a similar recall (0.882) and lower specificity (0.778).

The logistic regression model has the lowest AUC (0.941) and classification accuracy (0.846) of all the models. It also has the lowest F1 score (0.826), precision (0.822), recall (0.846), and specificity (0.652). This suggests that the logistic regression model may not be as effective at distinguishing between the positive and negative classes and may have a higher rate of false positives and false negatives than the other models.

C. ROC and AUC Curve

Knowing the associated Receiver Operating Characteristic (ROC) curve, True Positive Rate (TPR), and False Positive Rate (FPR) is important when evaluating the performance of classification models. In this study, it can be concluded that all machine learning classifiers predict with >89% accuracy on the type of recurrence in Boobs cancer patients, this shows that these classification algorithms work well to classify different types of recurrence. Using the following iteration type codes (0000 - 0100 - 0010 - 0001), the neural network obtained the maximum AUC (area under the curve) of the ROC (see Figure 3).

In the curve cube graph (Fig. 3), there are four ROC curves, each representing the performance of a different classifier for a different class. The classifiers include a neural network, a decision tree, logistic regression, and K-Nearest Neighbors (KNN).

For class code "0000," which represents non-recurrence, the ROC curve shows that the neural network and logistic regression have the highest sensitivity (TP rate) of 0.8, while the decision tree and KNN have a sensitivity of 0.6. The false positive rate (FP rate) is relatively low across all classifiers, indicating that they have good specificity.

For class code "0100," which represents local recurrence, the ROC curve shows that the neural network has the highest sensitivity of 0.6, followed by the decision tree and logistic regression with a sensitivity of 0.4, and KNN with a sensitivity of 0.2. The false positive rate is relatively high for all classifiers, indicating that they have poor specificity.

For class code "0010," which represents loco-regional recurrence; the ROC curve shows that the neural network and logistic regression have the highest sensitivity of 0.8, followed by the decision tree with a sensitivity of 0.6, and KNN with a sensitivity of 0.4. The false positive rate is relatively low for all classifiers, indicating that they have good specificity.

For class code "0001," which represents distant recurrence, the ROC curve shows that the neural network has the highest sensitivity of 1, followed by logistic regression with a sensitivity of 0.6, the decision tree with a sensitivity of 0.4, and KNN with a sensitivity of 0.2. The false positive rate is relatively high for all classifiers, indicating that they have poor specificity.

Overall, the ROC curves in the curve cube graph demonstrate that the neural network and logistic regression classifiers perform better than the decision tree and KNN classifiers, particularly for classes that are more difficult to classify, such as local recurrence and distant recurrence. The curve cube graph is a useful visualization tool for comparing the performance of multiple classifiers for different classes in a multi-class classification problem.

IV. DISCUSSION

This paper presents four different types of classifiers (neural network, decision tree, kNN, and logistic regression) for predicting recurrence type in breast cancer patients. The classifiers were evaluated for their ability to correctly predict recurrence type (0000, 0100, 0010, or 0001) for a data set of 1189 patients. The results show that the neural network classifier performed the best, correctly predicting recurrence type with an overall accuracy of 91%. The decision tree classifier was the second best performer with an accuracy of 90.1%, followed by kNN with 88.2% and logistic regression with 84.6%.

Indeed, the article also points out that incorporating biopsychological variables into recidivism prediction studies is important for improving understanding of recidivism risk in individual patients. This may lead to more personalized treatment decisions and better monitoring after initial treatment. In addition, regular psychological and social assessments can help identify patients who need additional support to improve their quality of life and overall well-being.

These findings underscore the importance of considering not only medical factors, but also psychological and social factors in the management of breast cancer. By incorporating these factors into clinical decision making, physicians can improve the quality of care for breast cancer patients.

Overall, the results of this study indicate that these classifiers can be used to accurately predict the type of recurrence in breast cancer patients. However, further studies are needed to confirm the effectiveness of these models and determine their utility in clinical practice. Nevertheless, this study is an important contribution to the field of medical research, as it shows the potential of machine learning techniques to improve outcomes for cancer patients.

A. Limitations

Validation of our results using other datasets would be necessary to generalize our findings to other populations. Additionally, our study focused only on predicting the type of breast cancer recurrence and did not consider other factors such as disease-free survival or overall survival. Further studies may investigate the potential use of machine learning techniques to predict these outcomes.

V. CONCLUSION

The study used a dataset of 1189 patients with breast cancer and applied various machine learning techniques, including logistic regression, decision tree, K-Nearest Neighbors and artificial neural network, to predict the type of recurrence. The results showed that the artificial neural network outperformed the other models in terms of accuracy, precision, recall, and F1-score.

The high performance of the artificial neural network can be attributed to its ability to capture complex non-linear relationships between the features and the target variable. The logistic regression model, which is a linear model, achieved a lower performance than the other models, indicating that non-linear relationships exist between the features and the target variable.

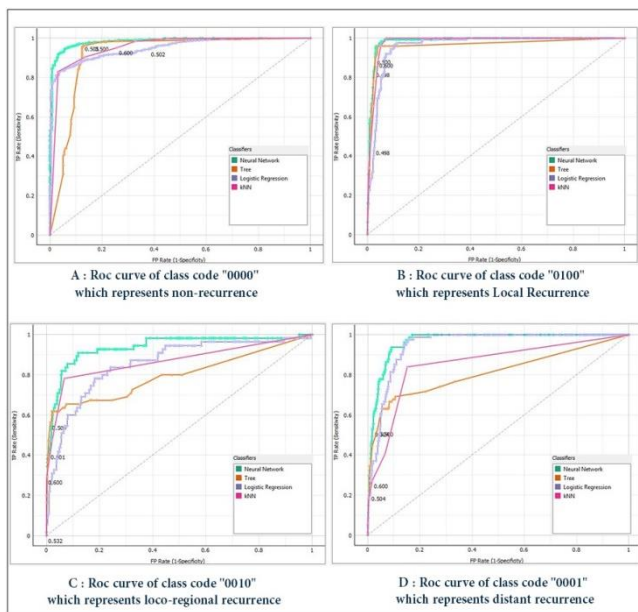


Fig. 3. AUC - ROC curve of classifiers used in the prediction of types of recurrence in patients with breast cancer.

The findings of this study have significant implications for breast cancer patients and clinicians. Accurate prediction of the type of recurrence can help to guide treatment decisions and improve patient outcomes. Machine learning techniques can provide a valuable tool in predicting breast cancer recurrence and may lead to more personalized treatment plans.

However, it is essential to note that machine learning techniques are not without limitations. One potential limitation is the need for large datasets to train the models effectively. Additionally, machine learning models may not always be transparent, and it may be challenging to understand how the models arrive at their predictions. Further investigation is needed to address these limitations and improve the clinical application of machine learning techniques in predicting breast cancer recurrence.

REFERENCES

- [1] "The Global Cancer Observatory - March, 2021. Page 1."
- [2] B. Holleczeck, C. Stegmaier, J. C. Radosa, E.-F. Solomayer, and H. Brenner, "Risk of loco-regional recurrence and distant metastases of patients with invasive breast cancer up to ten years after diagnosis – results from a registry-based study from Germany," *BMC Cancer*, vol. 19, no. 1, p. 520, Dec. 2019, doi: 10.1186/s12885-019-5710-5.
- [3] E. Merouane, A. Said, and E. F. Nour-eddine, "Prediction of Metastatic Relapse in Breast Cancer using Machine Learning Classifiers," *International Journal of Advanced Computer Science and Applications*, vol. 13, no. 2, p. 6, 2022.
- [4] A. G. V. Bitencourt et al., "MRI-based machine learning radiomics can predict HER2 expression level and pathologic response after neoadjuvant therapy in HER2 overexpressing breast cancer," *EBioMedicine*, vol. 61, p. 103042, Nov. 2020, doi: 10.1016/j.ebiom.2020.103042.
- [5] N. Adnan, C. Lei, and J. Ruan, "Robust edge-based biomarker discovery improves prediction of breast cancer metastasis," *BMC Bioinformatics*, vol. 21, no. S14, p. 359, Sep. 2020, doi: 10.1186/s12859-020-03692-2.
- [6] H. Alkhadar, M. Macluskey, S. White, I. Ellis, and A. Gardner, "Comparison of machine learning algorithms for the prediction of five - year survival in oral squamous cell carcinoma," *J Oral Pathol Med*, vol. 50, no. 4, pp. 378-384, Apr. 2021, doi: 10.1111/jop.13135.
- [7] R. Bhardwaj and N. Hooda, "Prediction of Pathological Complete Response after Neoadjuvant Chemotherapy for breast cancer using ensemble machine learning," *Informatics in Medicine Unlocked*, vol. 16, p. 100219, 2019, doi: 10.1016/j.imu.2019.100219.
- [8] F. J. Candido dos Reis et al., "An updated PREDICT breast cancer prognostication and treatment benefit prediction model with independent validation," *Breast Cancer Res*, vol. 19, no. 1, p. 58, Dec. 2017, doi: 10.1186/s13058-017-0852-3.
- [9] M. Ertel, S. Azeddine, A. Said, and E. F. Nour-eddine, "PREDICTION OF THE MOST EFFECTIVE ADJUVANT THERAPEUTIC COMBINATIONS FOR BREAST CANCER PATIENTS USING MULTINOMIAL CLASSIFICATION," *Journal of Theoretical and Applied Information Technology*, vol. 100, no. 23, Dec. 2022, [Online]. Available: <http://www.jatit.org/volumes/onehundred23.php>.
- [10] H. Rizki, C. Hillyar, O. Abbassi, and S. Miles-Dua, "The Utility of Oncotype DX for Adjuvant Chemotherapy Treatment Decisions in Estrogen Receptor-positive, Human Epidermal Growth Factor Receptor 2-negative, Node-negative Breast Cancer," *Cureus*, Mar. 2020, doi: 10.7759/cureus.7269.
- [11] G. Altan, "Deep Learning-based Mammogram Classification for Breast Cancer," *ijisae*, vol. 8, no. 4, pp. 171–176, Dec. 2020, doi: 10.18201/ijisae.2020466308.
- [12] P. Chandrakar, A. Shrivastava, and N. Sahu, "Design of a Novel Ensemble Model of Classification Technique for Gene-Expression Data of Lung Cancer with Modified Genetic Algorithm," *EAI Endorsed Transactions on Pervasive Health and Technology*, vol. 7, no. 25, p. 167845, Jan. 2021, doi: 10.4108/eai.8-1-2021.167845.
- [13] G. C. Wishart et al., "PREDICT Plus: development and validation of a prognostic model for early breast cancer that includes HER2," *Br J Cancer*, vol. 107, no. 5, pp. 800–807, Aug. 2012, doi: 10.1038/bjc.2012.338.
- [14] S. Agatonovic-Kustrin and R. Beresford, "Basic concepts of artificial neural network (ANN) modeling and its application in pharmaceutical research," *Journal of Pharmaceutical and Biomedical Analysis*, vol. 22, no. 5, pp. 717–727, Jun. 2000, doi: 10.1016/S0731-7085(99)00272-1.
- [15] P. J. Drew and J. R. T. Monson, "Artificial neural networks," vol. 127, no. 1, p. 9, 2000.
- [16] M. Ertel and S. Amali, "'Predicting the efficacy of chemotherapy applied to breast cancer by machine learning'. (2021). 1st International Meeting on The health system: Managing the health crisis between public action and future prospects. April 07-08, Meknes, Morocco," 2021.
- [17] E. Bisong, "Logistic Regression," in *Building Machine Learning and Deep Learning Models on Google Cloud Platform*, Berkeley, CA: Apress, 2019, pp. 243–250. doi: 10.1007/978-1-4842-4470-8_20.
- [18] S. E. Buttrey, "Nearest-neighbor classification with categorical variables," *Computational Statistics & Data Analysis*, vol. 28, no. 2, pp. 157–169, Aug. 1998, doi: 10.1016/S0167-9473(98)00032-2.
- [19] S. Murugan, B. M. Kumar, and S. Amudha, "Classification and Prediction of Breast Cancer using Linear Regression, Decision Tree and Random Forest," in *2017 International Conference on Current Trends in Computer, Electrical, Electronics and Communication (CTCEEC)*, Mysore: IEEE, Sep. 2017, pp. 763–766. doi: 10.1109/CTCEEC.2017.8455058.
- [20] D.-Z. Du, P. Pardalos, and J. Wang, Eds., *Discrete Mathematical Problems with Medical Applications*, vol. 55. in *DIMACS Series in Discrete Mathematics and Theoretical Computer Science*, vol. 55. Providence, Rhode Island: American Mathematical Society, 2000. doi: 10.1090/dimacs/055.
- [21] J. McCarthy, "Artificial Intelligence, Logic and Formalizing Common Sense," in *Philosophical Logic and Artificial Intelligence*, R. H. Thomason, Ed., Dordrecht: Springer Netherlands, 1989, pp. 161–190. doi: 10.1007/978-94-009-2448-2_6.
- [22] T. Fawcett, "An introduction to ROC analysis," *Pattern Recognition Letters*, vol. 27, no. 8, pp. 861–874, Jun. 2006, doi: 10.1016/j.patrec.2005.10.010.

Automated Decision Making ResNet Feed-Forward Neural Network based Methodology for Diabetic Retinopathy Detection

A. Aruna Kumari¹, Avinash Bhagat², Santosh Kumar Henge^{3*}, Sanjeev Kumar Mandal⁴

School of Computer Science & Engineering, Lovely Professional University, Phagwara, Punjab, India^{1,2}

Associate Professor, Department of Computer Applications-Directorate of Online Education, Manipal University Jaipur, Jaipur, Rajasthan, India^{3*}

Assistant Professor, School of CS & IT, Jain (Deemed-to-be University) Bangalore, India⁴

Abstract—The detection of diabetic retinopathy eye disease is a time-consuming and labor-intensive process, that necessitates an ophthalmologist to investigate, assess digital color fundus photographic images of the retina, and discover DR by the existence of lesions linked with the vascular anomalies triggered by the disease. The integration of a single type of sequential image has fewer variations among them, which does not provide more feasibility and sufficient mapping scenarios. This research proposes an automated decision-making ResNet feed-forward neural network methodology approach. The mapping techniques integrated to analyze and map missing connections of retinal arterioles, microaneurysms, venules and dot points of the fovea, cottonwool spots, the macula, the outer line of optic disc computations, and hard exudates and hemorrhages among color and back white images. Missing computations are included in the sequence of vectors, which helps identify DR stages. A total of 5672 sequential and 7231 non-sequential color fundus and black-and-white retinal images were included in the test cases. The 80 and 20 percentage rations of best and poor-quality images were integrated in testing and training and implicated the 10-fold cross-validation technique. The accuracy, sensitivity, and specificity for testing and analysing good-quality images were 98.9%, 98.7%, and 98.3%, and poor-quality images were 94.9%, 93.6%, and 93.2%, respectively.

Keywords—Retinal lesion (RL); Fundus Images (FunImg); Microaneurysms (MAs); Principal Component Analysis (PCA); Standard Scaler (StdSca); Feed-Forward Neural Network (FFNN); cross pooling (CxPool)

I. INTRODUCTION

Diabetic Retinopathy (DR) eye disease (ED) is correlated with chronic type diabetes, which is the primary trigger of sightlessness in children, workforce employees, and elderly people across the globe, and it is impacting more than 96 million people [1]. DR is a type of diabetes that causes damage to the retinal blood vessels (BV). Primarily, it is symptomless and changes vision-based issues. As it becomes more severe, it disturbs both eyes and ultimately causes partial to complete vision loss. It principally arises when blood sugar levels are uncontrollable. The premature detection of DR can prevent the possibility of permanent blindness. Consequently, it needs an effective screening scheme [2]. Detection of the initial stages of DR-ED is one of the challenging tasks in the DR diagnosis process, it helps in the advancement to vision loss, which can

be decelerated, but it can be complicated as DR-ED regularly indicates rare symptoms until it is extremely late to deliver efficient medication [4] [5]. Consequently, uncovering DR at an early stage is crucial in preventing the complications of this illness, as shown in Fig. 1 [2]. CNN in DL manages to deliver helpful results while it comes up to the job of classification of medical images [5].

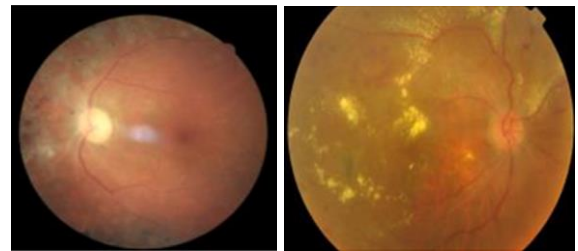


Fig. 1. Hard exudates, hemorrhages, abnormal growth of blood vessels, aneurysm and cotton wool spots of DR affected retina.

Recognition of the initial clinical signs of DR initiation is a crucial constraint for interference-free and efficient medication. Ophthalmologists qualified to detect DR focus on analyzing minor fluctuations in patient microaneurysms (MAs) of the eyes, retinal bleeds, macular edema, and fluctuations in retinal blood vessels. Segmentation of MAs is another crucial constraint for primary identification of DR, which has attracted the major attention of the research community across the early years [27]. According to the International Clinical DR Disease Severity Scale, DR seriousness is marked into five degrees, such as non-DR, mild-NPDR, moderate-NPDR, PDR, or severe-NPDR [7] [8]. Mild-NPDR is specified as the occurrence of microaneurysms. Moderate NPDR is specified as being further than exactly micro-aneurysms, although less severe NPDR produces CWS, retinal hemorrhages, and hard exudates. DME was analyzed if difficult exudates were identified in the interior of 500 μ m of the macular centre corresponding to the specification of the initial medication for DR research [9]. Ascribable-DR is specified as DME, moderate NPDR, or both. Based on the recommendations for image procurement and clarification of DR assessment in China [10], the image quality was rated conferring to requirements specified in terms of three characteristic factors such as field definition (FD), clarity, and artifacts (AF). The overall result was equivalent to a grade for transparency plus a

grade for FD and minus the score for AF; the overall count was less than 12, which counted as ungradable [8]. Recognizing the first clinical signs of DR is a significant barrier to effective intervention and treatment. Ophthalmologists who are trained to identify DR focus on analyzing minute changes in patient microaneurysms (MAs), retinal bleeding, macular edema, and changes in retinal blood vessels. Another important barrier to the initial identification of DR is the segmentation of MAs, which has received significant attention from the academic community in recent years.

The article is planned in a section wise manner: Section I included an introduction and research objectives; Section II comprised the associated works along with the background of the research; and Section III included the proposed methodology of the Automated Decision Making ResNet Feed-Forward Neural Network (RNFFNN) Methodology for Recognition of DR Stages and its executional scenarios. Section IV described the experimental setup and analysis through Image Normalization Principal Component Analysis (PCA) and Multi-level ConvNets based Pooling and Feature Integrations, along with the results and discussion; Section V contains the results and discussions. Finally, Section VI addresses the conclusion and future direction.

II. RELATED WORK

DR is one of the significant interests that have captured the healthy world. Accepting the interest from numerous scientists to discover the ideal solutions for initial recognition of DR disease, subsequently prominent to avoidance of early oscillations in eyesight. Several investigations were performed and continued in this field with the intention of improving the lives of patients. This section articulates an analysis of DR-related research [2].

The author, Anumol Sajjan et al., proposed the detection of DR stages using deep learning (DL). It proposed an automatic classification system, in which it analyzes fundus images (FunImg) with fluctuating illumination and fields of assessment and produces a severity grade for DR using ML replicas such as VGG-16, Convolutional Neural Network (CNN), and VGG-19 through five groups of classified images ranging from 0 to 4, where 0 is no DR and 4 is proliferative DR. It accomplishes 82%, 80%, and 82% accuracy, sensitivity, and specificity, respectively [1]. Author Mushtaq et al. proposed detection of DR using DL-based densely connected CNN (DenseNet-169) for identification of early recognition of DR, which categories the FunImgs based on their levels of severity: Proliferative-DR, Severe, Moderate, Mild, and No-DR with integration of DR-Recognition-2015 and Aptos-2019-Blindness-Recognition from Kaggle in the inclusion of data-gathering, pre-processing, augmentation, and modeling levels and achieved 90% accuracy (ACU) [2]. The fifth most common cause of blindness in the world is now diabetes. One of the main causes of vision loss and blindness among diabetes individuals worldwide is diabetic retinopathy. According to the WHO, diabetic retinopathy is a serious eye condition that needs to be addressed right once by government agencies and medical specialists. [3]. Image artifact, clarity, and field definition are the three main criteria used to evaluate the quality of fundus images. Unfortunately, the majority of

quality assessment techniques now in use only consider overall image quality without providing comprehensible quality feedback for real-time correction. Furthermore, these models frequently lack generalizability under various imaging settings and are susceptible to the particular imaging devices [11].

The author, J. De Calleja et al. [31], integrated a 2-stage scheme for DR recognition. FE was processed through local binary patterns, and the classification stage was processed through ML-based Support Vector machines (SVM) and Random Forest (RF) and attained a 97.46% ACU rate with a test case of 71 images. M. Gandhi et al. [32] proposed automatic DR recognition through SVM by sensing exudates from FunImgs with manual FE with DL for J. Orlando et al. [24] integrated CNN with manual and enhanced features for FE for sensing RED-lesion in the retina eye. U. Acharya et al. [33] integrated 331 FunImgs through MAs, BV, haemorrhages, exudates-based features using SVM and attained 85% of ACU. K. Anant et al. [26] integrated texture and wavelet features for DR recognition in basic level analysis with involvement of DM and IP on the DIARETDB1 database and accomplished 97.95% of ACU. In a different study, 331 fundus images were analyzed and morphological image processing and support vector machine (SVM) techniques were utilized for the automatic detection of eye health [34]. S. Preetha et al. [14] described DM and ML methods in their analysis for the prediction of various diabetic-related diseases such as DR, skin cancer, and heart disease. S. Sadda et al. [13] used a quantitative based method to recognize new parameters for sensing proliferative DR based on hypotheses of lesions location, surface area, number, and distance from the ONH center, which progressed the prediction procedure of DR with the involvement of imaging data and quantitative lesion parameters. The authors, J.Amin et al. [27], deliver an assessment of numerous practices for DR by sensing hemorrhages, MAs, exudates, and BV and analyzing numerous outcomes obtained from these practices experimentally. Y. Kumaran et al. [18] emphasize the dissimilar types of pre-processing and segmentation methods typically used for the detection of DR in the human eye, which contain several classification models. I. Sadek et al. [25] proposed automatic DR detection through DL with the integration of four CNNs to categorize DR into three classes: normal, exudates, and drusen and achieved 91%–92% ACU. G. Zago et al. [6] proposed a lesion localization model using a deep NN through CNN with integration of regions in the place of segmentation localization processes and 2-CNNs implicated for training through the Standard DR Database and DIARETDB1 and achieved 95% sensitivity. P. Kaur et al. [17] proposed the NN method for the categorization of several RIs using the MATLAB environment. A comparison study was done among the proposed methods using SVM. SVM helped generate an accurate result.

M. Voets et al. [12] proposed a study that integrated the Kaggle dataset EyePACS for finding DR from retinal FunImgs test cases and experimented on existing work on several data sets that provided 95% of ACU [2]. It aimed to improve the performance of detecting certain retinal lesions (RL) with their grading levels through a cost-effective ResNet implicated RL-aware sub-network (RLASN) for reducing vanishing gradient complexity, which was improved with more sensitive FE for

small lesions compared to VGG and Inception's existing net designs [15]. The RLASN included a feature pyramid structure that was intended to describe features of multi-scale and dig out lesion types and position relationships [16] [23]. Identifying several types of RIs can help with making decisions in the clinical process, like fenofibrate for patients with hard exudate [19] and antiplatelet drugs used thoroughly in patients with bleeding retina [20]. Progression is another major problem in DR screening, as advancement of RIs is symptomatic of improving sight-threatening DR [21–23]. It stated that, as a substitute for direct end-to-end training from FunImgs to DR grades, a cost-effective RLASN was established to improve the capability of acquiring features of lesion [26]. For the purpose of ultimately detecting nonproliferative diabetic retinopathy, the author outlined different ways for detecting microaneurysms, hemorrhages, and exudates. Techniques for detecting blood vessels are also covered for proliferative diabetic retinopathy [28]. Author Veena Mayya et al. [30] proposed an analytical study through automated MAs recognition and segmentation for DR early diagnosis, which was achieved using color fundus photography, optical coherence tomography angiography, or fluorescein angiography images. This study was categorized into classical IP, conventional ML, and DL based practices and achieved significant analytical progress.

This section articulates the DR study based on the accessibility of FunImgs data. A fundus camera is utilized to acquire two-dimensional digital RIs. The highly accessible early-stage DR recognition works make use of databases, including images obtained by dilating the pupil. While many RI datasets such as Kaggle DR [38] [39], MESSIDOR [35] [36], STARE [30], DeepDR [41], HRF [37], ODIR [40], UoA-DR [42], DRIVE [31], and so on are openly accessible for the persistence of DR research studies, MAs are generally the initial visible sign of DR; their recognition can decrease beyond difficulties and loss of vision. The present manual assessment is hard to scale and a time-consuming process for a large patient population. Efficient automated detection and segmentation (ADS) of MA will be able to decrease the liability of ophthalmologists to a certain level by computerizing the assessment activity and assisting in the early stages of DR diagnosis. The research society for ADS in MA has developed numerous methodologies for early DR diagnosis [29]. In order to evaluate deep learning models and further investigate the clinical applications, particularly for lesion recognition, the author T. Li et al. [43] developed a new dataset called DDR. Using the ideas of mathematical morphology, the authors B. Lay et al. [44] devised a computerized method for the detection of microaneurysms (MA) in fluorescein angiograms.

The authors, Wejdan L. et al. [45], proposed an analysis of the detection of DR using DL practices. It has reviewed various detection and classification techniques using DL techniques, which analyze DR stages based on color fundus retina images. Author S. Mishra et al. [46] proposed DR recognition using DL. It integrated artificial intelligence (AI) techniques and used DenseNet to train the model on a massive dataset consisting of 3662 images to instinctively distinguish the DR stage, which has been categorized as having superior FunImgs resolution. It integrated APTOS data derived from Kaggle with

DR's five stages, categorized into 1 to 4 numbers. By using patients' fundus eye images as input, DenseNet's FE process produced results through activation function, achieved 0.9611 ACU, and described the distinction between the VGG16 and DenseNet121 designs. The authors, Ayala et al. [47], proposed DR-improved detection using DL. It integrated CNN to perform a fundus oculi image to identify the structure of the eyeball and establish the occurrence of DR. The factors improved using the TL approach for mapping an image with the subsequent labeling structure. Training, testing are accomplished with a medical fundus oculi image dataset, and a pathology seriousness scale appears in the eyeball as labels and attains 97.78% of ACU.

Author M. Mohsin Butt et al. [48] proposed a multi-channel CNN-based approach for the detection of DR from eye fundus images. It integrated 35,126 images from EyePACS and achieved 97.08% ACU. The authors, Fatima, Muhammad Imran, et al. [49], proposed a unified method for entropy improvement-based DR recognition using a hybrid NN. It devised manipulating the discrete wavelet transforms to enhance the visibility of medical imaging by making the delicate features more prominent, and it classified images for further stages. It integrated three datasets, such as those from the Asia Pacific Tele Ophthalmology Society (APTOS), Ultra-Wide Field (UWF), and MESSIDOR-2. The authors, Yuhao Niu, Lin Gu, et al. [50], intended explicable DR recognition through RIs. It has proven a direct relationship between the lesions and isolated neuron activation for pathological justification. Initially, it described new pathological signifiers using triggered neurons of the DR detector to determine both lesions appearance and spatial data, then visualized the DR indication encoded in the descriptor through Patho-GAN, which was used to produce medically possible RIs. The author, Abdel Maksoud E. et al. [51], proposed the E-DenseNet computer-aided diagnosis system for detecting various diabetic retinopathy grades based on a hybrid DL technique. E-DenseNet integrated DenseNet and EyeNet versions based on TL. It modified conventional EyeNet by incorporating blocks of dense and improving the resultant hyperparameters of blended E-DensNet versions. The author, Sikder, N. et al. [52], proposed classification of DR severity with integration of collaborative learning algorithmic sequences through examining RIs. It included various additional IP practices and steps of FE and feature selection and attained 94.20% classification accuracy with 0.32% boundary error and a 93.51% F-measure with 0.5% boundary error.

The authors, Nikos Tsiknakis, Dimitris, et al. [53], proposed DL integrated recognition and classification for DR based on FunImgs. It included a description of all DR recognition stages, such as DR grading, complexity levels. The author, M. T. Al-Antary et al. [54], integrated features to enhance the interpretation, and after that, a pyramid of multi-scale features was incorporated to define the retinal structure in a distinct region. It has trained a model in the traditional sense using cross-entropy loss to categorize severity levels of DR through healthy and non-healthy RTs, and it has integrated EyePACS and APTOS datasets. The author, Veena Mayya et al. [55], proposed a study on automated MAs recognition for early diagnosis of DR with a description of various DR

diagnosis techniques with their advantages and limitations. The author, Shah P. et al. [56], proposed validation of deep CNN-based algorithmic sequences for recognition of DR-AI against the screening clinician process. The authors, Chetoui M. et al. [57], proposed reasonable end-to-end DL for DR recognition across multiple datasets. It included 90,000 images from nine open datasets, which were employed to evaluate the effectiveness of the planned procedure. The planned DL process tunes a pre-trained deep CNN for DR recognition. The author, Sebt, R. et al. [58], proposed a DL-based methodology for the recognition of DR. It presented an automated classification scenario from a certain set of RI to identify the DR. An automatic retinal image analysis (ARIA) method has been created by authors Shi, C. et al. [59] that combines transfer net ResNet50 deep network with the automatic features generation approach to automatically assess image quality and differentiate between eye abnormalities and artefacts that are associated with poor quality on color fundus retinal images. According to individual risk variables, authors Alfian, G. et al. [60] suggest using a deep neural network (DNN) in conjunction with recursive feature elimination (RFE) to offer an early diagnosis of diabetic retinopathy (DR). Color fundus photography, fluorescein angiography, B-scan ultrasonography, and optical coherence tomography are a few of the crucial imaging modalities that are utilized to diagnose diabetic retinopathy [61].

A multi-classification prototype has been generated through CNN algorithmic sequences with numerous parameters on a dataset of DR with several structures. The authors R K. Jha et al. [64] stated an analysis to assess various categorization algorithmic sequences for estimation of HD where several conventional processes like SVM, KNN, DT-DNN, NB, and RF [65–66] were utilized to be valid selection of features over the Rapid Minor (RM) instrument to train-learn employing the Cleveland dataset from the UCI repository environment [67–72]. The Diabetic Retinopathy Debrecen Data Set from the UCI machine learning repository was taken into account by the author Nagaraja Gundluru et al. [73] who then designed a deep learning model with principal component analysis (PCA) for dimensionality reduction and Harris hawks optimization algorithm to extract the most crucial features. To distinguish the stages of DR, the author Asia, A.-O et al. [74] use fundus photography and a deep learning tool called a convolutional neural network (CNN). The Xiangya No. 2 Hospital Ophthalmology (XHO), Changsha, China, provided the study's pictures dataset, which is very vast, sparse, and labeled in an uneven manner. A hybrid method for the detection and classification of diabetic retinopathy in fundus pictures of the eye is proposed by author Butt, M.M. [75]. On pre-trained Convolutional Neural Network (CNN) models, transfer learning (TL) is applied to extract features that are then combined to produce a hybrid feature vector. The literature on AI approaches to DR, such as ML and DL in classification and segmentation, that has been published in the open literature within six years (2016-2021), is covered by author Lakshminarayanan, V [76]. A thorough list of the accessible DR datasets is also presented. The PICO (Patient, I-Intervention, C-Control, O-Outcome) and Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) 2009 search methodologies were both used to create this list.

Many researchers have achieved significant progress in early DR diagnosis and detection, but various complexities and disparities still occur, emphasizing a significant possibility for the advancement of completely automated early DR diagnosis [29].

III. METHODOLOGY

The Deep Convolutional Neural Network (D-CNN) designs are extensively used in multi-labeling mapping and classification, which improves the analysis of the various DR grades such as normal, mild, moderate, severe, proliferative DR, and non-proliferative DR. DR degrees are articulated by seeming multiple DR lesions concurrently on the color retinal FunImgs. The various lesion types have numerous features that are difficult to segment and recognize by employing conventional methods. Consequently, the practical solution is to utilize an effective CNN model with a dual image ResNet mapping approach. Retinal diagnosis promotes early detection of DR stages, which helps with timely treatment.

To accelerate the screening process, this research uses the Automated Decision Making ResNet Feed-Forward Neural Network (RNFFNN) Methodology to detect early-to-late stages of DR. The majority of the uses for CNN's high-level features are in the detection and classification of retinal lesions. This research is mainly focused on developing the best RI interpretation, which further helps to enhance the implementation of DR detection simulations. To obtain the best possible interpretation, features obtained from various pre-trained ConvNet simulations were intermingled using the intended multi-modal blended module.

The final stage of descriptions is employed to train a D-CNN used for DR recognition and severity level prediction. Each ConvNet obtains unique features, blending them using 1D and cross pooling, which leads to improved interpretation compared to using features extracted from a single ConvNet. This research will adopt deep learning-based convolutional neural networks to achieve varying objectives. First, an exploratory research study is to be carried out to gain an in-depth understanding of AD. The second objective is the core objective of my research, in which we are going to propose a new framework and apply this framework to the public dataset. The proposed methodology module for training the image with labeled deep understanding could satisfy unlabeled data because deep learning could satisfy supervised and unsupervised segmentation. Finally, to check the feasibility of the proposed framework, an empirical evaluation will be carried out. The classification and detection of DR stages are integrated using the dual image approach of integration and aggregation of color fundus images and black-and-white images. Both photos are analyzed separately and combined with the missing points of each image sequence of the color fundus and black-and-white images. This research has integrated more than ten thousand images from different age groups, such as 10 to 25 years, 26 to 35 years, 36 to 45 years, and above 56 years. Initially, all color fundus images are collected from the various age-group patients; we consider these to be the primary input images. In data collection, all gathered color fundus images are classified into two groups: sequential and non-sequential images.

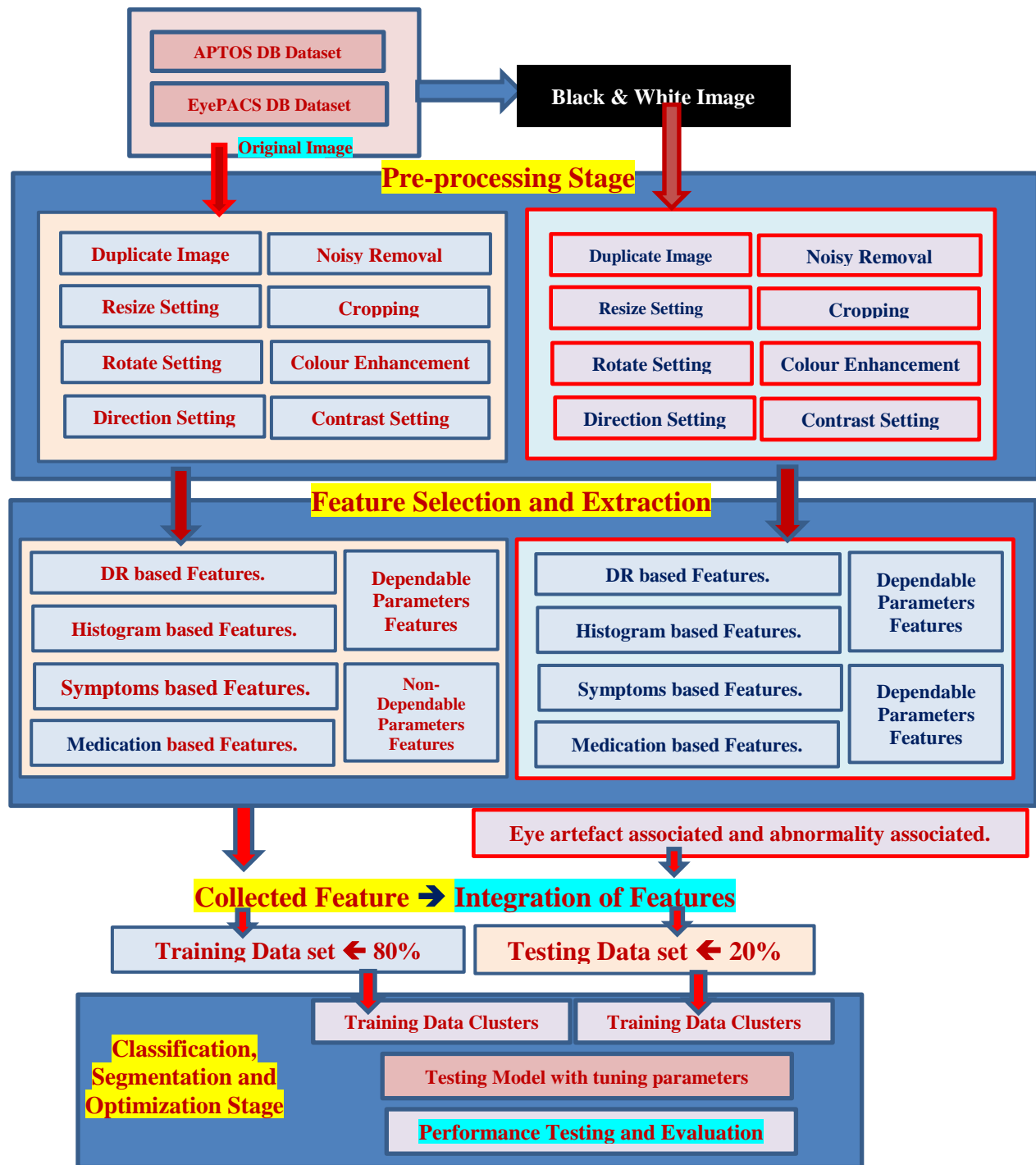


Fig. 2. Dual-image multi-layer mapping methodology for identification of DR early stages.

The sequential images are the images that have been picked from the same patient and age group. The various sequential images hold a slight variation in the color fundus and help the research generate the best outcomes and high predictions for the five stages of DR. The automated system feels complex when it tries to tune non-sequential images. The proposed methodology for training proficiency completely depends on balanced error-free data, so it's required to tune the data for training and testing purposes to process it further in the proposed deep learning-based CNN implicated dual-image

multi-layer mapping approach. The color fundus and black-and-white image-based data uniformly divide according to every DR stage, such as Non-DR, MiDR, MoDR, SeDR, and PrDR, which helps the model minimize any inequality during the training and progression of the proposed approach. All input color fundus and black-and-white images are equally sized, then processed in a systematic series way that is elected the combination images for analyzing the grading for further predictions as shown in Fig. 2. The classification task is mainly performed based on the deep learning Inception-Resnet model.

Furthermore, the classification task has initiated the cross-entropy loss function based on two variations: binary-class and multi-class classification.

IV. EXPERIMENTAL SETUP

The integration of dual-type sequential and non-sequential cluster images is required for auto-detection of DR stages. This research proposes an auto-fine-tuning system for the recognition of DR stages using a dual-image ResNet mapping approach. The sequential and non-sequential images were processed parallelly in the pre-processing and classification stages. The mapping techniques integrated to analyze and map missing connections of retinal arterioles, microaneurysms, venules and dot points of the fovea, cottonwool spots, the macula, the outer line of optic disc computations, and hard exudates and hemorrhages among color and back white images. Missing computations are included in the sequence of vectors, which helps identify DR stages. A total of 5672 sequential and 7231 non-sequential color fundus and black-and-white retinal images were included in the test cases. The 80 and 20 percentage ratios of best and poor-quality images were integrated in testing and training and implicated the 10-fold cross-validation technique.

The proposed methodology's training ability is variable on reasonable error-free data, which is essential to tune the data for training-testing purposes and manage it for the advanced process in the anticipated deep learning-based CNN (DL-CNN) implicated dual-image multi-layer mapping approach. The color fundus and black-and-white image-based data uniformly divide according to every DR stage, such as Non-DR, MiDR, MoDR, SeDR, and PrDR, which helps the model eliminate any inequality during the progression of training and testing the proposed approach. All input color fundus and black-and-white images are equally sized, then processed and tuned in a systematic series way, which are elected as the combination images for analyzing the grading for further predictions. The Fig .3 representing the dual-image Structural design of custom-built DL-CNN based network stem segment with extracted features

A. Image Normalization Principal Component Analysis (PCA)

The Eq. (1) has integrated for normalizing the dataset features, X signifies the features of dataset, μ signifies mean value for separately feature $x(i)$ of dataset, and σ signifies subsequent standard deviation. This normalization method was executed using the scikit-learn based Standard Scaler (StdSca) [62] and employed Principal Component Analysis (PCA) for dimensionality decrease if in case of MNIST and Fashion-MNIST which has selected for representing features of image data. Which is achieved using the scikit-learn based PCA.

$$z = \frac{X - \mu}{\sigma} \quad (1)$$

It has implicated a feed-forward neural network (FFNN) and CNN, mutually come up with two different classification functions such as ReLU and SoftMax. DL solutions to classification difficulties typically utilize the SoftMax function

to perform classification task, which indicates a discrete probability distribution (DPD) for K classes, expressed as

$$\sum_{k=1}^K P_k \quad (2)$$

If it takes x as the activation at the penultimate layer of a neural network, and θ as its weight parameters at the SoftMax layer, it has 'o' as the input to the SoftMax layer,

$$o = \sum_i^{n-1} \theta_i x_i \quad (3)$$

Subsequently, y^{\wedge} is expected class.

$$P_k = \frac{\exp(O_k)}{\sum_{k=0}^{n-1} \exp(O_k)} \quad (4)$$

$$y^{\wedge} = \max \arg \max_{i \in \{1, \dots, N\}} p_i \quad (5)$$

ReLU is an activation function presented by, which has strong biological and mathematical Underpinning [63].

$$y^{\wedge} = \operatorname{argmax}_i; i \in \{1, \dots, N\}; \max(0, o) \quad (6)$$

$$l(\theta) = - \sum y \cdot \log(\max(0, \theta x + b)) \quad (7)$$

Let the input x be replaced the penultimate activation output h ,

$$\frac{\partial l(\theta)}{\partial h} = \frac{\theta \cdot y}{\max(0, \theta h + b) \cdot \ln 10} \quad (8)$$

The backpropagation algorithm as shown in the eq. 8. is the same as the conventional SoftMax-based deep neural network.

$$\frac{\partial l(\theta)}{\partial \theta} = \sum_i \left[\frac{\partial l(\theta)}{\partial p_i} \left(\sum_k \frac{\partial p_i}{\partial O_k} \frac{\partial O_k}{\partial \theta} \right) \right] \quad (9)$$

B. Multi-level ConvNets based Pooling and Feature Integrations

This research has integrated two distinct pooling-based methods such as cross pooling (CxPool) and 1D pooling (1DPool) to merge multi-level feature extraction from VGG32 through fc1 and fc2 with integration of Xception net environment. The CxPool has implicated with two distinct feature vectors (FV) of A and B are adopted as input and a further FV C is produced, where A, B, C $\in \mathbb{R}^d$. Every feature element c_i , of the output vector C, is processed employing through the Eq. (10) to Eq. (13).

$$c_i = \max(a_i, b_i) \forall i \in \{1, 2, \dots, d\} \quad (10)$$

$$c_i = \min(a_i, b_i) \forall i \in \{1, 2, \dots, d\} \quad (11)$$

$$c_i = \text{mean}(a_i, b_{i+1}) \forall i \in \{1, 2, \dots, d\} \quad (12)$$

$$c_i = a_i + b_{i+1} \forall i \in \{1, 2, \dots, d\} \quad (13)$$

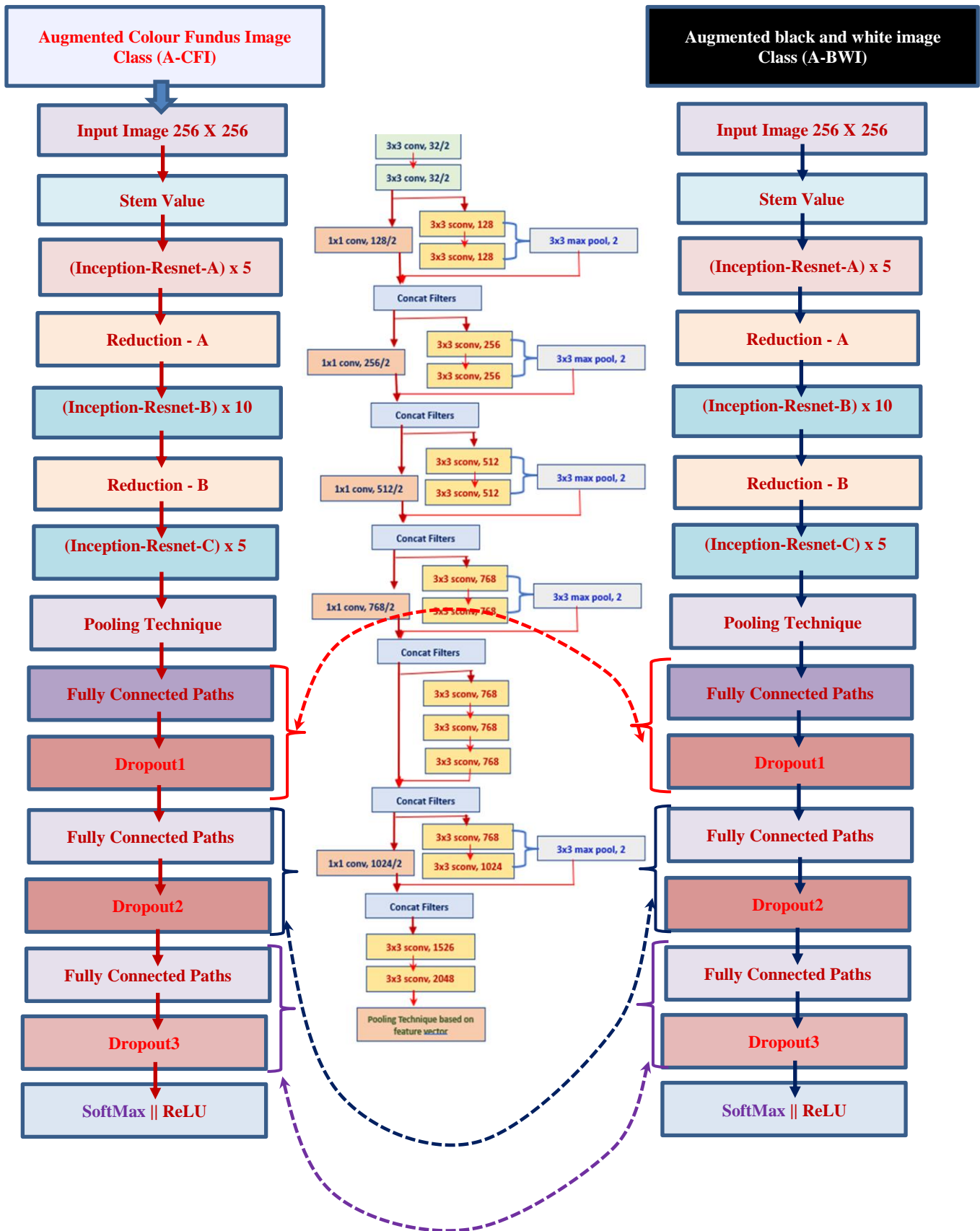


Fig. 3. The Structural design of custom-built DL-CNN based network stem segment with extracted features.

The 1D Pool is employed to choose leading regional features from every VGG32 region, where the Cr-Pool permits accumulating the leading features achieved by 1D Pool with global interpretation of Xception net environment. The 1D Pool based synthesis brings one FV 'K' as an input and which generates a further FV of K^{\wedge} , where K belongs to $Rd1$, K^{\wedge} belongs to $Rd2$ with the executional condition of $d2 \leq d1$. K^{\wedge} is a decreased interpretation of K, where $K = \{k1, k2, \dots, kd1\}$ and $K^{\wedge} = \{k^{\wedge}1, k^{\wedge}2, \dots, k^{\wedge}d1\}$. In this environment, every feature element $k^{\wedge}i$, of the output vector K^{\wedge} , is calculated employing through the Eq. (14) to Eq. (17).

$$k^{\wedge}i = \max(ki*2, ki*2+1) \forall i \in \{1, 2, \dots, d2\} \quad (14)$$

$$k^{\wedge}i = \min(ki*2, ki*2+1) \forall i \in \{1, 2, \dots, d2\} \quad (15)$$

$$k^{\wedge}i = \text{mean}(ki*2, ki*2+1) \forall i \in \{1, 2, \dots, d2\} \quad (16)$$

$$k^{\wedge}i = ki*2 + ki*2+1 \quad \forall i \in \{1, 2, \dots, d2\} \quad (17)$$

The 1D Pool has been employed individually on extracted features of VGG32 based fc1 and fc2 layers. After that, the CxPool method has been employed on the subsequent pooled features, which FV has unified with the extracted features from the Xception, which are generated from the two individual sets of input image classes, such as the Augmented Color Fundus Image Class and the Augmented Black and White Image Class sets, using CrPool, as shown in Fig. 3 and 4. As the final FV is a unified form of the global and local interpretations of the RIs, it offers robust hyper features.

V. RESULTS AND DISCUSSION

The multi-decision Inception-ResNet blended hybrid model has integrated with multi-layers of dual image-based parameters that process sequential and non-sequential images. The proposed model has been trained with a multi-layered transfer learning mechanism that has been tuned with 172 weighted multi-layers, of which 86 weighted layers are connected with color fundus images and 86 more weighted layers are connected with black-and-white images. The images are graded manually on a scale of 0 to 4 (0, normal DR; 1, mild; 2, moderate; 3, severe; and 4, proliferative DR) to indicate different severity levels, and the grading process has been extended to binary bit form, such as:

Dual Labeling Mechanism (P, Q) \leftrightarrow (~P, ~Q).

where $Q1 = \{q1 / q1 \in \{000, 001, 010, 011, 100\}\}$ and $Q2 = \{q2 / q2 \in \{00, 01, 10, 11\}\}$.

Q1 representing primary case of labeling and Q2 representing secondary case of labeling based on positive (1), true-positive (11), true-negative (10), false-positive (01), false-negative (00).

Grade-0: Normal \leftarrow 000.00.

Grade-1: Mild DR \leftarrow 001 Various levels \rightarrow {001.01, 001.10, 001.11}.

Grade-2: Moderate DR \leftarrow 010 Various levels \rightarrow {010.01, 001.10, 001.11}.

Grade-3: Severe DR \leftarrow 011 Various levels \rightarrow {011.01, 001.10, 001.11}.

Grade-4: Proliferate DR \leftarrow 100 Various levels \rightarrow {100.01, 001.10, 001.11}.

The DL-CNN based Layered Integration with training and testing scenario with grading process has shown in the Fig. 4 which are integrated for detection of DR stages. The data has collected for training and testing purpose which are clustered according to the DR stage and according to the DR symptoms through binary bit formation which is shown in the Table I.

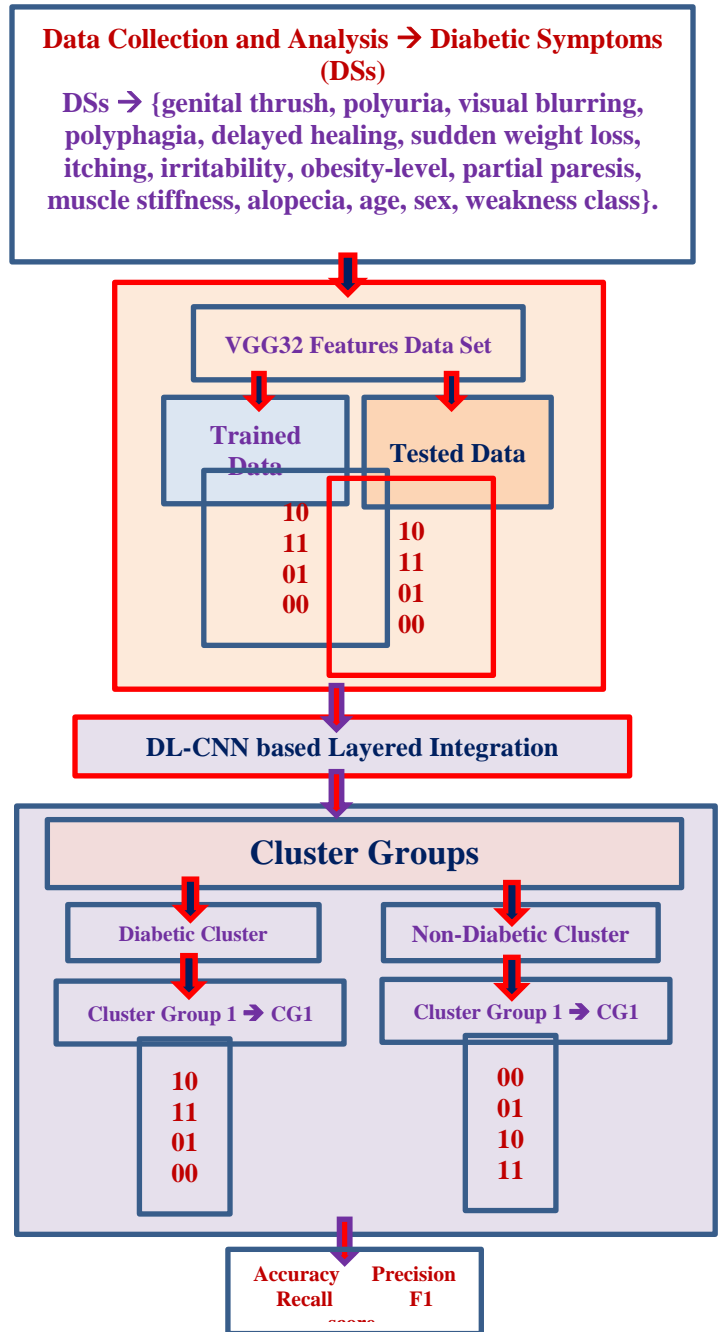


Fig. 4. DL-CNN based Layered Integration with training and testing scenario for detection of DR stages.

TABLE I. INTEGRATED SET OF IMAGES AND DR GRADING CLASS

DR Stages / Grade	Impact	Base binary class	Supporting sub-class	Sampling	Sequential and Non-sequential Images	Single / Dual Image Processing
Grade-0	Normal	000	000.00	2150	Sequential	Dual Image
Grade-1	Mild DR	001	{001.01, 001.10, 001.11}	526	both	Dual Image
Grade-2	Moderate DR	010	{010.01, 001.10, 001.11}	1325	both	Dual Image
Grade-3	Severe DR	011	{011.01, 001.10, 001.11}	372	both	Dual Image
Grade-4	Proliferate DR	100	{100.01, 001.10, 001.11}	158	both	Dual Image

TABLE II. PARAMETERS TURNING AND INTEGRATION FOR CLASSIFICATION-BASED DECISION MAKING, AND TEST-CASE CONDITIONS BASED ON STOCHASTIC GRADIENT DESCENT OPTIMIZATION (SGD) ← PARAMETERS TURNING AND INTEGRATION

Test conditions	Epochs Value	Image Learning Rate (imlr)	Momentum1
Test condition 1 (TC1)	epochs>70 then	0.0001	0.4
Test condition 2 (TC2)	epochs>140 then	0.0002	0.5
Test condition 3 (TC3)	epochs>210 then	0.0003	0.6
Test condition 4 TC4	epochs>280 then	0.0004	0.7
Test condition 5 (TC5)	epochs>350 then	0.0005	0.8

The Table II is representing the dual-image-based multi-layer mapping approach based on classification and regression → used at the end to classify the five stages of DR based on the features extracted from a series of networks. Each stage consists of the following data. The Table III representing the A dual-image-based multi-layer mapping approach based on classification and regression which used at the end to classify the five stages of DR based on the features extracted from a series of networks for further decision making (dm).

Every dual image based multi-layer mapping approach.

$imlr1 = 0.001$, $momentum1 = 0.4$.

$imlr2 = 0.005$, $momentum2 = 0.8$.

$cim1$ ← first moment of color image based exponential decomposition rate in AOpt.

$cim2$ ← second moment of color image based exponential decomposition rate in AOpt.

$bwim1$ ← first moment of black-white image-based exponential decomposition rate in AOpt.

$bwim2$ ← second moment of black-white image-based exponential decomposition rate in AOpt.

$cim1 = 0.7$, $cim2 = 0.890$.

$bwim1 = 0.7$, $bwim2 = 0.890$.

The experimental scenarios are framed based on the Kaggle APTOS dataset, which has shown that the proposed trained modelized approach represents a greater contribution to the active methodologies through blended features. The proposed methodology has been compared with the existing approaches based on integrated DR symptoms, their affecting factors, data metrics, and dual image processing techniques. This research has experimented with dual images, which has helped to analyze the images in depth for detection of DR stages and has helped to identify and map the missing patches with color fundus images and black-and-white images.

TABLE III. A DUAL-IMAGE-BASED MULTI-LAYER MAPPING APPROACH BASED ON CLASSIFICATION AND REGRESSION WHICH IS USED AT THE END TO CLASSIFY THE FIVE STAGES OF DR BASED ON THE FEATURES EXTRACTED FROM A SERIES OF NETWORKS FOR FURTHER DECISION MAKING (DM)

Test Condition stage1	Test Condition stage2	Each epoch range	tiny cluster	cim1	cim2	bwim1	bwim2
initialized Adaptive Moment Estimation → bhm	Adaptive Moment Estimation (Adam) ← Parameters turning and integration.	1 to 70	for each tiny-cluster1 → $(P_{mini}, Q_{mini}) \in (P, Q)$	0.7	0.890	0.4	0.5
initialized Adaptive Moment Estimation → bhm then.	Adaptive Moment Estimation (Adam) ← Parameters turning and integration.	71 to 90	for each tiny-cluster2 $(P_{mini}, Q_{mini}) \in (P, Q)$	0.7	0.890	0.5	0.6
Adaptive Moment Estimation →	Update the multitasking parameters	above 90	If validation error is not improving for four epochs, then $imlr1 = avg((imlr1 * 0.01) + ((imlr2 * 0.01)))$ $imlr2 = avg((imlr1 * 0.01) + ((imlr2 * 0.01)))$	0.7	0.890	0.7	0.8

VI. CONCLUSION

A trained clinician or ophthalmologist must analyze and estimate digital color fundus photographs of the retina to identify DR based on the presence of lesions associated with the vascular malformations brought on by the disease. This labour-intensive and manual process takes time. This study suggested ResNet feed-forward neural network technology for automated decision-making. In the pre-processing and classification steps, the sequential and non-sequential pictures were analyzed concurrently. The mapping approaches combined to evaluate and map the hard exudates and hemorrhages, microaneurysms, venules and dot points of the fovea, cottonwool spots, the macula, the outside line of computations of the optic disc, and retinal arterioles between color and black-white pictures. Missing computations are incorporated into the vector sequence, which makes it easier to recognize DR phases. The test cases comprised a total of 5672 sequential and 7231 non-sequential color fundus and black and white retinal pictures. The 10-fold cross-validation technique was used in testing and training using the 80 and 20% ratios of high- and low-quality photos. For testing and analyzing high-quality photographs, the ACU, sensitivity, and specificity were 98.9%, 98.7%, and 98.3%, respectively; for low-quality images, they were 94.9%, 93.6%, and 93.2%.

AUTHORS' CONTRIBUTION

Conceptualization: A., AK, and Henge. S.K.; Methodology: Henge. S.K., and Bhagat., A.; Software: A., AK, and Henge. S.K.; Validation: A., AK, and Henge. S.K., Mandal. S.K.; Formal analysis: Henge. S.K. and Bhagat., A.; Investigation: Bhagat., A, and A., AK; Resources: A., AK and Henge. S.K.; Data curation: A., AK, Mandal. S.K. and Henge. S.K.; Writing—original draft preparation, A., AK, Bhagat., A and Henge. S.K.; Writing—review and editing: A., AK, and Henge. S.K.; Visualization: Bhagat., A, and A., AK; Supervision: Henge. S.K.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

- [1] Anumol Sajjan, Anamika K, Simy Mary Kurian, Diabetic Retinopathy Detection using Deep Learning, International Journal of Engineering Research & Technology, Special Issue – 2022, Volume 10, Issue 04, pp. 154-159.
- [2] Mushtaq and Farheen Siddiqui 2021, Detection of diabetic retinopathy using deep learning methodology IOP Conf. Ser.: Mater. Sci. Eng. 1070 012049, pp. 1-13. DOI 10.1088/1757-899X/1070/1/012049.
- [3] S. K. Pandey and V. Sharma, "World diabetes day 2018: Battling the Emerging Epidemic of Diabetic Retinopathy," Indian J Ophthalmol.
- [4] https://www.health.harvard.edu/a_to_z/retinopathy-a-to-z.
- [5] <https://missinglink.ai/guides/convolutional-neural-networks/convolutional-neural-networks-architecture-forging-pathways-future/>.
- [6] G. T. Zago, R. V. Andreão, B. Dorizzi, and E. O. Teatini Salles, "Diabetic retinopathy detection using red lesion localization and convolutional neural networks," Comput. Biol. Med., vol. 116, p. 103537, 2020, doi: 10.1016/j.compbiomed.2019.103537.
- [7] Wilkinson, C. et al. Proposed international clinical diabetic retinopathy and diabetic macular edema disease severity scales. *Ophthalmology* 110, 1677–1682 (2003).
- [8] Dai, L., Wu, L., Li, H. et al. A deep learning system for detecting diabetic retinopathy across the disease spectrum. *Nat Commun* 12, 3242 (2021). <https://doi.org/10.1038/s41467-021-23458-5>.
- [9] Group ETDRSR. Treatment techniques and clinical guidelines for photocoagulation of diabetic macular edema: Early Treatment Diabetic Retinopathy Study report number 2. *Ophthalmology* 94, 761–774 (1987).
- [10] Fundus disease Group in Ophthalmology Branch of Chinese Medical Association. Guidelines of retinal image acquisition and reading for diabetic retinopathy screening in China. *Chin. J. Ophthalmol.* 53, 890–896 (2017).
- [11] Shen, Y. et al. Domain-invariant interpretable fundus image quality assessment. *Med. Image Anal.* 61, 101654 (2020).
- [12] 16M. Voets, K. Møllersen, and L. A. Bongo, "Reproduction study using public data of: Development and validation of a deep learning algorithm for detection of diabetic retinopathy in retinal fundus photographs," *PLoS One*, vol. 14, no. 6, pp. 1–11, 2019, doi: 10.1371/journal.pone.0217541.
- [13] S. R. Sada et al., "Quantitative assessment of the severity of diabetic retinopathy," *Am. J. Ophthalmol.*, 2020, doi: 10.1016/j.ajo.2020.05.021.
- [14] S. Preetha, N. Chandan, K. Darshan N, and B. Gowrav P, "Diabetes Disease Prediction Using Machine Learning," *Int. J. Recent trends Eng. Res.*, vol. 6, no. 5, 2020, doi: 10.23883/IJRTER.2020.6029.65Q5H.
- [15] He, K., Zhang, X., Ren, S. & Sun, J. Deep residual learning for image recognition. In Proc. IEEE Conference on Computer Vision and Pattern Recognition 770–778 (IEEE, 2016).
- [16] Lin T.-Y. et al. Feature pyramid networks for object detection. In Proc. IEEE Conference on Computer Vision and Pattern Recognition 2117–2125 (IEEE, 2017).
- [17] P. Kaur, S. Chatterjee, and D. Singh, "Neural network technique for diabetic retinopathy detection," *Int. J. Eng. Adv. Technol.*, vol. 8, no. 6, pp. 440–445, 2019, doi: 10.35940/ijeat.E7835.088619.
- [18] Y. Kumaran and C. M. Patil, "A brief review of the detection of diabetic retinopathy in human eyes using pre-processing & segmentation techniques," *International Journal of Recent Technology and Engineering*, vol. 7, no. 4. pp. 310–320, 2018.
- [19] Keech, A. C. et al. Effect of fenofibrate on the need for laser treatment for diabetic retinopathy (FIELD study): a randomised controlled trial. *Lancet* 370, 1687–1697 (2007).
- [20] Ying, G.-s. et al. Association between antiplatelet or anticoagulant drugs and retinal or subretinal hemorrhage in the comparison of age-related macular degeneration treatments trials. *Ophthalmology* 123, 352–360 (2016).
- [21] Ribeiro, M. L., Nunes, S. G. & Cunha-Vaz, J. G. Microaneurysm turnover at the macula predicts risk of development of clinically significant macular edema in persons with mild nonproliferative diabetic retinopathy. *Diabetes Care* 36, 1254–1259 (2013).
- [22] Hove, M. N., Kristensen, J. K., Lauritzen, T. & Bek, T. Quantitative analysis of retinopathy in type 2 diabetes: identification of prognostic parameters for developing visual loss secondary to diabetic maculopathy. *Acta Ophthalmol. Scand.* 82, 679–685 (2004).
- [23] Klein, R., Klein, B. E. & Moss, S. E. How many steps of progression of diabetic retinopathy are meaningful? The Wisconsin Epidemiologic Study of Diabetic Retinopathy. *Arch. Ophthalmol.* 119, 547–553 (2001).
- [24] J. I. Orlando, E. Prokofyeva, M. del Fresno, and M. B. Blaschko, "An ensemble deep learning based approach for red lesion detection in fundus images," *Comput. Methods Programs Biomed.*, vol. 153, pp. 115–127, 2018, doi: 10.1016/j.cmpb.2017.10.017.
- [25] I. Sadek, M. Elawady, and A. E. R. Shabayek, "Automatic Classification of Bright Retinal Lesions via Deep Network Features," pp. 1–20, 2017.
- [26] Gülçehre, Ç. & Bengio, Y. Knowledge matters: importance of prior information for optimization. *J. Mach. Learn. Res.* 17, 226–257 (2016).
- [27] K. A. Anant, T. Ghorpade, and V. Jethani, "Diabetic retinopathy detection through image mining for type 2 diabetes," in 2017

- International Conference on Computer Communication and Informatics, ICCCI 2017, 2017, doi: 10.1109/ICCCI.2017.8117738.
- [28] J. Amin, M. Sharif, and M. Yasmin, "A Review on Recent Developments for Detection of Diabetic Retinopathy," *Scientifica*, vol. 2016. 2016, doi: 10.1155/2016/6838976.
- [29] Veena Mayya, Sowmya Kamath S., Uma Kulkarni, Automated microaneurysms detection for early diagnosis of diabetic retinopathy: A Comprehensive review, *Computer Methods and Programs in Biomedicine Update*, Volume 1, 2021, 100013, <https://doi.org/10.1016/j.cmpbup.2021.100013>.
- [30] A.D. Hoover, V. Kouznetsova, M. Goldbaum, Locating blood vessels in retinal images by piecewise threshold probing of a matched filter response, *IEEE Trans. Med. Imaging* 19 (3) (2000) 203–210, doi: 10.1109/42.845178.
- [31] J. Staal, M.D. Abramoff, M. Niemeijer, M.A. Viergever, B. van Ginneken, Ridge-based vessel segmentation in color images of the retina, *IEEE Trans. Med. Imaging* 23 (4) (2004) 501–509. [20] M.D. Abramoff, J.C. Folk, D.P. Han, et al., Automated analysis of retinal images for detection of referable diabetic retinopathy, *JAMA Ophthalmol.* 131 (3) (2013) 351–357.
- [32] J. De Calleja, L. Tecuapetla, and M. A. Medina, "LBP and Machine Learning for Diabetic Retinopathy Detection," pp. 110–117, 2014.
- [33] M. Gandhi and R. Dhanasekaran, "Diagnosis of diabetic retinopathy using morphological process and SVM classifier," *Int. Conf. Commun. Signal Process. ICCSP 2013 - Proc.*, pp. 873–877, 2013, doi: 10.1109/iccsp.2013.6577181.
- [34] U. R. Acharya, C. M. Lim, E. Y. K. Ng, C. Chee, and T. Tamura, "Computer-based detection of diabetes retinopathy stages using digital fundus images," *Proc. Inst. Mech. Eng. Part H J. Eng. Med.*, vol. 223, no. 5, pp. 545–553, 2009, doi: 10.1243/09544119JEIM486.
- [35] M.D. Abramoff, J.C. Folk, D.P. Han, et al., Automated analysis of retinal images for detection of referable diabetic retinopathy, *JAMA Ophthalmol.* 131 (3) (2013) 351–357.
- [36] E. Decencière, X. Zhang, G. Cazuguel, et al., Feedback on a publicly distributed database: the messidor database, *Image Anal. Stereol.* 33 (3) (2014) 231–234.
- [37] A. Budai, R. Bock, A. Maier, J. Hornegger, G. Michelson, Robust vessel segmentation in fundus images, *Int. J. Biomed. Imaging* 2013 (2013) 154860, doi: 10.1155/2013/154860.
- [38] Kaggle Diabetic Retinopathy Detection Training Dataset (DRD), 2013, (<https://www.kaggle.com/c/diabetic-retinopathy-detection>). Online; accessed 5 January 2023.
- [39] APTOS 2019 Blindness Detection, 2019, (<https://www.kaggle.com/c/aptos2019-blindness-detection>). Online; accessed 5 January 2023.
- [40] Ocular Disease Intelligent Recognition (ODIR-2019), 2013, (<https://odir2019.grand-challenge.org/introduction/>). Online; accessed 5 January 2023.
- [41] DeepDR Diabetic Retinopathy Image Dataset (DeepDRiD), 2013, (<https://isbi.deepdr.org/data.html>). Online; accessed 5 January 2023.
- [42] W. Abdulla, R.J. Chalakkal, University of Auckland Diabetic Retinopathy (UoA-DR) Database, 2018, 10.17608/k6.auckland.5985208.v5.
- [43] T. Li, Y. Gao, K. Wang, S. Guo, H. Liu, H. Kang, Diagnostic assessment of deep learning algorithms for diabetic retinopathy screening, *Inf. Sci. (Ny)* 501 (2019) 511–522.
- [44] B. Lay, C. Baudoin, J.-C. Klein, Automatic detection of microaneurysms in retinopathy fluoro-angiogram, in: *Proceedings of SPIE - The International Society for Optical Engineering*, vol. 432, 1983, pp. 165–173.
- [45] Wejdan L. Alyoubi, Wafaa M. Shalash, Maysoun F. Abulkhair, Diabetic retinopathy detection through deep learning techniques: A review, *Informatics in Medicine Unlocked*, Volume 20, 2020, 100377, ISSN 2352-9148, <https://doi.org/10.1016/j.imu.2020.100377>.
- [46] S. Mishra, S. Hanchate and Z. Saquib, "Diabetic Retinopathy Detection using Deep Learning," 2020 International Conference on Smart Technologies in Computing, Electrical and Electronics (ICSTCEE), 2020, pp. 515-520, doi: 10.1109/ICSTCEE49637.2020.9277506.
- [47] Ayala, Angel, Tomás Ortiz Figueroa, Bruno Fernandes, and Francisco Cruz. 2021. "Diabetic Retinopathy Improved Detection Using Deep Learning" *Applied Sciences* 11, no. 24: 11970. <https://doi.org/10.3390/app112411970>.
- [48] M. Mohsin Butt, Ghazanfar Latif, D.N.F. Awang Iskandar, Jaafar Alghazo, Adil H. Khan, Multi-channel Convolutions Neural Network Based Diabetic Retinopathy Detection from Fundus Images, *Procedia Computer Science*, Volume 163, 2019, Pages 283-291, ISSN 1877-0509, <https://doi.org/10.1016/j.procs.2019.12.110>.
- [49] Fatima, Muhammad Imran, Anayat Ullah, Muhammad Arif, Rida Noor, A unified technique for entropy enhancement based diabetic retinopathy detection using hybrid neural network, *Computers in Biology and Medicine*, Volume 145, 2022, 105424, ISSN 0010-4825, <https://doi.org/10.1016/j.combiomed.2022.105424>.
- [50] Yuhao Niu, Lin Gu, Yitian Zhao, Feng Lu, Explainable Diabetic Retinopathy Detection and Retinal Image Generation, *GENERIC COLORIZED JOURNAL*, VOL. XX, NO. XX, XXXX 2017, <https://doi.org/10.48550/arXiv.2107.00296>.
- [51] AbdelMaksoud E, Barakat S, Elmogy M. A computer-aided diagnosis system for detecting various diabetic retinopathy grades based on a hybrid deep learning technique. *Med Biol Eng Comput.* 2022 Jul;60(7):2015-2038. doi: 10.1007/s11517-022-02564-6. Epub 2022 May 11. PMID: 35545738; PMCID: PMC9225981.
- [52] Sikder, N.; Masud, M.; Bairagi, A.K.; Arif, A.S.M.; Nahid, A.-A.; Alhummyani, H.A. Severity Classification of Diabetic Retinopathy Using an Ensemble Learning Algorithm through Analyzing Retinal Images. *Symmetry* 2021, 13, 670. <https://doi.org/10.3390/sym13040670>.
- [53] Nikos Tsinakakis, Dimitris Theodoropoulos, Georgios Manikis, Emmanouil Ktistakis, Ourania Boutsora, Alexa Berto, Fabio Scarpa, Alberto Scarpa, Dimitrios I. Fotiadis, Kostas Marias, Deep learning for diabetic retinopathy detection and classification based on fundus images: A review, *Computers in Biology and Medicine*, Volume 135, 2021, 104599, ISSN 0010-4825, <https://doi.org/10.1016/j.combiomed.2021.104599>.
- [54] M. T. Al-Antary and Y. Arafa, "Multi-Scale Attention Network for Diabetic Retinopathy Classification," in *IEEE Access*, vol. 9, pp. 54190-54200, 2021, doi: 10.1109/ACCESS.2021.3070685.
- [55] Veena Mayya, Sowmya Kamath S., Uma Kulkarni, Automated microaneurysms detection for early diagnosis of diabetic retinopathy: A Comprehensive review, *Computer Methods and Programs in Biomedicine Update*, Volume 1, 2021, 100013, ISSN 2666-9900, <https://doi.org/10.1016/j.cmpbup.2021.100013>.
- [56] Shah P, Mishra DK, Shanmugam MP, Doshi B, Jayaraj H, Ramanjulu R. Validation of Deep Convolutional Neural Network-based algorithm for detection of diabetic retinopathy - Artificial intelligence versus clinician for screening. *Indian J Ophthalmol.* 2020 Feb;68(2):398-405. doi: 10.4103/ijo.IJO_966_19. PMID: 31957737; PMCID: PMC7003578.
- [57] Chetoui M, Akhloufi MA. Explainable end-to-end deep learning for diabetic retinopathy detection across multiple datasets. *J Med Imaging (Bellingham)*. 2020 Jul;7(4):044503. doi: 10.1117/1.JMI.7.4.044503. Epub 2020 Aug 28. PMID: 32904519; PMCID: PMC7456641.
- [58] Sebti, R., Zroug, S., Kahloul, L., Benharzallah, S. (2022). A Deep Learning Approach for the Diabetic Retinopathy Detection. In: Ben Ahmed, M., Boudhir, A.A., Karaş, İ.R., Jain, V., Mellouli, S. (eds) *Innovations in Smart Cities Applications Volume 5*. SCA 2021. Lecture Notes in Networks and Systems, vol 393. Springer, Cham. https://doi.org/10.1007/978-3-030-94191-8_37.
- [59] Shi, C., Lee, J., Wang, G. et al. Assessment of image quality on color fundus retinal images using the automatic retinal image analysis. *Sci Rep* 12, 10455 (2022). <https://doi.org/10.1038/s41598-022-13919-2>.
- [60] Alfian, G.; Syafrudin, M.; Fitriyani, N.L.; Anshari, M.; Stasa, P.; Svub, J.; Rhee, J. Deep Neural Network for Predicting Diabetic Retinopathy from Risk Factors. *Mathematics* 2020, 8, 1620. <https://doi.org/10.3390/math8091620>.
- [61] Salz DA, Witkin AJ. Imaging in diabetic retinopathy. *Middle East Afr J Ophthalmol.* 2015 Apr-Jun;22(2):145-50. doi: 10.4103/0974-9233.151887. PMID: 25949070; PMCID: PMC4411609.

- [62] F. Pedregosa, G. Varoquaux, A. Gramfort, V. Michel, B. Thirion, O. Grisel, M. Blondel, P. Prettenhofer, R. Weiss, V. Dubourg, J. Vanderplas, A. Passos, D. Cournapeau, M. Brucher, M. Perrot, and E. Duchesnay. 2011. Scikit-learn: Machine Learning in Python. *Journal of Machine Learning Research* 12 (2011), 825–2830.
- [63] Richard HR Hahnloser, Rahul Sarpeshkar, Misha A Mahowald, Rodney J Douglas, and H Sebastian Seung. 2000. Digital selection and analogue amplification coexist in a cortex-inspired silicon circuit. *Nature* 405, 6789 (2000), 947.
- [64] Jha, R.K., Henge, S.K. and Sharma, A., 2020. Optimal machine learning classifiers for prediction of heart disease. *Int. J. Control Autom*, 13(1), pp.31-37. Available: <http://serisc.org/journals/index.php/IJCA/article/view/6680>.
- [65] S. K. Henge and B. Rama, "Neural fuzzy closed loop hybrid system for classification, identification of mixed connective consonants and symbols with layered methodology," *2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, 2016, pp. 1-6, doi: 10.1109/ICPEICES.2016.7853708.
- [66] Bhupinder Singh, Dr Santosh Kumar Henge, Neural Fuzzy Inference Hybrid System with SVM for Identification of False Singling in Stock Market Prediction for Profit Estimation, *Intelligent Systems and Computing*, https://doi.org/10.1007/978-3-030-51156-2_27, July 2020.
- [67] Rahul Kumar Jha, Santosh Kumar Henge, Sanjeev Kumar Mandal, Amit Sharma, Supriya Sharma, Ashok Sharma, Afework Aemro Berhanu, "Neural Fuzzy Hybrid Rule-Based Inference System with Test Cases for Prediction of Heart Attack Probability", *Mathematical Problems in Engineering*, vol. 2022, Article ID 3414877, 18 pages, 2022. <https://doi.org/10.1155/2022/3414877>.
- [68] S. K. Henge and B. Rama, "Comparative study with analysis of OCR algorithms and invention analysis of character recognition approached methodologies," *2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, 2016, pp. 1-6, doi: 10.1109/ICPEICES.2016.7853643.
- [69] Jha, R.K., Henge, S.K., Sharma, A. (2022). Heart Disease Prediction and Hybrid GANN. In: Kahraman, C., Cebi, S., Cevik Onar, S., Oztaysi, B., Tolga, A.C., Sari, I.U. (eds) *Intelligent and Fuzzy Techniques for Emerging Conditions and Digital Transformation. INFUS 2021. Lecture Notes in Networks and Systems*, vol 308. Springer, Cham. https://doi.org/10.1007/978-3-030-85577-2_52.
- [70] Singh, B., Henge, S.K. (2021). Neural Fuzzy Inference Hybrid System with Support Vector Machine for Identification of False Singling in Stock Market Prediction for Profit Estimation. In: Kahraman, C., Cevik Onar, S., Oztaysi, B., Sari, I., Cebi, S., Tolga, A. (eds) *Intelligent and Fuzzy Techniques: Smart and Innovative Solutions. INFUS 2020. Advances in Intelligent Systems and Computing*, vol 1197. Springer, Cham. https://doi.org/10.1007/978-3-030-51156-2_27.
- [71] Henge, S.K., Rama, B. (2017). Five-Layered Neural Fuzzy Closed-Loop Hybrid Control System with Compound Bayesian Decision-Making Process for Classification Cum Identification of Mixed Connective Consonants and Numerals. In: Bhatia, S., Mishra, K., Tiwari, S., Singh, V. (eds) *Advances in Computer and Computational Sciences. Advances in Intelligent Systems and Computing*, vol 553. Springer, Singapore. https://doi.org/10.1007/978-981-10-3770-2_58.
- [72] Henge, S.K., Rama, B. (2018). OCR-Assessment of Proposed Methodology Implications and Invention Outcomes with Graphical Representation Algorithmic Flow. In: Saeed, K., Chaki, N., Pati, B., Bakshi, S., Mohapatra, D. (eds) *Progress in Advanced Computing and Intelligent Engineering. Advances in Intelligent Systems and Computing*, vol 563. Springer, Singapore. https://doi.org/10.1007/978-981-10-6872-0_6.
- [73] Nagaraja Gundluru, Dharmendra Singh Rajput, Kuruva Lakshmana, Rajesh Kaluri, Mohammad Shorfuzzaman, Mueen Uddin, Mohammad Arifin Rahman Khan, "Enhancement of Detection of Diabetic Retinopathy Using Harris Hawks Optimization with Deep Learning Model", *Computational Intelligence and Neuroscience*, vol. 2022, Article ID 8512469, 13 pages, 2022. <https://doi.org/10.1155/2022/8512469>.
- [74] Asia, A.-O.; Zhu, C.-Z.; Althubiti, S.A.; Al-Alimi, D.; Xiao, Y.-L.; Ouyang, P.-B.; Al-Qaness, M.A.A. Detection of Diabetic Retinopathy in Retinal Fundus Images Using CNN Classification Models. *Electronics* 2022, 11, 2740. <https://doi.org/10.3390/electronics11172740>.
- [75] Butt, M.M.; Iskandar, D.N.F.A.; Abdelhamid, S.E.; Latif, G.; Alghazo, R. Diabetic Retinopathy Detection from Fundus Images of the Eye Using Hybrid Deep Learning Features. *Diagnostics* 2022, 12, 1607. <https://doi.org/10.3390/diagnostics12071607>.
- [76] Lakshminarayanan, V.; Kheradfallah, H.; Sarkar, A.; Jothi Balaji, J. Automated Detection and Diagnosis of Diabetic Retinopathy: A Comprehensive Survey. *J. Imaging* 2021, 7, 165. <https://doi.org/10.3390/jimaging7090165>.

Proactive Acquisition using Bot on Discord

Niken Dwi Wahyu Cahyani¹, Daffa Syifa Pratama², Nurul Hidayah Ab Rahman³

Informatics Faculty, Telkom University, Bandung, Indonesia^{1,2}

Centre of Information Security Research-Faculty of Computer Science and Information Technology, Universiti Tun Hussein Onn Malaysia, Parit Raja, Malaysia³

Abstract—Data deletion increases challenges in cybercrime investigation. To address the problem, proactive forensics for evidentiary collection is acknowledged to help investigators to acquire the potentially needed digital evidence. This study proposes a bot machine to record data from the Discord server in advance, hashing and saving it in proper storage for further forensic analysis. The recording process can be managed to collect activities and their related data (intact, modified, deleted), including text, pictures, videos, and audio. The Discord bot is designed by utilizing the main features of the Discord Social Networks Application Programming Interface (API). This paper examines how this approach is applicable by embedding the bot in a Discord server. Observation showed that the bot records the real-time data as it is always alive on the server, including the deleted or modified messages and their timestamps. All the recorded data is saved locally on the server's storage in easy-to-read formats, CSV and JSON. The results showed that the bot could conduct the data acquisition for 37 concurrent users with a 2.3% error rate and 97.7% accuracy.

Keywords—Discord; bot; cybercrime; social networks API; digital evidence

I. INTRODUCTION

One of the challenges digital forensics investigators face is the inability of forensic tools to acquire deleted data [1]. The challenge makes investigative activities require more time and effort to find data remnants from other sources that can provide more evidence. In addition, from an information security perspective, there is a need to guarantee data deletion [2].

Proactive forensics supports investigators in collecting data before an incident occurs [3]. This approach will collect live data, thus enabling all data and changes that occur to the data to be collected [4]. For example, keystroke logging methods have been proposed to logically acquire keystrokes in cloud applications for forensic readiness [5]. The method shows how forensic activities can be assisted through data collection techniques initially considered malicious acts.

It is understood that many bots are known for their harmful impact. Even several guides for conducting bot crime investigations are available [6]–[8], and IoT-Botnet datasets have also been developed for network forensic analytics [9]. However, no known study in this area examines the benefits of bots for acquiring potential evidence data. This gap is identified by a previous study that stated some important future works in instant messaging forensic investigation, including users editing/deleting messages and Discord bots [10]. Therefore, this current research examines proactive forensics using bots by taking the example of the Discord application.

The Discord data is collected in advance to reduce the time and complexity of investigations to obtain more complete data. The proposed bot is tested for positive reasons and measured how far this acquisition method could help. Understanding its advantages and identifying its issues are essential to guide investigators' practice and academics in developing the proper bot system.

Discord enables users to indirectly publish substantial amounts of information, including voice calls, video calls, text messages, media, and file sharing. From cybercriminals' perspective, these features can be exploited to conduct cybercrimes. However, the offender could modify evidence of interest by deleting, editing, and clearing messages on the cache. The action is anti-forensics - data concealment by implementing data hiding and trail obfuscation techniques to remain anonymous or undetected [11], [12]. In addition to anti-forensic issues, it could lead to incomplete attributes of collected artifacts and affect the integrity of digital evidence [13].

Therefore, it is necessary to have an acquisition method that can acquire the attributes of digital evidence completely and does not affect its integrity. An example of the potential method is by using the Social Networks API. The API is used in the acquisition process by focusing on features that the Discord application API has fully provided, and it can be modified and adjusted according to acquisition needs [14]. These characteristics of the APIs can complement the lack of attributes from collecting digital evidence. In this study, a Discord Bot is developed based on the features of the Social Networks API's Discord to facilitate digital evidence acquisition. A test scenario of the Social Networks API based on Discord Bots was set up to simulate digital evidence collection from the Social Networks API method. Another key point is to improve the performance of the acquisition process and extract complete digital evidence.

The rest of this paper is organized as follows: Section II outlines the related work of proactive forensics, and Discord acquisition. Section III explains the bot design. Section IV presents the results and discussion. Section V contains the conclusion and suggestions for future work.

II. RELATED WORKS

Proactive forensics involves collecting data before or during the incident by promoting the automation of live investigation [3], [15]. Applying proactive forensics in incident response teams would equip the team to respond appropriately to an incident. At the same time, for investigators, advanced data collection would help speed up the investigation process

because the data is already available. This proactive approach is essential in digital investigation, especially in environments like social networks where editing and deleting messages are common for users to remove their unwanted traces; also, in critical systems such as Industrial Control Systems where real-time analysis may enable rapid triaging and response to attack [16], [17]. Meanwhile, the live data collection approach can be conducted by recording data from the running activities. For example, previous authors proposed a method of keystroke logging to acquire keystrokes in cloud applications for forensic readiness [5] and installing software on the target system to preserve deleted files that might interest forensic examiners [3].

Motivated by the best communication feature for gamers, Anderson ran a qualitative ethnography study to understand if Discord helps enforce the values and behaviors of the Harbormen gaming community [18]. This study revealed that the ease of use and the convenience of interacting with different communities on various servers are experienced by its users. With this positive experience, the gamer's community and other fields, such as education, utilize Discord. It was used as a platform for physical education learning during the COVID-19 pandemic in a high school [19]. Some higher education institutions have innovatively used Discord to deliver teaching listening as an e-learning tool in the sciences and humanities [20].

Instant messenger provides communication via text, voice, videos, and photos. However, there is an increasing trend of cyber criminals who use instant messaging applications to do malicious acts. The ease of their registration and usage attracts many users, including criminals. The vast amount of user data inside the apps becomes potential evidence in digital forensic investigations. As different apps manage their data differently, it is essential to conduct application-specific forensics.

A previous study analyzed the Google Chrome cache structure inherited from Discord [21]. The study showed it could successfully get Discord-related metadata through the cache on Discord apps for the PC version. Nevertheless, further work still needs to be conducted to cover evidence from Discord Web Applications and Discord Mobile Applications. Another study examined Discord desktop applications on Windows 10 from a forensic value and cybersecurity perspective [22]. Similarly, the study demonstrated that Discord metadata could be successfully acquired through the cache on Discord Applications. A recent study on Discord forensics based on data from the Google Chrome browser also recovered various artifacts [23]. However, while much important information can be acquired through cached data, an issue of its deletion may prevent the acquisition.

Research on Linux OS computers found Discord-specific data, including messages, usernames, and passwords [10]. Examination of the broader platform by including the Discord mobile app identified locations of artifacts, such as received/sent messages, shared files, chat rooms, and user account information [24]. Conducting forensic analysis on client-based devices can successfully acquire interesting data remnant, but the analysis should be done individually for each device.

As Discord provides services on instant messaging and VOIP, there has been a significant interest in examining the forensic analysis of other similar tools. A study conducted a forensic survey and analysis of Tango VoIP for iOS and Android platforms [25]. A research environment was set up for different mobile devices by installing WhatsApp, Skype, Viber, and Tango, and a list of target artifacts was defined. In addition to the forensic analysis, this study investigated how cloning IM sessions and intercepting communications can facilitate data acquisition. It was observed that encrypted data presents challenges to the acquisition process.

Research on WhatsApp discussed forensic approaches to creating real-time insights into WhatsApp communications [26]. This approach uses eavesdropping, decrypting WhatsApp databases, open-source information, and analyzing WhatsApp web communications. The research evaluated the method in various WhatsApp forensic scenarios to prove its feasibility and efficiency. It was found that various data, including profile pictures, user activities, location data, remote access to suspicious WhatsApp accounts, voice messages, shared contacts, documents, images, and videos, are accessible.

Tools are needed for application-specific forensics analysis to acquire and analyze the data. A study has presented a brief overview and a comparative analysis of various commercial and open-source mobile forensic tools [27]. The review used a cross-device and test-driven approach to predefined software parameters. Test scenarios addressed digital threats and assessed whether the tool has the expected functionality. The parameters used to compare are cost, MD5 hash mechanism, ease of use, and platform support.

To the extent of our review, existing studies on tools to support Discord forensic analysis depend on the data remnant of the apps, both on the client and server sides. There is no study on proactive evidence acquisition by recording all user activities at once using a bot. In this study, the usage of a bot installed on the Discord server is proposed to obtain all the exchanged messages, including text and multimedia data, for the intact and the deleted data.

A. Discord

Discord is a social networking app used by people (over 13) to discuss many topics, including games. It hosts communities of all sizes but is primarily used by small, active groups that interact regularly. It hosts communities of all sizes but is primarily used by small, active groups that interact regularly. Therefore, Discord comprises artifacts that contain vital information such as text, attachment files, and member lists in one event. Unlike other popular social network apps, no algorithm is involved in deciding what to watch, infinite scrolling, and no news feeds on Discord. Table I presents the commonly used Discord features by users.

B. Social Network API

Application Programming Interface (API or WEB API) is a module that enables interaction with application service resources. Examples of resources owned by application services are documents, images, and text messages [28]. Therefore, there is a potential to utilize Social Networks API to collect evidence artifacts from social network apps. Utilization

is possible because the generated resources comprise metadata that describes the corresponding data. Furthermore, Social Networks API allows us to adjust the code according to the acquisition needs.

TABLE I. DISCORD FEATURES

Function	Description
Text channels	Feature for users to send messages to each other
Voice channels	Feature for users to communicate with each other
Share screen	Feature for users to share videos live with other users
Sharing images	Feature for user sharing images
Text channels	Feature for users to send messages to each other
Upload files	Feature for users to share documents

The Discord API provides another user account dedicated to automation called a bot account. Anyone can create a bot account from the app page and authenticate with a token (i.e., without a username and password). Unlike the regular Open Authorization (OAuth2) API, a bot account has full access to all API routes and can connect to a real-time gateway without an authentication token.

III. RESEARCH METHOD

Discord provides various functions via API. The bot uses the official Web API Discord to acquire the data stored on the Discord cloud server.

A. API Usage

The flowchart in Fig. 1 presents the two steps of using Discord API. Firstly, Discord API records every message and returns the log or cache in the bot. Before the log or cache returns, Discord Bot will check any edited or deleted message/data. Secondly, Discord API is used to request features and give responses. After these two main usages of the API, the bot performs read or write disk operations to save the messages in CSV or JSON format.

B. Discord Bot Design

Discord bot is an application created by the user with the admin group role. For example, user A as the admin, creates a discord server, and user B join the discord server created by user A. After that, user B sent message on the text channel. The message from user B will record by the discord bot and reproduce the cache. Discord bot is designed to hook websites as a function to get message channel history which can list

return message attributes, including the deleted and edited messages. The Discord bot will save all record messages on private channel that can be seen by user A as the group admin. The use case of the designed Discord bot is presented in Fig. 2.

Before starting the Discord bot, the admin must create a guild and text chat channel. Next, the admin can create a bot, enter it into the created guild or channel, and share the guild. Users could then join the guild and interact with other users by sending messages, pictures, documents, videos, and audio. Subsequently, these activities are recorded, and their data will be acquired and saved in the Discord bot. This flow is presented in Fig. 3.

C. System Requirement

The bot is built using Python and utilizes the currently available Discord API. The details of our bot specification are presented in Table II.

To acquire Discord data from the server, the required functions are implemented on the bot to get the messages, data attachment, timestamp, and message id, calculate data hash value, and prepare the data saving on local storage. Table III lists these functions embedded in the Discord Bot.

D. Testing Scenarios

During the testing, 37 users accessed the Bot server simultaneously. The users simulated the common activities as follows:

- Sending:
 - text messages.
 - document files.
 - audio files.
 - video files.
 - picture files.
- Deleting the first sent text, document, audio, video, and picture files.

Comparison between the actual sent and deleted data and the successfully acquired data are examined to measure the bot's performance.

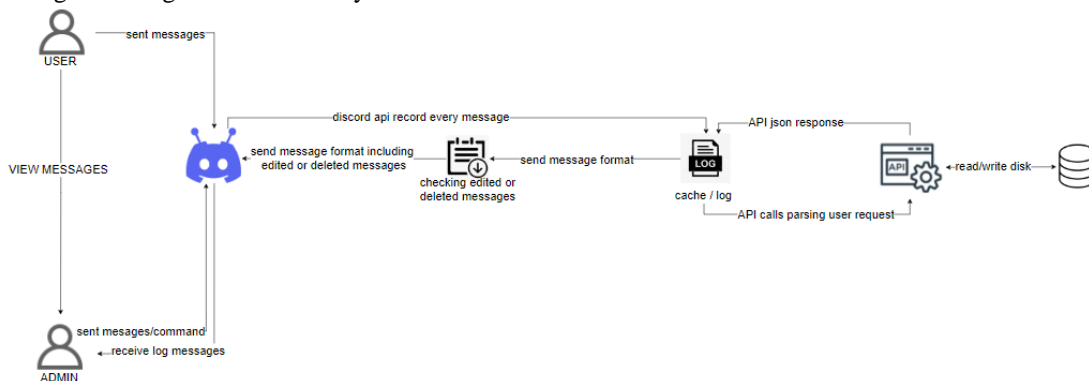


Fig. 1. The flow of API usage.

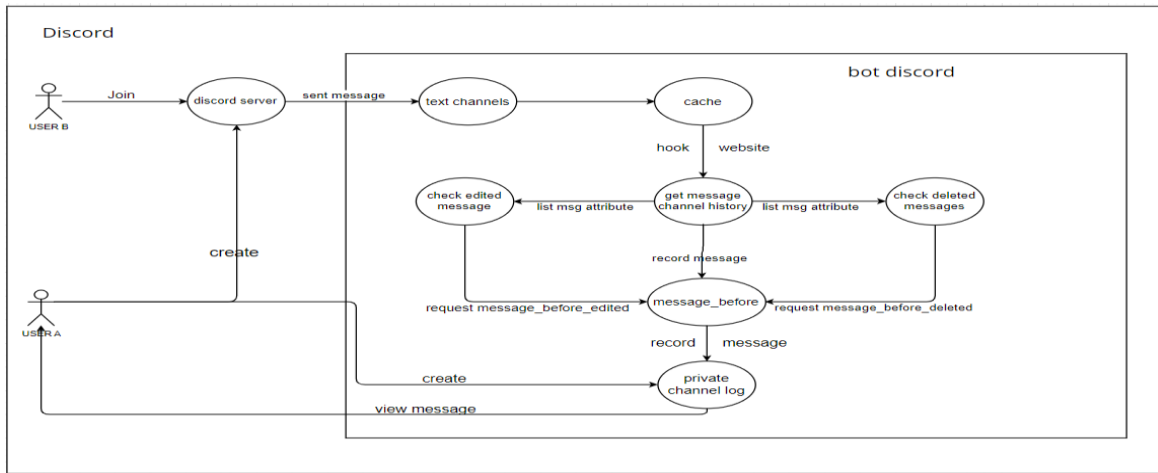


Fig. 2. The use case of the discord bot.

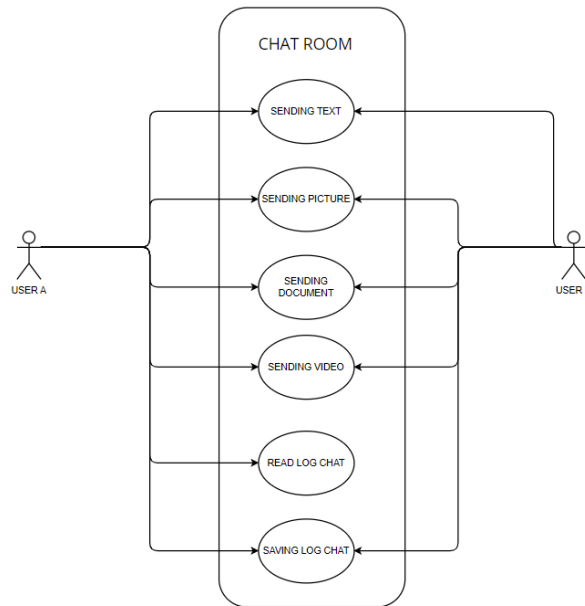


Fig. 3. User interaction in the bot.

TABLE II. THE BOT SPECIFICATION

Discord Bot Application		
No	Specification	Detail
1	Name	DEVICO BOT
2	Version Name	1.0
3	Application ID	936165836010426369
4	API Version	9.0
5	Token	OTM2MTY1ODM2MDEwNDI2MzY5.GMbjAH.SwcAiKb_s_1-kWLt53TQnz9KCUqxxxxxxxxxxxx
Discord Account		
No	Specification	Detail
1	Name	Simpleman (as admin) Simpleman1 (as normal user)
2	Authorization	OTI5NjM4ODIxNzkwOTA0MzMx.YjHTaQ.TKBgkamryyoHa5G2EGMWnpyxxxx (authorization admin) OTI5NjQxODk4NjczNTkwMzIy.YjHTrg.TIEmtB-sBtm-dzSg3OpvV5Rxxxx (authorization normal user)
Python		
No	Specification	Detail
1	Name	Python
2	Version	3.10.2

TABLE III. THE BOT FUNCTION DETAILS

No	Function	Detail
1	get_messages	get chat messages sent
2	get_images	get the picture sent
3	get_attachment	get documents sent
4	get_message author	get the author who sent the message
5	get_timestamp	get time sending message
6	get_editedtimestamp	get the time when the message was edited
7	get_guildname	get the name of the guild or group
8	get_channelname	get channel name in group
9	get_editedmessage	get edited message
10	get md5 and sha256	get md5 and sha256 hashing
11	get_deletedmessage	get deleted messages
12	get_url_attachment	get all URL where attachments are stored on the Discord database
13	save json.dumps	save all deleted or edited messages and regular messages
14	save embed_message	save all deleted or edited messages and regular messages in one private channel
15	save CSV	Save all messages CSV format

IV. RESULTS AND DISCUSSION

This section presents acquisition results as part of internal testing to test the functionality and external testing to measure the bot's performance. It is followed by a discussion that explores how the bot supports available research to acquire Discord's data.

A. Experimental Configuration

The tests in this paper were carried out using a custom-built experimental apparatus. The following information describes the system setup used for the investigations:

1) *System configuration:* The studies were carried out on an ASUS TUF Gaming FX504 laptop, which served as the study's principal hardware platform. This laptop model, noted for its durability and dependability, provided a suitable computing environment for experimental activities. The laptop, which included a 2.2 GHz Intel Core i7-8750H CPU with six cores, gave the processing capability to tackle difficult computations. With 16 GB of DDR4 RAM, it provided sufficient memory capacity to accommodate huge datasets and ensure the smooth execution of the experimental methods. The laptop also has a 512 GB NVMe SSD for quick and efficient data storage and retrieval. An NVIDIA GeForce GTX 1050 Ti graphics card with 4 GB provided the graphical capabilities.

2) *Software environment:* The Windows 10 operating system (version 10.0) was used as the platform for the studies in the experimental setup. For the study, Windows 10 offered a user-friendly and generally compatible environment. Python (version 3.9.6) was used as the primary programming language for carrying out the experiments and analyzing the results. Python's adaptability and vast library ecosystem made it an excellent choice for scientific computing jobs. The Discord API interfaced with the Discord platform to gather and analyze data. The most recent version of the Discord API was used, assuring compatibility with the most recent Discord

features and functions. The Pandas package (version 1.3.4) was used for data processing and analysis in the studies. Pandas provide efficient data structures and handling tools.

B. Acquisition Results

Internal testing ensures all features are working as intended and ready to be used by external users.

1) *Text acquisition:* The bot automatically saves all text messages in the Discord server, whether intact, deleted, or edited. The messages are captured on the admin's private channel text created previously and stored in the embedded_message format. The output of text acquisition is shown in Fig. 4.

The detailed content of the acquired text data is presented in Table IV. There is a title as the type of message, a Message ID as a unique id denoted by the message, and the hash value of the data is computed to support data integrity checking.

2) *Document acquisition:* The bot is set to be able to acquire various document formats such as pdf, docx, xlsx and others. Like text acquisition, the document acquisition results are stored directly in the private channel text. Fig. 5 presents two scenario results: the acquisition of the intact document and the deleted document. The hash value of the acquired documents was calculated for both scenarios. The detailed attributes of the documents are presented in Table V.

3) *Audio acquisition:* The bot collected its attributes for audio data, namely name, extension, resolution, and size. The acquired data is stored directly on the private channel text. The screen capture of the example result can be seen in Fig. 6, while the complete type of the acquired data from the audio is presented in Table VI.

4) *Image and video acquisitions:* Users can upload various images and video formats. Fig. 7 presents the details acquisition results of the files. The data are stored directly on the private channel text. The detailed data is shown in Table VII.

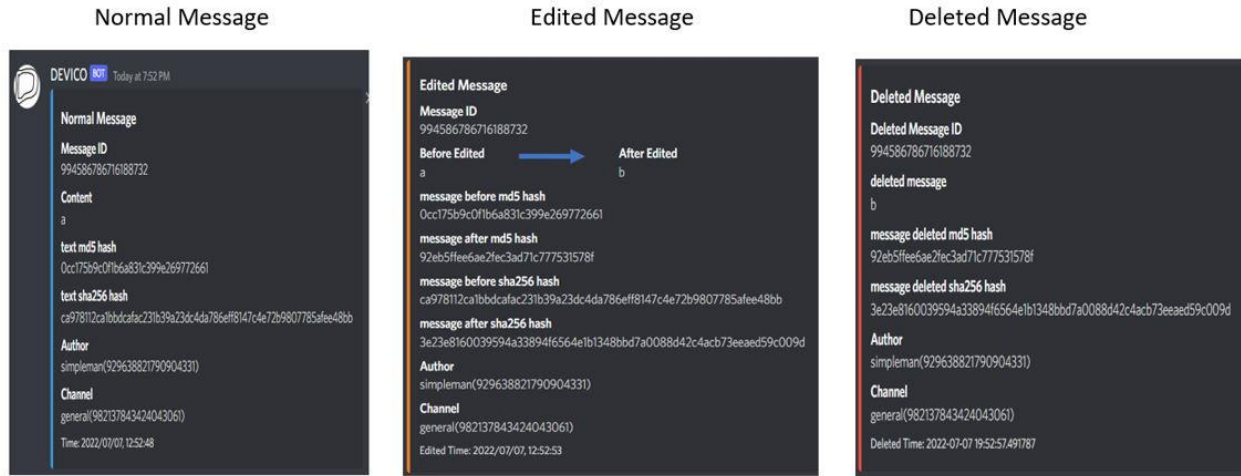


Fig. 4. Sample output of the text acquisition.

TABLE IV. SAMPLE OUTPUT OF THE TEXT CHAT ATTRIBUTES

Name	Normal Test	Deleted Text
Message ID	977928168189067274	977928168189067274
Content	---	---
Attachments id	977928168017125416	977928168017125416
Attachments URL	https://cdn.discordapp.com/attachments/977921779253260308/977928168017125416/download.pdf	https://cdn.discordapp.com/attachments/977921779253260308/977928168017125416/download.pdf
Attachments content type	application/pdf	application/pdf
Attachments file name	download.pdf	download.pdf
Attachments height	None	None
Attachments width	None	None
Attachments Size	20098	20098
Attachments MD5	45B5851169845355E70BDA140915EE6A	45B5851169845355E70BDA140915EE6A
Attachments Sha256	53f169c91ef7258e5909683decf2ca1f04c96724fa8a42284db7af914b3b4b61	53f169c91ef7258e5909683decf2ca1f04c96724fa8a42284db7af914b3b4b61
Author	simpleman(929638821790904331)	simpleman(929638821790904331)
Channel	jurnal(977921779253260308)	jurnal(977921779253260308)
Time	2022/05/22, 13:37:24	2022/05/22, 13:37:48

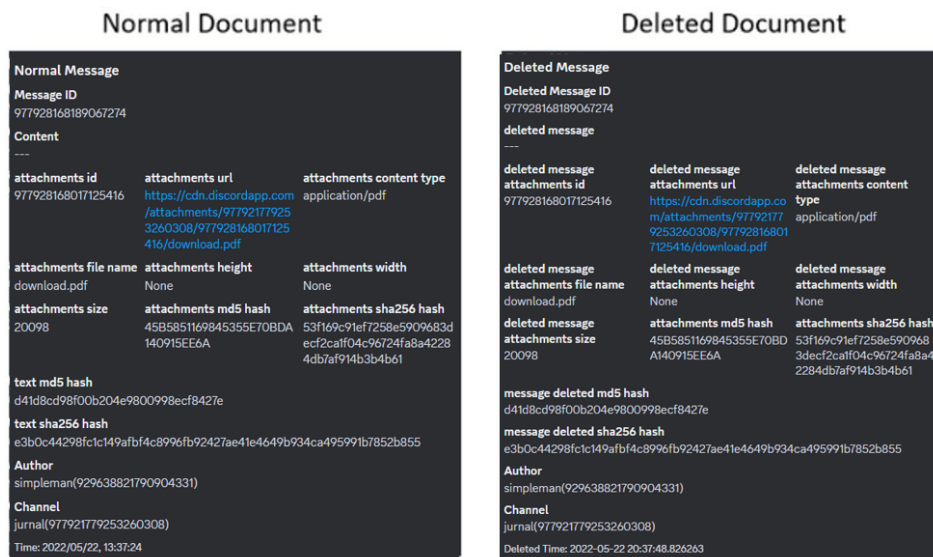


Fig. 5. Sample output of the document acquisition.

Normal Audio

```

Normal Message
Message ID
1046680120229888010
Content
---
attachments id      attachments url      attachments content
1046680119944687717 https://cdn.discordapp.com/attachments/1046315028267147264/1046680119944687717/Acumalaka_sound_effect_01.mp3 audio/mpeg

attachments file name attachments height attachments width
Acumalaka_sound_effect_01.mp3 None None

attachments size attachments md5 hash attachments sha256 hash
345009 CDCD831E484249D8B44E80BF0DB8E184 eafbf417b1915da1db6ef4151a47b340ac50e3c1ec59af9826218aa997fe9278

text md5 hash
d41d8cd98f00b204e9800998ecf8427e
text sha256 hash
e3b0c44298fc1c149afbf4c8996fb92427ae41e4649b934ca495991b7852b855

Author
Garry(689474699838619762)
Channel
general(1046315028267147264)
Time: 2022/11/28, 06:53:07
    
```

Deleted Audio

```

Deleted Message
Deleted Message ID
1046680120229888010
deleted message
---
deleted message attachments id      deleted message attachments url      deleted message attachments content
1046680119944687717 https://cdn.discordapp.com/attachments/1046315028267147264/1046680119944687717/Acumalaka_sound_effect_01.mp3 audio/mpeg

deleted message attachments file name deleted message attachments height deleted message attachments width
Acumalaka_sound_effect_01.mp3 None None

deleted message attachments size deleted message attachments md5 hash deleted message attachments sha256 hash
345009 CDCD831E484249D8B44E80BF0DB8E184 eafbf417b1915da1db6ef4151a47b340ac50e3c1ec59af9826218aa997fe9278

message deleted md5 hash
d41d8cd98f00b204e9800998ecf8427e
message deleted sha256 hash
e3b0c44298fc1c149afbf4c8996fb92427ae41e4649b934ca495991b7852b855

Author
Garry(689474699838619762)
Channel
general(1046315028267147264)
Deleted Time: 2022-11-28 13:59:21.046648
    
```

Fig. 6. Sample output of the audio acquisition.

TABLE V. SAMPLE OUTPUT OF THE DOCUMENT ATTRIBUTES

No	Attribute	Detail
1	Title	Normal Message; Edited Message; Deleted Message
2	Message ID	994586786716188732; 994586786716188732; 994586786716188732
3	Content	a; a(before edited) -> b(after edited); b
4	Md5 hash	0cc175b9c0f1b6a831c399e269772661; 0cc175b9c0f1b6a831c399e269772661 (before edited) -> 92eb5ffee6ae2fec3ad71c777531578f (after edited); 92eb5ffee6ae2fec3ad71c777531578f
5	Sha256 hash	ca978112ca1bbdcaf231b39a23dc4da786eff8147c4e72b9807785afee48bb; ca978112ca1bbdcaf231b39a23dc4da786eff8147c4e72b9807785afee48bb (before edited) -> 3e23e8160039594a33894f6564e1b1348bbd7a0088d42c4acb73eeaed59c009d (after edited); 3e23e8160039594a33894f6564e1b1348bbd7a0088d42c4acb73eeaed59c009d;
6	Author	simpleman(929638821790904331).
7	Channel	general(982137843424043061)
8	Time	2022/07/07 12:52:48; 2022/07/07 12:52:53; 2022-07-07 12:52:57.491787 UTC

TABLE VI. SAMPLE OUTPUT OF THE AUDIO ATTRIBUTES

Name	Normal Audio	Deleted Audio
Message ID	1046680120229888010	1046680120229888010
Content	---	---
Attachments id	1046680119944687717	1046680119944687717
Attachments URL	https://cdn.discordapp.com/attachments/1046315028267147264/1046680119944687717/Acumalaka_sound_effect_01.mp3	https://cdn.discordapp.com/attachments/1046315028267147264/1046680119944687717/Acumalaka_sound_effect_01.mp3
Attachments content type	audio/mpeg	audio/mpeg
Attachments file name	Acumalaka_sound_effect_01.mp3	Acumalaka_sound_effect_01.mp3
Attachments height	None	None
Attachments width	None	None
Attachments Size	345009	345009
Attachments MD5	CDCD831E484249D8B44E80BF0DB8E184	CDCD831E484249D8B44E80BF0DB8E184
Attachments Sha256	eafbf417b1915da1db6ef4151a47b340ac50e3c1ec59af9826218aa997fe9278	eafbf417b1915da1db6ef4151a47b340ac50e3c1ec59af9826218aa997fe9278
Author	Garry(689474699838619762)	Garry(689474699838619762)
Channel	general(1046315028267147264)	general(1046315028267147264)
Time	2022/11/28, 06:53:07	2022-11-28 06:59:21

Image Format

Video Format

```
Normal Message
Message ID
977921814544150581
Content
---
attachments id      attachments url      attachments
content type
97792181433021242  https://cdn.discord  image/jpeg
3                  pp.com/attachment
                    s/9779217792532603
                    08/977921814330212
                    423/angkasa.jpg
attachments file    attachments height  attachments width
name
angkasa.jpg        550                 1070
attachments size    attachments md5      attachments
sha256 hash
138110             3E07AEBAB1019BCF   31ce44579264730c4
                    6B29635EB340480D  174f1bd394f6181733d
                    3ca331e795e9325c0
                    d255c592d66
text md5 hash
d41d8cd98f00b204e9800998ecf8427e
text sha256 hash
e3b0c44298fc1c149afb4c8996fb92427ae41e4649b934ca495991
b7852b855
Author
simpleman(929638821790904331)
Channel
jurnal(977921779253260308)
Time: 2022/05/22, 13:12:09
```

```
Normal Message
Message ID
977931074791411772
Content
---
attachments id      attachments url      attachments content type
977931074392956928 https://cdn.discordapp.com  video/mp4
                    /attachments/97792177925
                    3260308/977931074392956
                    928/nasehat.mp4
attachments file    attachments height  attachments width
name
nasehat.mp4        960                 540
attachments size    attachments md5 hash  attachments sha256 hash
1118335            1984EBB808030AE83A787B  90456d607f66ebf1a05981
                    EF76C445B4             50d277c56f4ffc1407f1265c2
                    b3cf4ed330a0b99d
text md5 hash
d41d8cd98f00b204e9800998ecf8427e
text sha256 hash
e3b0c44298fc1c149afb4c8996fb92427ae41e4649b934ca495991b7852b855
Author
simpleman(929638821790904331)
Channel
jurnal(977921779253260308)
Time: 2022/05/22, 13:48:57
```

Fig. 7. Sample output of the image and video acquisitions

TABLE VII. SAMPLE OUTPUT OF THE IMAGE AND VIDEO ATTRIBUTES

Name	Image Format	Video Format
Message ID	977921814544150581	977931074791411772
Content	---	---
Attachments id	977921814330212423	977931074392956928
Attachments URL	https://cdn.discordapp.com/attachments/977921779253260308/977921814330212423/angkasa.jpg	https://cdn.discordapp.com/attachments/977921779253260308/977931074392956928/nasehat.mp4
Attachments content type	image/jpeg	video/mp4
Attachments file name	angkasa.jpg	nasehat.mp4
Attachments height	550	960
Attachments width	1070	540
Attachments Size	138110	1118335
Attachments MD5	3E07AEBAB1019BCF6B29635EB340480D	1984EBB808030AE83A787BEF76C445B4
Attachments Sha256	31ce44579264730c4174f1bd394f6181733d3ca331e795e9325c0d255c592d66	90456d607f66ebf1a0598150d277c56f4ffc1407f1265c2b3cf4ed330a0b99d
Author	simpleman(929638821790904331)	simpleman(929638821790904331)
Channel	jurnal(977921779253260308)	jurnal(977921779253260308)
Time	2022/05/22, 13:12:09	2022/05/22, 13:48:57

C. Error Rate and Accuracy

The testing was conducted with 37 users running the bot simultaneously for about one hour. Our record showed that the total sent text messages, files, and deleted data during the testing phase were 74, 296, and 185, respectively. Meanwhile, the acquired data are 74, 289, and 177. Details of the acquired data are presented in Table VIII. It can be observed that the bot

cannot identify seven intact and eight deleted files; therefore, these files cannot be acquired.

The error rate (ERR) and Accuracy (ACC) metrics are measured based on the dataset and the acquired data by using Eq. (1) and (2). ERR is calculated as the number of all incorrect predictions divided by the total number of data sets.

Accuracy (ACC) is calculated as the number of all correct predictions divided by the total number of data sets.

$$\text{Error Rate (ERR)} = \frac{FP+FN}{TP+TN+FN+FP} \quad (1)$$

$$\text{Accuracy (ACC)} = \frac{TP+TN}{TP+TN+FN+FP} \quad (2)$$

where,

FP = the application falsely predicts the true dataset

FN = the application falsely indicating the false dataset

TP = the application accurately predicts the dataset

TN = the application accurately predicts the incorrect dataset

Based on the ERR and ACC formulas above, Table IX presents the confusion matrix based on the performance test results.

TABLE VIII. THE ACQUIRED DATA FROM THE PERFORMANCE TEST

User	Number and Type of Sent Data					Deleted
	Text	Document	Audio	Video	Picture	
1	2	2 (pdf)	2 (mpeg)	2 (mp4)	2 (png, jpeg)	5
2	2	2 (docx)	2 (mpeg)	2 (mov)	2 (jpeg)	4
3	2	1 (docx)	2 (mpeg)	2 (mp4)	1 (jpeg)	0
4	2	2 (docx)	2 (mpeg)	2 (mp4)	2 (jpg)	3
5	2	2 (docx)	2 (mpeg)	2 (mp4)	2 (png)	5
6	2	2 (pdf)	2 (mpeg)	2 (mp4)	2(png)	4
7	2	2 (docx)	2 (ogg)	2 (mp4)	2 (png, jpg)	5
8	2	3 (docx, txt)	2 (mpeg)	2 (mp4)	2 (png)	5
9	2	2 (pdf,docx)	2 (mpeg)	-	1 (jpg)	6
10	2	2 (txt)	2 (ogg)	2 (mov)	2 (png)	5
11	2	2 (docx)	2 (ogg)	2 (mov)	1 (jpeg)	3
12	2	3 (docx)	2 (mpeg)	2 (mp4)	4 (png, jpg)	5
13	2	2 (docx)	2 (mpeg)	2 (mp4)	2 (jpg)	5
14	2	2 (pdf)	2 (ogg)	2 (mp4)	2 (jpg)	5
15	2	2 (docx)	2 (mpeg)	2 (mp4)	2 (jpg)	11
16	2	-	2 (mpeg)	2 (mp4)	2 (jpeg)	3
17	2	2 (pdf, docx)	2 (mpeg)	2 (mov)	2 (jpg)	5
18	2	2 (docx)	2 (wav)	2 (mp4)	3 (jpg)	5
19	2	3 (csv,docx,txt)	1 (mpeg)	0	4 (gif, jpeg, png)	1
20	2	2 (docx)	2 (ogg)	2 (mp4)	2 (jpg)	5
21	2	5 (pdf)	3 (mpeg)	4 (mp4)	5 (jpg, png)	10
22	2	2 (docx, pdf)	2 (mpeg)	2 (mp4)	2 (png, jpg)	5
23	2	1 (txt)	-	-	2 (jpg, png)	3
24	2	2 (pdf)	2 (mpeg)	2 (mp4)	2 (jpg)	5
25	2	2 (docx)	2 (mpeg)	2 (mp4)	2 (jpg)	5
26	2	2 (txt)	2 (ogg)	2 (mp4)	2 (jpg)	5
27	2	1 (pdf)	2 (ogg)	2 (mp4)	2 (png)	5
28	2	2 (pdf)	2 (wav)	2 (mkv)	2 (png)	5
29	2	2 (txt)	2 (mpeg)	2 (mp4)	2 (jpg, jpeg)	5
30	2	2 (pptx ,txt)	2 (mpeg)	2 (mkv)	2 (png)	5
31	2	2 (pdf)	2 (mpeg)	2 (mp4)	2 (jpg)	5
32	2	-	-	-	-	2
33	2	2 (pdf, docx)	2 (mpeg)	2 (mp4)	2 (jpg)	5
34	2	2 (txt)	2 (mpeg)	2 (mp4)	2 (jpg)	5
35	2	2 (docx)	2 (mpeg)	2 (mp4)	2 (png, jpg)	6
36	2	2 (docx)	2 (mpeg)	2 (mp4)	3 (png, jpg)	6
37	2	2 (docx, pptx)	2 (mpeg)	2 (mkv)	2 (jpg)	5

TABLE IX. CONFUSION MATRIX FOR A BINARY CLASSIFIER PREDICTING ACCURACY AND ERROR RATE STATUS

	Predicted Positive	Predicted Negative
Actual Positive	289 (TP)	0 (FN)
Actual Negative	7 (FP)	0 (TN)

In Table IX, there are 289 true positives (TP), meaning the classifier correctly identified 289 messages sent by the user. However, there are seven false positives (FP), meaning the classifier predicts seven users have already sent the message, but the fact is not sent yet.

Looking at the values in the confusion matrix in Table IX, the number of error rates generated by the Bot Discord application is 2.3%, and its accuracy is 97.7%.

D. Discussion

The observed results show that the bot successfully recorded messages sent through the Discord app, including the edited and deleted data. However, it is noticed that some data could not be recorded and acquired from the performance results. A potential explanation is that this testing was conducted for the 37 concurrent users, and some data arrived simultaneously. Managing the buffer for storing the consecutive arriving data shall become our concern for future work. It is also necessary to consider storing the acquired data on special storage, including the cloud, because it is possible to get a vast amount of data.

The proposed bot is designed by utilizing the Discord API. The acquired data is presented in Table X. The implementation of the bot by using the Discord API approach gives flexibility because it can be modified according to the acquisition needs, for example, to acquire a guild that contains text messages, images, documents, videos, and audio. This approach opens the possibility of gathering more data as a digital forensic investigation is needed, as much as the app's API can access them.

The other benefit of the bot approach to conduct the acquisition is it can be used to proactively collect the data from all users at once, as it is conducted on the server side. Nevertheless, implement it without compromising user privacy [29] needs to be considered; this could be achieved by providing a notice to the users.

TABLE X. ARTIFACTS ACQUIRED FROM THE PROPOSED DISCORD BOT

Type	Discord Data	API-based Bot Discord
Guild	Name, name_channel, created_at, Id, Category name	✓
Messages	Id, Type, Content (intact, edited, deleted), Attachment (id, filename, size, url, for intact and deleted attachment), Chanel id, Author (id, username, avatar, discriminator, public flag), Embeds, Mentions (roles, everyone), Pinned, Tts, Timestamps (intact, edited, deleted), Flags, Hash (md5 and sha256)	✓

V. CONCLUSION

This study proposed a novel way to collect Discord data using a bot in proactive forensics. The Discord API-based bot saves the data as the embedded message card, stored in a private channel created by the admin. The real-time data can be recorded as the bot is always alive on the server. Therefore, intact, edited, and deleted data are available in advance to be analyzed as needed. All the recorded data is saved locally on the server's storage in easy-to-read formats (i.e., CSV and JSON). The bot is equipped with calculating hash values (i.e., md5 and sha256) for the individual data. Future works may focus on improving the bot's performance to handle massive users, adding remote/cloud storage access, and handling data acquisition for VoIP and encrypted messages.

REFERENCES

- [1] V. Fernando, "Cyber Forensics Tools: A Review on Mechanism and Emerging Challenges," in 2021 11th IFIP International Conference on New Technologies, Mobility and Security, NTMS 2021, Institute of Electrical and Electronics Engineers Inc., Apr. 2021. doi: 10.1109/NTMS49979.2021.9432641.
- [2] L. Yang, C. Li, T. Wei, F. Zhang, J. Ma, and N. Xiong, "Vacuum: Efficient and Assured Deletion Scheme for User Sensitive Data on Mobile Devices," IEEE Internet Things J, vol. 9, no. 12, pp. 10093–10107, Jun. 2022, doi: 10.1109/IIOT.2021.3119514.
- [3] C. Shields, "Towards proactive forensic evidentiary collection," in Proceedings of the Annual Hawaii International Conference on System Sciences, 2010. doi: 10.1109/HICSS.2010.408.
- [4] A. Sivaprasad, "Secured Proactive Network Forensic Framework," in 2017 International Conference on Current Trends in Computer, Electrical, Electronics and Communication (CTCEEC), 2017, pp. 695–699. doi: 10.1109/CTCEEC.2017.8455003.
- [5] S. M. Makura, H. S. Venter, R. A. Ikuesan, V. R. Kemande, and N. M. Karie, "Proactive Forensics: Keystroke Logging from the Cloud as Potential Digital Evidence for Forensic Readiness Purposes," in 2020 IEEE International Conference on Informatics, IoT, and Enabling Technologies (ICIoT), 2020, pp. 200–205. doi: 10.1109/ICIoT48696.2020.9089494.
- [6] D. M. Beskow and K. M. Carley, "Bot-hunter: A Tiered Approach to Detecting & Characterizing Automated Activity on Twitter."
- [7] R. U. Rahman and D. S. Tomar, "A new web forensic framework for bot crime investigation," Forensic Science International: Digital Investigation, vol. 33, Jun. 2020, doi: 10.1016/j.fsidi.2020.300943.
- [8] X. Zhang, O. Upton, N. L. Beebe, and K. K. R. Choo, "IoT Botnet Forensics: A Comprehensive Digital Forensic Case Study on Mirai Botnet Servers," Forensic Science International: Digital Investigation, vol. 32, Apr. 2020, doi: 10.1016/j.fsidi.2020.300926.
- [9] N. Koroniotis, N. Moustafa, E. Sitnikova, and B. Turnbull, "Towards the development of realistic botnet dataset in the Internet of Things for network forensic analytics: Bot-IoT dataset," Future Generation Computer Systems, vol. 100, pp. 779–796, Nov. 2019, doi: 10.1016/j.future.2019.05.041.
- [10] M. Davis, B. McInnes, and I. Ahmed, "Forensic investigation of instant messaging services on linux OS: Discord and Slack as case studies," Forensic Science International: Digital Investigation, vol. 42, p. 301401, Jul. 2022, doi: 10.1016/j.fsidi.2022.301401.
- [11] İ. Yıldırım, E. Bostancı, and M. S. Güzel, "Forensic Analysis with Anti-Forensic Case Studies on Amazon Alexa and Google Assistant Build-In Smart Home Speakers," in 2019 4th International Conference on Computer Science and Engineering (UBMK), 2019, pp. 1–3. doi: 10.1109/UBMK.2019.8907007.
- [12] M. A. Wani, "Privacy Preserving Anti-forensic Techniques," in Multimedia Security: Algorithm Development, Analysis and Applications, S. A. and B. R. and M. K. Giri Kaiser J. and Parah, Ed., Singapore: Springer Singapore, 2021, pp. 89–108. doi: 10.1007/978-981-15-8711-5_5.

- [13] M. K. Rogers, K. C. Seigfried-Spellar, S. Bates, and K. Rux, "Online child pornography offender risk assessment using digital forensic artifacts: The need for a hybrid model," *J Forensic Sci*, vol. 66, no. 6, pp. 2354–2361, 2021, doi: <https://doi.org/10.1111/1556-4029.14820>.
- [14] Lokesh Gupta, "What is REST," <https://restfulapi.net/>, Apr. 07, 2022.
- [15] J. and T. I. Alharbi Soltan and Weber-Jahnke, "The Proactive and Reactive Digital Forensics Investigation Process: A Systematic Literature Review," in *Information Security and Assurance*, H. and R. R. J. and B. M. Kim Tai-hoon and Adeli, Ed., Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 87–100.
- [16] M. Cook, A. Marnerides, C. Johnson, and D. Pezaros, "A Survey on Industrial Control System Digital Forensics: Challenges, Advances and Future Directions," *IEEE Communications Surveys and Tutorials*, 2023, doi: [10.1109/COMST.2023.3264680](https://doi.org/10.1109/COMST.2023.3264680).
- [17] M. Azzam, L. Pasquale, G. Provan, and B. Nuseibeh, "Forensic readiness of industrial control systems under stealthy attacks," *Comput Secur*, vol. 125, Feb. 2023, doi: [10.1016/j.cose.2022.103010](https://doi.org/10.1016/j.cose.2022.103010).
- [18] M. Anderson, "Discord and the Harbormen Gaming Community," 2019.
- [19] Mashud, H. Warni, S. Arifin, M. Ferry, Pebriyandi, and A. Kristiyandaru, "The application of discord as an effort to increase students' wellbeing in physical education learning during the COVID-19 emergency," *Journal Sport Area*, vol. 6, no. 3, pp. 335–348, 2021, doi: [https://doi.org/10.25299/sportarea.2021vol6\(3\).6612](https://doi.org/10.25299/sportarea.2021vol6(3).6612).
- [20] Y. E. Dayana, O. M. Andre, and L. Andrade-Arenas, "Design of the Discord application as an E-learning tool at the University of Sciences and Humanities," in *Proceedings of the LACCEI international Multi-conference for Engineering, Education and Technology, Latin American and Caribbean Consortium of Engineering Institutions*, 2021. doi: [10.18687/LACCEI2021.1.1.9](https://doi.org/10.18687/LACCEI2021.1.1.9).
- [21] M. Motylinski, A. MacDermott, F. Iqbal, M. Hussain, and S. Aleem, "Digital Forensic Acquisition and Analysis of Discord Applications," in *Proceedings of the 2020 IEEE International Conference on Communications, Computing, Cybersecurity, and Informatics, CCCI 2020*, Institute of Electrical and Electronics Engineers Inc., Nov. 2020. doi: [10.1109/CCCI49893.2020.9256668](https://doi.org/10.1109/CCCI49893.2020.9256668).
- [22] K. Moffitt, U. Karabiyik, S. Hutchinson, and Y. H. Yoon, "Discord Forensics: The Logs Keep Growing," in *2021 IEEE 11th Annual Computing and Communication Workshop and Conference, CCWC 2021*, Institute of Electrical and Electronics Engineers Inc., Jan. 2021, pp. 993–999. doi: [10.1109/CCWC51732.2021.9376133](https://doi.org/10.1109/CCWC51732.2021.9376133).
- [23] K. Gupta, C. Varol, and B. Zhou, "Digital forensic analysis of discord on google chrome," *Forensic Science International: Digital Investigation*, vol. 44, Mar. 2023, doi: [10.1016/j.fsidi.2022.301479](https://doi.org/10.1016/j.fsidi.2022.301479).
- [24] S. Shin, E. Park, S. Kim, and J. Kim, "Artifacts Analysis of Slack and Discord Messenger in Digital Forensic," *Journal of Digital Contents Society*, vol. 21, no. 4, pp. 799–809, Apr. 2020, doi: [10.9728/dcs.2020.21.4.799](https://doi.org/10.9728/dcs.2020.21.4.799).
- [25] M.-T. and L.-K. N.-A. Sgaras Christos and Kechadi, "Forensics Acquisition and Analysis of Instant Messaging and VoIP Applications," in *Computational Forensics*, F. Garain Utpal and Shafait, Ed., Cham: Springer International Publishing, 2015, pp. 188–199.
- [26] D. Wijnberg and N.-A. Le-Khac, "Identifying interception possibilities for WhatsApp communication," *Forensic Science International: Digital Investigation*, vol. 38, p. 301132, 2021, doi: <https://doi.org/10.1016/j.fsidi.2021.301132>.
- [27] R. Padmanabhan, K. Lobo, M. Ghelani, D. Sujana, and M. Shirole, "Comparative analysis of commercial and open source mobile device forensic tools," in *2016 Ninth International Conference on Contemporary Computing (IC3)*, 2016, pp. 1–6. doi: [10.1109/IC3.2016.7880238](https://doi.org/10.1109/IC3.2016.7880238).
- [28] Discord Teams, "Developer Portal," <https://discord.com/developers/docs/change-log>, Apr. 06, 2023.
- [29] A. R. Javed, W. Ahmed, M. Alazab, Z. Jalil, K. Kifayat, and T. R. Gadekallu, "A Comprehensive Survey on Computer Forensics: State-of-the-Art, Tools, Techniques, Challenges, and Future Directions," *IEEE Access*, vol. 10, pp. 11065–11089, 2022, doi: [10.1109/ACCESS.2022.3142508](https://doi.org/10.1109/ACCESS.2022.3142508).

The Contribution of Numerical EEG Analysis for the Study and Understanding of Addictions with Substances

Aziz Mengad¹, Jamal Dirkaoui², Merouane Ertel³, Meryem Chakkouch⁴, Fatima Elomari⁵

Centre for Doctoral Studies "Life and Health Sciences"-Drug Sciences Formation, Laboratory of Pharmacology and Toxicology (LPTR), Faculty of Medicine and Pharmacy of Rabat (FMPH), Impasse Souissi Rabat 10100, Morocco^{1,2}

Informatics and Applications Laboratory (IA)-Faculty of Sciences, Moulay Ismail University Meknes, Morocco^{3,4}

IBN SINA University Hospital of Rabat/Salé-ARRAZI Psychiatric Hospital, National Centre for Addictology Salé Morocco⁵

Abstract—Computerised electroencephalography (EEG) is one of a wide variety of brain imaging techniques used in addiction medicine. It is a sensitive measure of the effects of addiction on the brain and has been shown to show changes in brain electrical activity during addiction. But, the clinical value of computerised EEG recording in addictions is not yet clearly established. However, several studies argue that this non-invasive technique has an undeniable contribution to the understanding, prediction, diagnosis and monitoring of addictions. The aim of this article is to assess, through a systematic review, the contribution and interest of computerised EEG in the study and understanding of substance abuse by describing the different electrical activities that underlie it across the main frequency ranges: delta, theta, alpha, beta and gamma. We have been conducting a systematic review according to the recommendations of Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) and the Cochrane Group. We included 25 studies with a total of 1897 cases of addiction and 1504 controls. The studies dealt with addictions related to 05 licit and illicit psychoactive substances (alcohol, nicotine, cannabis, heroin and cocaine). The group of addicted patients showed significantly different brain electrical characteristics from the group of controls in the different EEG rhythms, whether during acute substance intoxication, abuse, withdrawal, abstinence, relapse, progression or response to treatment. The majority of studies have used EEG for diagnostic, predictive, monitoring purposes and also to discover electro-physiological markers of certain addictions.

Keywords—*Electroencephalography (EEG); quantitative electroencephalography; drug addiction; spectral analysis; coherence analysis*

I. INTRODUCTION

Over the past twenty years, we have witnessed some important advances in the study of the human brain. Possibly the most challenging has been the development of structural and functional brain imaging techniques, which have revolutionised cognitive and behavioural neuroscience by offering us a view into the brain activity underlying complex human behaviour. These technological progresses have also allowed to the rapid conversion of basic neuroscience discoveries into more specific therapies for clinical application.

There is a rich diversity of brain imaging techniques, which can be categorised into three main types: (1) nuclear medicine

imaging techniques; (2) magnetic resonance imaging techniques and (3) electro-physiological imaging techniques, which comprise electroencephalography (EEG). Each one of these techniques reveal a distinct facet of brain structure and/or function, providing a wide range of findings on the biochemical, electro-physiological and functional processes of the brain.

Electroencephalography (EEG) has been used to investigate brain function since the publication of Berger's paper in 1929. It registers the synchronised activity of excitatory (EPSP) and inhibitory (IPSP) postsynaptic potentials in the cerebral cortex and exhibits the activity as a tension change in amplitude with time [1]. Over the past forty years, the EEG has been used extensively in drug addiction research. It is known to be a sensibly measurement of the effects of substances on the brain and, in particularly, of the effects of drugs on the size and time course of postsynaptic potentials [2]. The enhancing effects of many substances modulated by the mesolimbic dopamine (MD) channel have been shown to alter EEG recordings [3]. Five frequency ranges are generally recognised and studied: delta (0-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (15-30 Hz) and gamma (<30 Hz).

EEG analysis methods included quantitative EEG, spectral analysis, coherence analysis and visual analysis. Substance use has been found to be associated with broad alterations in intrinsic neural activity, typically expressed as neuronal hyperactivation and decreased neuronal communication between brain regions. Some studies have shown that the use of alcohol, tobacco, cocaine, cannabis and heroin was positively correlated with these changes. These alterations may partially recover after abstinence, which differs between drugs and may reflect their degree of neurotoxicity. In summary, EEG can be used for diagnostic, predictive and monitoring purposes and also to discover electrophysiological biomarkers of certain addictions.

Therefore, this article presents a systematic review of EEG studies in substance addiction, to guide further work in the field. The main objective is to review the empirical research of the last decades, providing crucial information on EEG findings in addiction to the most commonly used substances. It therefore aims to investigate the interest and contribution of EEG in these addictions.

II. METHOD

A. Inclusion and Exclusion Criteria

The selected studies included people with addiction, without restrictive geographical, age, gender, ethnicity or nationality criteria. To be included in this review, studies had to be based on samples of subjects with substance addiction investigated by electroencephalography as the main investigative tool.

In order to limit the abundance of data from different databases, the studies included in this review were those that could provide us with data dealing with the role or use of EEG in addictology in English or French only. All were concerned with the study of brain activity in addicts. They were essentially quantitative studies carried out on addicted subjects without any other concomitant pathology. Priority was given to studies that used quantitative EEG with coherence analysis or spectral analysis.

We excluded any papers that did not directly address the brain activity of addicts as measured by EEG. For example, we eliminated all studies that only dealt with the use of other means of brain investigation such as scans, MRIs, PET scans, etc., without a direct link to the EEG.

B. Research Strategy

MEDLINE, PSYCHINFO, PUBMED, SCIENCE DIRECT and GOOGLE SCHOLAR databases were searched in January, February and March 2022 with publication date limitation since 1990 when computerised automated EEG analyses began using the following search terms: "Electroencephalography, EEG, substance addiction, drug abuse". Both authors (M.A. and D.J.) independently examined the title, abstract and keywords of each identified reference and then selected the studies according to the inclusion criteria. The same method was then used to review the full text of each selected study. In order to identify additional relevant articles that this search strategy would have missed, we also managed and examined the bibliographic references of each article included in the review using ZOTERO software. In case of incongruence

between the data extracted by authors M.A. and D.J., the review and opinion of author E.F. was sought.

The initial database search identified 165 references. Following an initial review of titles, abstracts and keywords, 61 studies were not included because they did not correspond to the inclusion criteria. Following a full text review, 25 studies were included in the systematic review. The search strategy is detailed in a flow chart (Fig. 1).

C. Extracted Data

The authors (M.A. and D.J.) independently extracted data from the articles included in the review. A list of analysis criteria was compiled in the form of a reading grid (Table I) to extract data from the articles: author and year of publication, country, characteristics and size of the sample, substance studied, method of electroencephalographic analysis and the main rhythms studied.

The different types of EEG analysis that will be discussed in this paper are: 1) Quantitative analysis (QEEG) which is a modern type of EEG analysis that involves recording digital EEG signals that are processed, transformed and analysed using complex mathematical algorithms; 2) Spectral analysis, which is a frequency analysis technique that breaks down a complex cyclic signal into several sub-functions. This analysis technique is used in particular to finely dissect the electroencephalographic (EEG) signal. It provides information on fluctuations in the quantity and strength of cortical activities that are not visually perceived during the inspection of the trace; 3) EEG coherence, defined as the frequency-normalized cross-power spectrum of two signals recorded simultaneously at different scalp locations, is a sensitive method for assessing the integrity of the structural connection between brain areas, describing the temporal, spatial and frequency relationships of brain activities and 4) Visual analysis of the EEG: It relied heavily on waveform recognition, the EEG trace during wakefulness is much less synchronous than during sleep, but more homogeneous. The amplitude of the awake EEG trace in adults varies on average between 10 and 50 microvolt and the frequency of the wave's ranges from 0.3 to 70 Hz.

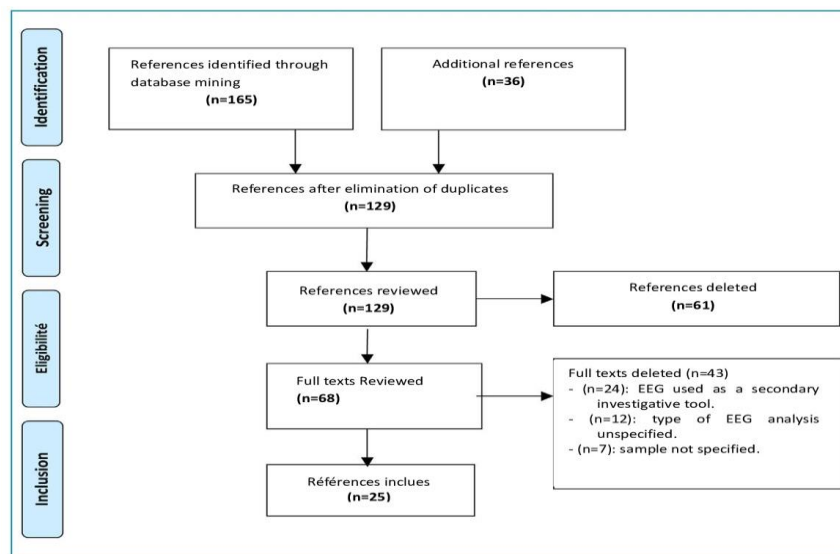


Fig. 1. Flow chart of the search strategy.

TABLE I. LIST OF INCLUDED STUDIES

Author	Year	Country	Sample size				Addiction studied	EEG and Analysis method	Main rhythms studied:				
			case		control				yes (1) no (0)				
			M	F	M	F			α	β	δ	θ	γ
[4] Levin KH et al.	2007	USA	16	4	8	0	Cocaine	Quantitative EEG	1	1	1	1	0
[5]Bauer, L. O.	2001	USA	73	34	13	9	Alcohol, heroin and cocaine	Quantitative EEG	0	1	0	0	0
[6] Böcker, K.B.E.	2010	Netherlands	16	0	0	0	THC	Quantitative EEG	0	0	0	1	0
[7] Rass et al.	2016	USA	13	9	14	16	tobacco	Spectral analysis	1	1	1	1	1
[8]Cortes-Briones, J.	2015	USA	14	6	0	0	THC	Quantitative EEG	0	0	0	0	1
[9]Costa, L., & Bauer, L.	1997	USA	63	25	10	4	Heroin, alcohol and cocaine	Quantitative EEG	0	1	0	0	0
[10]Domino EF.	2003	USA	65	0	20	0	tobacco	Quantitative EEG	1	1	1	1	0
[11]Ehlers C.L.	2010	USA	141	147	118	220	Cannabis and alcohol	Quantitative EEG	0	1	1	0	1
[12]Fingelkurts, A.	2006	Finland	14	8	6	8	Opioids	Visual analysis	1	1	0	0	0
[13] Herrera-Morales et al.	2019	Mexico	28	17	22	26	alcohol	Quantitative EEG	1	1	1	1	0
[14]Franken, I. H. A.	2004	Netherlands	18	0	12	0	heroin	Coherence analysis	0	1	0	0	1
[15]Grace Y. Wang	2015	New Zealand	29	20	14	11	Methadone and opiates	Spectral analysis	0	1	0	1	0
[16]Herning, R. I.	2008	USA	48	27	18	15	Marijuana	Quantitative EEG	1	1	0	0	0
[17]Herning, R. I.	1994	USA	14	0	0	0	Cocaine	Quantitative EEG	1	1	0	0	0
[18]Polunina, A. G., & Davydov, D. M.	2004	Russia	33	0	13	0	Heroin	Spectral analysis	1	0	0	0	0
[19] Pritchep, L. S.	1996	USA	42	25	0	0	Crack	Quantitative EEG	1	0	1	1	0
[20]Rangaswamy M, et coll	2003	USA	150	157	150	157	alcohol	Spectral analysis	0	0	0	1	0
[21]Rangaswamy M, et coll	2004	USA	94	77	89	115	alcohol	Spectral analysis	0	1	0	0	0
[22]Rangaswamy M.,	2002	USA	150	157	150	157	Alcohol	Spectral analysis	0	1	0	0	0
[23]Reid, MS.	2006	USA	11	2	0	0	Cocaine	Spectral analysis	1	1	1	1	0
[24]Saletu-Zyhlarz, G. M.et coll.	2004	Austria	15	7	15	7	Alcohol	Spectral analysis	1	1	1	0	0
[25]Shikha,P et col.	2018	USA	17	6	21	9	Cannabis	Quantitative EEG	0	1	1	1	1
[26]Struve, F. A et col.	1998	USA	15	0	57	0	Cannabis	Quantitative EEG	1	1	1	1	0
[27]Teneggi V et col.	2004	Italy	12	0	0	0	tobacco	Spectral analysis	1	1	1	1	0
[28]Winterer, G., et coll	1998	Germany	45	33	0	0	alcohol	Quantitative EEG	1	1	1	1	0
			$\Sigma =1897$		$\Sigma =1504$								

III. RESULTS

A. EEG and Substance Addiction

1) *Alcohol*: Several studies have found a more accentuated theta rhythm in alcoholics when compared to corresponding controls, theta power appears higher in the central and parietal regions in male alcoholics, and in the parietal region in female alcoholics[20]. The offspring of alcoholics do not show an increase in resting theta, which suggests that this measurement may signify a state of alcohol dependence [29].

Previous EEG mapping studies have found increased beta power and decreased alpha and delta/theta power in de-addictive alcoholic patients, compared to normal controls. Since slow activity is considered inhibitory, fast beta activity excitatory and alpha activity an expression of normal brain function, the desynchronised low-voltage fast patterns can be translated as CNS hyperexcitation [30], [31].

Opinions as to the cause of these EEG changes in alcoholics show that incoherencies in brain function, particularly in frontal parts of the brain, may be participating in the development of alcoholism [5], [30], [31]. This is documented by a variety of studies: beta activity has been linked to the combination of the two pre-morbid factors of childhood behaviour disorders and paternal alcoholism. [5]. As well as subjects with a positive family history of alcoholism have EEGs characterized by an increase in relative beta power and a reduction in absolute and relative alpha power in both the occipital and frontal regions. Also Hazardous alcohol consumption (HAC) is a pattern of alcohol use that may result in harm for the user and/or for those around them. Prior research has suggested that HAC and alcohol dependence share some neurophysiological features but differ in others, the HAC group presented with higher beta absolute power and relative power, as well as a lower beta mean frequency than the control group, while the group with risk of alcohol dependence presented lower delta absolute power than controls [13]. Therefore, the majority of this research has found that alcoholics are distinct from controls in that their beta power is increased [5], [22].

Furthermore, beta power is faster in relapsing alcoholics than in abstainers[5], which suggests that desynchronised beta activity may be a precious indicator of relapse in abstinent alcoholics. Given that, the augmentation of beta power in abstinent alcoholics is not correlated with the period of abstinence[22] and is also found in children of alcoholics at risk of alcohol addiction[21], the increased beta power is thought to be a marker of vulnerability rather than a trait or state variable (that's to say it may predate the development of alcoholism).

Beta activity has also been used as a predictor of relapse in alcohol addicts. It was found[5] that high-frequency beta activity can significantly distinguish between relapse-prone and abstinence-prone patients. Also, prediction [28] of relapse in chronic alcoholics using quantitative EEG (Q-EEG) was able to successfully classify 83-85% of patients, outperforming most previous efforts to predict relapse rates based on clinical assessments.

The results of some studies [5], and those reported by others, indicate that the value of rapid EEG power in predicting relapse can be generalised to all patients with a history of addiction to alcohol, cocaine, cocaine and alcohol or opioids. In summary, the EEGs of alcoholic patients clearly differ from those of both normal controls and patients with other psychiatric disorders, and the EEG can therefore be used for diagnostic reasons[32]. Therefore, EEG mapping can be used also as an objective method to predict relapse in chronic alcoholism[5].

2) *Nicotine*: A seminal work on smoking [33] reviewed previous research on the effects of smoking on the EEG. The immediate effect of smoking generates an "arousal" or "activation" EEG profile as smoking produces an increase in the beta band (14-30 Hz), an increase or decrease in the alpha band (8-13 Hz), a decrease in the delta (1-4 Hz) and theta (4-8 Hz) bands, and a passage to a higher dominant alpha frequency. EEG topographic representations show important regional spatial distributions and smoking induced changes in brain waves.

The administration of acute nicotine has been related to strong increases in brain activity from low frequencies (delta, theta, lower alpha) to high frequencies (alpha, higher beta), which reflects an excited state [10], [27]. Research has also revealed an increase in craving, a decrease in excitation and a deterioration in mood with a decrease in alpha frequencies during smoking abstinence [27].

Daily smokers had reduced resting delta and alpha EEG power and higher impulsiveness (Barratt Impulsiveness Scale) compared to nondaily smokers and non-smokers. Both daily and nondaily smokers discounted delayed rewards more steeply, reported lower conscientiousness (NEO-FFI), and reported greater disinhibition and experience seeking (Sensation Seeking Scale) than non-smokers. Nondaily smokers reported greater sensory hedonia than nonsmokers. [7].

It is very important to separate the different components of smoking, including psychological and pharmacological, by studying the EEG effects of fake and real smoking of a cigarette of the subject's preferred brand Nicotine-free cigarettes contain other components, such as tar and a very little quantity of nicotine. The inhalation of the fictitious cigarette concerns only the ambient air. EEG theta power was decreased when subjects smoked their cigarette in a telic (excitation avoiding) state. Beta 2 power was elevated when subjects smoked their cigarettes in a paratelic (excitation searching) state.

3) *Cannabis*: Cannabis is the most commonly consumed illicit recreational substance in the world, with an estimated annual prevalence of 3.8 per cent of the adult population having used cannabis in 2021 [34]. At present, cannabis use has been legally established in many countries, both as a recreational and medical drug [35].

Resting-state activity in cannabis users has been characterised as the inverted of typical frequency dynamics, because it reduced delta and augmented theta, beta and gamma

[25]. This neural oscillation tendency is generally observed in task-related EEG signals, indicating that cannabis users presented increased cortical activation, also during the resting state. Similar resting state patterns have been found in heroin users [14], alcohol users [5], [22], and cocaine dependent users [9].

Smoking marijuana cigarettes [6] modify the strength and coherence of the alpha, theta and beta EEG bands. However, very few studies have analysed the influence of cannabis on the high frequency EEG bands, like gamma and high frequency oscillations (HFO) [8]. These oscillations have been related to a wide range of higher cerebral functions such as consciousness, working memory and perception [36].

The association between cannabis use and resting EEG is still ambiguous. Researchers discovered [6] that the theta resting state, with eyes closed, had a correlation with performance on a working memory task after acute cannabis intoxication, reflecting that the resting EEG can be related to cognitive performance. They also found effects in the dose-induced theta and beta bands, suggesting that these particular frequencies could be more sensitive to cannabis-related changes in cortical activity [6].

The relationship between resting EEG with eyes closed in cannabis and alcohol users [11] reported a positive correlation between delta power and cannabis dependence. Other researchers [26] have consistently found an increase in alpha and theta power and a decrease in delta and beta power at rest with eyes closed in long-term cannabis users and that cumulative exposure to marijuana over a very long period of time may be associated with slower cognitive processing; however, other studies have found a decrease in alpha and beta frequencies in posterior regions in abstinent cannabis users [16].

In addition, delta-9-tetrahydrocannabinol (THC) in the acute phase can disturb gamma oscillations via inhibitory interneurons [37]–[39], which suggests that cannabis users may have impaired gamma oscillations. Furthermore, a link between disruption of neuronal γ -band oscillations and cannabinoid-induced psychosis has been reported [8]. These results add to a large literature which proposes some overlapping of the acute effects of cannabinoids with the behavioural and psycho-physiological abnormalities identified in the psychotic diseases.

4) *Cocaine*: Cocaine's effects on human EEG [17] have been described as increasing beta-band activity. This has been repeated in more recent researches with larger sample sizes [4], [9], [19]. Excessive alpha activity and decreased delta activity [4], [7], [19] were observed, however others have found increased beta power [17] in cocaine addicts during resting conditions with eyes closed. Alterations in the EEG, predominantly in the anterior cortical regions, have been found to be associated with the quantity of cocaine previously consumed [19]. The EEG has been widely applied to characterise the effects of withdrawal in cocaine addicts. Many researches have shown that during prolonged cocaine abstinence, EEG effects are characterised by sustained

increases in the alpha and beta bands and decreased activity in the delta and theta bands. [4], [19].

Recently, qEEG profiles [23] have been studied in cocaine addicts in reaction to acute self-administered smoked cocaine (50 mg) versus placebo. Theta, alpha and beta absolute potentials were elevated in prefrontal cortical areas for up to 25 minutes after cocaine use. Increased theta power was related to a positive subjective effect of the drug (high), and elevated alpha was correlated with nervousness. Cocaine also induced a Delta Coherence increase over the prefrontal cortex, which was related to nervousness. The placebo produced only a small alpha power elevation over the prefrontal cortex. These qEEG data reveal the implication of the prefrontal cortex in acute cocaine and suggest that the slow waves of qEEG activity, delta and theta, are implicated in the processes associated with experiencing the gratifying properties of cocaine [23].

The notion of linking baseline EEG activity to cocaine dependence in subjects in treatment programmes shows that cocaine addicts have a durable change in brain function as measured by qEEG, present at baseline assessment 5 to 14 days after the latest report of cocaine use, and persisting at one-month and six-month follow-up assessments [4], [19], [40]. A number of recent QEEG studies have shown an increased beta activity in the EEG to be related to relapse to cocaine abuse [5]. A reduction in the delta and theta bands of the EEG can be interpreted as a strong indicator of brain disturbances.

5) *Heroin*: A limited number of investigations have examined QEEG changes in heroin addicts. In more than 70% of heroin users, changes were seen at the beginning of the abstinence period (acute withdrawal), and they included low-voltage activity in the background with decreased alpha activity, increased beta rhythm, and a large quantity of delta and theta waves of low amplitude in the central regions [18]. Abstinent heroin addicts [14] have increased rapid beta power when compared to normal controls, and this result is consistent with several other EEG findings in cocaine and alcohol users [4], [17], [21]. Most studies have shown considerable, if not complete, normalisation of EEG spectral power in formerly dependent heroin users who have been abstinent for at least three months [9], [18].

Another study on heroin [18] found that heroin users who had been using heroin for at least 18 months showed frequency changes in the fast alpha band at frontal and central sites and a slowdown in the average frequency of slow alpha at central, temporal and posterior recording sites. Acute heroin withdrawal is typically characterised by marked desynchronisation, but as noted above, studies [9], [18] show that EEG spectral power tends to return to near-normal after several weeks of abstinence. The most consistent changes in the EEG of heroin users were observed in the alpha and beta frequencies. In early heroin withdrawal, there was a lack of alpha activity and overactivity in fast beta. This latter abnormality, which can be considered an acute withdrawal effect, appears to be significantly reversed when heroin use is discontinued for several months.

The increased power of beta, alpha and theta rhythms in people with a history of opiate use suggests potential deficits in cognitive function, according to a quantitative study of resting EEG changes after methadone treatment in opiate users [15] suggests that the increased power of beta, alpha and theta rhythms in people with a history of opiate use signals potential deficits in cognitive function. In fact, studies have shown that chronic opioid users are impaired in visual memory, perception, motor function and inhibitory control [41], [42]. However, it seems that these deficiencies are not so severe in patients undergoing methadone maintenance treatment, as their EEG measures are less impaired than those of healthy controls.

IV. DISCUSSION

Electroencephalography (EEG) has revealed for the first time how addiction affects the brain and how it is diagnosed. For example, acute exposure to nicotine is associated with a large increase in scalp activity from lower (Delta, Theta, Low Alpha) to higher (Alpha, High Beta) frequencies, which is indicative of excitement. [10], [27]. Theta power was reduced when the participants in the telic state were smoking, whereas beta 2 power was increased when the participants in the paratelic state were smoking; this finding was only true for men. On the other hand, changes in the beta and theta frequency bands have been shown in EEG studies to be caused by doses of alcohol. In alcohol-dependent subjects, an increase in absolute power was detected at all scalp locations in Beta 1 (12.5-16 Hz) and Beta 2 (16.5-20 Hz), the increase was most pronounced in the central region. Beta 3 (20.5-28 Hz) power increased frontally in alcoholics. Male alcohol dependent subjects had clearly higher beta power in all three bands but Female alcoholics did not show a statistically significant increase. [22].

In the same sense, the augmentation of absolute theta power was also observed in all locations of the scalp in alcohol addict subjects; this increase in theta power was significantly greater in the central and parietal cortex in male alcoholics and in the parietal cortex in female alcoholics. Increased theta power in the EEG may represent an impairment of the central nervous system's information processing capacity in alcoholics [20]. Therefore the EEG of alcoholics differs significantly from those of normal controls, so the EEG can be used for diagnostic purposes. Therefore, the EEG of alcoholics is considerably different from that of normal controls, and the EEG can be used for diagnostic purposes. Furthermore, EEG may also have predictive utility because relapsers differ from abstainers in that they present with significantly more pronounced CNS hyperexcitability [24].

Cannabis users showed increased resting-state cortical activation, reflecting changes in the timing of neural oscillations that may be associated with cognitive impairment in cannabis use [25], with increased alpha and theta power and decreased delta and beta power in long-term cannabis users [26]. Therefore, the impact of THC on theta power and memory performance was correlated. [6].

In the same way, heroin induces: (a) a marked reorganisation of cerebral waves, with an augmentation in the proportion of fast beta and mainly in alpha frequency

segments, (b) Prolonged temporal stabilisation for alpha and beta brainwaves and brief temporal stabilisation for polyrhythmic theta activity, and (c) dominance of the right hemisphere (greater presence of certain spectral characteristics in the EEG channels) than in the left hemisphere [12]. Similarly, there is some evidence that heroin addicts have an increase in relative beta 2 power and an increase in gamma coherence on intra-hemispheric and left hemisphere. In addition, coherence measures have shown significant correlations with clinical variables [14].

Increased absolute and relative alpha power have been seen with quantitative EEG correlates of crack cocaine addiction [4]. Cocaine also markedly increased beta at the front and centre, and increased alpha at the front and temporal parts of the brain. Cocaine produced a similar cortical distribution of increases in EEG beta power to that induced by benzodiazepines and barbiturates. [17]. Cocaine's acute effects [23] produce rapid increases in absolute, alpha and beta-theta power over prefrontal cortical areas (FP1 and FP2) that persist for up to 25 minutes after exposure. Increased theta power was associated with feeling good effect and increased alpha power was associated with nervousness. There is a similar increase of delta coherence measured in the prefrontal lobe, which were a positive correlation with plasma cortisol and a negative correlation with nervousness. These findings provide evidence for the prefrontal cortex being implicated in the qEEG response to the acute administration of cocaine.

EEG measurements may also have a predictive and biomarker role. For example, in the prediction of alcohol and drug abuse relapse, is related to an increase in high frequency beta activity (19.5 to 39.8 Hz) with the coexistence of two pre-morbid factors, paternal alcoholism and the childhood conduct disorder. [5]. This prediction of alcohol relapse was found [28] and it was noted that, compared to abstainers, relapsers had more desynchronised EEGs in frontal regions, which was explained as a prefrontal cortex dysfunction. The elevation in EEG beta power can therefore be seen as a probable risk marker for the development of alcohol addiction and can be considered as an endo-phenotype predictor [21]. This suggests that subjects with a family history of alcohol abuse show alpha decreases and beta over-activity and have reduced relative and absolute alpha power in the posterior (O1; O2) and frontal (F3; F4; Fz) and elevated relative beta in both areas when compared to controls who do not have a family history of alcohol dependence. [13]. EEG recordings are also useful for monitoring the evolution of the addictive state and in case of withdrawal or abstinence.

Grace Y. Wang (2015) [15] examined the electrophysiological activity related with methadone maintenance treatment (MMT) in opiate addicts and found that patients taking MMT or active opiate consumers showed a considerable increase in beta and theta band power compared to controls and that the abnormal electrical activity of the nervous system, which is present in people who are still illegal opiate users, can be reduced after MMT. This increase in beta power was considerably higher in the inpatient groups addicted to alcohol and cocaine and in the 1-6 months abstinent group [9].

A pronounced hyperactivity of alpha relative power and deficits in absolute and relative delta and theta power demonstrate the presence of anomalies in brain function in withdrawal cocaine dependent subjects (not dependent on any other substance), These changes tended to be higher in the anterior than in the posterior cortex, and inter-hemispheric relations were also disrupted [19]. The cumulative evolution of the effect of heroin on brain function shows that a significant desynchronisation is characteristic of acute heroin withdrawal, and there is an almost complete return to normal over several weeks of abstinence, with the mean alpha 1 frequency decreasing, most markedly in the central, temporal and occipital lobe, and frequency changes in the alpha 2 frequency, most pronounced in the frontal and central lobe [18]. This slowing of alpha frequency is similar in smoking cessation [27]

V. CONCLUSION

Although the literature on EEG in addictions is highly heterogeneous, some authors agree that it is a relevant technique for discerning the phenomenology of addictions. EEG is sensitive to how addiction affects the brain and has shown changes in brain electrical activity during addiction. However, the clinical value of EEG recording in addictions is not yet clearly established. However, several studies argue that this non-invasive technique has an undeniable contribution to the understanding, prediction, diagnosis and monitoring of addictions. But future EEG studies are needed to identify other robust brain-electrophysiological specificities in addiction. The collection of more comparative data between EEG findings and clinical changes in addicts could also be useful and be improved by methodological insights.

REFERENCES

- [1] A. Gevins, « The future of electroencephalography in assessing neurocognitive functioning », *Electroencephalography and Clinical Neurophysiology*, vol. 106, no 2, p. 165-172, févr. 1998, doi: 10.1016/S0013-4694(97)00120-X.
- [2] « Gevins, A., McEvoy, LK, Smith, ME, Chan, CS, Sam-Vargas, L., Baum, C. et Ilan, AB (2011). Variabilité à long terme et intra-journalière des performances de la mémoire de travail et de l'EEG chez les individus. *Neurophysiologie clinique*, 123 (7), 1291-1299. ».
- [3] G. G. Knyazev, « Motivation, emotion, and their inhibitory control mirrored in brain oscillations », *Neuroscience & Biobehavioral Reviews*, vol. 31, no 3, p. 377-395, janv. 2007, doi: 10.1016/j.neubiorev.2006.10.004.
- [4] Levin KH, Herning RI, Better WE, Epstein DH, Cadet JL, Gorelick DA. EEG Absolute power during extended cocaine abstinence. *J Addict Med*. 2007;1(3):139-144. doi:10.1097/ADM.0b013e3180f493ee
- [5] L. Bauer, « Predicting Relapse to Alcohol and Drug Abuse via Quantitative Electroencephalography », *Neuropsychopharmacology*, vol. 25, no 3, p. 332-340, sept. 2001, doi: 10.1016/S0893-133X(01)00236-6.
- [6] K. B. E. Böcker, C. C. Hunault, J. Gerritsen, M. Kruidenier, T. T. Mensinga, et J. L. Kenemans, « Cannabinoid Modulations of Resting State EEG Theta Power and Working Memory Are Correlated in Humans », *Journal of Cognitive Neuroscience*, vol. 22, no 9, p. 1906-1916, sept. 2010, doi: 10.1162/jocn.2009.21355.
- [7] Rass O, Ahn W-Y, O'Donnell BF. Resting-state EEG, impulsiveness, and personality in daily and nondaily smokers. *Clin Neurophysiol*. 2016;127(1):409-418. doi:10.1016/j.clinph.2015.05.007
- [8] J. Cortes-Briones et al., « $\Delta 9$ -THC Disrupts Gamma (γ)-Band Neural Oscillations in Humans », *Neuropsychopharmacol*, vol. 40, no 9, p. 2124-2134, août 2015, doi: 10.1038/npp.2015.53.
- [9] L. Costa et L. Bauer, « Quantitative electroencephalographic differences associated with alcohol, cocaine, heroin and dual-substance dependence », *Drug and Alcohol Dependence*, vol. 46, no 1-2, p. 87-93, juin 1997, doi: 10.1016/S0376-8716(97)00058-6.
- [10] E. F. Domino, « Effects of tobacco smoking on electroencephalographic, auditory evoked and event related potentials », *Brain and Cognition*, vol. 53, no 1, p. 66-74, oct. 2003, doi: 10.1016/S0278-2626(03)00204-5.
- [11] C. L. Ehlers, E. Phillips, I. R. Gizer, D. A. Gilder, et K. C. Wilhelmsen, « EEG spectral phenotypes: Heritability and association with marijuana and alcohol dependence in an American Indian community study », *Drug and Alcohol Dependence*, vol. 106, no 2-3, p. 101-110, janv. 2010, doi: 10.1016/j.drugalcdep.2009.07.024.
- [12] A. A. Fingelkurts et al., « Increased local and decreased remote functional connectivity at EEG alpha and beta frequency bands in opioid-dependent patients », *Psychopharmacology*, vol. 188, no 1, p. 42-52, sept. 2006, doi: 10.1007/s00213-006-0474-4.
- [13] Herrera-Morales WV, Ramirez-Lugo L, Santiago-Rodríguez E, Reyes-López JV, Núñez-Jaramillo L. Hazardous alcohol consumption and risk of alcohol dependence present different neurophysiological correlates. *Rev Neurol*. 2019;68(4):137-146. doi:10.33588/rn.6804.2018176
- [14] I. H. A. Franken, C. J. Stam, V. M. Hendriks, et W. van den Brink, « Electroencephalographic Power and Coherence Analyses Suggest Altered Brain Function in Abstinent Male Heroin-Dependent Patients », *Neuropsychobiology*, vol. 49, no 2, p. 105-110, 2004, doi: 10.1159/000076419.
- [15] G. Y. Wang, R. Kydd, T. A. Woules, M. Jensen, et B. R. Russell, « Changes in resting EEG following methadone treatment in opiate addicts », *Clinical Neurophysiology*, vol. 126, no 5, p. 943-950, mai 2015, doi: 10.1016/j.clinph.2014.08.021.
- [16] R. I. Herning, W. Better, et J. L. Cadet, « EEG of chronic marijuana users during abstinence: Relationship to years of marijuana use, cerebral blood flow and thyroid function », *Clinical Neurophysiology*, vol. 119, no 2, p. 321-331, févr. 2008, doi: 10.1016/j.clinph.2007.09.140.
- [17] R. I. Herning, B. J. Glover, B. Koepl, R. L. Phillips, et E. D. London, « Cocaine-Induced Increases in EEG Alpha and Beta Activity: Evidence for Reduced Cortical Processing », *Neuropsychopharmacol*, vol. 11, no 1, p. 1-9, août 1994, doi: 10.1038/npp.1994.30.
- [18] A. G. Polunina et D. M. Davydov, « EEG spectral power and mean frequencies in early heroin abstinence », *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, vol. 28, no 1, p. 73-82, janv. 2004, doi: 10.1016/j.pnpbp.2003.09.022.
- [19] L. S. Pritchep, K. Alper, S. C. Kowalik, et M. Rosenthal, « Neurometric QEEG Studies of Crack Cocaine Dependence and Treatment Outcome », *Journal of Addictive Diseases*, vol. 15, no 4, p. 39-53, nov. 1996, doi: 10.1300/J069v15n04_03.
- [20] M. Rangaswamy et al., « Theta Power in the EEG of Alcoholics », *Alcoholism Clin Exp Res*, vol. 27, no 4, p. 607-615, avr. 2003, doi: 10.1111/j.1530-0277.2003.tb04397.x.
- [21] M. Rangaswamy et al., « Resting EEG in offspring of male alcoholics: beta frequencies », *International Journal of Psychophysiology*, vol. 51, no 3, p. 239-251, févr. 2004, doi: 10.1016/j.ijpsycho.2003.09.003.
- [22] M. Rangaswamy et al., « Beta power in the EEG of alcoholics », *Biological Psychiatry*, vol. 52, no 8, p. 831-842, oct. 2002, doi: 10.1016/S0006-3223(02)01362-8.
- [23] M. S. Reid, F. Flammino, B. Howard, D. Nilsen, et L. S. Pritchep, « Topographic Imaging of Quantitative EEG in Response to Smoked Cocaine Self-Administration in Humans », *Neuropsychopharmacol*, vol. 31, no 4, p. 872-884, avr. 2006, doi: 10.1038/sj.npp.1300888.
- [24] G. M. Saletu-Zyhlarz, « DIFFERENCES IN BRAIN FUNCTION BETWEEN RELAPSING AND ABSTAINING ALCOHOL-DEPENDENT PATIENTS, EVALUATED BY EEG MAPPING », *Alcohol and Alcoholism*, vol. 39, no 3, p. 233-240, mai 2004, doi: 10.1093/alcac/agh041.
- [25] S. Prasad, E. S. Dedrick, et F. M. Filbey, « Cannabis users exhibit increased cortical activation during resting state compared to non-users », *NeuroImage*, vol. 179, p. 176-186, oct. 2018, doi: 10.1016/j.neuroimage.2018.06.031.
- [26] F. A. Struve, G. Patrick, J. J. Straumanis, M. J. Fitz-Gerald, et J. Manno, « Possible EEG Sequelae of Very Long Duration Marijuana Use: Pilot Findings from Topographic Quantitative EEG Analyses of Subjects with 15 to 24 Years of Cumulative Daily Exposure to THC », *Clinical*

- Electroencephalography, vol. 29, no 1, p. 31-36, janv. 1998, doi: 10.1177/155005949802900110.
- [27] V. Teneggi et al., « EEG power spectra and auditory P300 during free smoking and enforced smoking abstinence », *Pharmacology Biochemistry and Behavior*, vol. 77, no 1, p. 103-109, janv. 2004, doi: 10.1016/j.pbb.2003.10.002.
- [28] G. Winterer, B. Kloppel, A. Heinz, M. Ziller, L. G. Schmidt, et W. M. Herrmann, « Quantitative EEG & QEEG predicts relapse in patients with chronic alcoholism and points to a frontally pronounced cerebral disturbance », 1998.
- [29] B. Porjesz, M. Rangaswamy, C. Kamarajan, K. A. Jones, A. Padmanabhapillai, et H. Begleiter, « The utility of neurophysiological markers in the study of alcoholism », *Clinical Neurophysiology*, vol. 116, no 5, p. 993-1018, mai 2005, doi: 10.1016/j.clinph.2004.12.016.
- [30] M. Nonaka, K. Otake, et T. Namatame, « Research on the Relationship between Exploratory Behavior and Consumer Values using Eye Tracking Gaze Data », *IJACSA*, vol. 12, no 8, 2021, doi: 10.14569/IJACSA.2021.0120802.
- [31] S. Hussain, N. Pirzada, E. Saba, M. A. Panhwar, et T. Ahmed, « Evaluating Domain Knowledge and Time Series Features for Automated Detection of Schizophrenia from EEG Signals », *IJACSA*, vol. 12, no 11, 2021, doi: 10.14569/IJACSA.2021.0121160.
- [32] B. Saletu1, P. Anderer1, G.M. Saletu-Zyhlzar1, O. Arnold1 and R.D. Pascual-Marqui2, « Classification and Evaluation of the Pharmacodynamics of Psychotropic Drugs by Single-Lead Pharmacoe-EEG, EEG Mapping and Tomography (LORETA) ».
- [33] A. Al-Nafjan, M. Hosny, A. Al-Wabil, et Y. Al-Ohali, « Classification of Human Emotions from Electroencephalogram (EEG) Signal using Deep Neural Network », *ijacsa*, vol. 8, no 9, 2017, doi: 10.14569/IJACSA.2017.080955.
- [34] « ONUDC (2021). Rapport mondial sur les drogues 2021. Repéré à <https://www.unodc.org/wdr2021> ».
- [35] J. Mujica, « The Role of Cannabis Legalization in Uruguay ».
- [36] E. Rodriguez, N. George, J.-P. Lachaux, J. Martinerie, B. Renault, et F. J. Varela, « Perception's shadow: long-distance synchronization of human brain activity », *Nature*, vol. 397, no 6718, p. 430-433, févr. 1999, doi: 10.1038/17120.
- [37] N. Hájos et al., « Cannabinoids inhibit hippocampal GABAergic transmission and network oscillations: CB1 receptors suppress hippocampal GABAergic inhibition », *European Journal of Neuroscience*, vol. 12, no 9, p. 3239-3249, sept. 2000, doi: 10.1046/j.1460-9568.2000.00217.x.
- [38] M. Hájos, W. E. Hoffmann, et B. Kocsis, « Activation of Cannabinoid-1 Receptors Disrupts Sensory Gating and Neuronal Oscillation: Relevance to Schizophrenia », *Biological Psychiatry*, vol. 63, no 11, p. 1075-1083, juin 2008, doi: 10.1016/j.biopsych.2007.12.005.
- [39] D. Robbe, S. M. Montgomery, A. Thome, P. E. Rueda-Orozco, B. L. McNaughton, et G. Buzsáki, « Cannabinoids reveal importance of spike timing coordination in hippocampal function », *Nat Neurosci*, vol. 9, no 12, p. 1526-1533, déc. 2006, doi: 10.1038/nn1801.
- [40] K. Alper, M.D., « Persistent QEEG Abnormality in Crack Cocaine Users at 6 Months of Drug Abstinence », *Neuropsychopharmacology*, vol. 19, no 1, p. 1-9, juill. 1998, doi: 10.1016/S0893-133X(97)00211-X.
- [41] K. D. Ersche et B. J. Sahakian, « The Neuropsychology of Amphetamine and Opiate Dependence: Implications for Treatment », *Neuropsychol Rev*, vol. 17, no 3, p. 317-336, sept. 2007, doi: 10.1007/s11065-007-9033-y.
- [42] G. W. Hanks, W. M. O'Neill, P. Simpson, et K. Wesnes, « The cognitive and psychomotor effects of opioid analgesics ».

The Usability of Digital Game-based Learning for Low Carbon Awareness: Heuristic Evaluation

Nur Fadhilah Abdul Jalil¹, Umi Azmah Hasran², Siti Fadzilah Mat Noor³, Muhammad Helmi Norman⁴

Fuel Cell Institute, Universiti Kebangsaan Malaysia, Bangi, Malaysia^{1,2}

Institute of Teacher Education, Malay Women Campus, Melaka, Malaysia¹

Faculty of Information Science & Technology, Universiti Kebangsaan Malaysia, Bangi, Malaysia³

Faculty of Education, Universiti Kebangsaan Malaysia, Bangi, Malaysia⁴

Abstract—Digital Game-based Learning (DGBL) that attracts many practitioners to engage students in promoting low carbon awareness has been understudied. The evaluation phase plays a crucial part in determining the usability of the learning material. This study aims to identify the usability of DGBL which consists of four components: game usability (GU), mobility (MO), playability (P), and learning contents (LC) from the perspective of targeted end-user using heuristic evaluation. This study will also provide recommendations to help improve the quality of any related DGBL for novice designers or practitioners. A prototype of DGBL was developed which aims to promote low carbon awareness by learning about fuel cell. The study was designed in two phases, which are (1) developing the heuristic evaluation instrument validated by experts and (2) playtesting to identify the issues of usability in DGBL via heuristic evaluation by targeted end-users, which are forty-six selected students aged fourteen years old. Hence, it shows that the DGBL prototype developed for fuel cell learning has succeeded in achieving learning objectives while promoting low carbon awareness.

Keywords—Heuristic evaluation; digital game-based learning; usability; low carbon awareness

I. INTRODUCTION

Digital game-based learning (DGBL) refers to the combination of digital games and educational content because it can create an interesting yet challenging learning environment [1]. The problem with DGBL is that it is complex and often involves multiple components, such as game mechanics, instructional design, and user interfaces. As a result, identifying and addressing usability issues can be challenging [2,3]. Furthermore, DGBL may be used by learners with varying levels of technical proficiency and familiarity with gaming conventions, which can further complicate the usability evaluation process. For example, a game mechanic that is intuitive to one learner may be confusing to another.

Usability can be done in a variety of ways, including thinking aloud, cognitive walkthroughs, laboratory usability testing, questionnaires, and guideline reviews [4]. Heuristics evaluation is one usability evaluation that identifies usability problems based on usability principles or heuristics [5]. However, existing heuristics proved to be very generic and some were not validated [6]. Therefore, the issue for the usability of DGBL using heuristic evaluation is how to effectively apply heuristic evaluation methods to identify and address usability issues in DGBL systems, taking into account the complexity of the system and the diversity of user profiles.

This will enable designers to create more effective and engaging DGBL systems that support learning outcomes.

Digital game-based learning (DGBL) has become a popular choice for younger learners as it can enhance motivation and active learning [7, 8]. DGBL's flexibility and accessibility make it an effective tool for enhancing motivation and learning, which has prompted researchers to investigate its advantages [9]. The use of attractive features such as audio, graphics, and animations in DGBL has proven to be effective in motivating students, especially for complex subjects like science or chemistry [10].

DGBL can also be a powerful strategy for achieving the goals of environmental awareness education, which aims to change the younger generation's mindset toward preserving nature [11,12]. Environmental issues, such as carbon emissions, have caused a significant increase in climate change and have impacted human health due to high levels of industrialization and urbanization [13]. A case study on the impact of a DGBL called "2020 Energy" was carried out that focuses on Spanish and American teenagers aged 12 years old and above aimed to explore issues of climate change [14]. The findings show that the game has a positive influence on the student's intention towards low-carbon activities which is related to the attitudes toward environmental awareness.

Low-carbon technologies such as solar, wind, and fuel cell have increasingly become a priority study in promoting environmental sustainability. Fuel cell technology, particularly which uses hydrogen as fuel, has the potential for zero-carbon emission. This study used a DGBL prototype that has been developed to increase the awareness of secondary students towards low carbon emissions by focusing on fuel cell technology. This study aims to (1) develop a heuristic evaluation using a set of questionnaires validated by experts and (2) identify the issues of usability in DGBL via heuristic evaluation through playtesting by targeted end-users.

In conclusion, DGBL presents challenges in evaluating its usability due to its complexity and diverse user profiles. Heuristic evaluation is a potential method for addressing usability issues in DGBL systems. DGBL is an effective tool for enhancing motivation and learning for younger learners, and it can play a crucial role in environmental awareness education. This study aims to address usability issues in a DGBL prototype focused on fuel cell technology by developing questionnaires validated by experts and applying

heuristic evaluation through playtesting by targeted end-users. By addressing usability issues, designers can create more effective and engaging DGBL systems that support learning outcomes and contribute to environmental sustainability.

II. LITERATURE REVIEW

In this section, related work on the usability of DGBL and Heuristic evaluation will be discussed as the key themes of this study.

A. Usability of DGBL

A good DGBL is capable of encouraging players to learn and enjoy learning content while keeping the players motivated throughout the gameplay [15]. However, to understand the whole gameplay experience, the usability of the DGBL cannot be disregarded. Usability proposes basic requirements for the functionality of an object in use [16] and, in this context, refers to the capability of a DGBL to be understood, learned, operated, and attractive to users when used to achieve the determined goals. Moreover, it can be evaluated through the interface review and user experience using heuristic evaluation [17].

Measuring usability is crucial for any DGBL application, especially in the early stages of development [4, 18]. Several studies on the design of heuristic questionnaires have evaluated usability issues in DGBL areas. One study suggested that the intended end-users may contribute by involving them as co-designers either in the development or evaluation stage [19] as this helps ensure the effectiveness of DGBL. All essential stakeholders in [20], including language experts and targeted students, were involved in the study of the usability of DGBL for language through heuristics and think-aloud approaches. A study that involved end-users in their heuristic evaluation also shows that it has improved the quality of their electronic health record (EHR) [21]. By involving end-users in the usability phase, designers and developers can create a DGBL that is designed with the user in mind. This will help develop a user-centered design that meets the needs and preferences of the target audience.

B. Heuristic Evaluation

Heuristic evaluation was introduced by Nielsen and Molich [22] and consists of usability components to be evaluated in any product such as application software, digital games, or mobile applications but not specifically for DGBL. However, it has become widely researched and has been applied across varieties of disciplines including educational technology. Defining specific domains of heuristics for evaluating the usability of DGBL by upgrading an existing domain of specific heuristics is cost-effective [4]. A set of systematic procedures that include usability evaluation methods that can easily detect usability problems within a limited time frame should also be established [17].

While heuristic evaluation is a useful tool for evaluating the usability of DGBL, it still has some limitations. The number of heuristics used may not cover all aspects of usability in the context of DGBL and more comprehensive heuristics that are specifically tailored to evaluate the usability of DGBL need to be developed. Furthermore, heuristic evaluation is typically

conducted in a controlled laboratory setting, which may not accurately reflect the real-world context in which the DGBL will be used [16]. These limitations can restrain the generalizability of evaluation results and may not fully capture the complexities of user interactions with the DGBL in real-world settings.

Heuristic evaluation involving targeted end users is a usability evaluation approach that involves the direct participation of end users in the evaluation process. This approach is based on the premise that end users are the best judges of usability and can provide more meaningful feedback to improve DGBL [6] in terms of the DGBL interface, navigation, game mechanics, and overall usability [23]. The advantage of involving targeted end users in heuristic evaluation is that they can provide valuable insights into the usability of DGBL from the perspective of the intended audience. By incorporating end user's feedback in the evaluation process, the DGBL can be designed to meet their specific needs and preferences leading to a more effective and engaging learning experience.

III. METHODOLOGY

In this approach, end users were given a set of heuristics or usability principles and identified any usability issues based on these heuristics using the DGBL prototype. All the items proposed for this usability testing use Bahasa Malaysia (the Malay language), which is the national language of the targeted end-users, as the mediated language to make it easier for them to evaluate the usability of the DGBL.

A. Heuristic Evaluation Components

A review of pertinent literature served as the first step toward identifying the required data. In this context, the heuristic evaluation consists of four components that cover all the usability aspects in DGBL, which are Game Usability (GU), Mobility (MO), Playability (PL), and Learning Content (LC) adapted from [24].

The GU component focuses on the interaction between the game design interface and the player's responses through the gameplay. The MO component represents how the player can easily enter the game world without any technical difficulties. The PL component describes the gameplay of the DGBL and includes the player's experience throughout the gameplay session that involves interactions between the players with the game mechanics and rules. The LC component concentrates on the learning content incorporated in the DGBL as the players should understand and acknowledge the specific learning contents when playing the DGBL prototype.

The study was designed in two phases that consist of (1) developing heuristic evaluation using a set of questionnaires validated by experts and (2) playtesting to identify the issues of usability in DGBL via heuristic evaluation by targeted end-user which are forty-six selected students aged fourteen years old. All research processes and procedures for both parts of this study were adapted from [17] as shown in Fig. 1 because it recommends specific and clear instruction from developing heuristic, validation processes by experts until usability testing using the developed heuristic.

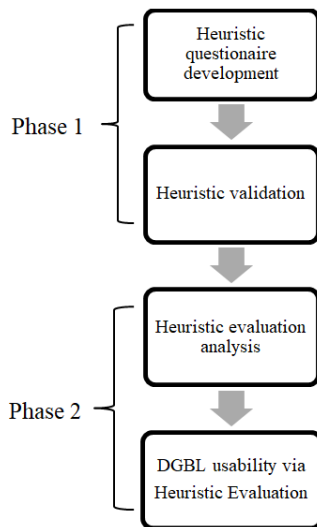


Fig. 1. Heuristic evaluation development process.

B. Phase 1

The first phase consists of developing and validating the heuristic evaluation. A questionnaire was developed that comprises 32 items based on the four components that specifically measure the Game Usability, Mobility, Playability, and Learning content. The questionnaire was rated using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) as recommended by [25] to allow respondents to indicate their level of agreement or disagreement with the items stated.

Next, all the items underwent a series of checking and review from a panel of experts to ensure the validity from the perspective of experts [26]. The expert panel review started with the sending of invitations via e-mail to the identified experts: three authorities from DGBL experts, a game developer, and a schoolteacher specializing in science secondary subject as shown in Table I. These experts, who did not take part in the design or the development of the DGBL, were given a set of heuristic evaluation questionnaires and a set of content validity instruments containing items adapted from [27]. Then, the findings from the panel expert review were calculated to determine the content validity level by dividing the total expert score (x) by the total maximum score (y) and then multiplying by 100%. These items for validation include the checking of the content for correctness in each item in the heuristic evaluation and verifying that the language is well chosen for the intended population.

TABLE I. EXPERTS PROFILE FOR HEURISTIC VALIDATION

Expert	Position	Academic qualification	Affiliation	Years of experiences
A	Associate Professor	PhD	School of Creative Industry Management & Performing Arts, Universiti Utara Malaysia (UUM)	21
B	Game Developer	Bachelor Degree	Nusantara	10
C	Practitioner	Bachelor Degree	SMK Seri Indah	15

C. Phase 2

The second phase involved conducting usability testing on forty-six students aged fourteen years old from selected schools in one state in Malaysia (Selangor) via the final heuristic evaluation. They are selected using purposive sampling with characteristics similar to the target end users. The characteristics of the students include the following: (1) already learned the topic of “air” in science subject taught in secondary school, (2) exhibit extremely high interest in playing mobile games, and (3) with prior experience in playing a game-based learning application at least once.

The Standard Curriculum for Secondary School (KSSM) is a curriculum designed by the Ministry of Education Malaysia for secondary students' comprehensive and integrated science education. Topics on “air” covers the various types of environmental pollution, including air, water, and soil pollution, and the impacts of pollution on human health and the environment [28]. All the students that have been selected participated in a playtesting session using the DGBL prototype to gather feedback on their experience to improve the gameplay, identify any usability issues, and evaluate the overall user experience.

There is no specific playtesting period as they can freely take their time to test and explore the DGBL, then answer the heuristic evaluation through a set of questionnaires given after the playtesting session. This is to ensure that the playtesting session happens in a natural setting without having any formal circumstances [24]. Therefore, evaluating aspects such as game usability, mobility, playability and learning content of the DGBL can be determined by the player’s feedback based on their experience.

IV. RESULTS

A. Heuristic Validation Result

The heuristic evaluation applied in the evaluation process by targeted end users is shown in Table II. The GU component was extended from having 10 items [24] to 14 items based on Expert A’s suggestion to specify the component in more detail.

The LC component was also extended from 4 items to 5 items [24], where LC5 focuses on language as one of the components and aims to evaluate the language used to ascertain whether it is understandable or not by the targeted end-user. This is a very important aspect of usability testing that can show the educational content’s relevance in the DGBL. The content validity scores from the expert panel for all the items in the questionnaire obtained an average of 96.7%, as shown in Table III. The content validity level is considered high when the value is more than 70% which indicates that the items are acceptable [27, 29].

B. Heuristic Evaluation Analysis

Table IV provides the results of the heuristic evaluation. The first component of the evaluation is GU. As seen in Fig. 2, mean = 4.079 (SD = 0.951) indicates all items, except for items 10, 11, and 13 have high mean scores between 4.0 to 4.3. The high value of GU shows that usability in a digital application gives a big impact on the interaction between the interface and the interaction of players throughout the gameplay. Overall, the

respondents are satisfied with the game’s visual graphics, game layout, and suitable audio used in this DGBL. However, respondents reported that there was an issue with using the game controls.

TABLE II. HEURISTIC COMPONENTS

Tag	Game Usability Component
GU1	Interesting game visual graphic
GU2	Suitable audio with the game
GU3	The Screen layout is visually pleasing
GU4	The interface is used for their purposes
GU5	The Navigation menu is easy to use
GU6	Control keys are consistent
GU7	Control keys follow standard conventions
GU8	The Interactive features provided are sufficient
GU9	Game controls are flexible
GU10	Game controls are convenient
GU11	The game gives feedback on the player’s actions
GU12	The player cannot make irreversible errors
GU13	The player does not have to memorize things unnecessarily
GU14	The game contains help
Tag	Mobility Component
MO1	The game and play sessions can be started quickly
MO2	The game accommodates with surroundings
MO3	Interruptions are handled reasonably
Tag	Playability Component
PL1	The game provides clear goals
PL2	The player sees the score progress in the game
PL3	The players are rewarded in the game
PL4	The player is in control of the game
PL5	Challenges in the game are in balance
PL6	The game is fun to be repeated
PL7	The game story is meaningful
PL8	There are no boring tasks
PL9	The game does not stagnate
PL10	The gameplay is consistent
Tag	Learning Content Component
LC1	The content can be learned easily
LC2	The game provides learning content
LC3	The learning objective from the game is achieved
LC4	The content is understandable
LC5	The language used is understandable

TABLE III. CONTENT VALIDITY SCORES

Expert	Total score	Content validity
A	10	100%
B	9	90%
C	10	100%
	Mean	96.7%

TABLE IV. MEAN AND STANDARD DEVIATION OF HEURISTIC COMPONENTS

Statistic	Heuristic Components			
	GU	MO	PL	LC
Mean	4.079	4.036	4.107	4.304
SD	0.951	1.017	0.925	0.782

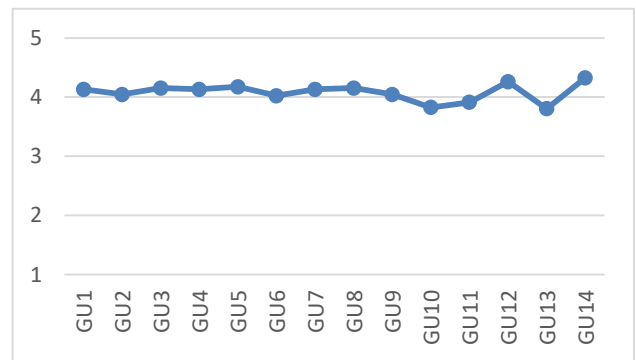


Fig. 2. Average score of game usability.

Respondents agreed that the MO of this DGBL prototype is high with an overall mean = 4.036 (SD = 1.017) as shown in Fig. 3. This indicates that the player can easily enter the game world without any technical difficulty.

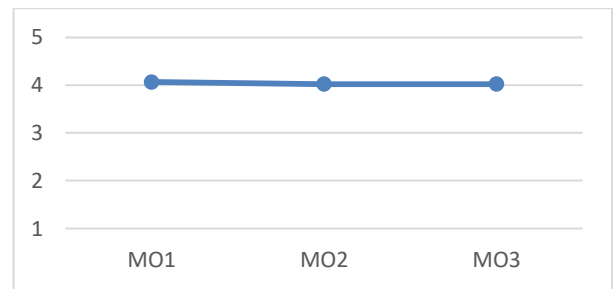


Fig. 3. Average score of mobility.

For the PL component, the relatively high mean = 4.107 (SD = 0.925) in Fig. 4 indicates that the respondents have a good experience throughout the gameplay session that involved interactions between the players with the game mechanics and the game rules. However, some respondents found that the task in bonus round is tedious due to repetition (item PL8 with mean = 3.956).

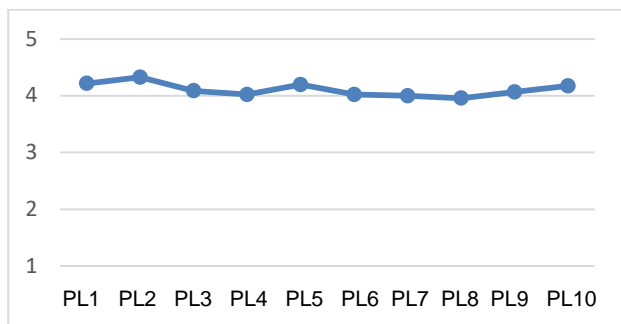


Fig. 4. Average score of playability.

For the LC components, the result in Fig. 5 shows the highest mean = 4.304 (SD = 0.782) compared to the other heuristic components. The majority of the respondents agreed that they can easily understand and acknowledge the specific fuel cell learning content when playing the DGBL prototype.

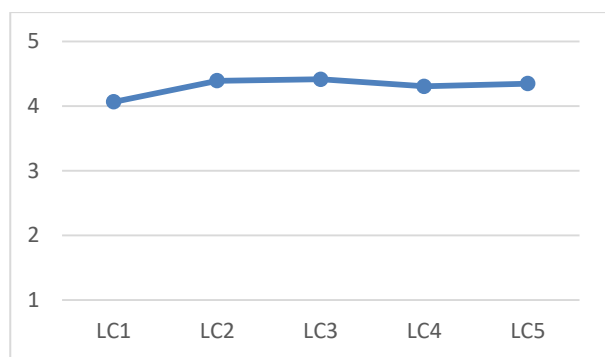


Fig. 5. Average score of learning content.

V. DISCUSSION

The expert panel's review findings verified that the language used was appropriate for the intended audience and validated the content's accuracy in each item's heuristic evaluation. The experts also agreed that all the items given are appropriate and can be used to test the usability of DGBL based on the four components stated.

According to the GU component results, the user interface, gaming controls, and user experience all have an impact on how the game plays out. Due to bugs found in the game controls, there are instances where gameplay is not running smoothly. These bugs need to be fixed to avoid the player feeling burdened and dissatisfied throughout the gameplay [23]. Game control is important in DGBL because it helps to create a structured learning experience that is effective in achieving the desired learning outcomes. Game control can also help to increase learner engagement and motivation. By carefully controlling the game mechanics, DGBL designers can create a sense of flow, where the player is completely absorbed in the game and loses track of time [30].

Finding form MO components emphasizes the importance of mobility in enhancing the overall user experience of the game. If the game is difficult to access or requires technical expertise, it can discourage players from engaging with it [24]. On the other hand, if the game is easy to access and play, players are more likely to enjoy the game and be motivated to

continue playing. This highlights the need for designers to prioritize accessibility and ease of use in game development to ensure a positive user experience.

The playability results showed that the respondents enjoyed their gaming session. However, several responders thought the bonus round work was boring because of the repetition. In the bonus stage, as shown in Fig. 6, the players need to drag Platinum, Hydrogen, and Oxygen molecules into the fuel cell. The task focuses on the correct locations of Platinum, Hydrogen, and Oxygen molecules in the fuel cell parts such as electrodes, Anode, or Cathode. The task was designed to be repeated three times in each phase of the bonus stage, where which will help the player to understand and remember the basic concept of the fuel cell. This was also supported by studies where repetitive tasks can help in memorizing as well as increasing understanding of basic knowledge [31, 32]. In order to keep player interest throughout the games, this task needs to be improved, for as by raising the level of difficulty in each bonus stage.

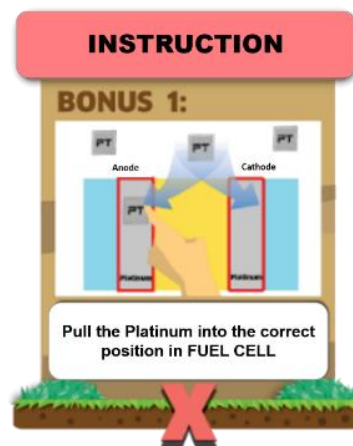


Fig. 6. Screenshot of the bonus stage.

Most of the participants in the survey acknowledged that, after using the DGBL prototype, they could quickly comprehend and acknowledge the particular fuel cell learning content. This is because the learning content itself has gone through a validation process from experts and a focus group test in the design phase of the DGBL. The learning content is also aligned with the players' existing knowledge as supported in Constructivism theory, e.g., the shape of Hydrogen molecules was designed by referring to their KSSM science textbooks used in standard schools (Fig. 7). This concern is supported by other studies where it is important to understand the basic knowledge to help in promoting environmental awareness [12, 33].

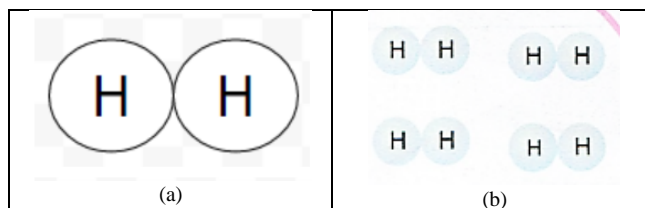


Fig. 7. (a) Shape of Hydrogen molecules in the DGBL prototype, (b) Shape of Hydrogen molecules in KSSM science textbooks.

The findings of this study can help improve the design and usability of DGBLs that can better promote low carbon awareness. By developing a set of questionnaires validated by experts and involving targeted end-users in playtesting, DGBL developers can obtain more meaningful feedback on the usability of their products. This can help identify and address usability issues early in the development process, leading to more effective and engaging DGBLs. While each study may focus on different aspects of usability, such as navigation, interaction design, or visual design, the use of heuristic evaluation allows researchers to identify potential issues and make recommendations for improvements. Additionally, the development of specific heuristics for evaluating the usability of DGBLs can provide a cost-effective and efficient way to detect usability problems within a limited time frame.

VI. CONCLUSION AND FUTURE WORK

Heuristic evaluation is an effective method for evaluating the usability of DGBL as this approach involves directly targeting the end user by applying a set of heuristics or guidelines to identify potential usability issues in the DGBL. This ensures that the game is more user-friendly, intuitive, and engaging for the targeted user group. By involving end users in the evaluation process, designers can better understand their needs and preferences, leading to more meaningful improvements to the game.

The heuristic evaluation in this work was adapted and extended for some items to specify the components accordingly. The findings may benefit any novice designer or practitioner in evaluating DGBL usability as this study provides a systematic guideline that can easily be followed. However, researchers and designers need to continue exploring new methods and approach for evaluating DGBL usability, particularly in the context of emerging technologies and changing user needs, to further improve the design and implementation of DGBL systems.

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REFERENCES

- [1] Chen, C.-H., C.-C. Shih, and V. Law, The effects of competition in digital game-based learning (DGBL): a meta-analysis. *Educational Technology Research and Development*, 2020. 68(4): p. 1855-1873.
- [2] Hussein, M.H., et al., Effects of digital game-based learning on elementary science learning: A systematic review. *IEEE Access*, 2019. 7: p. 62465-62478.
- [3] Clark, D.B., E.E. Tanner-Smith, and S.S. Killingsworth, Digital games, design, and learning: A systematic review and meta-analysis. *Review of educational research*, 2016. 86(1): p. 79-122.
- [4] Kumar, B.A. and M.S. Goundar, Usability heuristics for mobile learning applications. *Education and Information Technologies*, 2019. 24: p. 1819-1833.
- [5] Hussain, A.B., et al., Usability Evaluation of Mobile Game Applications: A Systematic Review. *environment*, 2015. 2: p. 5.

- [6] Othman, M.K., M.N.S. Sulaiman, and S. Aman, Heuristic evaluation: Comparing generic and specific usability heuristics for identification of usability problems in a living museum mobile guide app. *Advances in Human-Computer Interaction*, 2018. 2018.
- [7] Pesare, E., et al., Game-based learning and gamification to promote engagement and motivation in medical learning contexts. *Smart Learning Environments*, 2016. 3(1): p. 5.
- [8] Hussein, M.H., et al., Digital game-based learning in K-12 mathematics education: a systematic literature review. *Education and Information Technologies*, 2022: p. 1-33.
- [9] Behnamnia, N., et al., A review of using digital game-based learning for preschoolers. *Journal of Computers in Education*, 2022: p. 1-34.
- [10] Anuar, N.S.A., et al., Design and Development of Periodic Table Game for Students in Secondary School. *International Journal of Creative Multimedia*, 2021. 2(2): p. 15-29.
- [11] Dorji, U., P. Panjaburee, and N. Srisawasdi, A learning cycle approach to developing educational computer game for improving students' learning and awareness in electric energy consumption and conservation. 2015.
- [12] De Jans, S., et al., Using games to raise awareness: How to co-design serious mini-games? *Computers & Education*, 2017. 110: p. 77-87.
- [13] Dong, H., et al., Do carbon emissions impact the health of residents? Considering China's industrialization and urbanization. *Science of the total environment*, 2021. 758: p. 143688.
- [14] Ouariachi, T., J. Gutiérrez-Pérez, and M.-D. Olvera-Lobo, Can serious games help to mitigate climate change? Exploring their influence on Spanish and American teenagers' attitudes. *Psychology*, 2018. 9(3): p. 365-395.
- [15] Marcelino, L., et al. Conducting a usability playtest of a mathematics educational game with deaf and hearing students. in *12th International Conference on Videogame Sciences and Arts*, Mirandela, Portugal. <http://videojogos2020.ipb.pt>. 2020.
- [16] Quiñones, D. and C. Rusu, How to develop usability heuristics: A systematic literature review. *Computer standards & interfaces*, 2017. 53: p. 89-122.
- [17] Robson, R.S. and N. Sabahat, Heuristic Based Approach for Usability Evaluation of Mobile Games. in *2020 International Conference on Computing, Electronics & Communications Engineering (iCCECE)*. 2020. IEEE.
- [18] Olsen, T., K. Procci, and C. Bowers, Serious Games Usability Testing: How to Ensure Proper Usability, Playability, and Effectiveness. Vol. 6770. 2011. 625-634.
- [19] Din, R., et al., Universal Design & Agile Development Model For Meaningful Learning with Embedded Values, in *e-Learning Carnival and Conference 2018 UTeM*. 2018, Universiti Teknikal Malaysia Melaka. : Dewan UTeM 1, Kampus Teknologi, Universiti Teknikal Malaysia Melaka.
- [20] Ishaq, K., et al., Usability and design issues of mobile assisted language learning application. *Int. J. Adv. Comput. Sci. Appl*, 2020. 11(6).
- [21] Tremoulet, P.D., et al., Usability of Electronic Health Record-Generated Discharge Summaries: Heuristic Evaluation. *Journal of medical Internet research*, 2021. 23(4): p. e25657.
- [22] Nielsen, J. and R. Molich. Heuristic evaluation of user interfaces. in *Proceedings of the SIGCHI conference on Human factors in computing systems*. 1990.
- [23] Rajanen, M. and D. Rajanen. Heuristic evaluation in game and gamification development. in *GamiFIN*. 2018.
- [24] Zaibon, S.B., User Testing on Game Usability, Mobility, Playability, and Learning Content ff Mobile Game-Based Learning. *Jurnal Teknologi*, 2015. 77(29): p. 131-139.
- [25] Piaw, C.Y., *Kaedah Penyelidikan, Edisi Ketiga*. Vol. 3. 2014, Selangor McGraw-Hill Education.
- [26] Bostancıoğlu, A. and Z. Handley, Developing and validating a questionnaire for evaluating the EFL 'Total PACKAGE': Technological Pedagogical Content Knowledge (TPACK) for English as a Foreign Language (EFL). *Computer Assisted Language Learning*, 2018. 31(5-6): p. 572-598.

- [27] Ahmad, J., Modul motivasi diri. 2016, Kuala Lumpur: Dewan Bahasa dan Pustaka.
- [28] Curriculum Department Division, Science Form 2 Standard Based Curriculum For Secondary School 2017, Kuala Lumpur Ministry of Education, Malaysia.
- [29] Setambah, M.A.B., M. Adnan, and M.I.M. Saad, Adventure Based Learning Module: Content Validity and Reliability Process. *International Journal of Academic Research in Business and Social Sciences*, 2017. 7(2): p. 615-623.
- [30] Abdul Jabbar, A.I. and P. Felicia, Gameplay engagement and learning in game-based learning: A systematic review. *Review of educational research*, 2015. 85(4): p. 740-779.
- [31] Kao, C.-W., The effect of a digital game-based learning task on the acquisition of the English Article System. *System*, 2020. 95: p. 102373.
- [32] Rahman, F.A., T.D. Amalia, and M. Lutfi, Reducing Forgetting Rate in EFL Students Using a Spaced Repetition-Powered Digital Game-Based Learning Application. 2021.
- [33] Ouariachi, T., M.D. Olvera-Lobo, and J. Gutiérrez-Pérez, Serious Games and Sustainability. name *Encyclopedia of Sustainability in Higher Education*, 2019.

Optimization Design of Bridge Inspection Vehicle Boom Structure based on Improved Genetic Algorithm

Ruihua Xue^{1*}, Shuo Lv², Tingqi Qiu³

Wuhan CCCC Zhuan Kou Yangtze River Bridge Investment Co., Ltd., Wuhan 430000, China^{1,2}
Chengdu Xinzhu Road & Bridge Machinery Co., Ltd., Chengdu 611400, China³

Abstract—Excessive self-weight of bridge inspection vehicles increases the safety risk of the inspected bridge structures. In this study, a bridge inspection vehicle arm structure self-weight optimization design model is proposed to improve the efficiency and safety of bridge structure inspection. The model uses a finite element model of the arm structure to generate force data to validate and train a back propagation (BP) neural network-based self-weight prediction model of the arm structure, and uses an improved genetic algorithm to assist the prediction model in searching for the optimal solution. The experimental results show that the maximum stress and maximum deformation of the optimal solution from the optimization model designed in this study are lower than the allowable values of the material, and the total weight of the structure from the optimal solution is the lowest, 4687.5 kg. The computational time of the optimization model designed in this study is lower than all the comparison models. The experimental data show that the optimized model for the self-weight optimization of the bridge inspection vehicle arm structure designed in this study has good optimization effect and has some application potential.

Keywords—Genetic algorithm; Bridge inspection; Structural optimization; Finite element model; BP neural network

I. INTRODUCTION

Currently, the design of mechanical structures in China is generally completed through manpower, specifically relying on the personal experience and professional knowledge of engineers to complete the preliminary design of products [1-3]. This approach highly relies on the personal abilities of the designer, and the design cycle is long, and the design efficiency is also relatively low [4-6]. For large construction machinery such as excavators and bridge inspection vehicles, in most cases, their structural optimization design goal is to minimize the weight of the structure as much as possible while meeting the stress requirements, thereby improving the operational efficiency of the mechanical structure, saving energy and reducing emissions, and reducing construction risks caused by excessive mechanical self-weight [7-9]. As an important part of transport infrastructure, bridges play an irreplaceable role in maintaining traffic safety and ensuring economic development [10-12]. Periodic inspection and maintenance are essential during the operation of bridges [11-13]. As the main equipment for bridge inspection, the design and optimization of the bridge inspection vehicle arm directly affect the effectiveness and efficiency of bridge inspection [14-16]. With the rapid development of artificial intelligence technology represented

by neural networks, applying artificial intelligence technology to mechanical structure design has become one of the development trends in mechanical structure design [17-19]. Some previous research has attempted this type of method, but there are still some shortcomings, such as insufficient automation of the designed method and the need to incorporate a certain degree of expert experience into the method. The main reason for this phenomenon is that the parameters in mechanical structure design are complex and numerous, and it is difficult to model using a high level of automation. Therefore, this study attempts to combine finite element model analysis with artificial intelligence algorithms to explore a fast and sufficiently accurate lightweight design method for bridge inspection vehicle arm structures, and uses genetic algorithms to assist in searching for the optimal solution in the optimization model. In addition, considering the inherent drawbacks of genetic algorithms such as being prone to falling into local optima and having poor stability in optimization results, this study innovatively improves the selection operator, mutation, and poor probability calculation methods of genetic algorithms, which is also the importance of this study.

II. RELATED WORKS

Various artificial intelligence algorithms, including BP neural network algorithms, have been applied to a variety of industries and mechanical structure optimization design. Wang D et al. found that the traditional tunnel inspection and reconnaissance methods have high workload and high risk factor. Considering the high mobility of micro-rotor UAV, the authors designed an autonomous tunnel reconnaissance UAV incorporating information from multiple sensors such as inertial measurement units, vision and LIDAR, and used convolutional neural networks to optimize the self-weight of the UAV. The test results show that the optimized UAV reduces its self-weight by 15.7% compared to the pre-optimized UAV, which effectively improves the UAV's endurance [20]. The current additive design capability of Patel D's research team could not meet their production requirements well, so they designed an intelligent additive design system using two neural network architectures, and the test found that the system effectively improved the design efficiency of additive materials [21]. Kien DN et al. constructed a structural defect detection method for mechanical components using Alex neural network and tested that the method resulted in an 8.2% improvement in the accuracy of detecting production defects in mechanical structure design [22]. Li Y et al.

*Corresponding Author.

designed a lightweight optimization model for battery structure using radial-based neural network in order to solve the problem of lightweight design of automotive batteries. The experimental results showed that the application of the model reduced the mass of the designed battery pack by 17.62% and the maximum deformation by 30.78% [23]. Fan Y's research team found that the geometry of high-temperature sealed ceramic parts has a significant impact on their compressive resilience performance, so an accurate and large-scale artificial neural network was built to match the relationship between structural parameters and mechanical properties of ZrO_2 parts fabricated through 3D printing. The prediction results show that the combination of artificial neural network and finite element is a better method to optimize the structure and guide the 3D printing method to fabricate complex ceramic parts [24]. Han X et al. proposed a fast, efficient and convenient method to optimize the shape design of centrifugal pump impeller and worm housing by combining genetic algorithm and back propagation neural network. The experimental results showed that the optimized impeller increased the head and efficiency by 7.69% and 4.74%, respectively, at the design flow conditions, while the optimized power was reduced by 2.56%. The hydrostatic pressure across the optimized impeller is more uniform, and the hydraulic performance of the centrifugal pump with the optimized impeller exceeds that of the original centrifugal pump at low and design flow conditions [25]. To AC et al. proposed a new topological optimization method that uses a neural style to simultaneously optimize the mechanical structural performance and geometric similarity of the reference design for a given load condition; this method pre-trains the convolutional layers of the neural network and extracts the geometric similarity. This method also pre-trains the convolutional layers of the neural network and extracts quantitative features from the reference and input data to perform structural optimization. Test results show that the use of this method to optimize the design of mechanical components resulted in the production of components with a 16.7% reduction in dead weight with only a 2.82% increase in maximum stress [26].

In summary, experts in artificial intelligence and mechanical design have conducted extensive research to analyze the possibility and effectiveness of using intelligent algorithms for automatic design of mechanical components. The ideas behind designing these methods may have some inspiration for this study, which is also the connection between this study and previous studies. However, there are still some shortcomings in previous studies, such as insufficient automation of design methods, a certain degree of expert experience still needs to be incorporated into the method. At the same time, the application of this approach to the lightweight design of bridge inspection vehicle structures in previous studies is quite rare. At the same time, the automatic lightweight design of bridge inspection vehicle structures is of great significance in improving the work efficiency of bridge inspection vehicles, saving operating energy consumption, and even reducing the possibility of potential accidents caused by excessive self-weight of inspection vehicles. This is the

purpose or objective result of this study. The research may provide some improvement suggestions for the design and manufacturing of future bridge inspection vehicles, which is the impact of this study on the future.

III. MODEL DESIGN FOR WEIGHT OPTIMIZATION OF TRUSS BRIDGE INSPECTION VEHICLE ARM STRUCTURE

A. Finite Element Modeling of the Structure of the Inspection Arm of the Truss-type Bridge Inspection Vehicle

In order to optimize the arm structure of the inspection vehicle, the arm structure needs to be abstracted and modeled first, specifically by establishing its finite element model, in order to remove elements that have no or little influence on the optimization problem and highlight the computational elements that determine the structural optimization results [27]. The loading arm system of truss bridge inspection vehicle consists of gear slewing structure, telescopic working platform, inner and outer working platform, vertical lifting tower and lower slewing truss. The truss bridge inspection vehicle, which is commonly used in bridge construction projects, was selected as the object of this study, and the dimensions of the components to be optimized in its design structure are shown in Fig. 1.

In the optimization problem of truss bridge inspection vehicle arm structure, since the total length of the inner and outer telescopic working platform of the arm truss and the parameters of the lowering depth of the lift tower are determined through the working conditions, it is more reasonable to choose the constructed interface size as a design variable here. Specifically, the sheet thickness and profile dimensions of the interface are selected as design variables. Here, the design variables are first treated as continuous variables to solve the optimization problem, and then the values of the optimal solution are rounded to obtain the appropriate discrete values according to the actual situation. The distribution of design variables of interface dimensions for each type of carriage arm truss rod is shown in Fig. 2.

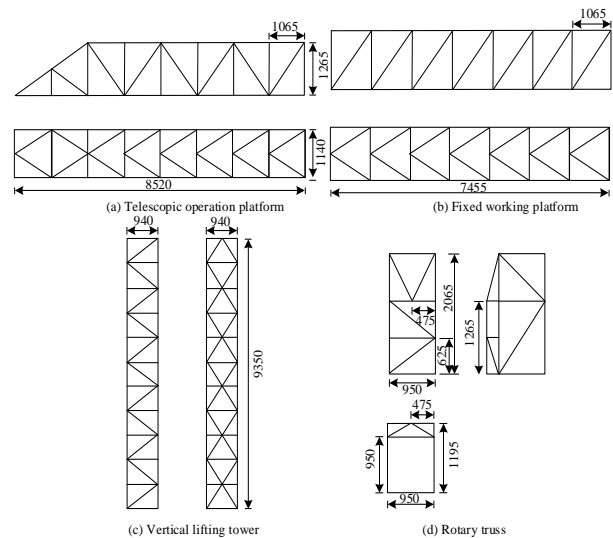


Fig. 1. Common truss bridge inspection vehicle core structure dimensions.

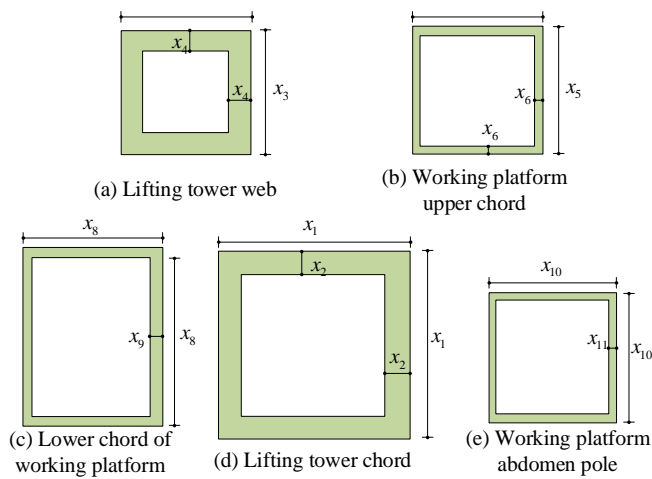


Fig. 2. Distribution of design variables of the arm section of truss bridge inspection vehicle.

The specific meaning of each section design variable, the range of variables, and the initial value of each section design variable of the truss bridge inspection vehicle arm truss in Fig. 2 are shown in Table I. The value range of each variable in Table I is obtained by referring to the corresponding design range of truss bridge inspection truck arm trusses in the industry, and the respective initial values are determined according to the most common values of the same type of products on the market.

TABLE I. DESIGN VARIABLE SPECIFIC INFORMATION DISPLAY TABLE

Parameter number	Variable Symbols	Initial Value	Value range/mm	Variable Meaning
*01	x_1	82	[60,90]	Lifting tower chord cross-sectional dimensions
*02	x_2	11	[5,15]	Cross-sectional material thickness of lift tower stringers
*03	x_3	50	[40,60]	Lifting tower web cross section size
*04	x_4	7	[5,17]	Lifting tower web material thickness
*05	x_5	50	[45,60]	Cross-sectional dimensions of stringers on workbench
*06	x_6	3	[1,8]	Material thickness of stringers on the workbench
*07	x_7	67	[42,75]	Cross-sectional dimensions of the lower chord of the working table
*08	x_8	22	[10,33]	Cross-sectional dimensions of the lower chord of the working table
*09	x_9	5	[2,10]	Material thickness of the lower chord of the working table
*10	x_{10}	45	[25,60]	Cross-sectional dimensions of the lower web of the working table
*11	x_{11}	2.5	[1,8]	Thickness of material of lower web bar of worktable

Considering all kinds of possible working conditions of the inspection vehicle, the most dangerous working condition was selected to carry out the study, i.e. the working condition when the vertical lift tower descends to the lowest position. In this case, the vertical relationship between the telescopic inspection platform and the bridge is vertical, the load borne by the inspection vehicle is 300 M/kg, and the safety factor is 1.5 according to industry regulations.

The parametric model of the truss structure of the inspection vehicle is designed again below. Considering the actual structure of the inspection vehicle arm, it is stipulated that the contact points between the guiding and positioning rollers and the lift tower flange plate are connected by fixed constraints, and the upper and lower end plates of the arm structure are connected by using the gears and bolts of the slewing structure. Although the rotating truss is also connected to the slewing structure and the inner and outer table lap joints using bolts, this part of the modeling is too complex and will significantly increase the number of finite element units and nodes, so the connection structure is ignored and the connection between them is considered as direct coupling. Using the established finite element model to carry out structural statistics and static calculations, it was found that the total mass of the model was 5519.48 kg, and the maximum equivalent stress of the structure was 250.4 MPa, which appeared at the bolt hole of the lower end plate of the rotary structure, while the stress at other locations was much smaller than this value. The strength requirement is satisfied. The maximum displacement of the structure is 98.58mm in the vertical direction of the arm truss, which also meets the structural requirements.

B. Mapping Relationship Model and Mathematical Model Design for Structure Optimization

The computational efficiency of using manual debugging of design variables and then running the finite element model to calculate the optimization target values is particularly low. Therefore, this study uses a BP neural network to construct a mapping relationship between the structural design variables and the optimization objective, i.e., the structural weight of the arm, in order to achieve the goal of fast optimization. The reason for using BP neural network instead of other more complex and advanced neural network algorithms to construct the mapping relationship model is that the target problem in this study is not complicated in terms of features and does not require repeated and high-latitude abstraction extraction, which would substantially increase the computational and training time of the mapping model. And it is difficult to provide a large number of data samples that can make the latter training effective in this study. Before building the mapping model, it is also necessary to select a suitable training sample set. Now, we choose to use the orthogonal test method to obtain the sample data because it generates data samples with neat comparability and balanced distribution, i.e., it is possible to obtain a data set with as complete a distribution as possible with fewer samples.

The orthogonal table $L_{50}(5^{11})$ is chosen to obtain the training samples, which contains 5 levels, 50 samples and 11 design factors, as shown in Table II. As shown in Table II, the truss self-weight, maximum deformation and maximum equivalent

force of the model structure are taken as the output in turn, and the required calculation results can be quickly generated by using the finite element model of the inspection vehicle arm.

TABLE II. $L_{50}(S^{11})$ ORTHOGONAL TEST DETAILS

Design Variables	Level 1	Level 2	Level 3	Level 4	Level 5
x_1	81	82	84	85	88
x_2	10	11	12	13	14
x_3	49	51	54	55	57
x_4	8	10	11	12	13
x_5	49	51	55	57	59
x_6	3.0	3.5	4.0	4.5	5.0
x_7	61	62	64	65	68
x_8	21	22	25	27	29
x_9	4.0	4.5	5.0	6.0	6.5
x_{10}	43	44	47	48	51
x_{11}	3.0	3.5	4.0	4.5	5.0

Therefore, the size of the designed BP neural network input data is fixed to 11×50 , and the output is the maximum equivalent force and overall mass of the model. Since some of the design variables vary greatly in order of magnitude and may even be out of oversaturation, thus slowing down the convergence or even failing to complete the convergence, the input data need to continue the normalization process. The BP neural network in the mapping model adopts the classical four-layer organization structure, and after several debugging, each layer is substituted with S-type tangent function, S-type logarithmic function, and pure linear function as the transfer function in turn.

The mapping model can be used to quickly calculate the predicted optimization results of the opposing structural solution for the input design variables, but the output value is not the global optimal solution. Therefore, it is also necessary to perform an optimization search operation on the neural network mapping model. The following is a mathematical model of structural optimization required for the optimization search process.

The optimization objective of the mathematical model is to minimize the total weight of the structure while satisfying all the constraints, so as to achieve the effect of improving the efficiency of the drive system and the whole vehicle. Therefore, the objective function and constraints of the structure optimization mathematical model of the detection vehicle are shown in formula (1) and (2), respectively, by calling the three trained BP neural network implicit functions.

$$\min f(x) = \text{sim}(\text{net } G, x) \quad (1)$$

$$\begin{cases} \sigma = \text{sim}(\text{net } S, x) < [\sigma] \\ f = \text{sim}(\text{net } f, x) < [f] \end{cases} \quad (2)$$

In formula (1), $f(x)$ and $\text{net } G$ are the self-weight function and auto-implicit function of truss respectively, the former is calculated by finite element model and the latter is obtained by BP mapping network training; in formula (2), σ and f are structural stress and vertical displacement respectively, $[\sigma]$ and $[f]$ are allowable stress and allowable stiffness respectively, $\text{net } S$ and $\text{net } f$ are structural stress implicit function and vertical maximum displacement implicit function respectively. The input data x satisfy the relationship of formula (3).

$$x \in X = [x_1, x_2, \dots, x_{11}]^T \quad (3)$$

C. Design of Optimization Model Solving Method Based on Improved Genetic Algorithm

Genetic algorithm is an optimization algorithm designed after biological genetic rules, which has excellent adaptive ability and large solution set coverage, so it is widely used in solving various complex optimization problems. This time, genetic algorithm is also chosen as the mapping model optimization method, but the traditional genetic algorithm has the following disadvantages. Firstly, the traditional genetic algorithm population initialization is carried out randomly, which may make the mapping model miss the optimal solution, secondly, due to the complex computational content of the mathematical model for structural optimization of the detection vehicle, it will lead to slow convergence of the algorithm, and finally, the traditional genetic algorithm also has the problem that it may fall into local convergence. To alleviate these problems, this study improves the traditional genetic optimization algorithm in many aspects, and the improvement process will be analyzed in detail below.

In the iterative process of genetic algorithm, variation probability and crossover probability play a significant role in the calculation results of the algorithm, and it is necessary to optimize these two parameters because they may even directly lead to the failure of optimization if they are not set properly. In classical genetic algorithms, the variation probability and crossover probability change with the increase of iterations, thus increasing the genetic diversity of the population and reducing the possibility of falling into local optimum. For the classical genetic algorithm, when the fitness of an individual is greater than the average fitness of the population, it means that it is a good individual, and the corresponding variation and crossover probabilities are both a small value, making it easier to save to the next generation. On the contrary, it means that the current individual is a poor adaptor, and its variation and crossover probability are larger values, aiming to improve the quality of its offspring. However, if the individual fitness is equal to the maximum fitness of the population, the corresponding two probability metrics will be reduced to 0. Although this internal regulation model is more reasonable in the later stages of the iteration, when the majority of individuals in the population are excellent and the impact of variation adjustment should be minimized. However, in other stages of the iteration, this approach makes the evolution and convergence process too slow, and this is the optimal individual may not be the global optimum. To address the

drawbacks of this adaptive adjustment, previous work has improved the calculation of the crossover probability P_c and the variance probability P_m , as in formulas (4) and (5).

$$P_c = \begin{cases} P_{c1} - \frac{(P_{c1} - P_{c2})(f' - f_{avg})}{f_{max} - f_{avg}}, & f' \geq f_{avg} \\ P_{c1}, & f' < f_{avg} \end{cases} \quad (4)$$

$$P_m = \begin{cases} P_{m1} - \frac{(P_{m1} - P_{m2})(f_{max} - f)}{f_{max} - f_{avg}}, & f' \geq f_{avg} \\ P_{m1}, & f' < f_{avg} \end{cases} \quad (5)$$

In formulas (4) and (5), P_{c1} , P_{c2} , P_{m1} , and P_{m2} are the parameters to be set, and f' , f_{avg} , and f_{max} represent the fitness values of the individuals to be mutated, the average fitness of the population, and the maximum fitness, respectively. This improved calculation method uses an elite retention strategy, which protects the best individuals in each generation. However, the parameter of the number of iterations of the population needs to be added to ensure that the two probabilities will change dynamically, so this study adjusts the calculation of the crossover probability and the variation probability to formulas (6) and (7).

$$P_c = \begin{cases} P_{c1} \left(1 - \cos^2 \left(\frac{f' - f_{avg}}{f_{max} - f_{avg} + \lambda} - 1 - \frac{\pi}{2} \right) \right), & f' \geq f_{avg} \\ P_{c1}, & f' < f_{avg} \end{cases} \quad (1)$$

$$P_m = \begin{cases} \frac{1}{\sqrt{n}} P_{m1} - \left(1 - \cos^2 \left(\frac{f_{max} - f}{f_{max} - f_{avg} + \lambda} - 1 - \frac{\pi}{2} \right) \right), & f' \geq f_{avg} \\ \frac{1}{\sqrt{n}} P_{m1}, & f' < f_{avg} \end{cases} \quad (2)$$

In formulas (6) and (7) λ is a very small positive number, which is added to prevent the occurrence of a situation in the population where the average fitness is equal to the maximum fitness. n , for the number of iterations, the two probabilities are combined with the number of iterations and the trigonometric function, so that they satisfy both non-zero and changeable with the fitness to avoid the situation of falling into local optimum. The selection operation is an indicator to judge whether an individual can be inherited or not. In the optimization problem of this study, the size of the adaptation degree of the optimized solution is closely related to its total structural weight, which means that when the total structural weight is too large, the corresponding solution should be eliminated. For this characteristic, elite retention and roulette selection methods can be chosen to screen genes. The roulette selection strategy allows individuals with greater fitness to be preferentially selected for inheritance to the next generation, facilitating the process of optimization and iteration, which is more common and will not be repeated here. The elite selection

strategy can make the better individuals not be destroyed by the hybridization strategy, so the elite selection strategy is chosen as the selection operator of the algorithm. The specific treatment of the elite selection strategy is that when the best individual appears in the population, it is directly copied to the next generation and the subsequent steps are skipped.

The mutation operation serves to increase the genetic richness of the population and prevent the algorithm from early convergence. For the characteristics of the inspection vehicle arm structure weight optimization problem, the mutation operation was chosen to be carried out in this genetic algorithm using the inversion mutation method. The specific processing method is shown in Fig. 3.

However, the disadvantage of this mutation algorithm is that there is no way to know whether the mutated chromosome is superior to the parent, and if the mutated chromosome becomes worse instead, it will instead increase the possibility of local convergence of the algorithm. To avoid this situation, the validity of this mutation needs to be judged after the inversion mutation operation is finished. Here, we choose to use fitness as an indicator to judge the level of chromosomal excellence of the offspring. If the judgment result shows that the chromosome fitness of the offspring is smaller than that of the parent, the mutation operation is deleted, and the result is accepted on the contrary. The improved genetic algorithm was designed by combining the above improved results, and its computational process is shown in Fig. 4. As shown in Fig. 4, firstly, the mapping model based on BP neural network was input into the algorithm, and then the binary coding method was applied to encode the parameters of the improved genetic algorithm, in which several populations were randomly generated, and the fitness function was used to calculate the genetic probability of each individual. Before carrying out the chromosome crossover mutation operation, it is necessary to retain a few good individuals according to the elite strategy, and then judge whether the current operation is inbred, because if it is inbred, it will bring serious adverse effects to the optimization results. If the judgment result is "yes", reselect the operation object and judge again. If the answer is "no", crossover and mutation operations are performed on all individuals according to formulas (6) and (7) to generate new offspring, and finally determine whether the current population and algorithm parameters meet the stop iteration condition, and if so, stop the iteration and output the optimal individual, i.e., the optimal detection vehicle arm structure optimization scheme, and if not, return to the calculation of genetic probability. Step to continue running the algorithm.

This completes the design of the optimized model for the weight of the arm structure of the truss bridge inspection vehicle.

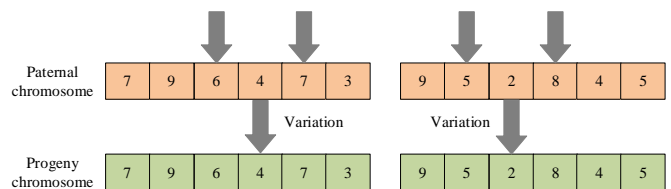


Fig. 3. Schematic diagram of inversion variant treatment.

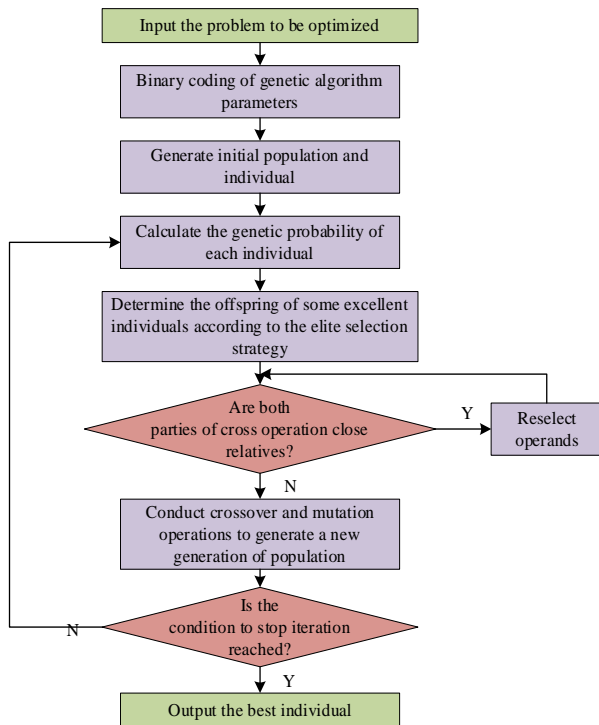


Fig. 4. Flow chart of improved genetic algorithm calculation.

IV. OPTIMIZE MODEL PERFORMANCE TESTING

In order to verify the effect of the optimization method designed in this study on the optimization of the bridge inspection vehicle arm structure, the optimization model designed was implemented using Python language, and its input interface with the finite element model calculation data was built. After several tests and adjustments, the experimental BP neural network model was selected from Trainlm learning method, the maximum number of training steps was fixed to 1000, and the target error was set to 1×10^{-10} . At the same time, the Faster-Regions with CNN features (Faster-RCNN) neural network algorithm, which is widely used in current application scenarios and has excellent performance, was selected to form a comparison model, and finally The following four optimization model schemes are formed: classical genetic algorithm + BP neural network, improved genetic algorithm + BP neural network, classical genetic algorithm + Faster-RCNN neural network, improved genetic algorithm + Faster-RCNN neural network, hereinafter referred to as CGA+BP, IGA+BP, CGA+FRCNN, IGA+FRCNN, respectively.

In order to verify the reasonableness of using neural network algorithm instead of finite element model, after constructing and training the mapping model based on BP and Faster-RCNN, five groups of data different from the training samples were randomly selected to carry out the simulation test, and the test results are shown in Fig. 5. The horizontal axis in Fig. 5 shows each prediction model and the prediction index of the output, the left vertical axis represents the total structural self-weight of the output of various models, and the right

vertical axis represents the maximum structural stress of the output of each model. The right vertical axis represents the maximum structural stress output of each model, and the data with percent sign in the figure is the absolute value of the relative error of the output value of the prediction model relative to the output value of the finite element model. As can be seen in Fig. 5, the predicted mean structural dead weight and maximum structural stress of the predictive models based on BP neural network and Faster-RCNN for the five groups of test design variables are 5164.8 kg, 5170.4 kg, 223.63 MPa, 223.95 MPa, and 0.81%, 0.92%, 1.62%, 1.48% respectively. It can be seen that the absolute values of the average relative errors are within the allowed range (less than 5%), indicating that the two selected prediction models can be used. Although the relative error of the structure maximum self-weight prediction value of the Faster-RCNN-based prognostic model is smaller than that of the BP network-based one, the fluctuation of the former prediction is significantly larger, so it is reasonable to select the BP algorithm to construct the prognostic model.

The following analysis of the BP and Faster-RCNN neural network training process in the structural optimization model is shown in Fig. 6. The horizontal axis is the number of model iterations and the vertical axis is the value of the loss function, with different line shapes representing different optimization models. Since the loss function decreases extremely fast in the early stage of model training, the vertical axis is shown in segments. The loss function values after convergence of the two models IGA+BP and IGA+FRCNN constructed using the improved genetic algorithm are significantly lower than those of the other two models, and the former is higher than the latter, at 1.52 and 3.15, respectively, indicating that the global search capability of the algorithm is indeed significantly enhanced after improving the genetic algorithm along the lines of this study. From the perspective of the number of iterations, the model using BP neural network converged significantly faster than the model using Faster-RCNN neural network, for example, IGA+BP and IGA+FRCNN converged after 91 and 169 iterations, respectively.

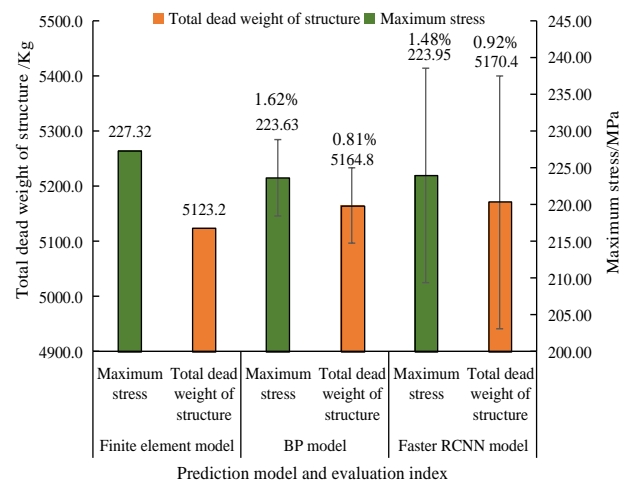


Fig. 5. Comparison of the prediction results of the prediction models.

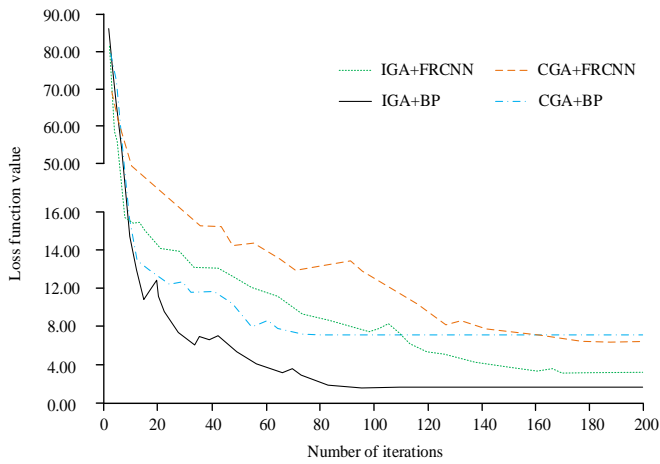


Fig. 6. Comparison of the training process of each optimization model.

In the following, the calculation results of the optimal solution parameters output from each model corresponding to the circular integer value scheme are compared again, as shown in Table III. Observing Table III, it can be seen that after the calculation and processing of each optimization model, some of the design variables of the four optimal integer solutions derived have increased compared to the initial values, but most of the design variables have a significant decrease. From the perspective of maximum stress and maximum deformation, the IGA+FRCNN model is the smallest with 213.9 MPa and 74.64 mm, respectively, followed by the IGA+B0P model with 219.50 MPa and 79.31 mm, respectively. But the maximum stress and maximum deformation of the optimal integer solutions of all the optimized models are smaller than the initial design values and lower than the allowable values. From the perspective of measuring the total structural weight of the measuring arm, the IGA+B0P model has the lowest total structural weight of 4687.5 kg.

Finally, the computational efficiency of each optimization model is analyzed, so different groups of design variables are input and the statistics are obtained in Fig. 7. The horizontal axis in Fig. 7 represents the number of groups of design variables processed by the model consecutively, and the vertical axis represents the total computational time spent. Different curve types represent different optimization models, and the gray vertical lines are auxiliary lines. As can be seen in Fig. 7, the computational time of the model incorporating the FRCNN algorithm is significantly more than that of the model constructed based on the BP algorithm, mainly because the former has a complex structure and more computational levels. Also the computation time of the model using the improved genetic algorithm is significantly lower than that of the model using the same prediction algorithm but without the improved genetic algorithm. For example, when the number of groups of variables with computation is 50, the computation time of each scheme of CGA+BP, IGA+BP, CGA+FRCNN, and IGA+FRCNN is 5.88s, 4.62s, 10.24s, and 9.57s, respectively.

To further compare and study the designed methods, a bridge inspection vehicle optimization method based on incremental algorithm is designed here, and the parameters in

the algorithm are determined through multiple debugging methods. The data obtained from the experiment is relatively simple, and it is described in text here. According to the statistical experimental data, it was found that the optimal structural parameters optimized by the IGA+BP model designed in this study still have lower self-weight than the incremental algorithm, indicating that the optimization effect of the latter is worse than that of the former.

TABLE III. COMPARISON OF OPTIMAL INTEGER SOLUTIONS FOR EACH OPTIMIZATION MODEL

Name	Initial design value	CGA+BP	IGA+BP	CGA+FRCNN	IGA+FRCNN
x_1 /mm	82	74	67	71	69
x_2 /mm	11.00	6.00	6.00	6.00	6.00
x_3 /mm	50	61	58	60	59
x_4 /mm	7.00	7.50	6.50	7.00	6.50
x_5 /mm	50	56	58	58	60
x_6 /mm	3.00	2.50	2.00	2.50	2.50
x_7 /mm	67	52	50	52	50
x_8 /mm	22	16	15	15	16
x_9 /mm	5.00	4.50	4.00	5.00	4.50
x_{10} /mm	45	54	60	62	60
x_{11} /mm	2.50	3.50	4.00	4.00	4.00
Maximum stress/MPa	250.48	227.1	219.50	224.8	213.9
Maximum deformation/mm	101.36	96.49	79.31	87.15	74.64
Self-weight/kg	5574.2	5271.0	4687.5	5188.3	4962.3

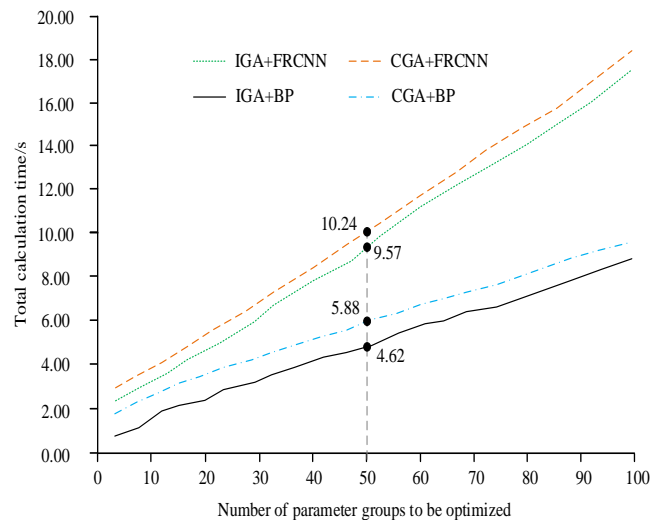


Fig. 7. Comparison of the computational efficiency of each optimization model.

In summary, the difference between the self-weight and maximum structural stress of the inspection vehicle designed in this study using neural networks instead of the finite element model output and the finite element model is less than 2%. In the engineering application environment of bridge inspection vehicles, this degree of error can be considered more accurate. The main reason for this situation is that neural networks have strong nonlinear relationship search and extraction capabilities, and there is indeed a complex nonlinear mapping relationship between the structural parameters of the bridge inspection vehicle and the corresponding structural self-weight and maximum stress. From the perspective of algorithm training speed, the IGA+BP model designed in this study has a slightly faster training speed than the comparison algorithm, because the BP neural network that makes up the algorithm itself is a three-layer structure, and the parameters to be optimized and the number of samples required for training are smaller than neural network algorithms such as Fast-RCNN. From the optimized parameter results, it can be seen that the optimal solution output by the design algorithm in this study corresponds to a significantly smaller self-weight than other algorithms, and the maximum stress and strain of the structure has not significantly increased compared to other methods, indicating that this method has certain application value in optimizing the structural parameters of bridge inspection vehicles.

V. CONCLUSION

In order to reduce the self-weight of the bridge inspection vehicle boom structure, this study designed an improved genetic algorithm and built an intelligent optimization model of the inspection vehicle boom structure by combining the BP neural network prediction model and the finite element model. The simulation experimental results show that the prediction value of the output of the test design variables from the prediction model constructed based on BP and Faster-RCNN neural network is less than 5% relative error to the calculation result of the finite element model, and can be used for the prediction model. The values of loss functions after convergence of the two models constructed using improved genetic algorithm, IGA+BP and IGA+FRCNN, are significantly lower than the other two models, and the former is higher than the latter with 1.52 and 3.15, respectively. Analysis of the optimal integer solutions of each optimized model reveals that the IGA+FRCNN model is the smallest in terms of maximum stress and maximum deformation, with 213.9 MPa and The maximum stress and maximum deformation of the IGA+FRCNN model are 213.9 MPa and 74.64 mm, respectively, followed by the IGA+BOP model with 219.50 MPa and 79.31 mm, respectively, which are lower than the allowable values of the material. From the perspective of measuring the total structural weight of the measuring arm, the IGA+BOP model has the lowest total structural weight of 4687.5 kg. Also the computation time of the model using the improved genetic algorithm is significantly lower than that of the model using the same prediction algorithm but without the improved genetic algorithm. When the number of groups with computational variables is 50, the computation time of CGA+BP, IGA+BP, CGA+FRCNN, IGA+ The computation time of each scheme is 5.88 s, 4.62 s, 10.24 s, and 9.57 s,

respectively. It can be seen that the optimization model designed this time can obtain better self-weight optimization results of the bridge inspection vehicle arm structure quickly. However, the optimization effect of the model on other uncommon types of bridge inspection vehicles was not analyzed in the study, and this part will be added in the subsequent study.

REFERENCES

- [1] S. Z. Tang, M. J. Li, F. L. Wang, et al., "Fouling potential prediction and multi-objective optimization of a flue gas heat exchanger using neural networks and genetic algorithms," *International Journal of Heat and Mass Transfer*, vol. 152, no. 5, pp. 119488.1-119488.15, 2020.
- [2] M. Xu, G. Zeng, D. Wu, et al., "Structural optimization of jet fish pump design based on a multi-objective genetic algorithm," *Energies*, vol. 15, no. 11, pp. 4104-4119, 2022.
- [3] Y. Xue, Q. Zhang, F. Neri, "Self-adaptive particle swarm optimization-based echo state network for time series prediction," *International Journal of Neural Systems*, vol. 31, no. 12, pp. 579-584, 2021.
- [4] D. J. Kozuch, F. H. Stillinger, P. G. Debenedetti, "Genetic algorithm approach for the optimization of protein antifreeze activity using molecular simulations," *Journal of Chemical Theory and Computation*, vol. 16, no. 12, pp. 7866-7873, 2020.
- [5] K. Noh, J. H. Chang, "Joint optimization of deep neural network-based dereverberation and beamforming for sound event detection in multi-channel environments," *Sensors*, vol. 20, no. 7, pp. 1-13, 2020.
- [6] J. Ren, H. Zhu, H. Wang, et al., "Multi-objective structural optimization of VL seal ring based on isight," *Journal of Physics: Conference Series*, vol. 1622, no. 1, pp. 012031.1-012031.6, 2020.
- [7] R. Ghiasi, M. R. Ghasemi, "Feature selection in structural health monitoring big data using a meta-heuristic optimization algorithm," *Journal of Computational Methods in Engineering*, vol. 39, no. 1, pp. 1-27, 2020.
- [8] M. Rabiei, A. J. Choobbasti, "Innovative piled raft foundations design using artificial neural network," *Frontiers of Structural and Civil Engineering*, vol. 14, no. 1, pp. 138-146, 2020.
- [9] C. Millan-Paramo, J. Filho, "Exporting water wave optimization concepts to modified simulated annealing algorithm for size optimization of truss structures with natural frequency constraints," *Engineering with Computers*, vol. 37, no. 1, pp. 763-777, 2021.
- [10] T. V. Varma, S. Sarkar, G. Mondal, "Buckling restrained sizing and shape optimization of truss structures," *Journal of Structural Engineering*, vol. 146, no. 5, pp. 4020048.1-4020048.12, 2020.
- [11] B. Adil, C. Baykasolu, "Optimal design of truss structures using weighted superposition attraction algorithm," *Engineering with Computers*, vol. 36, no. 3, pp. 965-979, 2020.
- [12] N. S. Usevitch, Z. M. Hammond, M. Schwager, "Locomotion of linear actuator robots through kinematic planning and nonlinear optimization," *IEEE Transactions on Robotics*, vol. 36, no. 5, pp. 1404-1421, 2020.
- [13] T. Wang, X. Zhou, H. Zhang, "Control of forming process of truss structure based on cold metal transition technology," *Rapid Prototyping Journal*, vol. 28, no. 2, pp. 204-215, 2021.
- [14] M. M. Kamiński, "On shannon entropy computations in selected plasticity problems," *International Journal for Numerical Methods in Engineering*, vol. 122, no. 18, pp. 5128-5143, 2021.
- [15] X. Zhang, K. Hanahara, Y. Tada, Z. Pei, Z. Li, P. Sun, "Optimal design of a hanging truss with shape memory alloy wires," *Transactions of the Canadian Society for Mechanical Engineering*, vol. 44, no. 1, pp. 95-107, 2020.
- [16] T. Nakamura, T. Yokaichiya, D. G. Fedorov, "Quantum-mechanical structure optimization of protein crystals and analysis of interactions in periodic systems," *Journal of Physical Chemistry Letters*, vol. 12, no. 36, pp. 8757-8762, 2021.
- [17] C. Liu, C. Zhang, Y. Q. Cao, D. Wu, P. Wang, A. D. Li, "Optimization of oxygen vacancy concentration in HfO₂/HfO_x bilayer-structure ultrathin memristor by atomic layer deposition and its biological

- synaptic behaviors,” *Journal of Materials Chemistry C*, vol. 8, no. 36, pp. 12478-12484, 2020.
- [18] E. Ching, J. Carstensen, “Truss topology optimization of timber-steel structures for reduced embodied carbon design,” *Engineering Structures*, vol. 252, (Feb.1 Pt.2), pp. 113540.1-113540.11, 2022.
- [19] V. Gasparetto, M. Elsayed, “Multiscale optimization of specific elastic properties and microscopic frequency band-gaps of architected microtruss lattice materials,” *International Journal of Mechanical Sciences*, vol. 197, no. 3, pp. 106320.1-106320.16, 2021.
- [20] D. Wang, F. Shao, “Research of neural network structural optimization based on information entropy,” *Chinese Journal of Electronics*, vol. 29, no. 4, pp. 632-638, 2020.
- [21] D. Patel, D. Bielecki, R. Rai, et al., “Improving connectivity and accelerating multiscale topology optimization using deep neural network techniques,” *Structural and Multidisciplinary Optimization*, vol. 65, no. 4, pp. 375-393, 2022.
- [22] D. N. Kien, X. Zhuang, “A deep neural network-based algorithm for solving structural optimization,” *Journal of Zhejiang University-Science A*, vol. 22, no. 8, pp. 609-620, 2021.
- [23] Y. Li, “Multi-objective optimization design for battery pack of electric vehicle based on neural network of radial basis function (RBF),” *Journal of Physics: Conference Series*, vol. 1684, pp. 012156, 2020.
- [24] Y. Fan, B. Feng, L. Yang, et al., “Application of artificial neural network optimization for resilient ceramic parts fabricated by direct ink writing,” *International Journal of Applied Ceramic Technology*, vol. 17, no. 1, pp. 264-281, 2020.
- [25] X. Han, Y. Kang, J. Sheng, et al., “Centrifugal pump impeller and volute shape optimization via combined NUMECA, genetic algorithm, and back propagation neural network,” *Structural and Multidisciplinary Optimization*, vol. 61, no. 1, pp. 381-409, 2020.
- [26] A. C. To, “Integrating geometric data into topology optimization via neural style transfer,” *Materials*, vol. 14, no. 16, pp. 4551-4556, 2021.
- [27] M. Baandrup, P. Noe Poulsen, J. Forbes Olesen, P. Henrik, “Optimization of truss girders in cable-supported bridges including stability,” *Journal of Bridge Engineering*, vol. 25, no. 11, pp. 4020099.1-4020099.11, 2020.

A Real-Time Automated Visual Inspection System for Printed Circuit Boards Missing Footprints Detection

Xiaoda Cao*

Laboratory Management Department, Northeast Agricultural University, Harbin, Heilongjiang, 150030, China

Abstract—Visual inspection systems (VIS) are vital for recognizing and assessing parts in mass-produced products at the fabricating lines. In the past, item review was carried out physically, which made finding imperfections repetitive, moderate, and prone to error. VIS may be a strategy to abbreviate preparing times, boost item quality, and increment fabricating competitiveness. For the reason of reviewing lost components on uncovered printed circuit sheets, a visual inspection framework is required. The assessment assignment has become more challenging to accomplish the specified quality due to the more compact and complex surface of structured electronic components. This study proposes a real-time visual inspection system to assess lost impressions on Printed Circuit Boards (PCB). This system is composed of hardware and software frameworks. The main contribution of this study is the proposed software framework. The software framework consists of components region analysis and missing detection using image processing, cross-correlation, and production rules. Experimental results show the viability and achievability of the proposed system for PCB missing component detection.

Keywords—Automated visual inspection; Printed Circuit Boards (PCB); quality control; image processing

I. INTRODUCTION

Printed circuit boards (PCBs) are a pillar of the electronic manufacturing sector [1,10]. The process of PCB inspection is challenging to perform manually because the surface of electronic goods is increasingly compact and complicated. This makes it harder for electronic boards to achieve quality control on the final products. The AVIS is the answer to boosting productivity and avoiding the challenges of manual inspection and mostly used in smart manufacturing [2,11]. Although many studies have been done on PCBs inspection, the issue of missing footprints has received less attention. When a "Printed Circuit Board" is created and released onto the market, the consumer of the board needs footprints (component shapes) in order to locate the location of the electronic component on the board [3,7].

The methods of human-based inspection for finding flaws depend on the expertise of the inspectors utilizing conventional tools, which makes finding flaws tedious, sluggish, and prone to mistakes [12]. This study thus concentrated on PCB footprint verification utilizing machine vision in the production line. These footprints are categorized by the AVIS utilizing a rule-based classifier and a machine vision system based on print quality [1,8]. As the global marketplace demands more

emphasis on quality, automated visual inspection of industrial items for quality control plays an increasingly important role in the manufacturing process [2,9]. Most of the time, people still do visual examinations for quality purposes. However, human-based inspection suffers from many challenges: low inspection speed and accuracy fluctuations.

This study presents an automatic visual inspection system for PCB missing component detection. This work is based on pure image processing algorithms which provide efficient and less computation cost techniques to represent and detect faulty PCB products. The categorization of fault types is done using a proposed production rule. Additionally, the finished footprints on the PCB are identified using Template matching.

In following section, related works are reviewed in Section II. The proposed method describes in Section III. Section IV presents the experimental result. Finally, the paper concludes in Section V.

II. RELATED WORKS

This section presents related works on automated visual inspection systems in the PCB quality control process.

Wu et al. [1] developed a method for automatic visual examination based on characteristics of solder connections on PCBs, such as their location, shape, and logical aspects. The suggested technique may be used to identify various PCB defects, including no solder, surplus solder, incorrect or missing components, and damaged components. The characteristics will be retrieved based on several locations and the geometry of the solder connections once the solder joints have been localized. From solder junctions, they obtain occupancy ratios for the area, color, center of gravity, and continuous pixels. The logical features are recovered by examining the tight relationships between form, location, and colour dispersing factors.

Matsushima et al. [2] proposed a neural network-based visual inspection solution for PCB solder connections. For the learning and inspection phases, input data characteristics are retrieved using principal component analysis (PCA). The camera angles and the light source determine the circumstances for capturing images. There are two phases in a neural network visual inspection system: learning and inspection. In the learning phase, the neural network system produces two outputs, the defect degree and the good degree of the sample, based on the inputs retrieved from a good or defective sample.

The neural network's input for the learning phase is the Principle Component Analysis (PCA) generated as a feature from the sample pictures.

After placing wet solder paste on a printed circuit board, Zhang et al. [3] created a real-time visual assessment method of the solder paste quality. In this approach, the extraction of the region of interest, which includes the solder paste and pad regions, begins with a segmentation procedure. The categorization of five kinds of solder pastes as Good, Excess, Insufficient, Horizontal displacement, and Vertical displacement is then performed using a neural network algorithm.

Brunetti et al. [4] proposed a solder connection flaw detection system using automatic optical inspection (AOI) for PCBs produced using the surface mounting method (SMT). The neural network technique solves this diagnostic as a pattern recognition issue. The pictures are obtained using horizontal, vertical, and correlation coefficients. Each region of interest is assessed using three different types of feature vectors: geometric features (G-feature), wavelet features (W-feature), and the combination of the two features (GW-feature). According to their experiment, the best recognition rate was attained using a Multi-Layer Perceptron (MLP) network and GW features.

Lin et al. [5] developed a method to inspect printed circuit boards more quickly and accurately. The inspection process consists of two steps. Only one image characteristic is abstracted from the picture in the first step, and it is utilized as a screening index to filter out most typical components quickly. The neural network is then used as a classifier along with picture indices such as the histogram index, correlation coefficient, high contrast index, and regional index.

III. PROPOSED SYSTEM

The architecture of the systems that are suggested in our study is shown.

A. Hardware Framework

Fig. 1 shows the hardware framework's organizational structure. It incorporates the web camera used for picture

acquisition, a conveyor belt, a light source, and a laptop system with image processing software.

The AVIS framework aims to classify the footprints into complete and incomplete shapes related to LED, Resistor, IC, Capacitor, and Transistor footprints. The specific algorithms are detailed in the paragraphs that follow. The camera, light source, and conveyor belt, which make up the three main parts of our real-time imaging system, are calibrated in simulated settings. Fig. 2 depicts the hardware for the suggested AVIS model and is explained in the following subsections.

As shown in Fig. 3, a webcam is used to capture images. The PCBs are moved along the conveyor belt at the chosen pace and in the desired direction, from left to right, simulating a true industrial setting. The stand is used to secure the camera to the conveyor belt and allows for up-and-down movement of the webcam. Additionally, the camera is fixed to a pedestal and is positioned in the middle of the conveyor belt. The webcam is best positioned in the center to catch the PCBs as they go along the conveyor belt. The actual capture of the picture, segmentation, and classification are done on the computer.

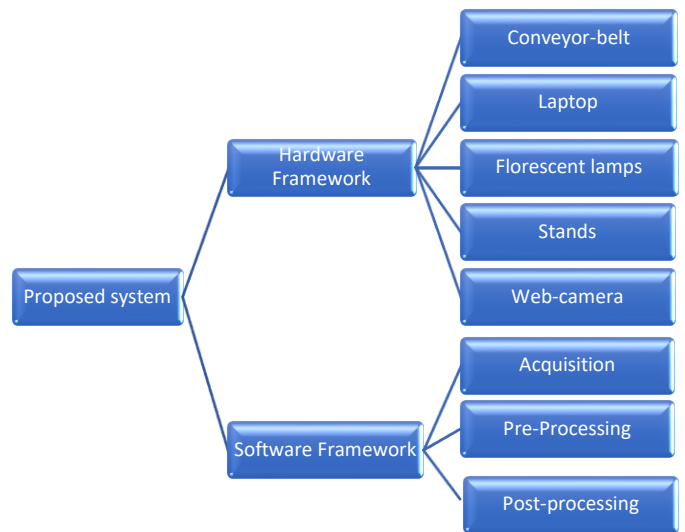


Fig. 1. The proposed system.

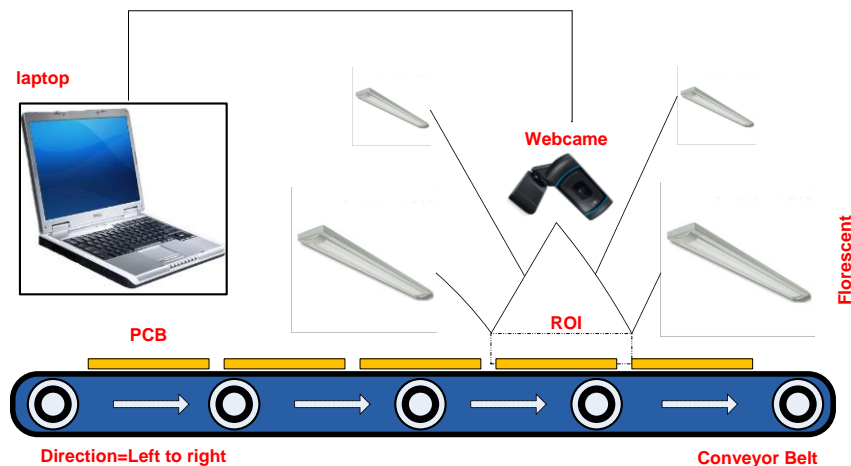


Fig. 2. The proposed hardware framework.

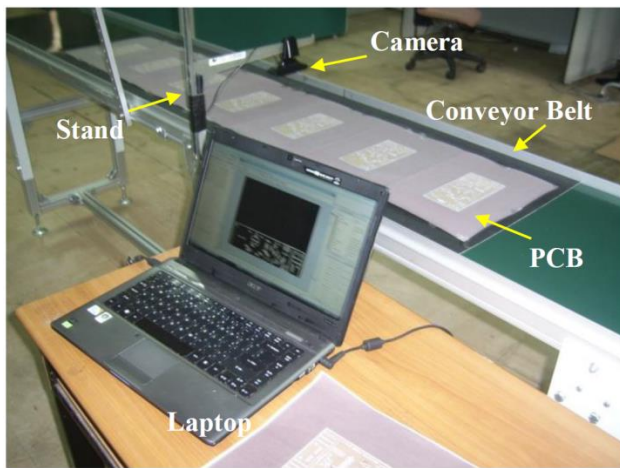


Fig. 3. AVIS model hardware in the real environment.

B. Software Framework

The software diagram depicted in Fig. 4 represents the proposed AVIS software framework. The processes for object detection and picture processing are included. Feature extraction, board location, segmentation of footprints, and image collection are the first five processes. The images are then categorized in terms of their geometrical features using a production rules method.

1) *Image acquisition*: The acquisition systems feature a mechanical positioning tool to move the camera or the product

being tested to a fixed position and acquire the picture. The program displays the outcome and waits for the following acceptable image. The program recorded RGB frame-by-frame photos of PCBs traveling on the conveyor belt at a set conveyor belt speed.

2) *Image segmentation*: The pre-processing stage consists of two steps of image segmentation. The first image segmentation step is to extract the board under inspection from the acquired images, while in the second step, the image of the footprint is obtained from the board image. We have explained the two steps in detail.

a) *Board localization*: The work carried out in this stage of pre-processing is the extraction of the board from the obtained image. In any instance, a procedure to lessen or eliminate discrepancies between the obtained picture and the ROI must be included in the pre-processing [4]. In this case, we used a connected component to locate the board from the collected picture. In this project, the connected-component labeling procedure will use an 8-connectivity pixel since it is assumed that forms are frequently far from one another. As a consequence, calculation complexity can be avoided [6]. The largest component among those found to be connected is then extracted from the group based on size, and in this case, the largest component is the whole board, as shown in the obtained image. The steps of board localization are depicted in Fig 5.

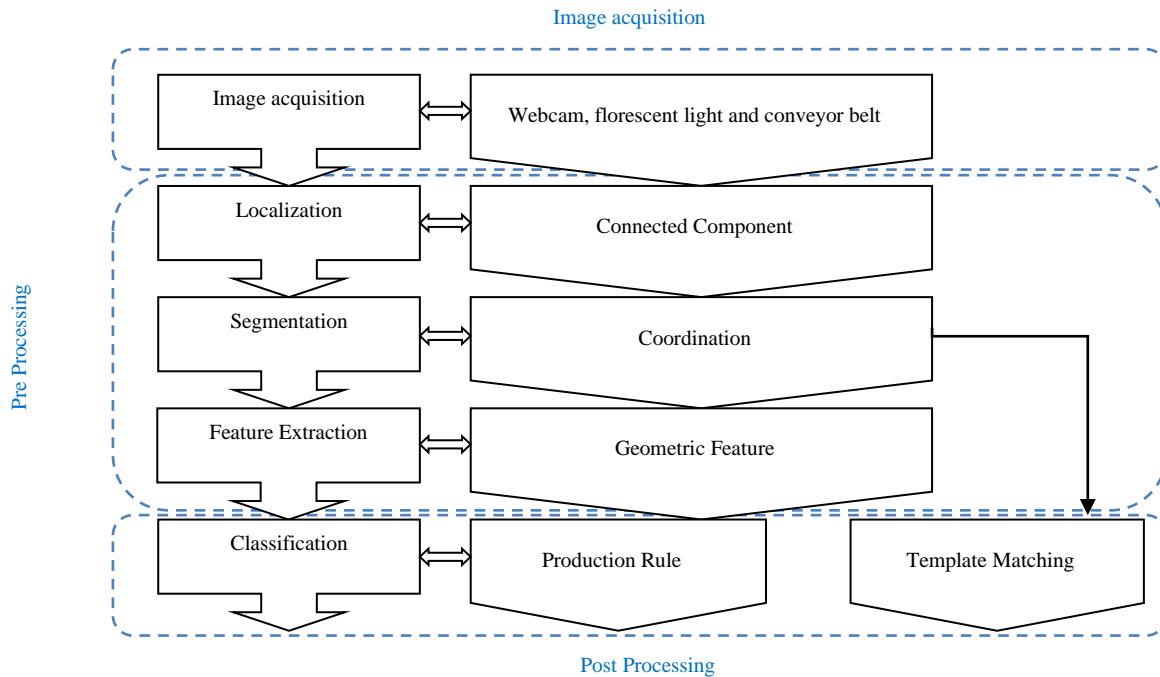


Fig. 4. The software framework.

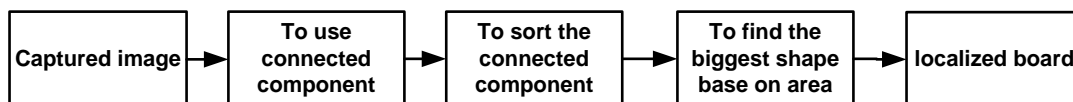


Fig. 5. The steps of board localization.

b) *Footprint segmentation*: In this step, each region of footprints is cropped based on its coordination in terms of PCB's size. In this instance, we cropped the bounding box using four parameters: X_{min} , Y_{min} (Coordination), width, and height. First, the segmented image's energy will be assessed. If the segmented image's energy is greater than 15 pixels, the following stage will be to assess the printing quality. The entire footprint would be missing if the energy level were below 15.

3) *Feature extraction*: The feature extraction stage of image processing is crucial. The application and success of every classification method in the next phase depend on choosing the most appropriate characteristics. The subsequent phase of our procedure is feature extraction. From linked components on the footprint that were acquired by segmentation, a geometric feature [4] has been retrieved in this part. This method investigates two types of significant geometric properties, Area and Perimeter, for each item in the image based on the previously given information.

4) *Classification*: Image classification is the last phase of the proposed software framework. When the features are retrieved, a classification may be made using a set of known features in this step. In this study, the area and perimeter

characteristics are the geometrical features chosen for the classifying footprint. Production guidelines are used to categorize the footprints into four groups in this step: 25%, 50%, 75%, and 100% for each type of footprint. Different types of footprints on a PCB are dealt with by the models for detection and categorization (Variable resistor, IC, Capacitor, LED, Transistor). Tables I, II, III, IV, and V show the types of footprints.

5) *Production rules* : In this work, the classifier is rules-based. An effective and simple system is founded on rules. The IF-Then structure states that IF can develop a set of rules that can achieve a high classification rate for these specified classes of footprint and can then claim that rule-based systems are feasible. Calculated rule-based output takes the form of rules based on the area and perimeter of forms. The variable resistor takes just Area. Each object can get one of the values: (25%, 50%, 75%, and 100%). Table VI shows the features and values in each segmented image. Fig. 6 shows the inference engine of the production rule for four classes of footprints.

The V1 to V6 represent the perimeter of shapes in a segmented image. The V7, V8, V9, and V10 represent the Area of shape in a segmented image. The values of perimeter and area are different for each type of footprint.

TABLE I. THE FOUR CLASSES OF THE CAPACITOR





Type of footprint	Quality of the printing	Percentage	Accept or reject
Capacitor		25%	Reject
		50%	Reject
		75%	Reject
		100%	Accept

TABLE II. THE FOUR CLASSES OF THE VARIABLE RESISTOR





Type of footprint	Quality of the printing	percentage	Accept or reject
Variable Resistor		25%	Reject
		50%	Reject
		75%	Reject
		100%	Accept

TABLE III. THE FOUR CLASSES OF THE IC





Type of footprint	Quality of the printing	Percentage	Accept or Reject
IC		25%	Reject
		50%	Reject
		75%	Reject
		100%	Accept

TABLE IV. THE FOUR CLASSES OF THE TRANSISTOR





Type of footprint	Quality of the printing	Percentage	Status
Transistor		25%	Reject
		50%	Reject
		75%	Reject
		100%	Accept

TABLE V. THE FOUR CLASSES OF THE LED





Type of footprint	Quality of the printing	percentage	Accept or reject
LED		25%	Reject
		50%	Reject
		75%	Reject
		100%	Accept

TABLE VI. THE FEATURES IN CLASSES OF FOOTPRINTS IN SEGMENTED IMAGE

Feature	value	Feature	value
	25%		100%
Perimeter	50%	Area	
	75%		Less 100%

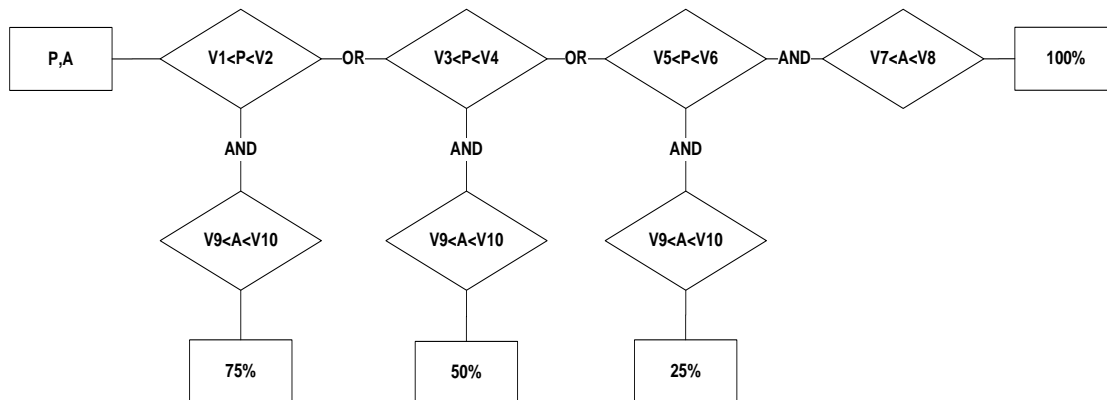


Fig. 6. The inference engine of production rule.

IV. EXPERIMENTAL RESULT

This section discusses and presents the results of each module using a standard for evaluating computer software. Each module's step's performance is calculated. These procedures comprise capturing the picture, board localization, segmentation, and classification of the footprint. When the PCBs are in the webcam's field of view, the program instructs the webcam to take a picture by using a region of interest

(ROI). Using three criteria, the program evaluates the ROI for each frame. The image's top, bottom, and middle thirds are our focus areas. Three regions' total quantity of white pixels will be determined. The PCB picture was taken in ROI by the technique chapter's instructions. Using a set threshold in the region of interest, the collected image's outcome is shown in Fig. 7. Table VII shows how well this technique performed.

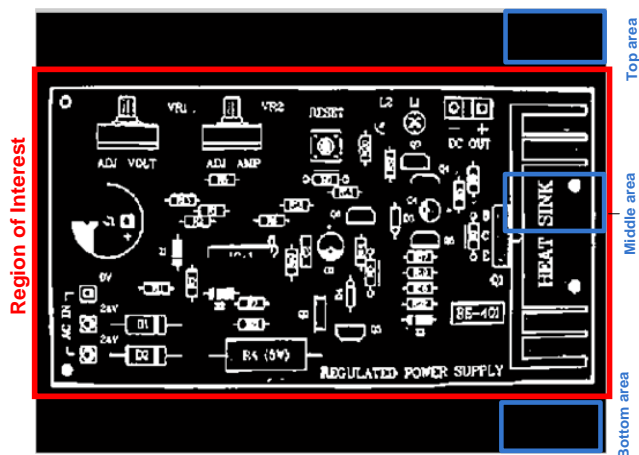


Fig. 7. The captured image.

TABLE VII. PERFORMANCE OF THE METHODOLOGY USED IN IMAGE ACQUISITION

Number of images	Number of Correct capturing	Performance of capturing step
211	207	98%

A. Image Segmentation Module

1) *Board localization*: The 8-connectivity component was utilized in this stage to sort every component found to be linked. Then, from the acquired picture displayed in Fig. 8, select the largest one among them based on its area, which is the entire board. The result of board localization is shown in Fig. 9. Table VIII shows the results of board localization.

2) *Footprint segmentation*: We cropped each footprint's bounding box depending on its coordination and the size of the PCB. Boxes with footprints for capacitors, variable resistors, integrated circuits, LEDs, and transistors are shown on the PCB in Fig. 10. The results of the segmentation process are displayed in Table IX.

B. Image Classification Module

The suggested AVIS model's performance was assessed in this study using the 207 photos for each proposed classification technique. Five different footprint kinds are included on each PCB. On the PCB, we fully show eleven footprints. The number of footprints on the PCB is displayed in Table X.

The boards include different kinds of uncompleted footprints as follows the footprints that are missed and four classes of footprints in percentage (25%, 50%, 75%, and 100%). Table XI shows the number of each class of footprint in 207 images.

The 207 photos are utilized in this manner, as indicated previously. One PCB has eleven (11) examined footprints. Production rule methodology is employed to execute real-time inspection in a real-world setting.

If the suggested system properly detects the form in a segmented picture, the accuracy value equals the percentage of footprints. Each component's footprint is assessed independently by the suggested segmentation. Finally, using the formula below, we demonstrate how the production rule performs for each footprint type.

$$\text{Accuracy of production rule} = \frac{\sum \text{correct classification of footprints}}{\text{number of related footprints}} \times 100$$

In the 207 photos, we counted the production rule accurate classifications, and Table XII shows the results. The final tables and figures, Table XIII and Fig. 11, show how the production rule performed.

In summary, an automated visual inspection technique for finding missing PCB components is presented in this paper. This study is built on pure image processing algorithms that offer effective and low-cost methods for representing and identifying defective PCB devices. A proposed production rule is used to classify the different sorts of faults. Additionally, template matching is used to identify the completed PCB footprints.

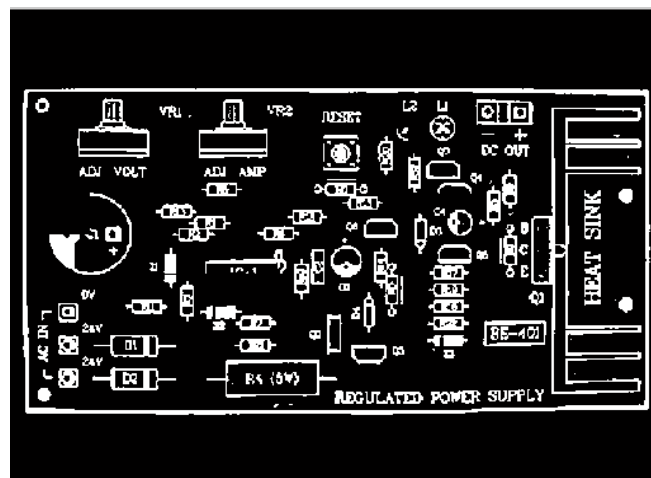


Fig. 8. The acquired image.

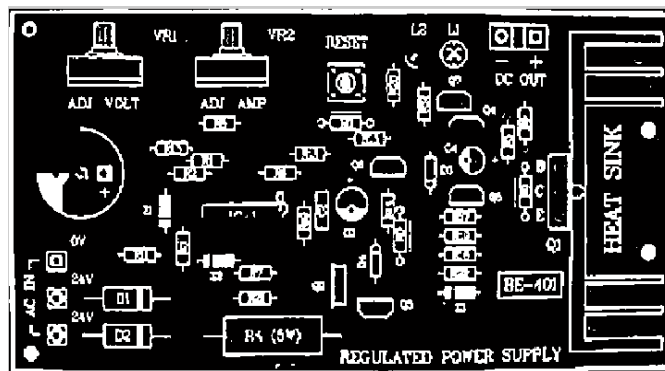


Fig. 9. The localized board.

TABLE VIII. THE PERFORMANCE OF LOCALIZING THE BOARD

Number of images	Number of Correct localizing	Performance of localizing step
207	207	100%



Fig. 10. The segmented footprints.

TABLE IX. THE PERFORMANCE OF THE IMAGE SEGMENTATION STEP

Number of segmented images	Number of Correct segmentations	Performance of segmentation step
2277	2214	97%

TABLE X. THE NUMBER OF FOOTPRINTS ON THE PCB

Number of image	Capacitor	Variable Resistor	IC	LED	Transistor	Number of footprints
1	1	2	1	2	5	11
207	207	414	207	414	1035	2277

TABLE XI. THE NUMBER OF EACH CLASSES OF FOOTPRINT IN THE 207 IMAGES

Type of footprint	25%	50%	75%	100%
Capacitor	23	69	46	23
Variable Resistor	23	92	23	253
IC	23	92	23	23
LED	23	46	46	207
Transistor	23	46	23	851

TABLE XII. THE NUMBER OF CORRECT CLASSIFICATIONS IN PRODUCTION RULE

Type of footprint	25% of footprint	50% of footprint	75% of footprint	100% of footprint
Capacitor	23	69	46	23
Variable Resistor	22	87	18	228
IC	23	89	23	23
LED	23	46	45	202
Transistor	19	37	19	813

TABLE XIII. THE PERFORMANCE OF PRODUCTION RULE

Type of footprint	25% of footprint	50% of footprint	75% of footprint	100% of footprint
Capacitor	100%	100%	100%	100%
Variable Resistor	96%	95%	78%	90%
IC	100%	97%	100%	100%
LED	100%	100%	98%	98%
Transistor	83%	80%	83%	96%

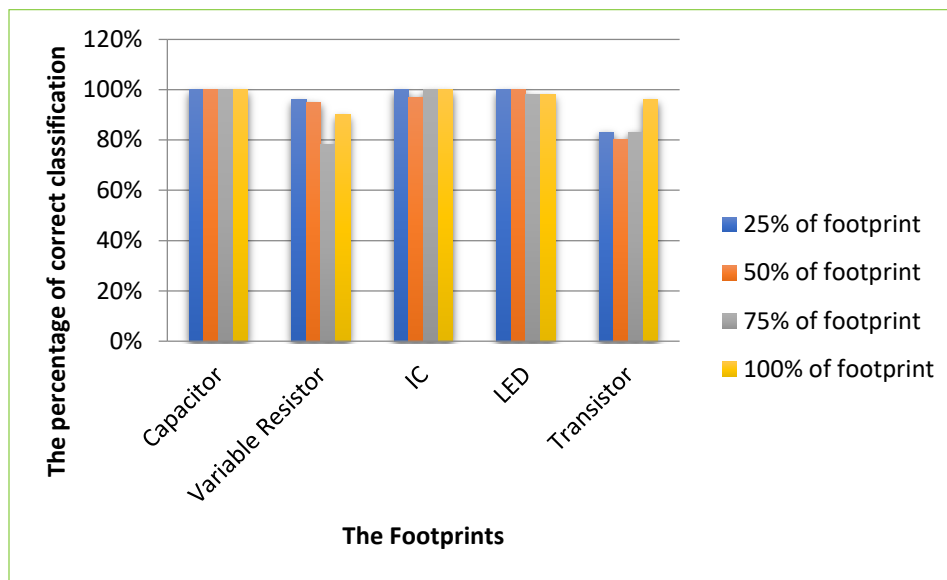


Fig. 11. The chart of performance of production rule.

V. CONCLUSION

This study presents a real-time automated visual inspection system using an image processing technique to detect the missing footprint components on printed circuit boards. This system consists of hardware and software components. The software involves pre-processing and post-processing stages. The capture step is finished, and the picture is segmented, localized, and extracted of its characteristics during the pre-processing stage. In order to categorize the footprints using the production rule, the post-processing step focuses on leveraging the feature extraction from the previous stage. Thus, we may conclude that the entire intelligent real-time machine vision system, whose design is presented in this study, can be utilized to enhance industrial quality control procedures.

REFERENCES

- [1] H. Wu, G. Feng, H. Li, X. Zeng, Automated visual inspection of surface mounted chip components, 2010 IEEE International Conference on Mechatronics and Automation, IEEE, 2010, pp. 1789-1794.
- [2] M. Matsushima, N. Kawai, H. Fujie, K. Yasuda, K. Fujimoto, Visual inspection of soldering joints by neural network with multi-angle view and principal component analysis, Service robotics and mechatronics, Springer 2010, pp. 329-334.
- [3] H. Wu, X. Zhang, Y. Kuang, S. Lu, A real-time machine vision system for solder paste inspection, 2008 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, IEEE, 2008, pp. 205-210.
- [4] G. Acciani, G. Brunetti, G. Fornarelli, Application of neural networks in optical inspection and classification of solder joints in surface mount technology, IEEE Transactions on industrial informatics 2(3) (2006) 200-209.
- [5] S.-C. Lin, C.-H. Su, A visual inspection system for surface mounted devices on printed circuit board, 2006 IEEE conference on cybernetics and intelligent systems, IEEE, 2006, pp. 1-4.
- [6] V.T. Shi, D.R. Nhg, Channel Estimation Optimization Model in Internet of Things based on MIMO/OFDM with Deep Extended Kalman Filter, Advances in Engineering and Intelligence Systems 1(02) (2022).
- [7] Aghamohammadi, A., Ang, M.C., Prabuwno, A.S., Mogharrebi, M. and Ng, K.W., 2013. Enhancing an automated inspection system on printed circuit boards using affine-sift and triz techniques. In Advances in Visual Informatics: Third International Visual Informatics Conference, IVIC 2013, Selangor, Malaysia, November 13-15, 2013. Proceedings 3 (pp. 128-137). Springer International Publishing.
- [8] Abd Al Rahman, M. and Mousavi, A. A review and analysis of automatic optical inspection and quality monitoring methods in electronics industry. IEEE Access, 2020, 8, pp.183192-183271.
- [9] Czimmermann, T., Ciuti, G., Milazzo, M., Chiurazzi, M., Roccella, S., Oddo, C.M. and Dario, P. Visual-based defect detection and classification approaches for industrial applications—A survey. Sensors, 2020, 20(5), p.1459.
- [10] Ding, R., Dai, L., Li, G. and Liu, H., 2019. TDD-net: a tiny defect detection network for printed circuit boards. CAAI Transactions on Intelligence Technology, 4(2), pp.110-116.
- [11] Ding, H., Gao, R.X., Isaksson, A.J., Landers, R.G., Parisini, T. and Yuan, Y., 2020. State of AI-based monitoring in smart manufacturing and introduction to focused section. IEEE/ASME Transactions on Mechatronics, 25(5), pp.2143-2154.
- [12] Narazaki, Y., Hoskere, V., Hoang, T.A., Fujino, Y., Sakurai, A. and Spencer Jr, B.F., 2020. Vision-based automated bridge component recognition with high-level scene consistency. Computer-Aided Civil and Infrastructure Engineering, 35(5), pp.465-482.

PM_{2.5} Estimation using Machine Learning Models and Satellite Data: A Literature Review

Mitra Unik¹, Imas Sukaesih Sitanggang², Lailan Syaufina³, I Nengah Surati Jaya⁴

Department of Computer Science, Institut Pertanian Bogor, IPB Bogor, Indonesia^{1,2}

Department of Silviculture, Institut Pertanian Bogor, IPB Bogor, Indonesia³

Department of Forest Management, Institut Pertanian Bogor, IPB Bogor, Indonesia⁴

Abstract—Most researchers are beginning to appreciate the use of remote sensing satellites to assess PM_{2.5} levels and use machine learning algorithms to automate the collection, make sense of remote sensing data, and extract previously unseen data patterns. This study reviews delicate particulate matter (PM_{2.5}) predictions from satellite aerosol optical depth (AOD) and machine learning. Specifically, we review the characteristics and gap-filling methods of satellite-based AOD products, sources and components of PM_{2.5}, observable AOD products, data mining, and the application of machine learning algorithms in publications of the past two years. The study also included functional considerations and recommendations in covariate selection, addressing the spatiotemporal heterogeneity of the PM_{2.5}-AOD relationship, and the use of cross-validation, to aid in determining the final model. A total of 79 articles were included out of 112 retrieved records consisting of articles published in 2022 totaling 43 articles, as of 2023 (until February) totaling 19 articles, and other years totaling 18 articles. Finally, the latest method works well for monthly PM_{2.5} estimates, while daily PM_{2.5} and hourly PM_{2.5} can also be achieved. This is due to the increased availability and computing power of large datasets and increased awareness of the potential benefits of predictors working together to achieve higher estimation accuracy. Some key findings are also presented in the conclusion section of this article.

Keywords—AOD; machine learning; PM_{2.5}; remote sensing; pollutant

I. INTRODUCTION

Interest in the study of PM_{2.5} (particulate matter aerodynamic diameter $\leq 2.5 \mu\text{m}/\text{m}^3$) concentration estimates from various outdoor and indoor particle sources has increased dramatically recently, as evidenced by the number of academic journals that have published articles on it. Studies identified the impact of PM_{2.5} contamination on humans as the initial problem of various adverse effects on the health of fetal growth during pregnancy to early death [1]. Direct and long-term exposure can significantly impact climate change, visibility degradation, ecosystem disruption, and social, ecological, and economic impacts [2]–[4].

PM_{2.5} monitoring is a critical need for public health, especially in densely populated areas, where exposure to airborne particles poses significant health risks [5]. Ground station monitoring is the most direct and accurate method of PM_{2.5} monitoring. However, it is impossible to fully identify the spatial distribution and obtain historical measurements of PM_{2.5} concentrations across the region. Most researchers are

beginning to appreciate the use of remote sensing satellites to assess PM_{2.5} levels. Estimating PM_{2.5} concentrations using Aerosol optical depth (AOD) as a remote sensing satellite derivative can be used to fill the gap of spatial and temporal data gaps left by ground stations [6]. Various remote sensing satellite sensors, such as Moderate Resolution Imaging Spectrometer (MODIS) [7], [8] The Visible-infrared Imaging Radiometer Suite (VIIRS) [9], [10], the Advanced Himawari Imager [11], [12] the Advanced Geosynchronous Radiation Image (AGRI) [13], [14] have been applied to estimate PM_{2.5} concentrations.

Models for predicting PM_{2.5} concentrations can be useful for filling data gaps from existing monitoring networks. Air pollutant concentration prediction methods can generally be classified into three categories: numerical, statistical, and artificial intelligence (AI) models. Numerical models simulate the physical and chemical changes and transport processes of atmospheric pollutants by specifying and solving complex differential equations. Recent representative numerical models include Community Multiscale Air Quality (CMAQ) and Weather Research and Forecasting coupled with Chemistry (WRF-Chem). The accuracy of these models relies heavily on detailed emission data from pollutant sources, which often need to be made more precise and available. In addition, the complex modeling process requires more time and computing power [15]. Therefore, it is necessary to develop a faster and more accurate model to improve the prediction of air pollutants.

Statistical models have not involved complex physical changes, chemical reactions, and transportation processes. Statistical models rely entirely on data-driven mining of internal relationships to historical data. Therefore, the computational effort is significantly lower compared to numerical models. It is easy to implement classical statistical models such as autoregressive integrated moving average (ARIMA) [16] and autoregressive moving average (ARMA). However, these models are suitable for small data sets and univariate time series models. In addition, these models are based on linear assumptions that require strict stationarity of the data. Therefore, capturing nonlinear relationships in the data is inherently complex. These limitations greatly restrict the performance and applicability of classical statistical models in air pollution forecasting.

In contrast, adopting machine learning models in remote sensing is considered the optimal solution for predicting PM_{2.5} concentration time series due to its advantages of flexible

nonlinear regression capabilities and classification features based on large data sets with complex data relationships between many variables. [17], [18]. The initial study that utilized a Neural Network (NN) to tackle the intricate correlation between AOD-PM_{2.5} [19]. Since the 1990s, Machine Learning algorithms have been used to automate the collection, understand remote sensing data, and extract previously unseen data patterns [20], [21].

Machine learning capabilities make it possible to non-parametrically examine the relationship between predictors of pollutant concentrations and measured pollutant concentrations [22], [23]. A number of research investigations have indicated that machine learning [17], [24], [25] such as deep learning [26], Random Forest [27], and deep ensemble models [28], have a remarkable ability to estimate PM_{2.5} concentrations at various temporal and spatial scales. Several models have been developed to predict indoor [29] and atmospheric PM_{2.5} concentrations based on data obtained from air quality monitoring stations, such as meteorological variables from weather stations such as air temperature (T), relative humidity (RH), wind speed (WS), wind direction, Precipitation (PRE). Land variables, such as NDVI. Variables related to population) such as population density, road network density, height, and the number of buildings, and others, including data on PM_{2.5}, carbon monoxide (CO), ozon (O₃), nitrogen oxides (NO), nitrogen dioxide (NO₂), and sulfur dioxide (SO₂) [10], [11], [14], [26], [30].

The success of PM_{2.5} concentration estimation studies using machine learning and satellite remote sensing data depends on the quantity and quality of the researcher's domain knowledge, regional knowledge, and time spent. This review article aims to summarize the literature on the use of machine learning and satellite remote sensing in estimating large-scale and long-term PM_{2.5} concentrations. This literature review includes articles from 2022 to 2023 related to this crucial topic. However, some articles that can provide insights into various remote sensing technologies on PM_{2.5}, air pollution, and other specific studies were also added without being limited by the year of publication period. Specific search terms and study selection are illustrated in the second section to summarize the current state of development in estimating PM_{2.5} concentrations. The third section investigates factors affecting PM_{2.5} concentrations, levels, and model measurements. The following section is a personal presentation on using machine learning models.

II. LITERATURE SEARCH AND SELECTION

In line with the multidisciplinary research topics, several other disciplines, ranging from computer science, forestry, remote sensing, atmosphere, and disaster, which intersect with the main topic without being limited by the year of publication period to provide additional insight, are included. Four general stages of literature search and determination were conducted, such as:

- Identification: The initial set was conducted by identifying keywords to search for articles relevant to the topic of this literature review from electronic databases Web of Science, Google Scholar, and sources of Elsevier, ScienceDirect, and Springer, both from

National and International journals. Based on the topic raised, this study needs to summarize (1) literature from indoor PM_{2.5} concentration research, (2) specific indoor PM_{2.5} sources (cooking, cigarettes, vacuum cleaners, and more.), and (3) monitoring via landline networks. Application of keywords as follows: "Estimating PM_{2.5}", "machine learning," "satellite remote sensing," "PM_{2.5}", and "outdoor." Findings of article titles corresponding to the research topic were then stored and evaluated. The search continued by checking for other articles cited or quoted in this set and removing double-identified documents. Due to the core topic of this literature review, we focused on published articles from January 2022 to February 2023.

- Screening: The articles found were screened by labeling them as relevant or not to this study after checking the abstracts. These potential papers were then carefully reviewed to ensure their eligibility as references in this literature review.
- Eligibility: Eligibility was determined by reading the main findings, use of data, results, and discussion. The authors considered journal articles and books published by reputable publishers as high-quality research and included them in summary. The authors used "Scimago Journal & Country Rank" to check the rankings of the included articles.
- Inclusion: The research then lists literature articles that correspond to the main topic.

Our initial search yielded 112 articles. After passing the initial screening to eligibility assessment, this study used 61 primary and 18 other articles.

is a summary flowchart of the following literature search and selection statistics:

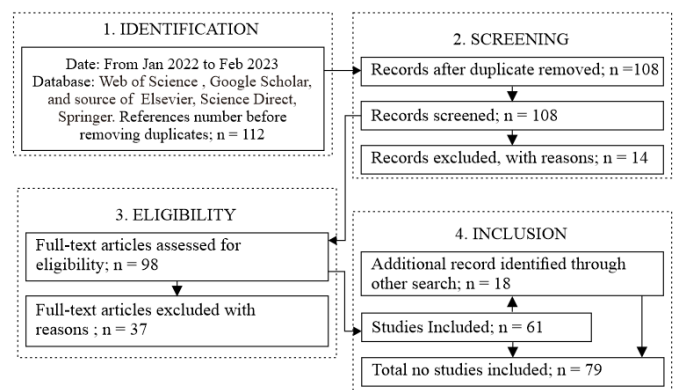


Fig. 1. Literature search and selection flow chart.

illustrates the number of references in the literature review. The collected articles from 2022 totaled 43 articles, 2023 (up to February) totaled 19 articles, and the other years totaled 18 articles.

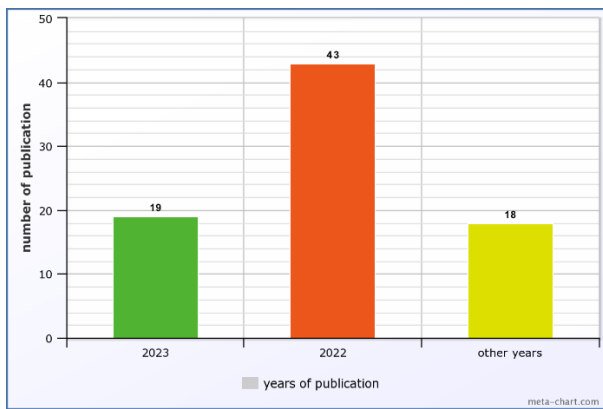


Fig. 2. Number of literature review references.

III. REMOTE SENSING TECHNIQUE

A. Moderate Resolution Imaging Spectroradiometer (MODIS)

MODIS is an instrument on the Aqua and Terra satellites capable of detecting small changes in surface reflectance due to changes in $PM_{2.5}$ concentrations. Reflectance changes estimate $PM_{2.5}$ concentrations through a statistical approach that does not require calibration or data collection from ground-level locations. In addition, this method is more resistant to noise than other methods [31]. The MODIS instrument captures data from 36 spectral bands with wavelengths ranging from 0.4 to 14.385 μm and observes the entire Earth's surface every one to two days. The Terra satellite follows a north-south orbit and crosses the equator in the morning, while the Aqua satellite travels in the opposite direction and flies over the equator in the afternoon. Various sources provide various MODIS data products:

- MODIS level 1 data, geolocation, cloud mask and atmospheric products: <http://ladsweb.nascom.nasa.gov/>
- MODIS ground products: <https://lpdaac.usgs.gov/>
- MODIS cryosphere products: <http://nsidc.org/daac/modis/index.html>
- MODIS ocean color and sea surface temperature products: <http://oceancolor.gsfc.nasa.gov/>

MODIS images have spatial resolutions of 250 m, 500 m, and 1km. The range of wavelengths between 0.47 and 2.12 μm in various channels is utilized to determine aerosol properties, specifically AOD, in order to estimate $PM_{2.5}$ [7], [8]. A research study based on theoretical analysis of data gathered by a multiangle imaging spectrometer aboard the Terra satellite in the US has shown that the range of particle sizes appropriate for AOD retrieval, which closely corresponds to the particle size range of $PM_{2.5}$, falls between 0.1-2 μm in the visible and near-infrared wavelength bands.

B. Himawari-8

The Japan Meteorological Agency (JMA) operates Himawari-8, a geosynchronous weather satellite. The satellite was launched on 7 October 2014, and is stationed at 140.7 degrees east longitude, providing uninterrupted observations over the Asia-Pacific region, which includes Southeast Asia, Australia, Japan and the Western Pacific. Himawari-8 carries a

suite of advanced instruments to observe the Earth's atmosphere and weather systems. These instruments include the Advanced Himawari Imager (AHI), which provides high-resolution images of the Earth's surface and clouds, and the Himawari Cast data collection system, which receives data from other weather satellites and ground-based weather stations [32]. Himawari-8 can be used to measure Aerosol Optical Depth (AOD) to investigate the diurnal variation of air pollution with high temporal resolution. [12]. Recently, some studies have started to estimate hourly ground-level $PM_{2.5}$ in real-time from Himawari-8 AOD products [33]–[35].

C. Sentinel 5-P

The Sentinel-5 Precursor Satellite (Sentinel-5P) was launched on October 13, 2017, carrying the following Tropospheric Monitoring Instrument (TROPOMI) to generate global high-coverage total/tropospheric vertical columns of precursors (e.g., NO_2) for $PM_{2.5}$ and PM_{10} . TROPOMI has a legacy to the Ozone Monitoring Instrument (OMI) as well as the Scanning Imaging Absorption spectroMeter for Atmospheric CartographY (SCIAMACHY) TROPOMI is a single instrument from the Sentinel-5P spacecraft covering wavelengths from ultraviolet (UV) to ShortWave InfraRed (SWIR). This hyperspectral spectrometer is designed to provide routine observations of key atmospheric constituents including ozone, NO_2 , SO_2 , CO , CH_4 , CH_2O and aerosol properties at high spatial resolution using passive remote sensing methods. [36]. The typical pixel size (near nadir) is defined as $7 \times 3.5 km^2$ for all spectral bands except UV1 ($7 \times 28 km^2$) and SWIR band ($7 \times 7 km^2$). In terms of accuracy, the evaluation results show that the quality of the TROPOMI atmospheric product meets the requirements in $PM_{2.5}$ pollutant estimation [37], [38].

IV. PREDICTORS USED FOR ESTIMATION OF $PM_{2.5}$ CONCENTRATIONS

A. Sources of $PM_{2.5}$

There are several types of outdoor $PM_{2.5}$ sources originating from the combustion of fossil materials, such as automotive vehicle exhaust emissions, coal, and biomass combustion [39], industrial activities, soil dust, secondary combustion, secondary nitrates, as well as through release into the volcanic atmosphere [40]. The sources and concentrations of $PM_{2.5}$ can vary significantly between locations due to the different characteristics of climatic conditions, emission sources, and distribution patterns [41]. Black carbon, aryl hydrocarbons, polycyclic aromatic hydrocarbons, volatile organic hydrocarbons, biological materials, heavy metals, minerals, inorganic ions, and organic compounds are the primary constituents of $PM_{2.5}$, which account for around 79-85% of the entire mass when considered together [42].

B. Explanatory Variables of $PM_{2.5}$

Two characteristics of variables used in $PM_{2.5}$ research are dependent and independent variables. The dependent variable contains $PM_{2.5}$ values ($\mu g/m^3$) obtained through air quality measurements using ground stations. On the other hand, the independent can contain co-pollutant, meteorological, and anthropic information that can significantly improve the model's accuracy. Regarding this critical difference,

independent data is essential information to help estimate $PM_{2.5}$, including AOD.

1) *Aerosol optical depth*: (AOD is a quantitative measure of the reduction of light by aerosol particles in the Earth's atmosphere. AOD describes how much light from the sun is reduced or blocked by aerosol particles in the atmosphere. The higher the AOD value, the more significant the attenuation of light caused by aerosol particles. AOD can be measured using devices such as spectrometers or photometers [43]. Thus, AOD is an essential predictor of $PM_{2.5}$, according to the close relationship with AOD.

The starting point for knowing satellite AOD about surface $PM_{2.5}$ is through Equation (1) [44], which shows the dependence of $PM_{2.5}$ and cloud-free AOD relationships on various factors:

$$AOD = PM_{2.5} \times H \times f(RH) \times \frac{3Q_{ext,dry}}{4\rho r_{eff}} = PM_{2.5} \times H \times S \quad (1)$$

where H is the boundary layer height (*BLH*), $f(RH)$ is the ratio of the ambient and dry extinction coefficient to the relative humidity (RH), ρ is the aerosol mass density ($g\ m^{-3}$), $Q_{ext,dry}$ is the Mie extinction efficiency, and r_{eff} is the effective radius of the particle. S is the specific extinction efficiency ($m^2\ g^{-1}$) of the aerosol at ambient RH . This equation assumes the aerosol is homogeneously distributed throughout the BLH .

The relationship between $PM_{2.5}$ and AOD could take the form of a multivariate function that is linked to numerous meteorological and spatial factors that influence it. [45], [46]. AOD is a variable that includes changes in $PM_{2.5}$, resulting from a comprehensive combination of emissions, chemical reactions, and others. However, there are still three main differences between AOD and $PM_{2.5}$ data:

- AOD is a unitless value that reflects the total light blackout effect of the aerosol in the column, while $PM_{2.5}$ is the mass concentration at the soil surface.
- In the presence of moisture, water-soluble particles will become more prominent through the water absorption process, thus affecting the light-extinguishing ability of the aerosol.
- $PM_{2.5}$ is only part of aerosols with a diameter equal to or less than $2.5\ \mu m$, but this does not apply to all aerosols.

Some AOD products that can be found:

a) *AERONET AOD*: The Aerosol Robotic Network (AERONET) is a global aerosol monitoring network widely recognized as the benchmark for evaluating satellite source AOD products. It provides long-term AOD ground measurements with low drift (0.01-0.02) and high time resolution (15 minutes). AOD measurements in the 550nm band are not available through AERONET. However, to estimate AOD in this band, the Angstrom exponent is typically used to interpolate AOD values between 440nm and 675nm. AERONET AOD is currently categorised into three quality levels: L1.0, L1.5, and L2.0, which represent unfiltered data, filtered and quality-controlled data, and quality-assured data, respectively. Version 3 of the database is currently under

development, which will feature more stringent quality control measures, particularly for cirrus cloud pollution [47].

b) *DT AOD*: The development of the Dark Target (DT) Algorithm is enabled to obtain AOD values in high vegetation cover, dark soil, and low sea surface albedo environments at 10 Km or 3 Km spatial resolution. DT selects dark pixels with atmospheric reflectance (TOA) of 0.01-0.25 in the 2.12 μm channel to retrieve AOD. DT provides fine (low, medium, high) and coarse three-surface aerosol models. Furthermore, it selects from these three models according to the season and geographical conditions [45]. Collection 6 DT AOD (C6 DT AOD) was established in early 2014 and has completed updates to calibration, cloud mask, and land/ocean symbols. Subsequently, the C6-based C6.1 DT AOD was released to address the continuous changes in surface reflectivity caused by the rapid growth of tall buildings worldwide [48]. Specifically, in a pixel network covering an area of 10km \times 10km, consisting of $\geq 50\%$ coastal pixels or $\geq 20\%$ water pixels, C6.1 DT will reduce the capture quality to zero and modify it with surface reflections in certain AOD areas [48]. The observed rise in value confirms a 2.17% increase in the correlation coefficient between C6.1 DT and AERONET AOD in certain urban locations, suggesting that C6.1 DT AOD provides a more accurate representation of the urban situation. The unfiltered product for AOD C6.1 DT, lacking quality detection, is denoted as "Image_Optical_Depth_Land_And_Ocean," whereas the filtered product with Quality Assurance (QA) greater than 1 (for ocean) and QA equal to 3 (for land) is denoted as "Optical_Depth_Land_And_Ocean."

c) *DB AOD*: The Deep Blue (DB) algorithm is designed to capture AOD at 10 km spatial resolution for environments with high surface albedo in deserts, drylands, and cities. It can overcome the defects of the DT algorithm on shiny surfaces. Contrary to DT, DB first picks up aerosols at 1Km resolution, and then combines the 10Km pixels. The Collection 6 DB AOD (C6 DB AOD) product is named "Enhanced Deep Blue" to differentiate it from C5 and extend to other global layers beyond snow and ice C6.1 DB has the following improvements over C6: (1) reduction of artefacts from heterogeneous terrain, (2) improved elevation terrain surface models, and (3) updated seasonal or regional aerosol models and better smoke detection [48]. The product without quality detection in AOD C6.1 DB is named "Deep_Blue_Aerosol_Optical_Depth_550_Land" and filtered by QA=2 and QA=3 is named "Deep_Blue_Aerosol_Optical_Depth_550_Land_Best_Estimate".

d) *MAIAC AOD*: MAIAC AOD refers to the atmospheric aerosol optical depth (AOD) product generated by the Multi-Angle Implementation of Atmospheric Correction (MAIAC) algorithm. The MAIAC algorithm is a sophisticated technique for atmospheric correction of satellite imagery, which allows for the retrieval of high-quality AOD data. MAIAC AOD is derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on board the Terra and Aqua satellites, which are operated by the National Aeronautics and Space Administration (NASA). MAIAC AOD

provides high-resolution AOD data with spatial and temporal coverage, making it a valuable tool for studying air pollution and its impacts on human health and the environment. Therefore, MAIAC has a high level of quality (L2) [49], [50]. In addition, the 1 km resolution is another important feature of MAIAC AOD. MAIAC has uncertainties under extreme conditions, indicating that MAIAC cannot obtain AOD accurately at high altitudes (>4.2 km). Lyapustin [51] showed that MAIAC could not get the AOD accurately at altitudes (>4.2 km). Tao [49] showed that daily bias varies dramatically in areas where airborne transportation and dusting occur. Otherwise, Lyapustin [51] compared MAIAC products with different surface cover types and found significantly different detection precision. The miscalculation of regression coefficients of surface reflectance at different wavelengths caused MAIAC to be systematically overestimated due to particle scattering properties in northwest China's desert areas.

e) Other AOD products: In addition to the aforementioned AOD products, several radiometers offer satellite-based AOD products, such as the Climate Change Initiative (CCI) products from the European Space Agency (ESA), which include AATSR Dual View (AATSR-ADV), AATSR Swansea University (AATSR-SU), AATSR Oxford-RAL Retrieval of Aerosol and Cloud (AATSR-ORAC), and AATSR-ENSEMBLE (AATSR-EN), as well as AOD products from other sensors, including the Advanced Very High-Resolution Radiometer (AVHRR), Multi-angle Imaging Spectroradiometer (MISR), Sea-viewing Wide Field-of-view Sensor (SeaWiFS), Visible Infrared Imaging Radiometer (VIIRS), and Polarization and Directionality of the Earth's Reflectance (POLDER) [52] and Advanced Himawari Imager (AHI). Some AOD products are not widely used for PM_{2.5} estimation due to low time resolution, poor overall accuracy, or limited application range.

2) Co-pollutant and meteorological variables: When hydrocarbons (HC) and nitrogen oxides (NO_x) react in sunlight, they produce the secondary pollutants ozone (O₃) and secondary organic carbon (SOC). The photochemical reaction of gaseous precursors of primary organic carbon (POC) results in the formation of SOC [53]. Meteorological factors affect the dispersion and transport of fine particles. Commonly used meteorological variables are relative humidity (RH), temperature (TEMP), u/v wind, surface pressure (SP), and wind direction (WD) [54]. Additional studies based on observation have demonstrated that the correlation between PM_{2.5} and AOD is influenced by the Planetary Boundary Layer Height (PBLH). When the PBLH is greater, the AOD is also higher; however, the PM_{2.5} concentration is lower. [55]. RH changes aerosol particles, affecting AOD by increasing humidity, hygroscopicity (the ability of a substance to take up water molecules from its surroundings, either by absorption or adsorption), and aerosol particles. Furthermore, evaporation has a strong positive correlation with temperature ($R > 0.6$) and a strong negative correlation with relative humidity ($R < -0.6$).

The survey results summarize the various source variables and individual chemical constituents of the data set used for the PM_{2.5} study. The chemical sources were divided into the categories of natural and anthropogenic-biogenic [42]:

- Natural Sources
 - Biomass (Potassium (K))
 - Sea spray aerosols (Sodium (Na))
 - Coal burning (Aluminium (Al), Selenium (Se), Cobalt (Co), Arsenic (As))
 - Soil and road dust (Aluminium (Al), Silicon (Si), Calcium (Ca))
 - Volcanic dust particles and wild land fire particles (Potassium (K), Zinc (Zn), Lead (Pb))
- Anthropogenic-biogenic sources
 - Diesel, petrol and coal combustion (Elemental carbon (EC), Sulfates (SO₄))
 - Heavy industry—high temperature combustion (Iron (Fe), Zinc (Zn), Copper (Cu), Lead (Pb), Nitrates (NO₃))
 - Fertilizer and animal husbandry (Ammonium (NH₄))
 - Oil burning (Vanadium (V), Nickel (Ni), Manganese (Mn), Iron (Fe), Organic carbon (OC))

3) Anthropogenic variables: According to existing research on PM_{2.5} forecasting, road and rail density, population density, and proportion of land use (agricultural land and forest land) as human influencing factors of PM_{2.5} [56], [57]. Land use variables have always been the conventional choice in PM_{2.5} driving research, representing the degree of landscape modification by humans and as a proxy for local emissions and background air pollution levels. Land use variables approximate air pollutant emissions, often at the kilometer or sub-kilometer scale. Land use can be (1) type of land use coverage, (2) distance to the nearest highway, (3) distance to the coastline, (4) elevation, and (5) NDVI (normalized vegetation difference index). (6) The distribution of PM_{2.5} is influenced by elevation due to the difficulty of reaching PM_{2.5} at a higher elevation above the earth's surface from sea level [58].

Land use variables are potential sources of PM_{2.5} and are the areas of most significant concern. Existing studies on the dependence of land use variables on AOD or PM_{2.5} show significant differences between lower and higher areas. Grassland, shrubs, water bodies, and artificial surfaces positively depend on AOD (maximum partial dependence of about 0.63) and are insignificant on PM_{2.5} [43]. Since land cover properties can be assumed to change gradually, missing values at the temporal scale are then replaced through linear interpolation between adjacent values [59].

Nighttime (Night Light (NLT)) population density variables, such as road network density, height, and number of buildings, are used to identify the degree of population agglomeration and urbanization in the scale of urban industrial development [30]. For example, coal, forest fires and vehicle emissions can be a

major source of haze, as the larger composition of released fine soot particles affects the higher AOD and PM_{2.5} measurements in MODIS. Another study showed that NLT has an increased MSE: about 30 n plots with partial dependence on PM_{2.5} generally increase slowly as NLT increases [60]. This suggests that high NLT represents densely populated areas and still operating factories. However, the impact of emissions in a short period is not very influential on high PM_{2.5}. Studies by [61] have shown that population density is significantly positively correlated with AOD, with PM_{2.5} concentrations increasing sharply near population density = 6 (people/KM) then increasing slowly. This pattern shows the contribution of population density to PM_{2.5} concentrations, which can rise above pollutant limits due to high human activity.

C. Analysis of Variables Affecting PM_{2.5}

Understanding the variables that trigger PM_{2.5} is essential. The study by Su [56], adopted spatial autocorrelation analysis to explain the spatial correlation of PM_{2.5} in the study area and period. This study uses spatial cluster and outlier methods to analyze the distribution and spatial-temporal variation of the PM_{2.5} surface. Meanwhile, the Random Forest algorithm was used to analyze the influence variables on PM_{2.5}. The relationship between PM_{2.5} concentration and the explanatory variables was well modeled, and the explanation level of the drivers to PM_{2.5} was more than 0.9. Temperature, rainfall, and wind speed are the main driving forces of PM_{2.5} emissions. The impact of forest fires is also slowly influencing the driving force of PM_{2.5} concentration [61]. Another study related to the importance of explanatory variables in explaining PM_{2.5} variations, using ensemble models (deep learning (DL), Random Forest Distribution (DRF), and Gradient Boosting Machines (GBM)) by explaining PM_{2.5} variations such as wind speed, inversion strength, and aerosol optical depth (AOD) to be the most influential in DRF and GBM models. For the deep learning algorithm, wind direction emerged as the most influential, followed by the land cover variable [62].

D. Missing Values

The relationship between AOD and PM_{2.5} varies considerably across regions, seasons, and time periods. Hence, studies that employ a single machine learning technique to estimate PM_{2.5} concentrations over a vast area require some enhancements in spatial distribution. Additionally, the accuracy of machine learning methods for PM_{2.5} estimation is linked to the training sample used. Since satellites cannot detect atmospheric aerosols below the clouds, it has a gap of missing values in the spatial distribution.

The advantages of atmospheric model data are fully utilized to obtain comprehensive coverage results. Therefore, the map produced by the interpolation analysis of PM_{2.5} concentration distribution using measured values from each monitoring station can be evidence of the validity of the PM_{2.5} concentration prediction technique. To obtain values for unknown spatial data, a spatial interpolation approach can be used. Various researchers have referred to standard spatial interpolation methods such as Trend Surface (TS) interpolation, Collaborative Kriging (CK), Inverse Distance Weighted (IDW) interpolation, Ordinary Kriging (OK) interpolation [56], and radial basis function.

1) *The OK*: interpolation method assumes that the spatial correlation of surface changes can be explained based on the distance or direction between sampling points, and it adjusts a mathematical function at all points to determine the value of each outlet by considering a certain number of nearby points or a certain radius. Calculated through Eq. (2) as follows:

$$z_v^*(x) = \sum_{i=1}^n \lambda_i Z(x_i) \quad (2)$$

Where $Z(x)$ is the measurement of position i , λ_i is the unknown weight of the measurement value at a position i , is the predicted position, and n is the number of measurements. Wong [56] used the OK method to generate continuous air pollutant concentrations and meteorological factors covering Taiwan.

2) *The IDW*: interpolation method calculates pixel values by linearly combining a series of sample points, with the goal of minimizing the distance between the mapped variable and the sample locations. Calculated through Equation (3) as follows:

$$z = \left[\sum_{i=1}^n \frac{z_i}{d_i^k} \right] / \left[\sum_{i=1}^n \frac{1}{d_i^k} \right] \quad (3)$$

This formula represents the calculation of the inverse distance weighting (IDW) method, which is a spatial interpolation technique used to estimate values at unsampled locations based on the values of neighboring sampled locations. In the formula, "z" represents the estimated value at the unsampled location, "n" is the number of neighboring sampled locations, "z_i" is the value at each neighboring sampled location, "d_i" is the distance from the unsampled location to each neighboring sampled location, and "k" is a power parameter that determines the influence of the distance on the estimated value. The formula calculates the weighted average of the neighboring sampled values based on their distances to the unsampled location, where the weights are determined by the inverse of the distances raised to the power of "k", and divides the sum of the weighted values by the sum of the weights to obtain the estimated value. Chae [63] used the IDW method to interpolate the missing values uniformly and generate grid-shaped data in the Convolutional Neural Network (ICNN) Interpolation prediction model in South Korea from January 1, 2018, to December 31, 2019, with PM_{2.5} and PM₁₀ measurements [63].

3) *The TS*: method involves applying statistical techniques to create continuous mathematical surfaces by matching them to known spatial points to examine patterns of change in regional and local geological variables. It is calculated through Equation (3) as follows:

$$z = \beta_1 + \beta_2 + \beta_{13y} + \beta_{4x^2} + \beta_{5xy} + \beta_{6y^2} + \dots \quad (4)$$

Where Z is the address variable, x and y are the coordinates of the observation point.

The CK method refers to kriging interpolation, which is a geostatistical method based on variogram theory and structural analysis. It is considered an unbiased and optimal estimation

method for regional variables [64], [65]. Liu [66], employed the CK Method to generate simulation maps depicting the spatial distribution of PM_{2.5} mass concentration on Changsha's Third Ring Road. Furthermore, an additional interpolation analysis map was generated using the measured values from each monitoring station, to serve as a reference for the map generated using predicted values. The aim is to validate the PM_{2.5} concentration prediction method, which uses the CK method. This method uses one or more secondary variables to interpolate the primary variable of interest. The method assumes that the correlation between these variables can improve the accuracy of the primary predictor [66]. Usually, some measurement points correspond to a normal distribution. To estimate each unknown point, the estimator is expressed as a linear combination of the valid sample values. In other words, a linear combination of valid sample values is used as an estimator for each unknown point to be estimated:

$$\hat{Z}(S_i) = \sum_{j=1}^n \lambda_j Z(S_j) \quad (5)$$

where $\hat{Z}(S_i)$ is the estimated value of the variable at location S_i , $Z(S_j)$ is the observed value of the variable at location S_j , λ_j is the weight assigned to the observed value at location S_j , and n is the total number of observed values used in the estimation.

One way to guarantee that the model provides unbiased estimates is by:

$$\sum_{j=1}^n \lambda_j = 1 \quad (6)$$

The value of $\hat{Z}(S_i)$ can be determined while ensuring that the kriging variance is kept at a minimum.

V. APPLIED MACHINE LEARNING MODELS

Advanced machine learning models have been applied to PM_{2.5} forecasting by developing methods that reflect transport and formation characteristics in suitable algorithms. Compared to classical statistical models and generalized additive models that have been used to calculate empirical models of PM_{2.5}[67], machine learning has become a popular method for developing satellite-based AOD-PM_{2.5} models due to its advantages in selecting and using many independent factors that can affect the dependent variable to be estimated [62], [68].

The feed-forward neural network [69] and Recurrent Neural Network (RNN) [41] are some of the fundamental algorithms to simulate the temporal variation of PM_{2.5} concentration by describing the stratigraphic characteristics of the predicted area. Observation data from monitoring stations in the forecast area and surrounding areas are utilized to develop Convolutional Neural Network (CNN) and Graph Neural Network (GNN) models that directly capture transportation characteristics [41], [70]. These models can effectively represent the spatial correlation between the forecast area and the downwind emission source.

Hybrid models that combine CNN and GNN with the temporal property of LSTM, such as CNN-LSTM and GNN-

LSTM, can reflect the temporal variation of the forecast area and the transmission of the wind direction area. Theoretically, the convolutional LSTM (ConvLSTM) network structure makes it an ideal algorithm for combining transportation and formation features; however, these features cannot be accurately predicted after 12 hours [71]. The ensemble technique of Deep Neural Network (DNN) [69], RNN, CNN algorithmic models for real-time estimation of PM_{2.5} is considered capable of reducing the average bias and improving the accuracy index of models that are substantially limited by the uncertainties in the input data of anthropogenic emissions and meteorological fields, as well as the inherent limitations of each model [65].

The paper by Wong [56] uses four types of machine learning algorithms GBM, eXtreme gradient boosting (XGBoost), LightGBM, and CatBoost, after influential variables are identified through interpolation models. The results of the study by comparing the ensemble mixed spatial model and LUR showed that the forecast performance increased from 0.514 to 0.895 (from 0.478 to 0.879) during the day and from 0.523 to 0.878 at night [56].

Note that both the LightGBM model [72] and the eXtrem Gradient Boosting (XGBoost) model [72], [73] are decision tree-based Gradient Boosting frameworks. The XGBoost objective function equation is as follows:

$$Ob^{(t)} = \sum_{j=1}^T \left[G_j W_j + \frac{1}{2} (H_j + \lambda) w_j^2 \right] + \gamma T \quad (7)$$

where:

- $Ob^{(t)}$ is the objective function at iteration t
- T is the total number of leaf nodes in the tree
- G_j and H_j are the cumulative sum of the first-order and second-order partial derivatives of the samples contained in leaf node j , respectively
- λ and γ are constants
- W_j is the score value of the j -th leaf node
- w_j is the weight of the j -th leaf node

LightGBM uses the same gain formula $G_j W_j + \frac{1}{2} (H_j + \lambda) w_j^2$ as XGBoost, however, it employs a histogram-based algorithm, as well as techniques like leaf-wise growth with depth restrictions and Gradient-based One-Side Sampling (GOSS) to accelerate the training process. These approaches enable LightGBM to attain better prediction accuracy and lower memory consumption.

The Random Forest (RF) regression algorithm produced a good fit in detecting the relationship between PM_{2.5} and its drivers [61], [74], [75]. Liu [12] utilized RF as a gap filler on the Himawari-8 AOD, using MERRA-2 to estimate hourly PM_{2.5} concentrations, respectively. The results of this random forest study indicate that a set of input variables are used at each node to grow the tree. The algorithm (random forest) used resulted in gap-filling capability with AOD MERRA-2 can

provide reliable spatial and temporal PM_{2.5} predictions and significantly reduce errors in PM_{2.5} estimation [12]. The PM_{2.5} concentration estimation model (night) was also conducted by Ma [77] by integrating Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB) radiance, moon phase angle, and meteorological data in the Beijing Tianjin-Hebei region. The study developed a NightPMES model using random forests and compared its cross-validation results with those of MLR and DNN models. The NightPMES model achieved an R2 of 0.82, and an RMSE and MAE of 16.67 and 10.20, respectively. In addition, the NightPMES model performed better than most previous models [76].

The general framework for estimating PM_{2.5} concentrations in RF is as follows:

$$f(x) = \sum_{z=1}^Z C_z I(x \in R_z)$$

$$\hat{c}_z = \text{mean}(y_i | x \in R_z) \tag{8}$$

The formula involves the regression tree function, $f(x)$ where the output value is the estimated PM_{2.5} value. The sample (x_i, y_i) is taken from the Z region (R1, R2, ..., Rz), and there are N samples in total. The best estimate of the output mean for the data set is denoted as \hat{c}_z . The RF division strategy is expressed as follows:

$$z_1(m, n) = \{X | X_j \leq N\} \& z_2(m, n) = \{X | X_j > N\}$$

$$\min_{m,n} \left[\min_{x_i \in R_1(m,n)} \sum (y_i - C_1)^2 + \min_{x_i \in R_2(m,n)} \sum (y_i - C_2)^2 \right] \tag{9}$$

$$\hat{c}_z = \text{mean}(y_i | x_i \in R_1(m, n)) \& \hat{c}_2$$

$$= \text{mean}(y_i | x_i \in R_2(m, n))$$

where, m is the splitting variable, n is the split point. Diagrammatic representation of it is given in Fig. 3.

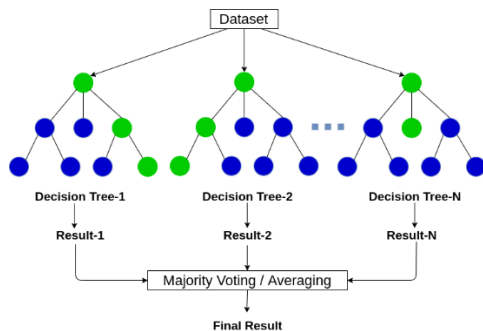


Fig. 3. Random forest based prediction process.

The study by Aguilera [62], used three base learners available within the H2O framework for machine learning: deep learning, random forest (RF), and Gradient Boosting. Each model was trained individually on all response (PM_{2.5}) and independent variables, with the optimal parameters of each machine learning algorithm selected by performing a grid search which was then stacked to find the optimal combination of the set of prediction algorithms (H2O's Stacked Ensemble method). Of the three machine learning algorithms, the optimal

combination of three base learners (RF, deep learning, and gradient boosting) achieved excellent prediction performance (R2 of 0.78 and RMSE of 3.51 $\mu\text{g m}^{-3}$) [62].

Feng conducted a study in the Beijing-Tianjin-Hebei region, where they developed an integrated model using RF and LightGBM after wavelet decomposition of PM_{2.5} observations. The study showed a high degree of consistency between the estimated and actual values. The cross-validation using time-based R2, RMSE, and MAE showed good model performance, with respective values of 0.91, 11.60, and 7.34 [77]. A later study by Falah [73] explored the use of RF and XGBoost models based on the fusion of multiple satellite-borne remote sensing aerosol products retrieved from two platforms (Aqua and Aura), two sensors (MODIS and OMI), and three retrieval algorithms (MAIAC, DB, and OM AE RUV). This study developed thirteen different performance models for each algorithm based on the input data sources MODIS/MAIAC (AOD, aerosol type), MODIS/DB (Angstrom exponent), and OMI (UV Aerosols Index). The UVAI OMI is used to classify aerosols into three categories: scattering aerosols, UVAI < 0.25; mixed-type aerosols, 0.25 ≤ UVAI < 0.25; and absorbing aerosols, 0.25 ≤ UVAI. Similarly, MODIS/DB AE is used to classify aerosols into three size fractions: coarse, e.g., dust, AE < 0.7; mixed mode, 0.7 ≤ AE < 1.3; and delicate, e.g., smoke, 1.3 ≤ AE. Overall, both RF and XGBoost models showed good performance, with variance (RF; R2 0.753 and NRMSE 0.884 - XGBoost R2 0.741 and NRMSE 0.874) explained by high cross-validation and low normalized root mean square error even for the base model (MAIAC AOD: AOD, CWV, PBLH, SP), with both models showing much better overall weighting performance when the model input data is subdivided into categories representing different aerosol types/properties [72].

Mahmud [54] conducted a study that used six supervised machine learning algorithms for regression and classification to predict PM_{2.5} values from 2015 to 2019 in the North Paso region. The variables were analyzed by six different machine learning algorithms using various evaluation metrics. The study showed that the ML model successfully detected the effects of other variables on PM_{2.5}, made accurate predictions, and identified areas of potential risk. The random forest algorithm showed the best performance among all machine learning models with 92% accuracy[54]. This technique has several advantages over other machine learning methods, such as shorter computation time, ease of handling high-dimensional data, strong fault tolerance, and parallel processing, making it suitable even for very high-dimensional data.

Support Vector Machines (SVMs) are flexible and powerful techniques for supervised machine learning, which are used for classification, pattern recognition, and functional regression problems. SVMs find an N-dimensional hyperplane with large margins to classify data into specific groups or labels [78]. A hyperplane divides the class into two, and the margin is used to divide the hyperplane. The predicted value, close to the best margin, is sampled to one of the classes. The predicted output includes one of the high-dimensional spaces as class 1 or 0, which concludes the prediction as traffic or less traffic area.

Recent research indicates that artificial neural networks are effective in both classification and regression tasks. One approach to predict areas with high levels of air pollution is by utilizing support vector machines (SVM), which aim to identify an N-dimensional hyperplane that maximizes the separation gap (margin) for the training data points. The optimal hyperplane is located at the center of the margin, and the data points located close to this hyperplane are known as support vectors. SVMs use kernel functions, such as linear, radial basis function, polynomial, Fisher, and Bayesian, to bridge linearity to non-linearity. In Masood's work [25], kernel functions were found to be crucial in this process. This study employed both linear and polynomial kernel functions. A visual representation of the SVM approach is shown in Fig. 4.

$$\text{Linear Kernel} = k(X_i, X_j) = x_j^T x_i \quad (10)$$

$$\text{Polynomial Kernel} = k(X_i, X_j) = (1 + x_j^T x_i)^p \quad (11)$$

Where X_i and X_j are independent random vectors, and p is a polynomial kernel order.

The efficacy of the SVM kernels depends on the calibration of controlling parameters such as kernel width (σ), regularization parameter (C), and gamma parameter (γ). In this research, two kernels (linear and polynomial) were employed for modeling. The SVM_lin model had NSE, RMSE, IA, R2, and R values of 0.938, 22.733, 0.983, 0.938, and 0.968, respectively, for the training phase, and 0.896, 29.634, 0.970, 0.923, and 0.961 for the testing phase. For the SVM_poly model, the NSE, RMSE, IA, R2, and R values for the training phase were 0.934, 23.334, 0.982, 0.935, and 0.967, respectively, and for the testing phase, they were 0.893, 30.071, 0.939, 0.840, and 0.916. Overall, the results of the SVM_lin and SVM_poly models were satisfactory for both the training and testing phases, indicating their ability to accurately predict PM2.5 concentrations. [25].

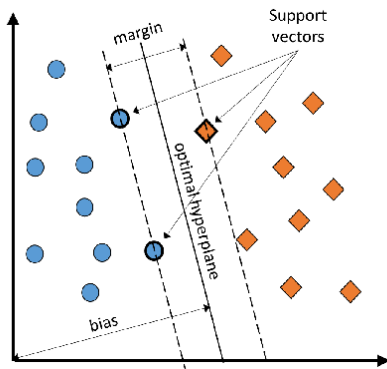


Fig. 4. This diagram illustrates the ideal hyperplane that effectively separates the data points, with the support vectors located near it.

A. Model Validations and Predictions for the Model

Statistical indicators such as coefficient of determination (R2, the higher, the better), correlation coefficient (R), Mean percentage error (MPE, the lower, the better), root means squared prediction error (RMSE, the lower, the better), index of agreement (IA), Mean Absolute Percentage Error, (MAPE

the lower, the better), mean absolute error (MAE) and Nash-Sutcliffe efficiency index (NSE), are evaluation metrics typically used for model evaluation. The mathematical expressions of these metrics are given as follows:

$$1) \text{ Determination coefficient } (R^2) \\ R^2 = \frac{\sum_{i=1}^N (I_o - \bar{I}_o) (I_p - \bar{I}_p)}{\sum_{i=1}^N (I_o - \bar{I}_o)^2 \sum_{i=1}^N (I_p - \bar{I}_p)^2} \quad (12)$$

$$2) \text{ Correlation coefficient } (R) \\ R = \frac{N \sum I_o I_p - (\sum I_o) (\sum I_p)}{\sqrt{N(\sum I_o^2) - (\sum I_o)^2} \sqrt{N(\sum I_p^2) - (\sum I_p)^2}} \quad (13)$$

$$3) \text{ Root mean square error } (RMSE) \\ RMSE = \sqrt{\frac{\sum_{i=1}^N (I_p - I_o)^2}{N}} \quad (14)$$

$$4) \text{ Index of Agreement } (IA) \\ IA = \left(\frac{\sum_{i=1}^N (|I_o - I_p|)^2}{\sum_{i=1}^N (|I_p - \bar{I}_o| + |I_o - \bar{I}_p|)^2} \right) \quad (15)$$

$$5) \text{ Mean Absolute Percentage Error } (MAPE) \\ M = \frac{1}{n} \sum_{t=1}^n \left| \frac{A_t - F_t}{A_t} \right| \quad (16)$$

$$6) \text{ Mean Absolute Error } (MAE) \\ MAE = \frac{1}{n} \sum_{i=1}^n |y_{true} - y_{predict}| \quad (17)$$

$$7) \text{ Nash-Sutcliffe efficiency index } (NSE) \\ NSE = 1 - \left(\frac{\sum_{i=1}^N (I_o - I_p)^2}{\sum_{i=1}^N (I_o - \bar{I}_o)^2} \right) \quad (18)$$

VI. CONCLUSIONS

Although ground stations are considered precise for measuring PM2.5 concentrations, obtaining values that reflect the overall situation is challenging due to their uneven presence. As a result, many researchers are turning to satellite remote sensing to fill in the gaps in spatial and temporal data left by ground stations. AOD, a satellite remote sensing derivative, has been utilized to calculate PM2.5 concentrations due to its relationship-based nature. However, satellite products have limitations such as being unable to detect atmospheric aerosols below clouds and the variation of AOD and PM2.5 relationship between regions, time, and seasons. To address this, researchers commonly use spatial interpolation methods like OK, IDW, TS, and CK to obtain missing spatial data.

In recent years, machine learning has become popular for predicting unknown values at spatial and temporal scales, and to establish the relationship between PM2.5 concentrations and AOD values at each grid. Many new methods, ensembles, and refinements of existing methods have been applied to PM2.5

estimation based on the derived satellite data. Large datasets, increased computing power, and awareness of the potential benefits of predictors working together have contributed to achieving higher estimation accuracy at different scales and spatial-temporal resolutions.

To support our explanations, we reviewed relevant papers, including classic papers, in this study. Key findings include:

- The distribution of ground-level PM_{2.5} observatories is generally uneven, which makes PM_{2.5} estimates less reliable in areas with fewer stations compared to those with more stations. This also raises concerns about the effectiveness of the commonly used cross-validation approach based on ground stations, as the observational data used for training and validation are concentrated in areas with more stations.
- Several factors determine the accuracy of PM_{2.5} estimates, including the specific conditions of the study area, the resolution of the source data, the use of predictors in a particular model, and the details of the methods used to estimate PM_{2.5} concentrations.
- The low consistency between independent and dependent variables in the same atmospheric environment can affect the estimation results. Therefore, it is essential to have different data as predictors to increase confidence in the results obtained. However, data availability is a challenge. In some research areas, the potential for predicting the temporal variation of PM_{2.5} based on satellite AOD needs to be further explored in the future.
- The use of classical methods to estimate PM_{2.5} concentrations is known to be not as accurate as those obtained using new methods. On the other hand, to estimate PM_{2.5} concentrations, there are more and more models and ensemble methods that can be implemented for various conditions.
- A simple and fast method is a spatial interpolation. Several improvements and integrations to various methods have been made to obtain more accurate results. However, the accuracy of these methods is relatively low compared to more complex methods (machine learning).
- Currently, research on PM_{2.5} concentration estimation models is starting to lead to the use of deep learning models. In some recent studies, especially those published in 2023, deep learning models dominate many studies.

From the importance of variables and correlations between variables in different articles, the following conclusions can be drawn:

- Meteorological variables are a class of predictors that make an essential contribution to PM_{2.5} after AOD;
- The contribution of land use variables has a low correlation with meteorological variables;

- The importance of population-related variables depends on the economic development of the study area.

REFERENCES

- [1] W. J. Chen et al., "Susceptible windows of exposure to fine particulate matter and fetal growth trajectories in the Spanish INMA (Infancia y Medio Ambiente) birth cohort," *Environ. Res.*, vol. 216, Jan. 2023, doi: 10.1016/j.envres.2022.114628.
- [2] J. Tan-soo and S. K. Pattanayak, "Seeking natural capital projects: Forest fires, haze, and early-life exposure in Indonesia," in *PNAS*, 2019, pp. 1–7. doi: 10.1073/pnas.1802876116.
- [3] T. Schikowski and H. Altuğ, "The role of air pollution in cognitive impairment and decline," *Neurochem. Int.*, vol. 136, no. February, p. 104708, 2020, doi: 10.1016/j.neuint.2020.104708.
- [4] L. Yang, C. Li, and X. Tang, "The Impact of PM_{2.5} on the Host Defense of Respiratory System," *Front. Cell Dev. Biol.*, vol. 8, no. March, pp. 1–9, 2020, doi: 10.3389/fcell.2020.00091.
- [5] S. Yin, T. Li, X. Cheng, and J. Wu, "Remote sensing estimation of surface PM_{2.5} concentrations using a deep learning model improved by data augmentation and a particle size constraint," *Atmos. Environ.*, vol. 287, Oct. 2022, doi: 10.1016/j.atmosenv.2022.119282.
- [6] Z. Ma et al., "A review of statistical methods used for developing large-scale and long-term PM_{2.5} models from satellite data," *Remote Sens. Environ.*, vol. 269, p. 112827, 2022, doi: <https://doi.org/10.1016/j.rse.2021.112827>.
- [7] D. K. and N. T. M. T. and P. V. H. Pham Phan Hong Danhand Le, "Estimating PM_{2.5} Mass Concentration from MODIS AOD Products in Ho Chi Minh City, Vietnam," in *ICSCSA 2021, 2023*, pp. 579–588.
- [8] P. and J. A. M. and A. J. S. and S. A. and V. G. K. Scaria Haritha P. and Avanthika, "Relational Study of PM_{2.5} Surface Concentration with MODIS Level 3 AOD Data Over India," in *Recent Advances in Civil Engineering*, 2023, pp. 99–113.
- [9] S. Gündoğdu, G. Tuna Tuygun, Z. Li, J. Wei, and T. Elbir, "Estimating daily PM_{2.5} concentrations using an extreme gradient boosting model based on VIIRS aerosol products over southeastern Europe," *Air Qual. Atmos. Heal.*, vol. 15, no. 12, pp. 2185–2198, 2022, doi: 10.1007/s11869-022-01245-5.
- [10] N. Erkin, M. Simayi, X. Ablat, P. Yahefu, and B. Maimaiti, "Predicting spatiotemporal variations of PM_{2.5} concentrations during spring festival for county-level cities in China using VIIRS-DNB data," *Atmos. Environ.*, vol. 294, p. 119484, 2023, doi: <https://doi.org/10.1016/j.atmosenv.2022.119484>.
- [11] Z. Song, B. Chen, and J. Huang, "Combining Himawari-8 AOD and deep forest model to obtain city-level distribution of PM_{2.5} in China," *Environ. Pollut.*, vol. 297, p. 118826, 2022, doi: <https://doi.org/10.1016/j.envpol.2022.118826>.
- [12] Z. Liu, Q. Xiao, and R. Li, "Full Coverage Hourly PM_{2.5} Concentrations' Estimation Using Himawari-8 and MERRA-2 AODs in China," *Int. J. Environ. Res. Public Health*, vol. 20, no. 2, Jan. 2023, doi: 10.3390/ijerph20021490.
- [13] Z. Song et al., "High temporal and spatial resolution PM_{2.5} dataset acquisition and pollution assessment based on FY-4A TOAR data and deep forest model in China," *Atmos. Res.*, vol. 274, p. 106199, 2022, doi: <https://doi.org/10.1016/j.atmosres.2022.106199>.
- [14] B. N. Vu, J. Bi, W. Wang, A. Huff, S. Kondragunta, and Y. Liu, "Application of geostationary satellite and high-resolution meteorology data in estimating hourly PM_{2.5} levels during the Camp Fire episode in California," *Remote Sens. Environ.*, vol. 271, p. 112890, 2022, doi: <https://doi.org/10.1016/j.rse.2022.112890>.
- [15] L. Wang, Y. Zhang, K. Wang, B. Zheng, Q. Zhang, and W. Wei, "Application of Weather Research and Forecasting Model with Chemistry (WRF/Chem) over northern China: Sensitivity study, comparative evaluation, and policy implications," *Atmos. Environ.*, vol. 124, pp. 337–350, 2016, doi: <https://doi.org/10.1016/j.atmosenv.2014.12.052>.
- [16] G. E. Kulkarni, A. A. Muley, N. K. Deshmukh, and P. U. Bhalchandra, "Autoregressive integrated moving average time series model for forecasting air pollution in Nanded city, Maharashtra, India," *Model.*

- Earth Syst. Environ., vol. 4, no. 4, pp. 1435–1444, 2018, doi: 10.1007/s40808-018-0493-2.
- [17] [17] H. Karimian, Y. Li, Y. Chen, and Z. Wang, “Evaluation of different machine learning approaches and aerosol optical depth in PM_{2.5} prediction,” *Environ. Res.*, vol. 216, Jan. 2023, doi: 10.1016/j.envres.2022.114465.
- [18] M. Unik and Sri Nadriati, “Overview: Random Forest Algorithm for PM_{2.5} Estimation Based on Remote Sensing,” *J. CoSciTech (Computer Sci. Inf. Technol.)*, vol. 3, no. 3, pp. 422–430, Dec. 2022, doi: 10.37859/coscitech.v3i3.4380.
- [19] P. Gupta and S. A. Christopher, “Particulate matter air quality assessment using integrated surface, satellite, and meteorological products: 2. A neural network approach,” *J. Geophys. Res. Atmos.*, vol. 114, no. 20, pp. 1–14, 2009, doi: 10.1029/2008JD011497.
- [20] D. J. Lary, A. H. Alavi, A. H. Gandomi, and A. L. Walker, “Machine learning in geosciences and remote sensing,” *Geosci. Front.*, vol. 7, no. 1, pp. 3–10, 2016, doi: 10.1016/j.gsf.2015.07.003.
- [21] K. J. Bergen, P. A. Johnson, M. V. De Hoop, and G. C. Beroza, “Machine learning for data-driven discovery in solid Earth geoscience,” *Science (80-.)*, vol. 363, no. 6433, 2019, doi: 10.1126/science.aau0323.
- [22] Q. Di et al., “An ensemble-based model of PM_(2.5) concentration across the contiguous United States with high spatiotemporal resolution,” *Environ. Int.*, vol. 130, p. 104909, Sep. 2019, doi: 10.1016/j.envint.2019.104909.
- [23] Q. Di et al., “Assessing NO₂ Concentration and Model Uncertainty with High Spatiotemporal Resolution across the Contiguous United States Using Ensemble Model Averaging,” *Environ. Sci. Technol.*, vol. 54, no. 3, pp. 1372–1384, Feb. 2020, doi: 10.1021/acs.est.9b03358.
- [24] P. Zhang, L. Yang, W. Ma, N. Wang, F. Wen, and Q. Liu, “Spatiotemporal estimation of the PM_{2.5} concentration and human health risks combining the three-dimensional landscape pattern index and machine learning methods to optimize land use regression modeling in Shaanxi, China,” *Environ. Res.*, vol. 208, p. 112759, 2022, doi: https://doi.org/10.1016/j.envres.2022.112759.
- [25] A. Masood and K. Ahmad, “Data-driven predictive modeling of PM_{2.5} concentrations using machine learning and deep learning techniques: a case study of Delhi, India,” *Environ. Monit. Assess.*, vol. 195, no. 1, Jan. 2023, doi: 10.1007/s10661-022-10603-w.
- [26] H. Feizi, M. T. Sattari, R. Prasad, and H. Apaydin, “Comparative analysis of deep and machine learning approaches for daily carbon monoxide pollutant concentration estimation,” *Int. J. Environ. Sci. Technol.*, vol. 20, no. 2, pp. 1753–1768, 2023, doi: 10.1007/s13762-022-04702-x.
- [27] X. Li, L. Li, L. Chen, T. Zhang, J. Xiao, and L. Chen, “Random Forest Estimation and Trend Analysis of PM_{2.5} Concentration over the Huaihai Economic Zone, China (2000–2020),” *Sustain.*, vol. 14, no. 14, Jul. 2022, doi: 10.3390/su14148520.
- [28] W. Yu, S. Li, T. Ye, R. Xu, J. Song, and Y. Guo, “Deep Ensemble Machine Learning Framework for the Estimation of PM_{2.5} Concentrations,” *Environ. Health Perspect.*, vol. 130, no. 3, Mar. 2022, doi: 10.1289/EHP9752.
- [29] Z. Li, Z. Di, M. Chang, J. Zheng, T. Tanaka, and K. Kuroi, “Study on the influencing factors on indoor PM_{2.5} of office buildings in Beijing based on statistical and machine learning methods,” *J. Build. Eng.*, vol. 66, p. 105240, 2023, doi: https://doi.org/10.1016/j.jobte.2022.105240.
- [30] M. D. Yazdi et al., “Predicting fine particulate matter (PM_{2.5}) in the greater London area: An ensemble approach using machine learning methods,” *Remote Sens.*, vol. 12, no. 6, 2020, doi: 10.3390/rs12060914.
- [31] M. Liu, X. Liu, L. Wu, X. Zou, T. Jiang, and B. Zhao, “A modified spatiotemporal fusion algorithm using phenological information for predicting reflectance of paddy rice in southern China,” *Remote Sens.*, vol. 10, no. 5, 2018, doi: 10.3390/rs10050772.
- [32] F. Yang et al., “Preliminary investigation of a new AHI aerosol optical depth (AOD) retrieval algorithm and evaluation with multiple source AOD measurements in China,” *Remote Sens.*, vol. 10, no. 5, 2018, doi: 10.3390/rs10050748.
- [33] J. Wei et al., “Himawari-8-derived diurnal variations in ground-level PM_{2.5} pollution across China using the fast space-time Light Gradient Boosting Machine (LightGBM),” *Atmos. Chem. Phys.*, vol. 21, no. 10, pp. 7863–7880, 2021, doi: 10.5194/acp-21-7863-2021.
- [34] J. Sun, J. Gong, and J. Zhou, “Estimating hourly PM_{2.5} concentrations in Beijing with satellite aerosol optical depth and a random forest approach,” *Sci. Total Environ.*, vol. 762, p. 144502, 2021, doi: https://doi.org/10.1016/j.scitotenv.2020.144502.
- [35] L. Zang, F. Mao, J. Guo, W. Gong, W. Wang, and Z. Pan, “Estimating hourly PM₁ concentrations from Himawari-8 aerosol optical depth in China,” *Environ. Pollut.*, vol. 241, pp. 654–663, 2018, doi: https://doi.org/10.1016/j.envpol.2018.05.100.
- [36] J. P. Veeffkind et al., “TROPOMI on the ESA Sentinel-5 Precursor: A GMES mission for global observations of the atmospheric composition for climate, air quality and ozone layer applications,” *Remote Sens. Environ.*, vol. 120, pp. 70–83, 2012, doi: https://doi.org/10.1016/j.rse.2011.09.027.
- [37] D. Griffin et al., “High-Resolution Mapping of Nitrogen Dioxide With TROPOMI: First Results and Validation Over the Canadian Oil Sands,” *Geophys. Res. Lett.*, vol. 46, no. 2, pp. 1049–1060, Jan. 2019, doi: https://doi.org/10.1029/2018GL081095.
- [38] K. Garane et al., “TROPOMI/S5P total ozone column data: global ground-based validation and consistency with other satellite missions,” *Atmos. Meas. Tech.*, vol. 12, no. 10, pp. 5263–5287, 2019, doi: 10.5194/amt-12-5263-2019.
- [39] Y. Pang et al., “In-vitro human lung cell injuries induced by urban PM_{2.5} during a severe air pollution episode: Variations associated with particle components,” *Ecotoxicol. Environ. Saf.*, vol. 206, Dec. 2020, doi: 10.1016/j.ecoenv.2020.111406.
- [40] L. Liu et al., “Chemical composition, oxidative potential and identifying the sources of outdoor PM_{2.5} after the improvement of air quality in Beijing,” *Environ. Geochem. Health*, 2022, doi: 10.1007/s10653-022-01275-z.
- [41] Q. Zhang, Y. Han, V. O. K. Li, and J. C. K. Lam, “Deep-AIR: A Hybrid CNN-LSTM Framework for Fine-Grained Air Pollution Estimation and Forecast in Metropolitan Cities,” *IEEE Access*, vol. 10, pp. 55818–55841, 2022, doi: 10.1109/ACCESS.2022.3174853.
- [42] P. Thangavel, D. Park, and Y. C. Lee, “Recent Insights into Particulate Matter (PM_{2.5})-Mediated Toxicity in Humans: An Overview,” *International Journal of Environmental Research and Public Health*, vol. 19, no. 12, MDPI, Jun. 01, 2022, doi: 10.3390/ijerph19127511.
- [43] R. Zhang et al., “A nonparametric approach to filling gaps in satellite-retrieved aerosol optical depth for estimating ambient PM_{2.5} levels,” *Environ. Pollut.*, vol. 243, pp. 998–1007, 2018, doi: https://doi.org/10.1016/j.envpol.2018.09.052.
- [44] R. B. A. Koelemeijer, C. D. Homan, and J. Matthijsen, “Comparison of spatial and temporal variations of aerosol optical thickness and particulate matter over Europe,” *Atmos. Environ.*, vol. 40, no. 27, pp. 5304–5315, 2006, doi: https://doi.org/10.1016/j.atmosenv.2006.04.044.
- [45] A. Mhawish et al., “Estimation of High-Resolution PM_{2.5} over the Indo-Gangetic Plain by Fusion of Satellite Data, Meteorology, and Land Use Variables,” *Environ. Sci. Technol.*, vol. 54, no. 13, pp. 7891–7900, 2020, doi: 10.1021/acs.est.0c01769.
- [46] J. Zhong et al., “Robust prediction of hourly PM_{2.5} from meteorological data using LightGBM,” *Natl. Sci. Rev.*, vol. 8, no. 10, 2021, doi: 10.1093/nsr/nwaa307.
- [47] D. M. Giles et al., “Advancements in the Aerosol Robotic Network (AERONET) Version 3 database - Automated near-real-time quality control algorithm with improved cloud screening for Sun photometer aerosol optical depth (AOD) measurements,” *Atmos. Meas. Tech.*, vol. 12, no. 1, pp. 169–209, 2019, doi: 10.5194/amt-12-169-2019.
- [48] J. Wei, Z. Li, Y. Peng, and L. Sun, “MODIS Collection 6.1 aerosol optical depth products over land and ocean: validation and comparison,” *Atmos. Environ.*, vol. 201, pp. 428–440, 2019, doi: https://doi.org/10.1016/j.atmosenv.2018.12.004.
- [49] M. Tao et al., “Performance of MODIS high-resolution MAIAC aerosol algorithm in China: Characterization and limitation,” *Atmos. Environ.*,

- vol. 213, pp. 159–169, 2019, doi: <https://doi.org/10.1016/j.atmosenv.2019.06.004>.
- [50] H. Bagheri, “A machine learning-based framework for high resolution mapping of PM_{2.5} in Tehran, Iran, using MAIAC AOD data,” *Adv. Sp. Res.*, vol. 69, no. 9, pp. 3333–3349, 2022, doi: <https://doi.org/10.1016/j.asr.2022.02.032>.
- [51] A. Lyapustin, Y. Wang, S. Korkin, and D. Huang, “MODIS Collection 6 MAIAC algorithm,” *Atmos. Meas. Tech.*, vol. 11, no. 10, pp. 5741–5765, 2018, doi: [10.5194/amt-11-5741-2018](https://doi.org/10.5194/amt-11-5741-2018).
- [52] J. Wei, Y. Peng, R. Mahmood, L. Sun, and J. Guo, “Intercomparison in spatial distributions and temporal trends derived from multi-source satellite aerosol products,” *Atmos. Chem. Phys.*, vol. 19, no. 10, pp. 7183–7207, 2019, doi: [10.5194/acp-19-7183-2019](https://doi.org/10.5194/acp-19-7183-2019).
- [53] Z. Wang et al., “The seasonal variation, characteristics and secondary generation of PM_{2.5} in Xi’an, China, especially during pollution events,” *Environ. Res.*, vol. 212, p. 113388, 2022, doi: <https://doi.org/10.1016/j.envres.2022.113388>.
- [54] S. Mahmud, T. B. I. Ridi, M. S. Miah, F. Sarower, and S. Elahee, “Implementing Machine Learning Algorithms to Predict Particulate Matter (PM_{2.5}): A Case Study in the Paso del Norte Region,” *Atmosphere (Basel)*, vol. 13, no. 12, Dec. 2022, doi: [10.3390/atmos13122100](https://doi.org/10.3390/atmos13122100).
- [55] S. Lu et al., “Impact of thermal structure of planetary boundary layer on aerosol pollution over urban regions in Northeast China,” *Atmos. Pollut. Res.*, vol. 14, no. 2, p. 101665, 2023, doi: <https://doi.org/10.1016/j.apr.2023.101665>.
- [56] P. Y. Wong, H. J. Su, S. C. C. Lung, and C. Da Wu, “An ensemble mixed spatial model in estimating long-term and diurnal variations of PM_{2.5} in Taiwan,” *Sci. Total Environ.*, vol. 866, no. 1, p. 161336, 2023, doi: [10.1016/j.scitotenv.2022.161336](https://doi.org/10.1016/j.scitotenv.2022.161336).
- [57] N. Liu, B. Zou, S. Li, H. Zhang, and K. Qin, “Prediction of PM_{2.5} concentrations at unsampled points using multiscale geographically and temporally weighted regression,” *Environ. Pollut.*, vol. 284, p. 117116, 2021, doi: <https://doi.org/10.1016/j.envpol.2021.117116>.
- [58] L. Yang, H. Xu, and Z. Jin, “Estimating ground-level PM_{2.5} over a coastal region of China using satellite AOD and a combined model,” *J. Clean. Prod.*, vol. 227, pp. 472–482, 2019, doi: [10.1016/j.jclepro.2019.04.231](https://doi.org/10.1016/j.jclepro.2019.04.231).
- [59] Z. Chen et al., “Influence of meteorological conditions on PM_{2.5} concentrations across China: A review of methodology and mechanism,” *Environment International*, vol. 139, Elsevier Ltd, Jun. 01, 2020, doi: [10.1016/j.envint.2020.105558](https://doi.org/10.1016/j.envint.2020.105558).
- [60] Y. Liu, G. Cao, N. Zhao, K. Mulligan, and X. Ye, “Improve ground-level PM_{2.5} concentration mapping using a random forests-based geostatistical approach,” *Environ. Pollut.*, vol. 235, pp. 272–282, 2018, doi: [10.1016/j.envpol.2017.12.070](https://doi.org/10.1016/j.envpol.2017.12.070).
- [61] Z. Su, L. Lin, Y. Chen, and H. Hu, “Understanding the distribution and drivers of PM_{2.5} concentrations in the Yangtze River Delta from 2015 to 2020 using Random Forest Regression,” *Environ. Monit. Assess.*, vol. 194, no. 4, Apr. 2022, doi: [10.1007/s10661-022-09934-5](https://doi.org/10.1007/s10661-022-09934-5).
- [62] R. Aguilera et al., “A novel ensemble-based statistical approach to estimate daily wildfire-specific PM_{2.5} in California (2006–2020),” *Environ. Int.*, vol. 171, Jan. 2023, doi: [10.1016/j.envint.2022.107719](https://doi.org/10.1016/j.envint.2022.107719).
- [63] S. Chae, J. Shin, S. Kwon, S. Lee, S. Kang, and D. Lee, “PM₁₀ and PM_{2.5} real-time prediction models using an interpolated convolutional neural network,” *Sci. Rep.*, vol. 11, no. 1, pp. 1–9, 2021, doi: [10.1038/s41598-021-91253-9](https://doi.org/10.1038/s41598-021-91253-9).
- [64] K. Zhao, X. Ma, H. Zhang, and Z. Dong, “Performance zoning method of asphalt pavement in cold regions based on climate Indexes: A case study of Inner Mongolia, China,” *Constr. Build. Mater.*, vol. 361, p. 129650, 2022, doi: <https://doi.org/10.1016/j.conbuildmat.2022.129650>.
- [65] Y. S. Koo et al., “A Development of PM_{2.5} Forecasting System in South Korea Using Chemical Transport Modeling and Machine Learning,” *Asia-Pacific J. Atmos. Sci.*, 2023, doi: [10.1007/s13143-023-00314-8](https://doi.org/10.1007/s13143-023-00314-8).
- [66] J. Liu, B. Zheng, and J. Fan, “Long Short-Term Memory Network and Ordinary Kriging Method for Prediction of PM_{2.5} Concentration BT - Proceedings of the 2022 International Conference on Green Building, Civil Engineering and Smart City,” 2023, pp. 1158–1169.
- [67] X. Yang et al., “Spatiotemporal estimates of daily PM_{2.5} concentrations based on 1-km resolution MAIAC AOD in the Beijing–Tianjin–Hebei, China,” *Environ. Challenges*, vol. 8, no. March, p. 100548, 2022, doi: [10.1016/j.envc.2022.100548](https://doi.org/10.1016/j.envc.2022.100548).
- [68] X. Xu, C. Zhang, and Y. Liang, “Review of satellite-driven statistical models PM_{2.5} concentration estimation with comprehensive information,” *Atmos. Environ.*, vol. 256, no. February, p. 118302, 2021, doi: [10.1016/j.atmosenv.2021.118302](https://doi.org/10.1016/j.atmosenv.2021.118302).
- [69] J. B. Lee et al., “Development of a deep neural network for predicting 6 h average PM_{2.5} concentrations up to 2 subsequent days using various training data,” *Geosci. Model Dev.*, vol. 15, no. 9, pp. 3797–3813, 2022, doi: [10.5194/gmd-15-3797-2022](https://doi.org/10.5194/gmd-15-3797-2022).
- [70] A. Gilik, A. S. Ogrenci, and A. Ozmen, “Air quality prediction using CNN+LSTM-based hybrid deep learning architecture,” *Environ. Sci. Pollut. Res.*, vol. 29, no. 8, pp. 11920–11938, 2022, doi: [10.1007/s11356-021-16227-w](https://doi.org/10.1007/s11356-021-16227-w).
- [71] C. Wen et al., “A novel spatiotemporal convolutional long short-term neural network for air pollution prediction,” *Sci. Total Environ.*, vol. 654, pp. 1091–1099, 2019, doi: <https://doi.org/10.1016/j.scitotenv.2018.11.086>.
- [72] S. Falah, F. Kizel, T. Banerjee, and D. M. Broday, “Accounting for the aerosol type and additional satellite-borne aerosol products improves the prediction of PM_{2.5} concentrations,” *Environ. Pollut.*, vol. 320, no. January, p. 121119, 2023, doi: [10.1016/j.envpol.2023.121119](https://doi.org/10.1016/j.envpol.2023.121119).
- [73] J. Wang et al., “A full-coverage estimation of PM_{2.5} concentrations using a hybrid XGBoost-WD model and WRF-simulated meteorological fields in the Yangtze River Delta Urban Agglomeration, China,” *Environ. Res.*, vol. 203, p. 111799, 2022, doi: <https://doi.org/10.1016/j.envres.2021.111799>.
- [74] W. Zhou, X. Wu, S. Ding, X. Ji, and W. Pan, “Predictions and mitigation strategies of PM(2.5) concentration in the Yangtze River Delta of China based on a novel nonlinear seasonal grey model,” *Environ. Pollut.*, vol. 276, p. 116614, May 2021, doi: [10.1016/j.envpol.2021.116614](https://doi.org/10.1016/j.envpol.2021.116614).
- [75] X. Y. Jin et al., “Machine learning driven by environmental covariates to estimate high-resolution PM_{2.5} in data-poor regions,” *PeerJ*, vol. 10, pp. 1–21, 2022, doi: [10.7717/peerj.13203](https://doi.org/10.7717/peerj.13203).
- [76] Y. Ma, W. Zhang, L. Zhang, X. Gu, and T. Yu, “Estimation of Ground-Level PM_{2.5} Concentration at Night in Beijing-Tianjin-Hebei Region with NPP/VIIRS Day/Night Band,” *Remote Sensing*, vol. 15, no. 3, 2023, doi: [10.3390/rs15030825](https://doi.org/10.3390/rs15030825).
- [77] Y. Feng, S. Fan, K. Xia, and L. Wang, “Estimation of Regional Ground-Level PM_{2.5} Concentrations Directly from Satellite Top-of-Atmosphere Reflectance Using A Hybrid Learning Model,” *Remote Sens.*, vol. 14, no. 11, 2022, doi: [10.3390/rs14112714](https://doi.org/10.3390/rs14112714).
- [78] M. M. Hameed, M. K. AlOmar, A. A. A. Al-Saadi, and M. A. AlSaadi, “Inflow forecasting using regularized extreme learning machine: Haditha reservoir chosen as case study,” *Stoch. Environ. Res. Risk Assess.*, vol. 36, no. 12, pp. 4201–4221, 2022, doi: [10.1007/s00477-022-02254-7](https://doi.org/10.1007/s00477-022-02254-7).

Developing A Predictive Model for Selecting Academic Track Via GPA by using Classification Algorithms: Saudi Universities as Case Study

Thamer Althubiti, Tarig M. Ahmed, Madini O. Alassafi

Department of Information Technology-Faculty of Computing and Information Technology,
King Abdulaziz University, Jeddah 21589, Saudi Arabia

Abstract—The main motivation of any educational institution is to provide quality education. Therefore, choosing an academic track can be clearly seen as an obstacle, for students and universities, which in turn led to imposing a mandatory preparatory year program in Saudi Arabia. One of the main objectives of the preparatory year is to help students discover the right academic track. Nevertheless, some students choose the wrong academic track which can be a stumbling block that may prevent their progress. According to the tremendous growth of using information technology, educational data mining technology (EDM) can be applied to discover useful patterns, unlike traditional data analysis methods. Most of the previous research focused on predicting the GPA after the students choose an academic track. On the contrary, our research focuses on using classification algorithms to develop a predictive model for advising students to select academic tracks via prediction of the GPA based on the preparatory year data at Saudi Universities. Then, compare classification algorithms to provide the most accurate prediction. The dataset was extracted from a Saudi university containing preparatory year data for 2363 students. This work was carried out using five classification algorithms: Gradient Boosting(GB), K-Nearest Neighbors (kNN), Logistic Regression (LG), Neural Network(NN) and Random Forest(RF). The results showed the superiority of the Logistic Regression algorithm in terms of accuracy over the other algorithms. Future work could add behavioral characteristics of students and use other algorithms to provide better accuracy.

Keywords—Data mining; educational data mining; classification algorithms; logistic regression; neural networks; gradient boosting; k-nearest neighbors; predicting students' performance

I. INTRODUCTION

In light of scientific progress and the development of communication and information technologies, there is a huge amount of data stored in database management systems (DBMS)[1]. It does not end with the ability to store this data, but it is more important how to use it in the production of knowledge [1] [2]. Recently, there is an increasing interest in science of data mining (DM). The concept of DM is simply a combination of artificial intelligence, statistics, machine learning, and databases [3] [4]. DM techniques can be used to discover unique patterns and hidden relationships. Data mining outcomes contribute to problem-solving, decision-making, and planning for organizations and companies [3]. It also plays a

key role in various fields such as economy, healthcare, and education [4].

Educational data mining (EDM) is interested in discovering hidden relationships in data obtained from educational institutions or learning management systems (LMS). This area of research is used to take advantage of the data to better understand the students and what they learn. EDM is mainly used to predict students' academic performance to help them choose their study track [5]. This helps in making the right decision at the right time.

All countries seek to increase the quality of education. The increasing concern with the quality of education can be clearly seen in the Ministry of Education of Saudi Arabia as it acquires the highest share of the country's budget. According to the budget report, the Kingdom of Saudi Arabia's education budget amounted to 189 billion riyals, representing 18% of the total general budget in 2023 [6]. Additionally, applied of the preparatory year program was started in Saudi universities in 2009 [7]. The preparatory year, the first year of a student's university journey is considered to be the most important in a student's academic study. One of its aims is to prepare the students to choose an academic track based on their results [7] [8].

Due to the increasing number of academic tracks in universities, sometimes students choose a track that is not suitable for them, even if the results of the preparatory year qualify them for this track. This causes the failure of students or graduating with an unsatisfactory GPA. Furthermore, some students have to change their academic tracks after studying for several years, causing wasted effort. A research study conducted by M.J. Foraker at Western Kentucky University (WKU) in 2012 found that 25% of the students changed an academic track once, and 5% more than once [9].

This research aims to predict the academic via GPA of students in Saudi universities. It can help teachers and academic advisors modify students' study plans and improve academic performance. For the purposes of this study, reliance was made on a data set extracted from a Saudi university. It contains data for the preparatory year, by employing five classification algorithms: Gradient Boosting(GB), kNN, Logistic Regression (LG), Neural Network(NN) and Random Forest(RF). In addition, the model is evaluated by comparing the algorithms in terms of accuracy and area under the

curve(AUC). To predict students' academic performance, we must get answers to these research questions.

1) How can we predict the right academic track via the GPA and preparatory year data of students in Saudi universities?

2) Which classification algorithm has the highest accuracy in predicting the right academic track for Saudi students?

Our paper is arranged as follows: Section II provides an overview of previous academic work in the field of predicting the academic performance of students in general and Saudi universities in particular and reviews the selected algorithms. Section III explains the methodology and materials used in preparing this paper to predict the academic track based on the GPA. It also describes the contents of the dataset and the tool used to extract the results and methods for evaluating the results of the proposed model. Section IV presents the results of predicting the GPA and the factors affecting students' academic performance in Saudi universities. We conclude our paper with Section V, in which we discuss the experimental results and answers to the research questions and offer the conclusion and future work.

II. BACKGROUND

A. Predicting Academic Performance for Students

In Nigerian universities, the duration of the study is five years in engineering colleges. Adekitan and Salau [10] questioned about the possibility of predicting the last cumulative GPA based on the results of the first three years. They developed a model by using the KNIME application that experiments with six data mining algorithms (PNN, Random Forest, The Decision Tree, Naive Bayes, Tree Ensemble, and Logistic Regression). The dataset contains a record of 1842 students from different engineering departments. The GPA of the first three years, the first year of academic study, and the department were considered as input. The results showed that the GPA of the third year was the most effective in the prediction of the last cumulative GPA. They also showed that the Logistic Regression algorithm provides higher accuracy than the other algorithms, with an accuracy of 89.15%.

Ginting and Rahman [11] presented a prediction system for the GPA of university students. The proposed system uses an Artificial Neural Network and combines it with a supervised Backpropagation algorithm. The system consists of 18 nodes at the input layer with 24 hidden nodes to produce one node in the output layer. The dataset contains 591 records of students who graduated from an Indonesian university. The system was tested using four different methods, each method changes the number of test and training data. The accuracy of the proposed system was 97.2%.

Zollanvari et al. [12] applied the maximum-weight dependence tree to propose a GPA prediction model. The proposed model is based on the behavioral characteristics of the students. A questionnaire containing 20 questions was distributed in order to find out the behaviors that affect GPA prediction. These questions are based on the educational objectives. The number of students in the dataset is 82 students. The accuracy of the proposed model was 65.85%. Better

results can be achieved by increasing the number of students in the dataset and incorporating academic performance with behavioral characteristics.

Putpuek et al. [13] compared the decision tree algorithm and data mining techniques to predict the students' GPA based on personal factors. The selected algorithms were (C4.5 and ID3) and the techniques were (Naïve Bayes and K-NN) and personal factors such as (gender, skills, type of acceptance, etc.). The dataset contains data of 2,281 students graduating from the same college in different years. The results showed the superiority of the Naïve Bayes techniques, as it achieved an accuracy of 43.18%. While ID3, C4.5, and K-NN achieved 41.65%, 42.88%, and 43.05% accuracy results, respectively.

In order to explore factors affecting the students' academic performance, Hamoud et al. [14] proposed a model that compares the algorithms of the Decision Tree (J48, Random Tree, and REPTree). The study was conducted on the students at Computer Science College at the Basra University in Iraq. Data was collected from 161 students' answers to a questionnaire containing 60 questions in different fields. The results showed the superiority of J48. The results also showed that the factors such as the GPA, the father's job, and the quality of food have a high effect on the students' performance. On the contrary, factors such as gender and age have a weak effect.

Pallathadka et al. [15] analyzed four machine learning algorithms to find out the most accurate one. The used algorithms are SVM, C4.5, ID3, and Naive Bayes. Examinations were conducted on the UCI machinery student performance dataset available online. The dataset contains 649 records and 33 factors. The results showed that the SVM algorithm is the most accurate.

B. Predicting Academic Performance for Students in Saudi Universities

In order to solve the problem of students graduating with a low GPA in Saudi Arabia and help through early intervention Alyahyan and Düşteör[16] developed a model predicting the final GPA based on the results of the first year after the preparatory year. This model is based on decision tree algorithms (Rep Tree, Random Tree, and J48). The dataset contains the record of 339 students and 15 factors such as gender, nationality, subjects' grades, and final GPA. According to the results, the J48 algorithm achieves the highest predictive ability of up to 69.3%.

Al-Barrak and Al-Razgan [17] applied the J48 algorithm on a dataset of 239 female students majoring in computer science at a Saudi university. In order to find which courses, have the most impact on the final cumulative GPA. The dataset contains 16 compulsory computer science courses. Based on the results of the experiment, it was found the two courses' Software Engineering-1 and JAVA-2' have the greatest effect on the final grade.

In order to measure the ability of classification algorithms to predict the GPA Mueen et al. [18] proposed a predictive model based on a student's record in only two courses. They used three classification techniques (Naive Bayes, C4.5, and MLP). This study was conducted on King Abdelaziz

University students in two courses (Programming and Operating Systems). Everything related to the subject, including assignments, tasks, tests, etc., were collected through the Learning Management System LMS. The results showed the superiority of the Naive Bayes classifier over the classifiers, and it achieved a prediction ability to 86%.

Altujjar et al. [19] presented a predictive model to the performance of undergraduate students in the College of Computers at King Saud University using classification algorithms. The model aims to identify important courses that have a significant impact on academic achievement. The ID3 algorithm was used to build the model for each academic year. The dataset consists of 100 student records. The dataset was split into 75% for training and 25% for testing. The results showed that the courses (IT 221), (CSC111), and (CSC113) have a significant and clear impact on the students' academic performance.

Hilal Al-Murabaha [20] analyzed the data of Saudi university students by using classification techniques. The objective is to predict student performance during the undergraduate semester. The dataset contains the record of 225 students and 10 features such as (midterm exams, attendance, final exam score, previous exams score, science experiments, projects, etc.). Five classifiers are applied to analyze student data (Naive Bayes, Bayesian Network, ID3, J48, and Neural Network) using the WEKA tool. The results showed the superiority of Bayesian Network over other classifiers, with an accuracy of 92% also, the amount of data affects the accuracy of the results.

C. Classification Algorithms

1) *Neural Networks (NN)*: Additionally referred to as artificial neural networks (ANNs) or simulated neural networks (SNNs), are at the top of deep learning algorithms. Their call and shape are inspired by the way of the human brain, mimicking the manner that biological neurons signal to each other [21] [22].

(ANNs) re-constructed from node layers, containing an enter layer, one or more hidden layers, and an output layer. each node, or artificial neuron, connects to some other and has an associated weight and threshold [21] [22]. If the output of any individual node is above the specified threshold fee, that node is activated, sending information to the following layer of the group, otherwise no information is surpassed.

2) *Gradient Boosting (GB)*: The Gradient Boosting algorithm is commonly used in the field of machine learning and is often used to build prediction and classification models. It aims to build a strong model using a succession of weak models. At each stage, a new model is built by improving the mistakes of the previous model, achieved by training the new model on the errors of the previous model. This procedure helps reduce bias errors in the final model [23] [24].

3) *K-Nearest Neighbors (kNN)*: In k-NN classification, the output is a class membership. An object is classed via a plurality vote of its pals, with the object being assigned to the class most commonplace amongst its okay nearest neighbors. If

$k = 1$, then the item is without a doubt assigned to the class of that single nearest neighbor [24][25].

4) *Logistic Regression (LR)*: This type of statistical version is regularly used for type and predictive analytics. Logistic regression estimates the possibility of an occasion taking place, together with voting or did not vote, based on a given dataset of impartial variables [26] [27] [28]. Because the final result is a possibility, the structured variable is bounded between 0 and 1. In logistic regression, a logit transformation is implemented on the odds this is the chance of fulfillment divided by way of the probability of failure. that is also typically referred to as the log odds or the natural logarithm of odds [26] [27] [28].

5) *Random Forest (RF)*: This classifier is the most popular. The primary dataset is used to construct a subset of random trees. Each tree contains a different set of features and data to predict a decision. In the end, the most common and frequent decision is chosen [24] [26] [29].

III. RESEARCH METHOD AND MATERIAL

In the method section, we present the data mining phases that we went go through to develop a predictive model for the academic tracks via GPA based on the preparatory year data in Saudi universities. Our research methodology consists of six phases (Fig. 1) as follows:

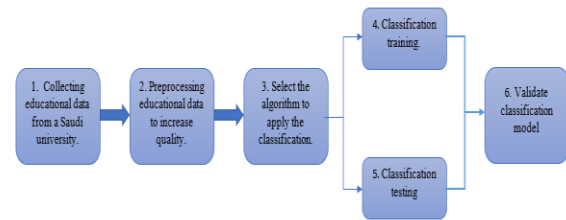


Fig. 1. Research methodology.

A. Data Collection

We obtained the dataset from a Saudi university, which preferred not to be named with taking care of the privacy of students and concealing any data indicating their personality. The dataset contains records of the preparatory year for the scientific subjects (Chemistry, Statistics, Math, Physics and BIO), the final GPA upon graduation from the university and the college to which the student is registered. All these records belong to students graduating from a university in the same year. The structure of the data set was not suitable for the data mining process. The number of records is 12393, and each student had five records in the data set, with each record representing a subject, as shown in the following Fig. 2:

2	1064702746	Female	IT	Statistics	A+	4.77
3	1064702746	Female	IT	BIO	A+	4.77
4	1064702746	Female	IT	Physics	A+	4.77
5	1064702746	Female	IT	Math	A+	4.77
6	1064702746	Female	IT	Chemistry	A+	4.77
7	1064702759	Male	Engineering	Math	A+	4.38
8	1064702759	Male	Engineering	Chemistry	B	4.38
9	1064702759	Male	Engineering	Physics	B+	4.38
10	1064702759	Male	Engineering	Statistics	B+	4.38
11	1064702759	Male	Engineering	BIO	B+	4.38
12	1064702761	Male	Engineering	Math	A+	4.95
13	1064702761	Male	Engineering	Statistics	A+	4.95
14	1064702761	Male	Engineering	Physics	A+	4.95
15	1064702761	Male	Engineering	BIO	A+	4.95
16	1064702761	Male	Engineering	Chemistry	A+	4.95

Fig. 2. Pure dataset.

Students are evaluated in each subject out of one hundred marks distributed as in the following Table I.

TABLE I. STUDENT EVALUATION

Mark	Grade symbol
From 95 to 100	A+
From 90 to less than 95	A
From 85 to less than 90	B+
From 80 to less than 85	B
From 75 to less than 80	C+
From 70 to less than 75	C
From 65 to less than 70	D+
From 60 to less than 65	D

B. Data Pre-Processing

1) Data cleaning and data reduction: During this phase, we made sure that all students took the same courses, so we deleted the data of students who transferred from other universities.

To increase the balance of the dataset and because of the large difference between the number of students graduating from some colleges we have deleted the data of students graduating from the following colleges (Table II):

TABLE II. DELETED COLLEGES

Deleted colleges	Number of students
Arts	23
Law and Political Science	7
Media	4

2) Data transformation: At this stage, the data has been transformed into a format that accepts modeling. The dataset structure for each student was five records. Each record represents a subject. Also, we changed the GPA formula from a numeric to a categorical as follows (Table III):

TABLE III. GPA SYMBOL

GPA	GPA symbol
From 5.00 to 4.50	Excellent
From 4.49 to 3.75	Very_Good
From 3.74 to 2.75	Good
From 2.74 to 2.00	Pass

After that, we added a new column named (OUTPUT). The students were divided into two values. Any student who achieved a GPA greater than or equal to four will be given in OUTPUT feature a value (RIGHT), and a student with a cumulative GPA of less than four will be given a (WRONG) value in the OUTPUT feature as Table IV.

This procedure helps us to form our hypothesis "When a student achieves a GPA higher than 4.00, then the academic track is correct".

TABLE IV. STUDENT OUTPUT SYMBOL

GPA	OUTPUT
From 4.00 to 5	RIGHT
Less than 4.00	WRONG

After completing the data pre-processing stage, we extracted a data set containing 2363 records in Excel format for this study. The features are the following (Table V):

TABLE V. FEATURES ON A DATASET

Features	No. of types	Type
Gender	2	Male, Female
College	12	Applied_Medical_Sciences, Dentistry, Design_and_Built_Environment, Eco_and_Admin_Sciences, Engineering, Home_Economics, Geology, IT, Medicine, Nursing, Pharmacy, Science
BIO	6	A+, A, B+, B, C+, C
Math	6	A+, A, B+, B, C+, C
Chemistry	6	A+, A, B+, B, C+, C
Physics	6	A+, A, B+, B, C+, C
statistics	6	A+, A, B+, B, C+, C
GPA		
Graduation Grade	4	Excellent, Very_Good, Good, Pass
OUTPUT	2	RIGHT, WRONG

Fig. 3 shows the structure of the final dataset.

Gender	College	BIO	Chemistry	Math	Physics	Statistics	GPA	Graduation Grade	OUTPUT
Female	IT	A+	A+	A+	A+	A+	4.77	Excellent	RIGHT
Male	Engineering	B+	B	A+	B+	B+	4.38	Very_Good	RIGHT
Male	Engineering	A+	A+	A+	A+	A+	4.95	Excellent	RIGHT
Male	Eco_and_Admin_Sciences	C	D+	B	C+	C	3.09	Good	WRONG
Female	IT	A	B+	B	C+	A	4.13	Very_Good	RIGHT
Female	IT	B+	A	A+	A	B+	4.61	Excellent	RIGHT
Female	Applied_Medical_Sciences	B+	C+	B+	B	B+	4.55	Excellent	RIGHT
Female	Science	A	A	A+	A+	A+	4.65	Excellent	RIGHT
Male	Engineering	B	A	A+	A+	B+	4.02	Very_Good	RIGHT
Male	Engineering	B+	B+	A+	A+	C+	4.17	Very_Good	RIGHT
Male	Engineering	B+	A	A+	A+	A+	4.78	Excellent	RIGHT
Male	Engineering	C	B	A+	A+	B	3.84	Very_Good	WRONG
Female	Home_Economics	C+	B+	A+	A+	A	4.89	Excellent	RIGHT
Female	Science	D	A	A+	A+	B	4.57	Excellent	RIGHT
Male	Engineering	B+	A	A+	A+	A+	4.37	Very_Good	RIGHT
Female	Science	B	A+	A	A+	B+	4.0	Excellent	RIGHT
Male	Engineering	A	A	A+	A+	A+	4.0	Excellent	RIGHT
Male	Science	D	D	C+	D+	B	2.75	Good	WRONG
Female	Engineering	A	A+	A+	A+	A+	4.13	Very_Good	RIGHT
Female	Science	D	D+	B+	A	C+	3.72	Good	WRONG

Fig. 3. Dataset after pre-processing.

C. Classification Algorithms Selection

After several experiments and an understanding of the characteristics of the classification algorithms, to achieve the best possible results from the data set, the following classification throws were used with default parameters values:

- Neural Network (ANN)
- Gradient Boosting (GB)
- K-Nearest Neighbors (kNN)
- Logistic Regression (LR)

- Random Forest (RF)

D. Experiments (Training and Testing)

We chose the Orange Data Mining software to conduct the experiments. Orange data mining is written in Python and is open-source. It was developed at the University of Ljubljana. The program's graphic interface offers an easy experience in handling and ease of learning [30] [31]. It supports several operating systems such as Windows and Linux. It provides the possibility to test algorithms, validation, and prediction.

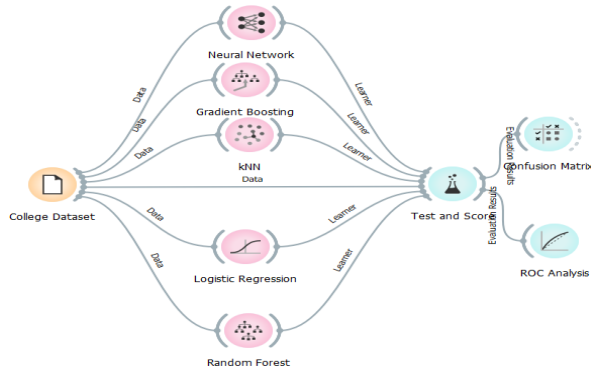


Fig. 4. Orange data mining model.

The data set was used for each student record with nine characteristics. Fig. 4 shows the model created in the orange data mining tool. To explain how the model works, the data set has been loaded and the feature to which each class of data belongs, and which feature of this data is the target as in Fig. 5.

Name	Type	Role	Values
1 Gender	☑ categorical	feature	Female, Male
2 College	☑ categorical	feature	Applied_Medical_Sciences, Dentistry, Design_and_Built_Environment, ...
3 BIO	☑ categorical	feature	A, A+, B, B+, C, C+, D, D+
4 Chemistry	☑ categorical	feature	A, A+, B, B+, C, C+, D, D+
5 Math	☑ categorical	feature	A, A+, B, B+, C, C+, D, D+
6 Physics	☑ categorical	feature	A, A+, B, B+, C, C+, D, D+
7 Statistics	☑ categorical	feature	A, A+, B, B+, C, C+, D, D+
8 GPA	☒ numeric	skip	
9 Graduation Grade	☑ categorical	skip	Excellent, Good, Pass, Very_Good
10 OUTPUT	☑ categorical	target	RIGHT, WRONG

Fig. 5. Model specifications.

In this model, the OUTPUT was determined as the target and the rest were as features and skipped GPA and Graduation Grade features as in Fig. 3 to 5. Then the data set was linked to the previously selected algorithms widget, as well as to the "Test and Score" widget to display the results. This procedure provides training and testing of all algorithms at the same time which saves a lot of time and effort rather than testing the algorithms individually. CROSS VALIDATION was used to split the data into test and training data. Cross-validation divides the data into several groups called FOLDS. This method splits the dataset randomly into 10 subsets [32]. The model training phase uses nine subsets, while the testing phase uses the final subset. This process is repeated 10 consecutive

times each time a different subset is selected in the testing phase [32].

E. Hypothesis

When the student graduates with a GPA greater than or equal to (4.00), this means that the academic track chosen by the student is correct and commensurate with the characteristics chosen in the dataset. On the contrary, when a student achieves a GPA less than (4.00), the academic track chosen by the student is wrong.

F. Validation

To evaluate the performance of the model, we will rely on the Accuracy, Area under the curve (AUC-ROC), and confusion matrix.

- Area under the curve (AUC-ROC):

Gives an idea of the effectiveness of the model and the AUC score is used to compare the different algorithms. Each classifier will predict either a true or false result. Whenever the AUC value was greater than 0.5 the classifier was able to separate the two results and give a correct result and vice versa if the AUC value were less than 0.5 the classifier would have predicted an opposite outcome. That is, the actual positive is expected to be negative. The use of AUC is used when the data set is unbalanced [33].

- Accuracy:

In machine learning and data technology, the term accuracy is inevitable almost in every category assignment. this is the most popular measurement or metric used to assess models [31]. We calculate the accuracy by using the equation:

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}$$

- Confusion Matrix :

A confusion Matrix is one way to measure the performance of classification models. It can be used when the outputs are two or more classes. The result is an extracted table with four areas. Each area represents the expected and actual value [27] [34] [35] . as shown in Fig.6 are prescribed.

		Actual Values	
		Positive (1)	Negative (0)
Predicted Values	Positive (1)	TP	FP
	Negative (0)	FN	TN

Fig. 6. Confusion matrix.

IV. EXPERIMENTS AND RESULTS

In this section, we will do the experiments based on the database described in the previous section and using Orange Data Mining Tool. The classification algorithms will be used with default parameters. The algorithm will be evaluated based on the following criteria: accuracy, an area under the curve (AUC-ROC) and a confusion matrix. The goal of the experiments will be to predict the student's GPA based on five subjects studied in the preparatory year by using classification

algorithms. To reach the answer to the question, "Is the academic track chosen by the student right or wrong?" The results were as follows in Table VI:

TABLE VI. RESULTS OF THE GPA PREDICTION MODEL

Model	AUC	CA	F1	precision	Recall	Specificity
GP	0.850	0.789	0.789	0.789	0.789	0.788
kNN	0.804	0.749	0.749	0.749	0.749	0.745
LR	0.854	0.791	0.791	0.791	0.791	0.790
ANN	0.846	0.786	0.786	0.786	0.786	0.784
RF	0.817	0.755	0.755	0.755	0.755	0.749

The results of the experiments showed that the LG algorithm provides the best performance with a slight distinction from the GP algorithm. The accuracy and AUC-ROC values for the LG algorithm were 79.1% and 85.4%, respectively. While the GB algorithm attained up to 78.9% accuracy and an AUC-ROC value of 85%. In the same context, the kNN algorithm performed the weakest with an accuracy of up to 75% and an AUC-ROC value of 80.4%. The performance of all algorithms used in the experiment is compared in Fig. 7.

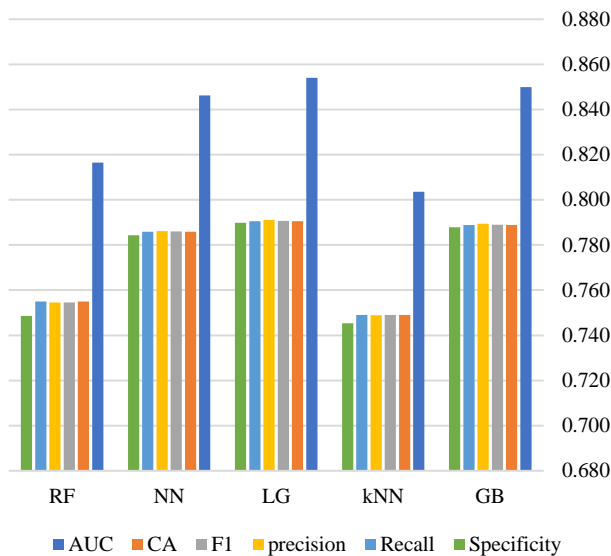


Fig. 7. Comparison performance metrics of algorithms.

The confusion matrix is constructed as shown in Table VII. Where diagonal entries reflect successfully categorized samples, and the remaining entries represent misclassified ones. The results demonstrate that, according to the LG algorithm, actually 1015 predicted the right academic track and 853 the wrong academic track.

TABLE VII. CONFUSION MATRIX FOR ALL ALGORITHMS

LG Algorithm			GB Algorithm		
Actual	Prediction		Actual	Prediction	
	Right	Wrong		Right	Wrong
	Right	1015		262	Right
Wrong	233	853	Wrong	236	850
NN Algorithm			kNN Algorithm		
Actual	Prediction		Actual	Prediction	
	Right	Wrong		Right	Wrong
	Right	1015		262	Right
Wrong	244	842	Wrong	300	786
RF Algorithm					
Actual	Prediction				
	Right	Wrong			
	Right	1001	276		
Wrong	327	759			

V. DECISION AND CONCLUSION

The main objective of this research was to develop a model to predict the right academic track Via GPA by using classification algorithms for Saudi university students. Therefore, we used a dataset of Saudi university students containing five scientific subjects studied in the preparatory year in addition to the student's gender, college, and final GPA. We made sure that all students studied the same subjects. Five classification algorithms serve as the basis for the proposed model: gradient boost, kNN, logistic regression, neural network, and random forest. We assumed that when the student achieves a GPA greater than or equal to 4.00 which means the academic track is correct. But if the student achieved a GPA less than 4.00, the student chose the wrong academic track. The results show that the logistic regression algorithm is the most accurate and able to predict correctly. It achieved an accuracy of 79.1% and an AUC of 85.4%. It can be seen that the accuracy of the model is somewhat low. This is due to the small number of features and their confinement to the academic subjects and the gender of the student. Other features can affect the accuracy of the model, such as behavioral characteristics, high school results, and Aptitude and achievement tests. The results justify the validity of the hypothesis that it is possible to predict the academic track based on the GPA where the proposed model was able to predict the final GPA that the student will achieve if he joins a specific academic track. The results of this study are expected to help educational institutions in early intervention to guide students who are struggling to choose the right academic track. Future research can improve accuracy by relying on additional

variables including behavioral characteristics, results from aptitude tests, and grades from high school.

REFERENCES

- [1] M. Fakhimuddin, U. Khasanah, and R. Trimiyyati, "Database Management System in Accounting: Assessing the Role of Internet Service Communication of Accounting System Information," *Research Horizon*, vol. 1, no. 3, Art. no. 3, Jun. 2021, doi: 10.54518/rh.1.3.2021.100-105.
- [2] M. O. Igbinoia and I. J. Ikenwe, "Knowledge management: processes and systems," *Information Impact: Journal of Information and Knowledge Management*, vol. 8, no. 3, Art. no. 3, 2017, doi: 10.4314/ijikm.v8i3.3.
- [3] J. Han, M. Kamber, and J. Pei, "1 - Introduction," in *Data Mining (Third Edition)*, J. Han, M. Kamber, and J. Pei, Eds., in *The Morgan Kaufmann Series in Data Management Systems*. Boston: Morgan Kaufmann, 2012, pp. 1–38. doi: 10.1016/B978-0-12-381479-1.00001-0.
- [4] T. Hastie, R. Tibshirani, and J. Friedman, "Introduction," in *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*, T. Hastie, R. Tibshirani, and J. Friedman, Eds., in *Springer Series in Statistics*. New York, NY: Springer, 2009, pp. 1–8. doi: 10.1007/978-0-387-84858-7_1.
- [5] C. Romero, S. Ventura, M. Pechenizkiy, and R. S. J. d. Baker, Eds., *Handbook of Educational Data Mining*, 0 ed. CRC Press, 2010. doi: 10.1201/b10274.
- [6] "Budget Statement 2023." <https://www.mof.gov.sa/en/budget/2023/Pages/default.aspx> (accessed Mar. 11, 2023).
- [7] D. of A. & Registration, "Preparatory Year." <https://admission.kau.edu.sa/Content-210-EN-260921> (accessed Mar. 11, 2023).
- [8] H. Brdesee and W. Alsaggaf, "Is There a Real Need for the Preparatory Years in Higher Education? An Educational Data Analysis for College and Future Career Readiness," *Social Sciences*, vol. 10, no. 10, pp. 1–16, 2021.
- [9] M. Foraker, "Does Changing Majors Really Affect the Time to Graduate? The Impact of Changing Majors on Student Retention, Graduation, and Time to Graduate," undefined, 2012, Accessed: Nov. 12, 2021. [Online]. Available: <https://www.semanticscholar.org/paper/Does-Changing-Majors-Really-Affect-the-Time-to-The-Foraker/cb8df7853c6937092ec842fde9f674b5a4767f68>
- [10] A. I. Adekitan and O. Salau, "The impact of engineering students' performance in the first three years on their graduation result using educational data mining," *Heliyon*, vol. 5, no. 2, p. e01250, Feb. 2019, doi: 10.1016/j.heliyon.2019.e01250.
- [11] S. L. B. Ginting and M. A. F. Rahman, "DATA MINING, NEURAL NETWORK ALGORITHM TO PREDICT STUDENT'S GRADE POINT AVERAGE: BACKPROPAGATION ALGORITHM," vol. 16, p. 10, 2021.
- [12] A. Zollanvari, R. C. Kizilirmak, Y. H. Kho, and D. Hernandez-Torrano, "Predicting Students' GPA and Developing Intervention Strategies Based on Self-Regulatory Learning Behaviors," *IEEE Access*, vol. 5, pp. 23792–23802, 2017. doi: 10.1109/ACCESS.2017.2740980.
- [13] N. Putpuek, N. Rojanaprasert, K. Atcharyachanvanich, and T. Thamrongthanyawong, "Comparative Study of Prediction Models for Final GPA Score: A Case Study of Rajabhat Rajanagarindra University," in *2018 IEEE/ACIS 17th International Conference on Computer and Information Science (ICIS)*, Singapore: IEEE, Jun. 2018, pp. 92–97. doi: 10.1109/ICIS.2018.8466475.
- [14] A. K. Hamoud, A. S. Hashim, and W. A. Awadh, "Predicting Student Performance in Higher Education Institutions Using Decision Tree Analysis," *IJIMAI*, vol. 5, no. 2, p. 26, 2018, doi: 10.9781/ijimai.2018.02.004.
- [15] H. Pallathadka, A. Wenda, E. Ramirez-Asís, M. Asís-López, J. Flores-Albornoz, and K. Phasinam, "Classification and prediction of student performance data using various machine learning algorithms," *Materials Today: Proceedings*, p. S221478532105241X, Jul. 2021, doi: 10.1016/j.matpr.2021.07.382.
- [16] E. Alyahyan and D. Dusteaur, "Decision Trees for Very Early Prediction of Student's Achievement," in *2020 2nd International Conference on Computer and Information Sciences (ICCIS)*, Sakaka, Saudi Arabia: IEEE, Oct. 2020, pp. 1–7. doi: 10.1109/ICCIS49240.2020.9257646.
- [17] M. A. Al-Barrak and M. Al-Razgan, "Predicting Students Final GPA Using Decision Trees: A Case Study," *IJIET*, vol. 6, no. 7, pp. 528–533, 2016, doi: 10.7763/IJIET.2016.V6.745.
- [18] A. Mueen, B. Zafar, and U. Manzoor, "Modeling and Predicting Students' Academic Performance Using Data Mining Techniques," *IJMCECS*, vol. 8, no. 11, pp. 36–42, Nov. 2016, doi: 10.5815/ijmcecs.2016.11.05.
- [19] Y. Altujjar, W. Altamimi, I. Al-Turaiki, and M. Al-Razgan, "Predicting Critical Courses Affecting Students Performance: A Case Study," *Procedia Computer Science*, vol. 82, pp. 65–71, 2016, doi: 10.1016/j.procs.2016.04.010.
- [20] H. Almarabeh, "Analysis of Students' Performance by Using Different Data Mining Classifiers," *IJMCECS*, vol. 9, no. 8, pp. 9–15, Aug. 2017, doi: 10.5815/ijmcecs.2017.08.02.
- [21] K. Mehrotra, C. K. Mohan, and S. Ranka, *Elements of artificial neural networks*. MIT press, 1997.
- [22] L. V. Fausett, *Fundamentals of neural networks: architectures, algorithms and applications*. Pearson Education India, 2006.
- [23] C. Bentéjac, A. Csörgő, and G. Martínez-Muñoz, "A comparative analysis of gradient boosting algorithms," *Artif Intell Rev*, vol. 54, no. 3, pp. 1937–1967, Mar. 2021, doi: 10.1007/s10462-020-09896-5.
- [24] S. B. Kotsiantis, I. Zaharakis, and P. Pintelas, "Supervised machine learning: A review of classification techniques," *Emerging artificial intelligence applications in computer engineering*, vol. 160, no. 1, pp. 3–24, 2007.
- [25] D. A. Adeniyi, Z. Wei, and Y. Yongquan, "Automated web usage data mining and recommendation system using K-Nearest Neighbor (KNN) classification method," *Applied Computing and Informatics*, vol. 12, no. 1, pp. 90–108, Jan. 2016, doi: 10.1016/j.aci.2014.10.001.
- [26] C. Zhenhai and L. Wei, "Logistic regression model and its application," *Journal of Yanbian University (natural science edition)*, vol. 38, no. 01, pp. 28–32, 2012.
- [27] M.-Y. Yuan, *Data mining and machine learning: WEKA application technology and practice*. Tsinghua University Press, Beijing, 2014.
- [28] C. Zabriskie, J. Yang, S. DeVore, and J. Stewart, "Using machine learning to predict physics course outcomes," *Phys. Rev. Phys. Educ. Res.*, vol. 15, no. 2, p. 020120, Aug. 2019, doi: 10.1103/PhysRevPhysEducRes.15.020120.
- [29] G. Kesavaraj and S. Sukumaran, "A study on classification techniques in data mining," in *2013 Fourth International Conference on Computing, Communications and Networking Technologies (ICCCNT)*, Jul. 2013, pp. 1–7. doi: 10.1109/ICCCNT.2013.6726842.
- [30] A. Jovic, K. Brkic, and N. Bogunovic, "An overview of free software tools for general data mining," in *2014 37th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, May 2014, pp. 1112–1117. doi: 10.1109/MIPRO.2014.6859735.
- [31] A. Naik and L. Samant, "Correlation Review of Classification Algorithm Using Data Mining Tool: WEKA, Rapidminer, Tanagra, Orange and Knime," *Procedia Computer Science*, vol. 85, pp. 662–668, Jan. 2016, doi: 10.1016/j.procs.2016.05.251.
- [32] M. W. Browne, "Cross-Validation Methods," *Journal of Mathematical Psychology*, vol. 44, no. 1, pp. 108–132, Mar. 2000, doi: 10.1006/jmps.1999.1279.
- [33] A. J. Bowers and X. Zhou, "Receiver Operating Characteristic (ROC) Area Under the Curve (AUC): A Diagnostic Measure for Evaluating the Accuracy of Predictors of Education Outcomes," *Journal of Education for Students Placed at Risk (JESPAR)*, vol. 24, no. 1, pp. 20–46, Jan. 2019, doi: 10.1080/10824669.2018.1523734.
- [34] E. Frank and M. A. Hall, *Data mining: practical machine learning tools and techniques*. Morgan Kaufmann, 2011.
- [35] O. Caelen, "A Bayesian interpretation of the confusion matrix," *Ann Math Artif Intell*, vol. 81, no. 3, pp. 429–450, Dec. 2017, doi: 10.1007/s10472-017-9564-8.

Combining GAN and LSTM Models for 3D Reconstruction of Lung Tumors from CT Scans

Cong Gu^{1*}, Hongling Gao²

College of Science, Zhongyuan University of Technology, Zhengzhou 450007, Henan, China¹
University Hospital, Zhongyuan University of Technology, Zhengzhou 450007, Henan, China²

Abstract—Generating a three-dimensional (3D) reconstruction of tumors is an efficient technique for obtaining accurate and highly detailed visualization of the structures of tumors. To create a 3D tumor model, a collection of 2D imaging data is required, including images from CT imaging. Generative adversarial networks (GANs) offer a method to learn helpful representations without annotating the training dataset considerably. The article proposes a technique for creating a 3D model of lung tumors from CT scans using a combination of GAN and LSTM models, with support from ResNet as a feature extractor for the 2D images. The model presented in this article involves three steps, starting with the segmentation of the lung, then the segmentation of the tumor, and concluding with the creation of a 3D reconstruction of the lung tumor. The segmentation of the lung and tumor is conducted utilizing snake optimization and Gustafson–Kessel (GK) method. To prepare the 3D reconstruction component for training, the ResNet model that has been pre-trained is utilized to capture characteristics from 2D lung tumor images. Subsequently, the series of characteristics that have been extracted are fed into a LSTM network to generate compressed features as the final output. Ultimately, the condensed feature is utilized as input for the GAN framework, in which the generator is accountable for generating a sophisticated 3D lung tumor image. Simultaneously, the discriminator evaluates whether the 3D lung tumor image produced by the generator is authentic or synthetic. This model is the initial attempt that utilizes a GAN model as a means for reconstructing 3D lung tumors. The suggested model is evaluated against traditional approaches using the LUNA dataset and standard evaluation metrics. The empirical findings suggest that the suggested approach shows a sufficient level of performance in comparison to other methods that are vying for the same objective.

Keywords—3D tumor reconstruction; lung cancer; LSTM; Generative adversarial network; ResNet

I. INTRODUCTION

Among men, lung cancer is the cancer type that occurs the second most frequently. In recent times, a number of data-based tools have been created by researchers to assist in the diagnosis and treatment of this condition. The ability to comprehend the 2D/3D shape of a tumor is crucial for visualizing the progression of its growth and for surgical purposes. 3D images offer comprehensive insights into the form and structure of the tumor [1].

CT is the favored imaging method for the detection of lung tumors among a variety of diagnostic imaging methods. Despite the fact that CT provides valuable information about

tumors, evaluating an increasing number of images can pose a challenge for radiologists, potentially creating risks. Consequently, it is crucial to create intelligent diagnostic approaches that can aid radiologists and doctors in making faster and more accurate judgments than those reliant exclusively on CT images [2].

Recently, several studies have been conducted on 3D tumor healing with a special focus on healing brain tumors. Although these methods have achieved promising results, they fail to offer a high-quality 3D reconstruction of lung tumors. This is due to the fact that tumors may have complex and random shapes. Additionally, high-quality 3D reconstruction heavily relies on the availability of accurate data in all three dimensions. To the knowledge, the most recent study [3] utilizes conventional methods to reconstruct lung cancer in three dimensions. In this study, significant characteristics are identified from a two-dimensional shape during the reconstruction process. This method includes multiple stages, such as surface reconstruction and smoothing, which can be computationally intensive. As a result, applying this approach in real-world situations where time is a crucial factor may be impractical. Furthermore, the proposed approach is tailored exclusively to lung tumors and may not be readily adaptable to other types of tumors or organs. Convolutional neural networks (CNNs) are capable of automatic feature extraction. Nonetheless, teaching CNNs necessitates a substantial quantity of classified information, which may be lacking, particularly in the medical sector. The processing power and memory requirements for CNNs training may also be high. Transfer learning (TL) may be used instead of training from scratch to deal with these difficulties. In TL, CNNs parameters are set to the values that have been trained on large-scale datasets. Many TL networks, particularly ResNet, have achieved satisfactory results in medical imaging applications [4]. The use of GAN in medical image reconstruction is not extensively studied [5]. Wang et al. [6] developed an U-Net model with skip connections that are sparse by merging two GAN methods, an encoder-decoder method, and an U-Net method, to enhance imaging quality and decrease the size of imaging equipment. Meanwhile, Yang et al. [7] created a generator network with skip connections based on the U-Net architecture, and they also incorporated a refinement learning approach to ensure the stability of GAN training and facilitate faster convergence with less parameter tuning. Despite achieving satisfactory results in their respective tasks, these methods lack the ability to perform 3D reconstruction of lung tumors.

To produce a 3D image, it is vital to extract a comprehensive representation from a series of 2D images in the form of a single vector that encapsulates all the necessary details. Recursive networks, such as LSTM [8], can address this challenge and have been found to be suitable for sequence data in previous studies [9, 10]. LSTM utilizes special blocks called cells. Each cell has three gates: input, output, and forget [11]. The input gate handles the storage of new information in the cell. The output gate is responsible for selecting which portion of the cell state should be transmitted to the cell's output. The forget cell is responsible for forgetting (throwing away) data as time passes, which helps with the vanishing gradient problem [12].

A GAN is composed of two neural networks, namely a generator and a discriminator. The generator creates synthetic data, and the discriminator attempts to tell actual samples from synthetic ones. The GAN model's capacity to generate superior synthetic data has made it highly popular in academics and business. Promising outcomes have been demonstrated by using GAN in different fields of application, including but not limited to generating high-resolution images, translating text to images, and transforming images to other types of images [13]. Acceptable generalization can be achieved by training DNNs using a combination of limited real data and large amounts of synthetic data generated by GANs. The creative technique of GANs has been employed in diverse medical imaging assignments, such as image partitioning, image enhancement, and image creation. By instructing the generator network on an extensive compilation of images, GANs can produce fresh images that have corresponding attributes to the source dataset. In medical imaging, this has been used to create new images that can help diagnose diseases or assist in surgical planning. On the other hand, the discriminative approach of GANs has been used to improve the quality of medical images. Discriminative GANs aim to distinguish between real and fake images and use this information to improve the generator network. By doing so, discriminative GANs can learn to regularize or normalize images and remove any artifacts or noise that might be present. Both approaches have shown great promise in medical imaging, and researchers are continually exploring new ways to apply GANs in this field. However, challenges remain, such as the need for large datasets and the difficulty of interpreting the outputs of GANs. Nevertheless, the potential benefits of GANs in medical imaging make it an area of active research and development [14].

For this study, a GAN-driven approach is suggested to produce 3D lung tumor reconstructions. The procedure comprises of three steps: segmentation of the lung, segmentation of the tumor, and creation of a 3D representation. The first stage employs the snake optimization method [15] to identify the left and right lungs. The suggested method simplifies the complexity of the issue by dividing it into multiple lower-dimensional problems with search areas that are gradually reduced [16]. The second stage utilizes GK clustering [17] to segment tumors and extract tumor masses from the affected lungs. The third stage involves an LSTM and a GAN. Initially, a pre-trained ResNet model extracts features from 2D lung tumor images, and subsequently, important features are extracted from the tumor sequence using the

LSTM and passed as input to the GAN. The generator uses the LSTM's output to construct the 3D reconstruction, while the discriminator distinguishes between the generated and real images. The proposed approach is tested and evaluated using the commonly used LUNA dataset. The LUNA dataset has been extensively used in lung cancer diagnosis and is considered a standard benchmark for evaluating algorithms related to lung nodule detection and classification. It comprises more than 1,000 chest CT scans, with each scan annotated with multiple nodules. The main contributions are listed below:

- The majority of current approaches for reconstructing 3D tumors concentrate on brain cancer and do not yield satisfactory outcomes for lung cancer tumors. Accordingly, this study concentrates only on the 3D construction of tumors related to lung cancer.
- Afshar et al. [3] conducted the latest research on the reconstruction of lung cancer tumors, which has a relatively high level of computational complexity. However, the suggested technique surpasses Afshar's investigation in regards to effectiveness and computational intricacy.
- Although GAN has the potential to generate high-quality synthetic images, its application in medical diagnosis, particularly for lung cancer diagnosis, has been limited. This investigation seeks to examine the utilization of GAN in constructing three-dimensional lung tumor representations, which is a novel approach in the field.
- In the medical domain, it is frequently encountered to have insufficient labeled training data. To address this, pre-trained models (transfer learning) are often used.
- Reconstructing 3D images of lung cancer tumors involves using a series of 2D CT images. To exploit the sequential nature of this information, recurrent neural networks such as LSTM are utilized.

The paper is structured in the following manner: Section II discusses related work, Section III details the suggested methodology, while Section IV displays the experimental findings, and Section V discusses the results. Section VI concludes the paper and provides future directions.

II. RELATED WORK

A. Generative Adversarial Network

Liao et al. [18] utilized incorrect sampling to reconstruct cone beam CT (CBCT). The model involved the utilization of pyramidal neural networks and computer-generated maps for descriptive discriminants. This approach enabled the reconstruction of results while simultaneously preserving the anatomical structure. MR image reconstruction evaluates k-space data in the frequency domain model. Different loss functions have been employed to identify localized image structures in image restoration, such as coherence loss and cycle consistency loss, when suppressing cardiac CT noise. Wolterink et al. [19] proposed a low-dose CT noise after attenuation of losses in several areas. However, the result prevented the projection of the local image. MRI image

reconstructions are uncommon because they have well-defined back-and-forth formulas such as Fourier transforms.

B. Pre-trained Model

More training data leads to deep models with better performance [20]. That is why significant efforts have been put into gathering and annotating large-scale datasets such as ImageNet, PASCAL VOC, MS COCO, etc [21]. At the start of training, setting the initial parameters of deep models to the parameters of deep models that have already been trained on these large datasets improves the convergence speed of training. It boosts the final performance of the model [22].

3D semantic segmentation is quite common in the medical domain. For example, small organ segmentation in 3D abdominal CT scans has been tackled using an RNN [23]. Most medical 3D image analyses, including [24], train a deep model from scratch, which is challenging due to insufficient annotated data. Alternatively, the model's parameters can be initialized to values pre-trained on a source dataset. The model can then be fine-tuned using (possibly limited) target dataset. To get reasonable results, the distribution of the source and target datasets should be as similar as possible [25]. Therefore, for training deep models on 3D medical images, the model should be initialized to values pre-trained on another 3D medical dataset.

C. 3D Tumor Reconstruction

Lately, 3D models have been created in various medical areas, allowing doctors to provide improved treatment to their patients [26-28]. For example, 3D models were applied to liver resection, assisting surgeons in studying the liver structure [29]. 3D reconstruction of the brain based on magnetic resonance imaging (MRI) [30, 31] has been tackled as well [32, 33]. Amruta et al. [34] proposed a 3D method for brain tumor recovery in which brain tumors were segmented by morphological manipulations and 3D shapes were generated using 3D interpolation. Jaffar et al. [35] considered a multi-step process for segmenting and visualizing brain tumors evaluated on different datasets. Kamencay et al. [36] used the medium screening method to segment the images. For modeling the 3D shape, a combination of the Sum of Squared Differences (SSD) and Speeded-Up Robust Features (SURF) was used to find the corresponding pixels in the image. The method provides an accurate 3D model of the human pelvis. Sun et al. [37] proposed a two-step 3D segmentation that involves identifying active shape models and finding the optimal surface. Several studies have developed valuable methods to address 3D tumor reconstruction [38].

In the context of lung cancer, Afshar et al. [3] recently proposed a method for tumor segmentation and 3D reconstruction of CT images. While this is a significant step towards improving lung cancer treatment, the method has a high computational complexity. This drawback limits its practical applications and motivates the development of new approaches with improved performance and reduced computational costs. Therefore, this study aims to explore a novel approach using GAN for 3D reconstruction of lung cancer tumors, which can potentially overcome the limitations of existing methods.

III. THE PROPOSED MODEL

GANs were first proposed by Goodfellow et al. [39], in which two separate networks are similarly trained: the generator and discriminator networks. The purpose of the generator is to produce data such as images, text, etc. [40], which are structurally similar to real data but are fake. On the other hand, the task of the discriminator network is to strengthen the generator. These two networks engage in a two-player min-max game with a value function $V(D,G)$ [41]:

$$\begin{aligned} \min_G \max_D V(D,G) \\ = E_{x \sim p_{data}(x)} [\log(D(x))] \\ + E_{z \sim p_z(z)} [\log(1 \\ - D(G(z)))] \end{aligned} \quad (1)$$

where x and z represent input data and noise, respectively. G and D denote the generator and discriminator, respectively. $p_{data}(x)$ and $p_z(z)$ show the probability distributions of the input data and the noise, respectively. E represents mathematical expectation.

The objective is to evaluate the 3D morphology of lung tumors using a limited set of 2D CT images. The general outline for the suggested model is presented in Fig. 1. Based on this illustration, the model comprises three stages, namely lung partitioning, tumor partitioning, and 3D rebuilding. Using the snake optimization method, lung segmentation aims to separate two lungs from a CT image. In the tumor localization phase, the region of the tumor in the lung is identified from the healthy region on each 2D slice using snake optimization and GK clustering. Then, a GAN-based model is utilized to reconstruct the 3D model of the tumor. The following sections will be described separately.

A. Lung Segmentation

Segmentation of the lungs is a vital stage in the task and can influence the model's efficacy considerably. The method used for lung segmentation was adopted from a recent study [42].

The approach involves using the snake optimization method to separate the lungs from the background. This method allows the lung outline of one section to serve as the initial outline for subsequent sections in the algorithm [43]. The snake model refers to a curve that starts at a specific point and then moves towards the boundaries of an object. This procedure is referred to as a semi-automated process since it requires some degree of user involvement. This article uses the point-based snake model, which considers a contour as a collection of distinct points, although there are various snake models available [44]. The procedure aims to reduce an energy function [45, 46] that includes internal and external energies, where the internal energy is associated with the form of the contour. On the other hand, external energy relies on image characteristics. Given coordinates $x(s)$ and $y(s)$ in the direction of the contour, where s is a variable between zero and one, the contour can be defined in the following way [47]:

$$v(s) = [x(s), y(s)] \quad (2)$$

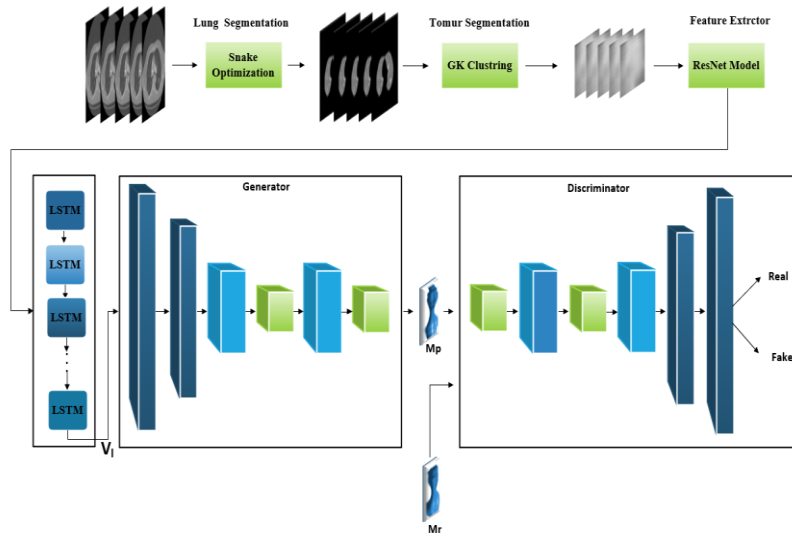


Fig. 1. The proposed model.

Where $v(s)$ represents the snake curve variable, the energy function is defined as follows:

$$E_{snake}^* = \int_0^1 E_{snake}^*(v(s)) ds \quad (3)$$

$$= \int_0^1 (E_{int}(v(s)) + E_{image}(v(s)) + E_{con}(v(s))) ds$$

where E_{con} indicates constant external forces. E_{int} and E_{image} denote the internal energy and the image forces, correspondingly, which can be calculated as:

$$E_{int} = \alpha(s) \left(\frac{dv}{ds}\right)^2 + \beta(s) \left(\frac{d^2s}{dv^2}\right)^2 \quad (4)$$

$$E_{image} = -|\nabla I(x, y)|^2 \quad (5)$$

The initial term turns the snake into a membrane. Increasing the value of β results in an increase in the internal energy, while the image energy comprises the energy of edge, line, and terminations. The value of $I(x, y)$ corresponds to the intensity of the pixel located at (x, y) . The negative sign at the beginning of Equation 5 is utilized since the image gradient is more prominent on the object boundary, and the objective of energy minimization is to detect the object boundary. The aim of the energy function with the damping term is to detect object boundaries. The Viterbi algorithm [48], a widely used technique for optimizing energy functions, is used in this study.

B. Tumor Segmentation

After the lung segmentation stage, tumors are segmented utilizing the GK clustering method. GK is a fuzzy-based approach with the benefits of using covariance and distance matrixes to make clusters with various shapes. The objective function of this method is defined as follows:

$$J_m(U, A_k) = \sum_{i=1}^M \sum_{k=1}^K u_{ik}^2 D^2_{ikA_k} \quad (6)$$

Where U stands for the membership matrix, and m is a coefficient describing the degree of fuzziness. A_k shows a regional norm-inducing matrix for each cluster optimized. M and K are the number of data points and clusters, respectively, and D^2 indicates the squared space between data points and cluster centers., which is calculated as:

$$D^2_{ikA_k} = (z_i - w_k)^T A_k (z_i - w_k) \quad (7)$$

The matrix is used to incorporate the topological characteristics of the data structure into the distance norm.

C. 3D Reconstruction Method

In this paper, 3D reconstruction is carried out using a deep learning model. As shown in Fig. 1, the tumor segmentation stage yields N sequences of 2D images. These images are fed to the pre-trained ResNet network to perform feature extraction. The parameters of this network have been determined by training on the ImageNet dataset. The output of the ResNet is used as input to LSTM units, the output of which is fed to a GAN model. GAN aims to reconstruct 3D images from sequences of 2D data fed to it. The GAN discriminator distinguishes between the synthetic images produced by the generator and the real ones.

D. Overall Algorithm

The overall algorithm of the suggested method is displayed in Algorithm 1. Let $Pateints = \{P^1, P^2, P^3, \dots, P^N\}$ be the set of available patients with N examples, where P^i corresponds to the i -th patient. Every P^i contains a collection of S CT images. In every iteration, for every minibatch with size M , the lung segmentation and tumor segmentation operations are performed, respectively. After that, the sequence of selected lung tumors for every patient whose length is L enters the ResNet model. The L -sample sequence outputted by ResNet is fed into an LSTM. Finally, LSTM output comes into the generator to generate a 3D lung tumor. Updating the components, i.e., LSTM, generator, and discriminator, is done based on introduced standard methods.

Algorithm 1 Overall algorithm for the suggested model.

Input: $Pateints = \{P^1, P^2, P^3, \dots, P^N\}$: the set of available patients, $Images = \{X^1, X^2, X^3, \dots, X^N\}$: the set of available real 3D images, N : the number of patients, S : the number of CT images for every patient, G : generator, D : discriminator;
 for the number of training iterations, do
 for every minibatch with size M do
 for $i = 1$ to M do
 for $j = 1$ to S do
 P_t^{ij} : segment P^{ij} using the snake algorithm; // P^{ij} shows the j -th CT image for the i -th patient
 for $i = 1$ to M do
 $\{P_t^{i1}, P_t^{i2}, P_t^{i3}, \dots, P_t^{iL}\}$: select $L(\leq S)$ consecutive samples containing tumors recognized by the GK clustering from
 $\{P_v^{i1}, P_v^{i2}, P_v^{i3}, \dots, P_v^{iL}\}$;
 $\{P_v^{i1}, P_v^{i2}, P_v^{i3}, \dots, P_v^{iL}\}$: extract features every item of $\{P_t^{i1}, P_t^{i2}, P_t^{i3}, \dots, P_t^{iL}\}$ using the ResNet model;
 V_v^i : enter $\{P_v^{i1}, P_v^{i2}, P_v^{i3}, \dots, P_v^{iL}\}$ into the LSTM network and get the latest unit of LSTM;
 update the LSTM network by its stochastic gradient;
 update the generator by descending its stochastic gradient:
 $\nabla_{\theta_g} \frac{1}{M} \sum_{i=1}^M \log(1 - D(g(V_v^i)))$
 Update the discriminator by ascending its stochastic gradient:
 $\nabla_{\theta_d} \frac{1}{M} \sum_{i=1}^M [\log D(x^i) + \log(1 - D(g(V_v^i)))]$

IV. EMPIRICAL EVALUATION

A. Dataset

The suggested method was evaluated using the LUNA subset of a dataset (referred to as LIDA-IDRI) [49]. The LIDA-IDRI is a lung CT scan public dataset, which includes 220 patients with more than 130 slices. The LUNA 2016 dataset was designed to analyze lung nodules and received 888 CT scans with a section thickness of less than 3 mm and 512×512 pixels picture size. The node has a total of 36,378 notes annotated by various radiologists. However, nodes 2290, 1602, 1186, and 777 are annotated by radiologists 1, 2, 3, and 4, respectively. Node annotations approved by at least three radiologists are called valid annotations. Diameter and position annotations are average annotations in LIDA-IDRI. The LUNA dataset originally was not a 3D image, so the 3D image was created manually using Rhinoceros 3D software.

B. Lung Segmentation and Tumor Detection

The lung and surrounding area have been isolated from the images utilising snake optimization. The method was contrasted with fuzzy-based techniques, namely FCM [50], KFCM [51], SAFCM [52], and FRFCM [53]. The evaluation was based on the metrics of Intersection over Union (IoU) [54] and Hausdorff distance [55], and the results are shown in Table I. The FRFCM method performed better than SAFCM and KFCM, with an improvement of approximately 20% and 13%, respectively. However, even though FRFCM is considered a robust algorithm, it still does not match the performance of Snake. The Snake algorithm showed a 22% improvement in the IoU metric compared to FRFCM. Examples of lungs delineated using the Snake algorithm are shown in Fig. 2.

Following the segmentation of lungs with the Snake algorithm, clustering methods including FCM, K-means, and GK were employed to create two clusters for lung tumor segmentation. Evaluation was carried out using the IoU and HD metrics, and the results are presented in Table II. According to the table, GK clustering is the most effective method for segmenting lung tumors. Lung cancers can also be segmented using FCM and K-means clustering, as shown in the table. Fig. 3 illustrates examples of tumor detection with the GK clustering technique.

TABLE I. EVALUATION OF THE SEGMENTATION EFFICIENCY OF DIFFERENT FUZZY ALGORITHMS

Method	IoU	HD
FCM	0.621	1.496
KFCM	0.746	1.715
SAFCM	0.721	1.852
FRFCM	0.785	2.019
Snake	0.831	2.151

TABLE II. ANALYSIS OF THE PROPOSED MODEL IN COMPARISON TO PREVIOUS WORKS

Method	IoU	HD
FCM	0.751	2.122
K-mean	0.780	1.615
GK	0.786	1.419

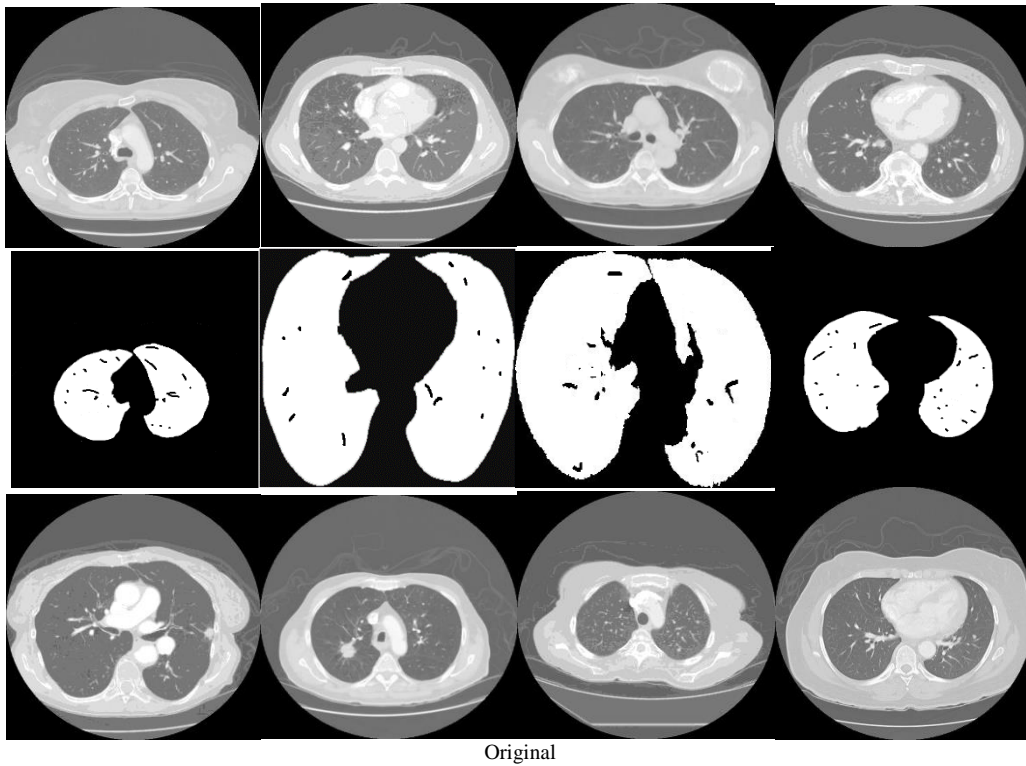


Fig. 2. The instances of lungs that were segmented using the snake algorithm.

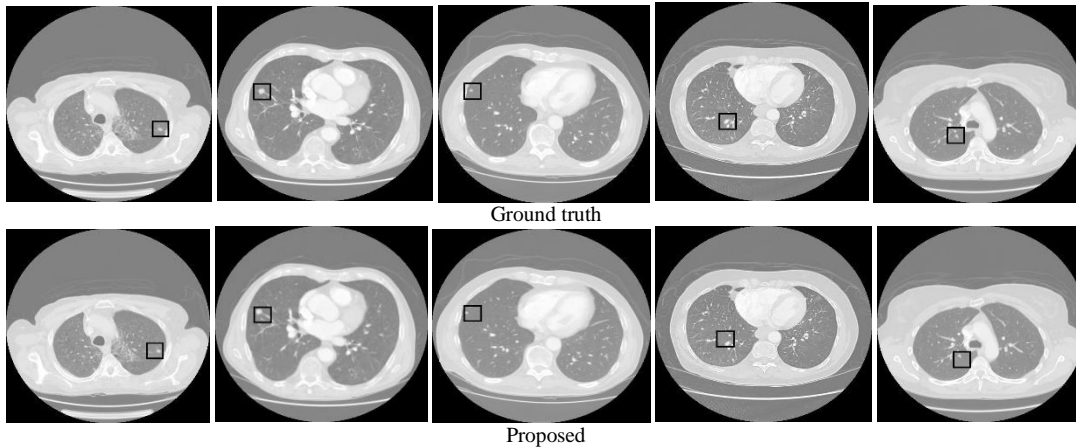


Fig. 3. The samples of identifying tumors using the GK method.

C. 3D Reconstruction

The evaluation of the 3D reconstruction model included comparing four different methods: MC [56], MC and fairing [57], interpolation [34], and MC, and Afshar et al. [3]. The evaluation metrics used were HD and ED, which measured shape accuracy and pixel-wise distance, respectively. The results of the evaluation are presented in Table III, where MC performed the worst with values of 8.50 and 3.21 for HD and ED, respectively. However, the addition of fairing to MC decreased the values to 6.82 and 2.99. Interpolation with MC further reduced the error by approximately 0.555 and 0.855 for the two metrics, respectively. Despite these improvements, the recent work of Afshar et al. outperformed all other methods, including MC and MC + fairing, with values of 5.39 and 1.45

for HD and ED, respectively. Interestingly, the proposed model, which uses a strong GAN to create 3D shapes, outperformed Afshar et al.'s method, even though they had similar lung segmentation and tumor detection. The difference in performance may be attributed to the nature of the methods, as the proposed model relies on GANs, which have proven to be effective in generating complex data distributions. On the other hand, other methods use mathematical operations to create 3D shapes, which may not capture the underlying complexity of the data as well as GANs. In conclusion, the proposed model with a strong GAN is a promising approach for accurate 3D reconstruction, especially for complex medical imaging data.











































TABLE III. THE EVALUATION AND COMPARISON OF THE SUGGESTED APPROACH WITH OTHER EXISTING METHODS

Model	HD	ED
MC	8.50	3.21
MC+ fairing	6.82	2.99
Interpolation + MC	5.85	2.57
Afshar et al. [3]	5.39	1.45
Proposed	2.99	1.06

Table IV demonstrates that the model is effective in accurately reconstructing 3D shapes from the provided input images. The reconstructed shapes closely resemble the original ones, and the input images are smooth, which is critical for accurate medical diagnoses. The smoothness issue faced by other methods can lead to incorrect diagnoses, and the generated images by these methods do not resemble the

original ones. The proposed model has successfully addressed these issues, demonstrating its superiority over other methods. Table V shows the computational efficiency of the suggested model and other approaches. The traditional methods take more time because of their lower computational efficiency. Nonetheless, the ResNet model, which is utilized for image recognition, consumes the most time in the proposed model. Despite this, the proposed model still outperforms other methods that use heavy computational operations, indicating its superiority in terms of accuracy and computational efficiency trade-off compared to existing methods. The results suggest that the proposed model has great potential for real-world medical applications. Its ability to generate smooth and accurate 3D images can help physicians make more precise diagnoses, which can lead to improved patient outcomes. Additionally, the model's computational efficiency makes it suitable for use in clinical settings where time is a critical factor.

TABLE IV. CREATED 3D SHAPES RESEMBLING TUMORS

Original	MC	MC+ fairing	Interpolation + MC	Afshar et al.	Proposed
					
					
					
					
					
					
					

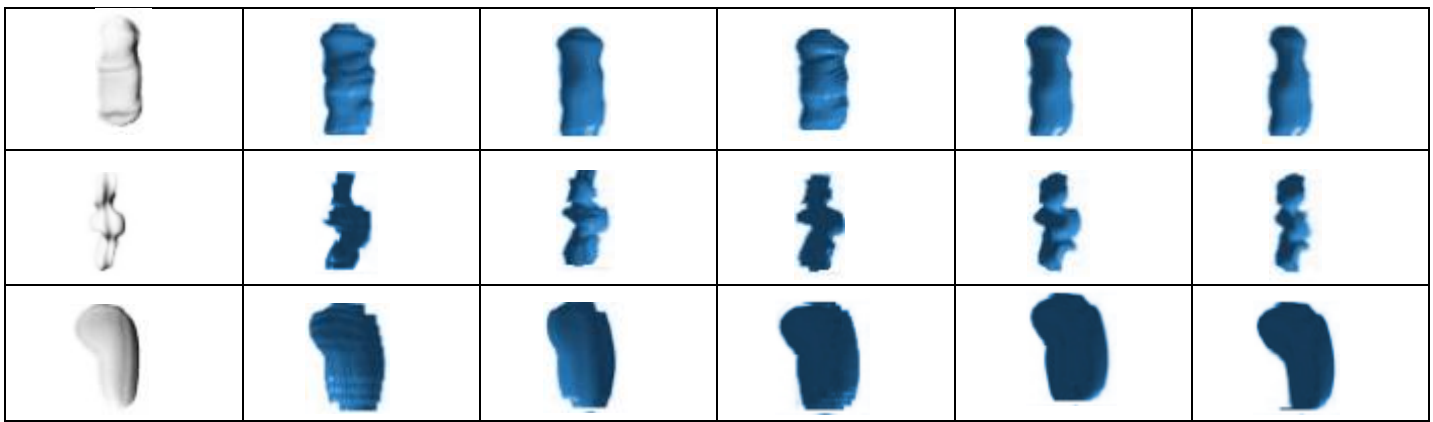


TABLE V. THE DURATION OF TIME TAKEN BY ALGORITHMS TO EXECUTE (IN MILLISECONDS)

Image \ Model	MC	MC+ fairing	Interpolation + MC	Afshar et al.	Proposed
1	506	496	435	408	351
2	475	527	498	449	410
3	365	336	279	319	230
4	614	595	591	585	563
5	651	639	626	574	480
6	720	661	705	680	621
7	561	538	477	499	425
8	741	729	742	691	670
9	481	507	489	452	430
10	558	579	578	539	500

1) *Analysis of pre-trained models:* The experiments carried out in this research demonstrate the superiority of the ResNet model compared to other pre-trained models, namely AlexNet [58], GoogleNet [59], Inceptionv3 [60], DenseNet [61], and MobileNet [62] (refer Table VI). Although other models have been extensively utilized in diverse image recognition works, they cannot match the ResNet model's performance in 3D reconstruction. The ResNet model significantly outperforms the other models, leading to a remarkable improvement in the HD and ED error metrics. These results highlight the importance of selecting an appropriate pre-trained model for achieving optimal performance in 3D reconstruction. Thus, the experimental findings provide solid evidence for the use of the ResNet model as the feature extractor in the suggested model.

2) *Explore the hidden size:* The LSTM network's hidden vector serves as a practical tool to compress data from a sequence of 2D images and aid in drawing 3D shapes. Increasing the hidden size can add more data to the model, but it may not always be useful. A limited capacity of the hidden size is inadequate to store the required data. Eight different values ranging from 16 to 2056 were evaluated to explore the influence of the hidden dimension on the suggested model. The outcomes are depicted in Fig. 4. Upon examination, it was observed that for HD and ED, the chart shows a descending trend when the hidden size is within the range of [16, 128], and an ascending trend from [128, 2056]. As a result, the optimal hidden size is 128.

3) *Analysis of loss function:* Selecting an appropriate loss function is vital for the success of deep learning models, as neglecting it may cause the model to be trapped in local optima. Therefore, the study aimed to assess how the discriminator's performance was affected by various loss functions. Five functions were selected for this purpose, namely Weighted Cross-Entropy (WCE) [63], Balanced Cross-Entropy (BCE) [64], Dice Loss (DL) [65], Tversky Loss (TL) [66], and Sensitivity Specificity Loss (SSL) [67]. WCE is a modified version of BCE that assigns different weights to examples from one class. Even though DL was originally developed to compare two images, it has been suggested as a loss function. The outcomes of these loss functions are presented in a tabular format in Table VII. Among the examined loss functions, TL exhibited the most superior performance, attaining an ED of 1.06 and an HD of 3.02. Although WCE assigns weights to the samples, TL still outperformed it, improving the error of WCE by approximately 1.64 and 2.50.

TABLE VI. THE RESULTS OBTAINED FOR USING VARIOUS PRE-TRAINED MODELS

Model	HD	ED
AlexNet	3.49	1.98
GoogleNet	4.85	3.11
Inceptionv3	4.19	2.51
DenseNet	6.46	3.79
MobileNet	6.84	4.93

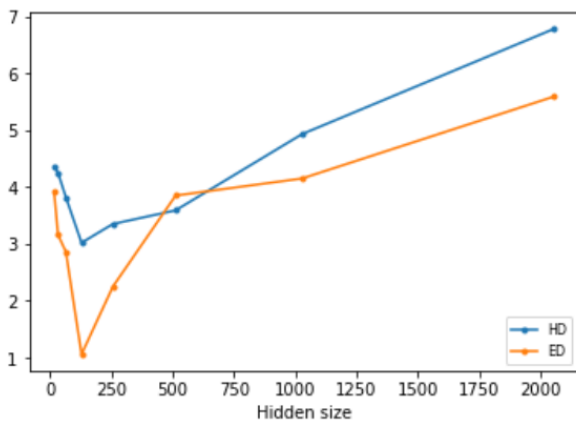


Fig. 4. The HD and ED performance metrics plot corresponding to different units in hidden layers.

TABLE VII. THE OUTCOMES ACHIEVED WITH VARIOUS DISCRIMINATOR LOSS FUNCTIONS

Loss function	HD	ED
WCE	4.58	3.49
BCE	3.80	3.16
DL	3.59	2.69
TL	3.09	1.08
SSL	3.32	2.15

V. DISCUSSION

The study's proposed approach for 3D lung tumor reconstruction using deep learning techniques offers promising results for medical diagnosis applications. The superior performance compared to traditional approaches on the LUNA dataset demonstrates the potential of deep learning techniques in the diagnosis and treatment of lung cancer. However, the study also highlights several limitations that should be addressed in future work.

One major limitation of the proposed method is the relatively small size of the LUNA dataset, which may limit the model's generalizability. Therefore, future studies could focus on expanding the dataset size to validate the proposed method's effectiveness on a larger scale. Additionally, incorporating other imaging modalities, such as PET scans, could improve the accuracy of the lung tumor reconstruction. Furthermore, the proposed method's generalizability to different datasets and populations should be thoroughly investigated in future studies to assess its practicality in clinical settings. The evaluation of the proposed method was done only on the LUNA dataset, and further evaluation on other datasets would be necessary to validate its performance. Additionally, the proposed method requires a large amount of labeled data for training, and the scarcity of such data in medical imaging remains a challenge. Therefore, further studies could focus on developing techniques for efficient data labeling to improve the availability of labeled data. Lastly, the interpretability of the proposed model could be improved. While the model can generate 3D lung tumor images, it is not always clear how the model arrived at a particular result. Future work could explore ways to make the model more interpretable, such as using attention mechanisms or visualization techniques. This could help

increase the transparency of the model's decision-making process and improve trust among clinicians and patients.

In addition to the limitations discussed earlier, there are also other aspects of the proposed method that could be improved in future work. For instance, the proposed method involves several complex steps, including lung isolation, tumor detection, and 3D lung tumor re-creation. Each of these steps requires careful tuning of hyperparameters and may introduce errors that can affect the overall performance of the model. Therefore, future studies could explore ways to simplify the proposed method by combining some of these steps or using alternative segmentation methods. Moreover, the proposed method assumes that the lung tumor is visible in the input image, which may not always be the case. For instance, small tumors or tumors that are located close to other organs may be challenging to detect using the proposed method. Therefore, future studies could explore ways to incorporate other features, such as patient history or genetic information, to improve the model's sensitivity and specificity. Another disadvantage of the suggested method is the computational cost, which may limit its practicality in clinical settings. While the proposed method shows promising results, it requires substantial computational resources, including high-end GPUs and extensive training time. Therefore, future studies could focus on developing more efficient models that can achieve similar performance with fewer computational resources. Lastly, the ethical implications of the proposed method should also be taken into account in future research. Deep learning models can be used to make critical medical decisions, and it is crucial to ensure that such models are fair and unbiased. Therefore, future studies could explore ways to ensure that the proposed method does not reinforce existing biases or discriminate against certain patient populations.

VI. CONCLUSION

The study proposes a novel method for constructing 3D lung tumors, which combines an LSTM and GAN network with a ResNet model serving as the feature extractor. The technique is divided into three stages: lung isolation, tumor isolation, and 3D lung tumor reconstruction. To achieve lung isolation and tumor isolation, the snake optimization and GK techniques are employed. In the 3D reconstruction phase, the pre-trained ResNet model is used to extract features from 2D lung tumor images, followed by the provision of these features into an LSTM to produce compressed features. The compressed characteristics are then utilized as input for GAN, where the generator is accountable for producing 3D lung tumor images, and the discriminator ascertains the authenticity of the image. The suggested model is evaluated on the LUNA dataset, and standard evaluation metrics are used to compare its effectiveness with conventional techniques.

One potential future work based on this study could be to investigate the proposed technique's applicability to other types of cancer or medical imaging modalities. It would be interesting to see how the proposed model could be adapted and optimized to handle different types of tumors, such as those found in breast or prostate cancer. Additionally, exploring the potential of incorporating other deep learning architectures or loss functions could further enhance the

accuracy and efficiency of the proposed method. Finally, conducting a clinical validation study to assess the proposed model's usefulness in real-world settings would be a valuable next step towards its eventual clinical adoption.

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REFERENCES

- [1] R. Raja, S. Kumar, S. Rani, K.R. Laxmi, Lung segmentation and nodule detection in 3D medical images using convolution neural network, *Artificial Intelligence and Machine Learning in 2D/3D Medical Image Processing*, CRC Press 2020, pp. 179-188.
- [2] J. Zhou, H. Xin, Emerging artificial intelligence methods for fighting lung cancer: A survey, *Clinical eHealth*, 5, pp. 19-34, 2022.
- [3] P. Afshar, A. Ahmadi, A. Mohebi, M. Fazel Zarandi, A hierarchical stochastic modelling approach for reconstructing lung tumour geometry from 2D CT images, *Journal of Experimental & Theoretical Artificial Intelligence*, 30, pp. 973-992, 2018.
- [4] A. Ashraf, S. Naz, S.H. Shirazi, I. Razzak, M. Parsad, Deep transfer learning for alzheimer neurological disorder detection, *Multimedia Tools and Applications*, 80, pp. 30117-30142, 2021.
- [5] X. Yi, E. Walia, P. Babyn, Generative adversarial network in medical imaging: A review, *Medical image analysis*, 58, pp. 101552, 2019.
- [6] R. Wang, Z. Fang, J. Gu, Y. Guo, S. Zhou, Y. Wang, C. Chang, J. Yu, High-resolution image reconstruction for portable ultrasound imaging devices, *EURASIP Journal on Advances in Signal Processing*, 2019, pp. 1-12, 2019.
- [7] G. Yang, S. Yu, H. Dong, G. Slabaugh, P.L. Dragotti, X. Ye, F. Liu, S. Arridge, J. Keegan, Y. Guo, DAGAN: deep de-aliasing generative adversarial networks for fast compressed sensing MRI reconstruction, *IEEE transactions on medical imaging*, 37, pp. 1310-1321, 2017.
- [8] S.V. Moravvej, S.J. Mousavirad, D. Oliva, G. Schaefer, Z. Sobhaninia, An Improved DE Algorithm to Optimise the Learning Process of a BERT-based Plagiarism Detection Model, 2022 IEEE Congress on Evolutionary Computation (CEC), IEEE, pp. 1-7, 2022.
- [9] M.S. Sartakhti, M.J.M. Kahaki, S.V. Moravvej, M. javadi Joortani, A. Bagheri, Persian language model based on BiLSTM model on COVID-19 corpus, 2021 5th International Conference on Pattern Recognition and Image Analysis (IPRIA), IEEE, pp. 1-5, 2021.
- [10] S.V. Moravvej, M.J.M. Kahaki, M.S. Sartakhti, A. Mirzaei, A method based on attention mechanism using bidirectional long-short term memory (BLSTM) for question answering, 2021 29th Iranian Conference on Electrical Engineering (ICEE), IEEE, pp. 460-464, 2021.
- [11] S.V. Moravvej, M. Joodaki, M.J.M. Kahaki, M.S. Sartakhti, A method Based on an Attention Mechanism to Measure the Similarity of two Sentences, 2021 7th International Conference on Web Research (ICWR), IEEE, pp. 238-242, 2021.
- [12] S.V. Moravvej, S.J. Mousavirad, M.H. Moghadam, M. Saadatmand, An lstm-based plagiarism detection via attention mechanism and a population-based approach for pre-training parameters with imbalanced classes, *Neural Information Processing: 28th International Conference, ICONIP 2021, Sanur, Bali, Indonesia, December 8-12, 2021, Proceedings, Part III 28*, Springer, pp. 690-701, 2021.
- [13] M. Jiang, M. Zhi, L. Wei, X. Yang, J. Zhang, Y. Li, P. Wang, J. Huang, G. Yang, FA-GAN: Fused attentive generative adversarial networks for MRI image super-resolution, *Computerized Medical Imaging and Graphics*, 92, p. 101969, 2021.
- [14] H.-C. Shin, N.A. Tenenholtz, J.K. Rogers, C.G. Schwarz, M.L. Senjem, J.L. Gunter, K.P. Andriole, M. Michalski, Medical image synthesis for data augmentation and anonymization using generative adversarial networks, *Simulation and Synthesis in Medical Imaging: Third International Workshop, SASHIMI 2018, Held in Conjunction with MICCAI 2018, Granada, Spain, September 16, 2018, Proceedings 3*, Springer, pp. 1-11, 2018.
- [15] P.V. Klimov, J. Kelly, J.M. Martinis, H. Neven, The snake optimizer for learning quantum processor control parameters, *arXiv preprint arXiv:2006.04594*, 2020.
- [16] F.A. Hashim, A.G. Hussien, Snake Optimizer: A novel meta-heuristic optimization algorithm, *Knowledge-Based Systems*, p. 108320, 2022.
- [17] D. Dovžan, I. Škrjanc, Recursive clustering based on a Gustafson-Kessel algorithm, *Evolving systems*, 2, pp. 15-24, 2011.
- [18] H. Liao, Z. Huo, W.J. Sehnert, S.K. Zhou, J. Luo, Adversarial sparse-view CBCT artifact reduction, *International Conference on Medical Image Computing and Computer-Assisted Intervention*, Springer, pp. 154-162, 2018.
- [19] J.M. Wolterink, T. Leiner, M.A. Viergever, I. Išgum, Generative adversarial networks for noise reduction in low-dose CT, *IEEE transactions on medical imaging*, 36, pp. 2536-2545, 2017.
- [20] C. Sun, A. Shrivastava, S. Singh, A. Gupta, Revisiting unreasonable effectiveness of data in deep learning era, *Proceedings of the IEEE international conference on computer vision*, pp. 843-852, 2017.
- [21] A. Karimi, S.M.R. Hashemian, Cytokine storm in COVID-19 and the treatment simulacrum, *Biomedical and Biotechnology Research Journal (BBRJ)*, 4, p. 41, 2020.
- [22] O. Russakovsky, J. Deng, H. Su, J. Krause, S. Satheesh, S. Ma, Z. Huang, A. Karpathy, A. Khosla, M. Bernstein, Imagenet large scale visual recognition challenge, *International journal of computer vision*, 115, pp. 211-252, 2015.
- [23] Q. Yu, L. Xie, Y. Wang, Y. Zhou, E.K. Fishman, A.L. Yuille, Recurrent saliency transformation network: Incorporating multi-stage visual cues for small organ segmentation, *Proceedings of the IEEE conference on computer vision and pattern recognition*, pp. 8280-8289, 2018.
- [24] X. Han, Automatic liver lesion segmentation using a deep convolutional neural network method, *arXiv preprint arXiv:1704.07239*, 2017.
- [25] H. Nam, B. Han, Learning multi-domain convolutional neural networks for visual tracking, *Proceedings of the IEEE conference on computer vision and pattern recognition*, pp. 4293-4302, 2016.
- [26] S. AlZu'bi, Y. Jararweh, H. Al-Zoubi, M. Elbes, T. Kanan, B. Gupta, Multi-orientation geometric medical volumes segmentation using 3d multiresolution analysis, *Multimedia Tools and Applications*, 78, pp. 24223-24248, 2019.
- [27] S. Al-Zu'bi, B. Hawashin, A. Mughaid, T. Baker, Efficient 3D medical image segmentation algorithm over a secured multimedia network, *Multimedia Tools and Applications*, 80, pp. 16887-16905, 2021.
- [28] A.A. Albishri, S.J.H. Shah, S.S. Kang, Y. Lee, AM-UNet: automated mini 3D end-to-end U-net based network for brain claustrum segmentation, *Multimedia Tools and Applications*, pp. 1-24, 2022.
- [29] R. Palomar, F.A. Cheikh, B. Edwin, A. Beghdadhi, O.J. Elle, Surface reconstruction for planning and navigation of liver resections, *Computerized Medical Imaging and Graphics*, 53, pp. 30-42, 2016.
- [30] S. Danaei, A. Bostani, S.V. Moravvej, F. Mohammadi, R. Alizadehsani, A. Shoeibi, H. Alinejad-Rokny, S. Nahavandi, Myocarditis Diagnosis: A Method using Mutual Learning-Based ABC and Reinforcement Learning, 2022 IEEE 22nd International Symposium on Computational Intelligence and Informatics and 8th IEEE International Conference on Recent Achievements in Mechatronics, Automation, Computer Science and Robotics (CINTI-MACRO), IEEE, pp. 000265-000270, 2022.
- [31] S.V. Moravvej, R. Alizadehsani, S. Khanam, Z. Sobhaninia, A. Shoeibi, F. Khozeimeh, Z.A. Sani, R.-S. Tan, A. Khosravi, S. Nahavandi, RLMD-PA: a reinforcement learning-based myocarditis diagnosis combined with a population-based algorithm for pretraining weights, *Contrast Media & Molecular Imaging*, 2022, 2022.
- [32] S. Momin, Y. Lei, Z. Tian, J. Roper, J. Lin, S. Kahn, H.-K. Shu, J.D. Bradley, T. Liu, X. Yang, Cascaded Mutual Enhancing Networks for Brain Tumor Subregion Segmentation in Multiparametric MRI, *Physics in Medicine & Biology*, 2022.

- [33] B. Yang, L. Zhou, L. Chen, L. Lu, H. Liu, W. Zhu, Cycle-consistent learning-based hybrid iterative reconstruction for whole-body PET imaging, *Physics in Medicine & Biology*, 2022.
- [34] A. Amruta, A. Gole, Y. Karunakar, A systematic algorithm for 3-D reconstruction of MRI based brain tumors using morphological operators and bicubic interpolation, 2010 2nd International Conference on Computer Technology and Development, IEEE, pp. 305-309, 2010.
- [35] M.A. Jaffar, S. Zia, G. Latif, A.M. Mirza, I. Mehmood, N. Ejaz, S.W. Baik, Anisotropic diffusion based brain MRI segmentation and 3D reconstruction, *International Journal of Computational Intelligence Systems*, 5, pp. 494-504, 2012.
- [36] P. Kamencay, M. Zachariasova, R. Hudec, M. Benco, R. Radil, 3D image reconstruction from 2D CT slices, 2014 3DTV-Conference: The True Vision-Capture, Transmission and Display of 3D Video (3DTV-CON), IEEE, pp. 1-4, 2014.
- [37] S. Sun, C. Bauer, R. Beichel, Automated 3-D segmentation of lungs with lung cancer in CT data using a novel robust active shape model approach, *IEEE transactions on medical imaging*, 31, pp. 449-460, 2011.
- [38] S.M. Ganji, M. Tehrani, A. Ehterami, H. Semyari, F. Taleghani, M. Habibzadeh, M.H. Tayeed, N. Mehrnia, A. Karimi, M. Salehi, Bone tissue engineering via application of a PCL/Gelatin/Nanoclay/Hesperetin 3D nanocomposite scaffold, *Journal of Drug Delivery Science and Technology*, 76, p. 103704, 2022.
- [39] I. Goodfellow, J. Pouget-Abadie, M. Mirza, B. Xu, D. Warde-Farley, S. Ozair, A. Courville, Y. Bengio, Generative adversarial nets, *Advances in neural information processing systems*, 27, 2014.
- [40] S. Moravvej, M. Maleki Kahaki, M. Salimi Sartakhti, M. Joodaki, Efficient GAN-based Method for Extractive Summarization, *Journal of Electrical and Computer Engineering Innovations (JECEI)*, 2021.
- [41] S.V. Moravvej, A. Mirzaei, M. Safayani, Biomedical text summarization using Conditional Generative Adversarial Network (CGAN), arXiv preprint arXiv:2110.11870, 2021.
- [42] P. Afshar, A. Ahmadi, M.F. Zarandi, Lung tumor area recognition in CT images based on Gustafson-Kessel clustering, 2016 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), IEEE, pp. 2302-2308, 2016.
- [43] M.S. Hakemi, A.A. Nassiri, A. Nobakht, M. Mardani, I.A. Darazam, M. Parsa, M.M. Miri, R. Shahrami, A.A. Koomleh, K. Entezarmahdi, Benefit of hemoabsorption therapy in patients suffering sepsis-associated acute kidney injury: a case series, *Blood Purification*, 51, pp. 823-830, 2022.
- [44] T. Yona, Y. Or, The wheeled three-link snake model: singularities in nonholonomic constraints and stick-slip hybrid dynamics induced by Coulomb friction, *Nonlinear Dynamics*, 95, pp. 2307-2324, 2019.
- [45] S. Vakilian, S.V. Moravvej, A. Fanian, Using the artificial bee colony (ABC) algorithm in collaboration with the fog nodes in the Internet of Things three-layer architecture, 2021 29th Iranian Conference on Electrical Engineering (ICEE), IEEE, pp. 509-513, 2021.
- [46] S. Vakilian, S.V. Moravvej, A. Fanian, Using the cuckoo algorithm to optimizing the response time and energy consumption cost of fog nodes by considering collaboration in the fog layer, 2021 5th International Conference on Internet of Things and Applications (IoT), IEEE, pp. 1-5, 2021.
- [47] M. Sonka, V. Hlavac, R. Boyle, *Image processing, analysis, and machine vision*, Cengage Learning 2014.
- [48] N. Shlezinger, Y.C. Eldar, N. Farsad, A.J. Goldsmith, Viterbinet: Symbol detection using a deep learning based viterbi algorithm, 2019 IEEE 20th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC), IEEE, pp. 1-5, 2019.
- [49] S.G. Armato III, G. McLennan, L. Bidaut, M.F. McNitt-Gray, C.R. Meyer, A.P. Reeves, B. Zhao, D.R. Aberle, C.I. Henschke, E.A. Hoffman, The lung image database consortium (LIDC) and image database resource initiative (IDRI): a completed reference database of lung nodules on CT scans, *Medical physics*, 38, pp. 915-931, 2011.
- [50] I.-D. Borlea, R.-E. Precup, A.-B. Borlea, D. Iercan, A unified form of fuzzy C-means and K-means algorithms and its partitional implementation, *Knowledge-Based Systems*, 214, p. 106731, 2021.
- [51] Y. Ding, X. Fu, Kernel-based fuzzy c-means clustering algorithm based on genetic algorithm, *Neurocomputing*, 188, pp. 233-238, 2016.
- [52] Q. Li, Z. Li, Z. Shi, H. Fan, Multi-Target Magnetic Positioning Using SAFCM Clustering and Invariants-Improved Tilt Angle, *IEEE Transactions on Geoscience and Remote Sensing*, 60, pp. 1-15, 2022.
- [53] Y. Shen, C. Tang, M. Xu, Z. Lei, Optical selective encryption based on the FRFCM algorithm and face biometric for the medical image, *Optics & Laser Technology*, 138, p. 106911, 2021.
- [54] H. Rezatofighi, N. Tsoi, J. Gwak, A. Sadeghian, I. Reid, S. Savarese, Generalized intersection over union: A metric and a loss for bounding box regression, *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 658-666, 2019.
- [55] J.M. Bogoya, A. Vargas, O. Schütze, The averaged hausdorff distances in multi-objective optimization: A review, *Mathematics*, 7, p. 894, 2019.
- [56] D. Luengo, L. Martino, M. Bugallo, V. Elvira, S. Särkkä, A survey of Monte Carlo methods for parameter estimation, *EURASIP Journal on Advances in Signal Processing*, 2020, pp. 1-62, 2020.
- [57] K. Hayashi, Y. Jikumar, M. Ohsaki, T. Kagaya, Y. Yokosuka, Mean curvature flow for generating discrete surfaces with piecewise constant mean curvatures, *Computer Aided Geometric Design*, 101, p. 102169, 2023.
- [58] M.Z. Alom, T.M. Taha, C. Yakopcic, S. Westberg, P. Sidike, M.S. Nasrin, B.C. Van Esesn, A.A.S. Awwal, V.K. Asari, The history began from alexnet: A comprehensive survey on deep learning approaches, arXiv preprint arXiv:1803.01164, 2018.
- [59] R. Anand, T. Shanthi, M. Nithish, S. Lakshman, Face recognition and classification using GoogleNET architecture, *Soft computing for problem solving*, Springer 2020, pp. 261-269.
- [60] X. Xia, C. Xu, B. Nan, Inception-v3 for flower classification, 2017 2nd international conference on image, vision and computing (ICIVC), IEEE, pp. 783-787, 2017.
- [61] G. Huang, Z. Liu, L. Van Der Maaten, K.Q. Weinberger, Densely connected convolutional networks, *Proceedings of the IEEE conference on computer vision and pattern recognition*, pp. 4700-4708, 2017.
- [62] A.G. Howard, M. Zhu, B. Chen, D. Kalenichenko, W. Wang, T. Weyand, M. Andreetto, H. Adam, Mobilenets: Efficient convolutional neural networks for mobile vision applications, arXiv preprint arXiv:1704.04861, 2017.
- [63] P. Sun, Y. Lu, J. Zhai, Mapping land cover using a developed U-Net model with weighted cross entropy, *Geocarto International*, 37, pp. 9355-9368, 2022.
- [64] T. Wu, Q. Huang, Z. Liu, Y. Wang, D. Lin, Distribution-balanced loss for multi-label classification in long-tailed datasets, *Computer Vision–ECCV 2020: 16th European Conference, Glasgow, UK, August 23–28, 2020, Proceedings, Part IV 16*, Springer, pp. 162-178, 2020.
- [65] C.H. Sudre, W. Li, T. Vercauteren, S. Ourselin, M. Jorge Cardoso, Generalised dice overlap as a deep learning loss function for highly unbalanced segmentations, *Deep learning in medical image analysis and multimodal learning for clinical decision support*, Springer 2017, pp. 240-248.
- [66] S.S.M. Salehi, D. Erdogmus, A. Gholipour, Tversky loss function for image segmentation using 3D fully convolutional deep networks, *International workshop on machine learning in medical imaging*, Springer, pp. 379-387, 2017.
- [67] S.R. Hashemi, S.S.M. Salehi, D. Erdogmus, S.P. Prabhu, S.K. Warfield, A. Gholipour, Asymmetric loss functions and deep densely-connected networks for highly-imbalanced medical image segmentation: Application to multiple sclerosis lesion detection, *IEEE Access*, 7, pp. 1721-1735, 2018.

Optimized Secure Federated Learning for Event Detection in Big Data using Blockchain Mechanism

K. Prasanna Lakshmi¹, K.Swapnika²

Professor, Information Technology Department, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, India¹
Ph.D Scholar, JNTUH, Hyderabad, India²

Abstract—Currently, cloud storage in blockchain and federated learning technology provides better security among data transmission and file access. But, in some of the cases, security issues arose. So, to avoid security problems and offer better protection in a cloud environment, a novel optimized buffalo-based Homomorphic SHA blockchain (OBHSB). In this model for accessing the cloud storage data with the key matching method, if any of the unauthenticated users are trying to access the file initially, the system checks the key matching parameter. The proposed model was developed to provide better security in big data presented in the cloud environment. However, the parameters in the proposed model were compared with the existing models to make sure better performance was attained through the proposed model. Attack was considered as an event in this research. In the performance analysis, the performance rate of the proposed model was validated. Subsequently, the case study was developed in this research to explain the working procedure of the proposed design; model performs hashing, encryption, decryption, and key matching mechanisms. The results proposed model is observed to have 100% confidentiality rate after attack.

Keywords—Blockchain; cloud storage; decryption; encryption; federated learning; hashing; homomorphism

I. INTRODUCTION

Federated Learning is a Machine Learning (ML) concept that trains the program through a decentralized edge system having local data [1]. Fig. 1 describes the general architecture of federated learning. The training process does not involve the exchange of data [2]. In conventional ML approaches, the entire local datasets are transferred to a single server/ device, whereas in classical ML approaches, the local dataset is distributed identically [3]. In the federated learning approach [4], the local sample dataset is trained without distributing the information [5]. Therefore, it is widely used in applications to overcome data privacy and security issues [6]. Event detection (ED) involves the investigation of several events to provide a better understanding of social events [7].

The event investigation by analyzing massive heterogeneous datasets such as audio, images, and video is called Multimodal ED [8]. The development of different image processing approaches helps identify various types of events automatically [9]. Unstructured multimedia data are created in recent types to search the data more flexibly [10]. Many different technologies were developed to identify the event in various scenarios, such as ED in the smart city [11], ED in social media [12], ED in road traffic [13], etc. Recently, event identification has been carried out with the help of big

data [14]. Big data is a massive collection of data whose size can be enhanced exponentially over time [15]. The conventional information management tool can store only a limited amount of data [16]. But big data can process and store massive amounts of data in it [17]. Moreover, event detection using big data is highly effective because of its high storage space [18]. However, multimodal event detection is one of the major concerns for machine learning approaches. In this research, the attack is considered as event. Here, we are performing homomorphism concept so single event detection has been performed. Thus, different machine learning-based multimodal ED such as message dissemination model with the assistance of blockchain [19], blade icing identification technique based on blockchain and imbalanced federated learning approach [20], incentive governor for FL approach based on blockchain technology [22] were developed for identifying events from audio, text, image and video. However, they cannot provide effective results. Hence, an optimized federated self-supervised learning for multimodal event classification in big data using blockchain is presented in this article. In this work, some of the recent literature related to this topic was discussed in the second Section. Moreover, the system model as well as the problem statement was presented in Section III, and in fourth section the proposed system model was discussed. Moreover, the result and a discussion of the proposed model were developed in Section V, and the paper was concluded with the conclusion in Section VI.

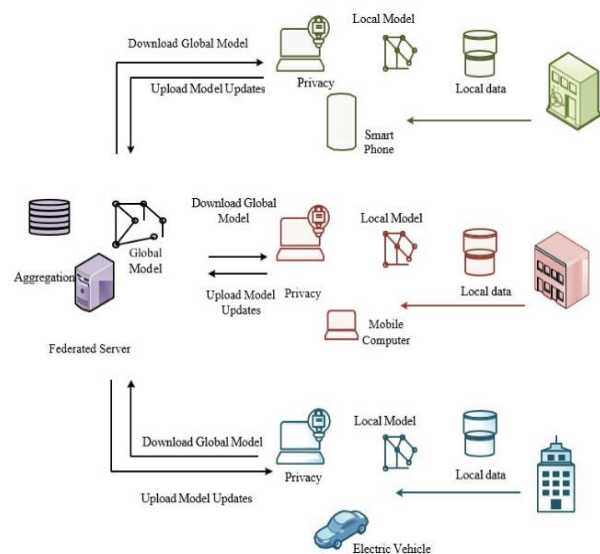


Fig. 1. General architecture of federated learning.

II. RELATED WORK

The recent works associated with this research are summarized below.

Nowadays, message dissemination plays a significant role in providing safety to Electric Vehicles (EVS). The messages are transferred among EVs using broadcasting technology. Moreover, high mobility and density in incoming vehicles affect the message dissemination process. To overcome the issues in message dissemination, Ferheen Ayaz et al. [19] developed the message dissemination model with the assistance of blockchain. This technique minimizes the delay and improves the message delivery rate. However, the practical implementation of this model provides inefficient results. Recently, renewable energy resources such as solar, wind, etc., have been widely used in different sectors. Wind energy is one of the rapidly growing renewable sources among these renewable sources. Blade icing is one of the significant concerns in wind power generation. To overcome this issue, data-driven technologies are widely used for blade icing identification. They require substantial resource data. Hence, Xu Cheng et al. [20] developed a blade icing identification technique based on blockchain and an imbalanced federated learning approach.

This technique identifies blade icing issues accurately. However, the implementation cost is high in this technique. Federated learning (FL) is an ML concept mainly used to provide data privacy in different applications. In the federated learning approach, the data is trained in a distributed way where the training dataset is located on the user side. The major problem with the FL approach is that it requires vast resources, and the computation of resources is complex. Hence, LiangGao et al. [21] developed an incentive governor for the FL approach based on blockchain technology to overcome these issues. This technique provides high security by neglecting the attackers. But the computation time is more in this approach.

As network applications are developing faster, it is widely used in different sectors. Thus, providing trustworthy applications to the user is the primary task of the researchers. Therefore, SafaOtoum et al. [22] developed a technique to provide security and network trustworthiness. This technique integrates the features of blockchain architecture and a federated learning approach. Moreover, they provide network trustworthiness by considering the trust of every individual. This method provides high accuracy. However, the detection rate of false statements is low in this approach. This technique integrates the features of blockchain architecture and a federated learning approach. Moreover, they provide network trustworthiness by considering the trust of every individual. This method provides high accuracy. However, the detection rate of false statements is low in this approach.

In a distributed network, the federated learning approach provides high data privacy by training data in a secure manner. It is a type of collaborative learning where the training dataset is located on the user's side to preserve privacy. YajingXu et al. [23] presented the FL approach based on blockchain methodology to identify malicious events in a unified model. This approach's experimental outcome improves FL's

performance on data protection and negative identification. However, malicious events are not neglected in this approach.

The key contribution of this proposed work was described as follows:

- Initially, three different data (audio, image, text) is gathered and trained in the system.
- Moreover, a novel OBHSB has been developed with different security parameters and monitoring functions.
- Then the data transmission from the different users was encrypted to hide the raw data among third parties.
- The encrypted data was stored at central cloud server, the homomorphism function has been performed during file access.
- Finally, the performance of the designed monitoring crypto model is validated by launching a DoS attack.
- The robustness has been measured regarding computation time, confidential rate, resource usage, throughput, and data transfer time.

III. SYSTEM MODEL AND PROBLEM STATEMENT

Cloud computing is the primary memory resource for intelligent digital gadgets because the collected information by the smart devices is stored in the cloud environment. So, the cloud memory must become secure to maximize user trust.

Hence, to secure the data sharing process in the cloud environment, federated learning has been introduced with security mechanisms. Usually, the federated system has security features, but some harmful events have broken the security. So, the blockchain system has been introduced. The blockchain module's main reasons are homomorphic concepts and data integrity validation. But in some cases, the data became injected by malicious events. So, the present work has planned to design the monitoring of the homomorphic blockchain system for cloud environment. Fig. 2 illustrates the system's basic model and common problem. Subsequently, the data transmission to the system with the help of blockchain provides more security because through the use of blockchain, the transmitted data was safer and stored in the cloud. In this proposed model, three different types of data sets were used, so a large amount of data was transmitted in a single transmission.

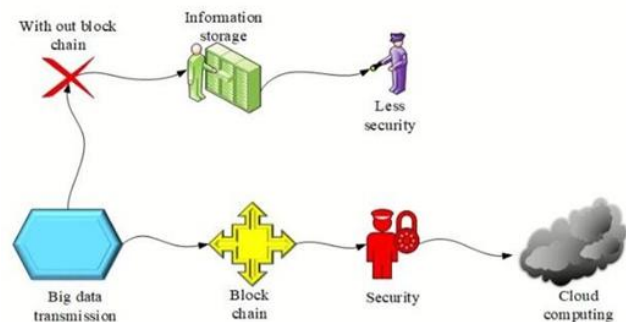


Fig. 2. System model with problem.

IV. PROPOSED METHODOLOGY

To enrich the security module of the federated learning, a novel Optimized Buffalo-based Homomorphic SHA Blockchain (OBHSB) has been designed with the required security parameters. Hence, to perform the federated learning concept, three different types of data have been considered. Initially, the collected data was trained to the system then a novel OBHSB was designed with the required data hiding and the homomorphic parameters. Here, the buffalo algorithm is incorporated to monitor the malicious activities in the designed federated learning system. Here, we provide three different types of data sets to the system. With the help of the proposed model, the system was monitored to detect malicious activities. The transferred data was stored in the cloud memory for better security. Here, finding the two hash values was termed homomorphism. After that, if the two hash values are the same, then through the help of a key, the file was accessed. Otherwise, the file was not able to access. However, the performance of the system was measured. Attack was launched to validate the proposed model; Fig. 3 illustrates architecture of the proposed model.

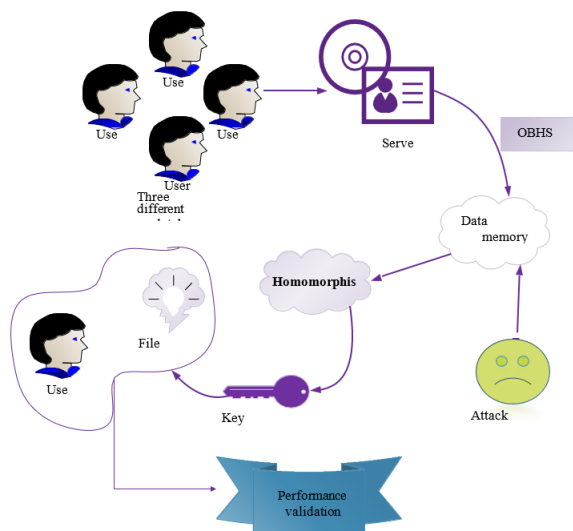


Fig. 3. Proposed architecture.

A. Design of OBHSB Model

The proposed model was designed based on the optimized buffalo algorithm and the Homomorphic SHA blockchain. At first, audio, image, and text data were collected and trained in the system to validate the implemented design. After that, the proposed model was designed to provide security for the ordered data sets. For better security, the data was stored in cloud storage. Moreover, with the help of the proposed model, encryption, decryption, and homomorphism were done. Initialization of the data set was declared through (1).

$$F[B_3] = (a_1 + i_1 + t_1, a_2 + i_2 + t_2, \dots \dots \dots a_n + i_n + t_n) \quad (1)$$

Where $F[B_3]$ defines the initializing parameter of the proposed model, $a_1 \dots a_n$ represents the amount of audio data presented in the data set, $i_1 \dots i_n$ defines the number of image data introduced in the initialized data set, and $t_1 \dots t_n$

refers to the number of test data presented in the dataset.

B. Attack Prediction and Neglection

After initializing the data sets, the system was monitored through the proposed model for detecting the attack. For attack detection, Neglection, and encryption, decryption was done under the proposed technique. While initializing the data, the data set contains both the attacknode and the normal node. Among them, the attack nodes were removed from the system, and the normal nodes were used for different processes. Here, the attack detection expression of the proposed model was declared in (2), (3).

$$Pa * (b_3) = \sum_{i=1}^n (a + i + t, a' + i' + t') \quad (2)$$

$$Na * (b_3) = b_3(a + i + t) - b_3(a' + i' + t') \quad (3)$$

Where $Pa * (b_3)$ defines the attack detecting parameters of the proposed model, $Na * (b_3)$ refers to the attack neglecting parameter of the implemented design, $a+i+t$ represents the normal data presented in the data set, and $a' + i' + t'$ defines the attack nodes of the proposed model.

C. Calculation of Hash 1

Hash 1 function was calculated after removing the attack nodes from the data set. After measuring the hash one value, the obtained value was stored in the cloud for more security. Subsequently, finding the hash one function of the proposed model was declared through the (4).

$$h^* = a \text{ mod } b \quad (4)$$

Where h^* defines the hashing function of the proposed design. Moreover, a describes the plain text and b represents the prime number. Furthermore, the hash one value of the model was used for finding the key matching operation.

D. Data Encryption

In this research, SHA encryption was used to encrypt the data. At SHA encryption, Hexa decimal numbers were chosen for key values. Encryption was done in the data to protect the data from the unauthenticated user. Through the encryption process, the data were protected as private data and sensed data. Moreover, the SHA defies the secure Hash Algorithm used for hashing the data and securing the files. SHA encryption of the proposed model was declared through (5).

$$E^* = a * k \quad (5)$$

Where the parameter E^* defines the encryption parameter of the proposed model and a refers to the plain text and k critical parameter of the SHA encryption.

E. Homomorphism

For finding the hash, two values were mentioned as homomorphism. Hash 2 was measured by encrypting the initialized data. If the hash one and the hash two values are equal. it was mentioned as key matching so the user can access the file. Moreover, the system can access the file while displaying data injection if the two values are not equal. For finding the hash, two value of the proposed model was expressed in (6)

$$h^{**} = \frac{E^*}{k} (a \bmod b) \quad (6)$$

Where h^{**} refers to the parameter used for finding the homomorphism. E^* represents the encrypted data, k refers to the key parameter, and a defines the plain text, as well as the parameter b was the prime number.

F. Key Matching

Key matching was done to find the exact user to access the file. Moreover, if the hash one and the hash two rates were the same, the system accomplishes the file accessing process. If the two values are not the same, then the system displays as data injected. The key matching expression of the proposed model was expressed through the 'if' condition and was declared in (7).

$$k_m = \begin{cases} \text{if } h^* = h^{**}; \text{file accessed} \\ \text{else ; data injected} \end{cases} \quad (7)$$

Where k_m represents the key matching parameter used in the proposed model. h^* Defines the hash one function of the system and h^{**} establishes the hash two parameters of the model.

G. Performance Validation and Attack Launching

The performance of the parameters was validated after finding the hash one and hash two values. Moreover, the proposed model attains a higher rate of parameters with better performance. After that, the robustness was validated by launching the attack. After launching, the attack's performance improved compared to the initial stage performances. After completing the file accessing process, the system was checked for malicious nodes. This research launched the Denial of Service (DoS) attack. Subsequently, the function of this attack was to shut down the system and quit the process when accessing the unauthenticated user, and here the unauthenticated user was considered the malicious node; after launching the attack, if any of the malicious nodes were presented.

The working procedure of the proposed model was developed in the pseudo-code format and represented in Algorithm 1 and the workflow diagram of the proposed model was shown in Fig. 4.

Algorithm 1: OBHSB

```

Start
{
  Initialization()
  int F[B3] = (a1 + i1 + t1, a2 + i2 + t2, an + in + tn)
  //Initialize the audio, image and text data set
  Attack Prediction & Neglection()
  {
    int P a *(b3) , Na *(b3)
    //initializing the attack detecting and neglecting
    parameters To neglect Na *(b3)
    //System was monitored, if the attack was predicted,
    then it was removed, and the attack detected node
    was considered as Na *(b3)
  }
  Hash1 ()
  {

```

```

int h*, a, b;
//initializing the parameters used for calculating the hash
one function
// hash one was calculated from the initialized data set,
and it was stored in the cloud storage for better security
}
Data encryption ()
{
  int E*, a, k;
  //initialize the data encryption parameters
  E* = a x k
  //SHA encryption method was followed for encryption
}
Homomorphism ()
{
  int h**, E*, a, k, b;
  //initializing the parameters for homomorphism

  h** = E*/k (a mod b)
  //hash two value was calculated
}
Key matching ()
{
  int h*, h**;
  //initializing the key matching parameters of the model
  km = { if h* = h** ; file accessed
        else ; data injected
        }
}
}
Stop

```

Flow chart which explains the process of the developed model is illustrated in Fig. 4.

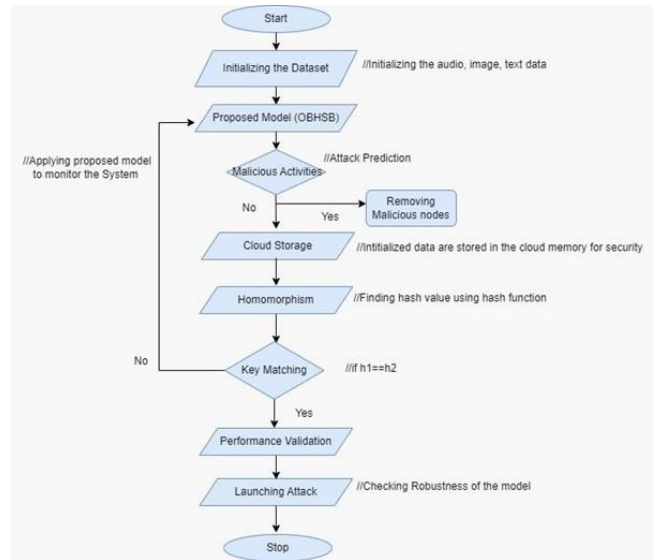


Fig. 4. Flow chart.

The primary aim of this present research was to provide security to the files presented in the cloud memory of the system. Through the proposed model, high security was attained. Consequently, the attack was launched on the cloud memory of the system.

H. Dataset Description

The proposed methodology uses datasets created manually using text dataset form Kaggle stocks data and audio mp4 has been collected randomly from google. The image dataset is created by using the images available on the Internet. Various kinds of images are available on the Internet, and the images suitable for event detection are collected for the proposed event detection process.

V. RESULT AND DISCUSSION

In this research, the proposed model was implemented and executed in the python platform to provide better security to the files. Here, the system provided three different types of data sets for analysis. After initializing the data sets with the help of the proposed model, the plan was monitored to predict the attack/event nodes. If any attack nodes were presented in the datasets, then the system neglected them. For more security, hash one and hash two functions were measured when both values were the same, and the user accessed the file. Subsequently, if not equal means the system displays data injection. However, the required parameters for developing the proposed design were tabulated in Table I.

TABLE I. PARAMETER VALIDATION OF THE DEVELOPED MODEL

Parameters	Requirement
OS	Windows 10
Platform	Python
Version	3.10

The present work was designed in the python software 3.10 version. The performance analysis section mentioned the result after and before attack launching. Moreover, the comparative analysis of the model was evaluated and compared with the existing techniques for assuring the presentation of the implemented model.

A. Case Study

Here, the working procedure of the implemented design was explained in detail. The primary aim of this particular research was to provide security for the files from the attackers. Initially, the system was monitored through the proposed model. The file was accessed only when both the hash values were the same. Consequently, from this method, more security was provided for files. After that, the DoS attack was launched to validate the system's performance. At the performance analysis, the version of the proposed model, such as encryption time, decryption time, confidential rate, throughput, and data transfer time, were calculated. Fig.5. presents the calculated performance metrics.

The total time it takes the system to encrypt and decrypt the data is called encryption and decryption time. The encryption time, decryption time as well as the confidential rate of the proposed model is shown in Fig. 6. Here, the encryption time of the audio signal was about 10.35ms, the encryption time of the image data was approximately 17.56, and the encryption time of the text data was about 5.29ms. Subsequently, in the proposed model, the decryption rate of the audio signal was about 1.6ms, the decryption rate of the

image data was about 28.2ms, decryption rate of the text data was about 6.233ms. Data transfer time was the time needed to transfer the data, and in the proposed model, less time was required to move the high amount of data. Moreover, the data transfer rate of the proposed model is 18.8ms for audio signal, 19.2ms for image data and 3.3ms for text data.

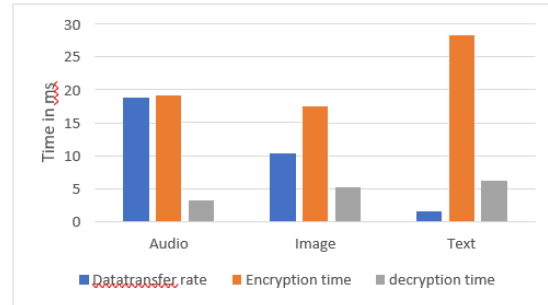


Fig. 5. Performance metrics of the proposed model.

Fig. 6 depicts the rate of throughput in the model.

The system's throughput was calculated based on the rate of exactness and time needed to complete the process. Here, the throughput range was varied at image, audio, and text data sets. However, the throughput range of the image data set was about 73%, throughput attained through the audio data set was about 94% and 85% of the throughput was attained through the text data set.

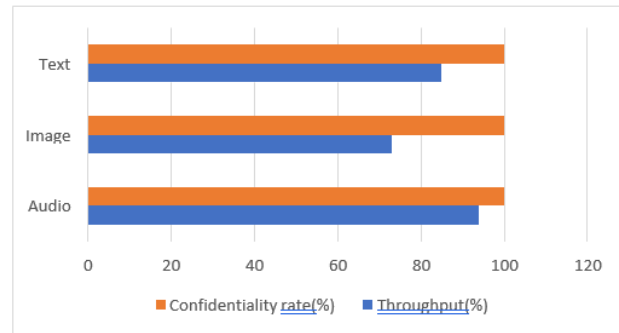


Fig. 6. Confidential rate and throughput of the model.

B. Comparison Analysis

A higher performance rate was attained through the proposed model, and validating the performance of the proposed model comparison analysis was done. In this section, the proposed model's stability, scalability, and resource usage were compared with the existing models. Moreover, the parameters of the developed model were comparing with the current models like DNN+GRM+MFO, DNN+GRM, CNN+HHO+GRM+MFO, and CNN+GRM+MFO as well as the scalability and the stability rate of the proposed model was compared to the existing models such as Recurrent neural network (RNN), Convolution neural network (CNN), Deep convolution Neural network (DNN), Deep belief network (DBN) as well as the proposed MLFC.

1) Resource usage: Here, the resource usage of the proposed model was compared with the existing models such

as DNN+GRM+MFO, DNN+GRM, CNN+HHO+GRM+MFO, and CNN+GRM+MFO. But, the proposed model uses a lower rate of resources. Moreover, the proposed model uses 8.5MB of audio data, 7.3MB of image resources, and 9.4MB of text data. Based on the time and the performance rate, resource usage was measured. The resource usage was measured through (8).

$$R_u^* = P_y * \Delta t \tag{8}$$

Where R_u^* defines the model's resource usage function, P_y represents the proposed model's performance rate, and Δt defines the time required to complete the process. Consequently, the resource usage comparison of the proposed model was illustrated in Fig. 7. After comparison, the proposed model needs a lower rate of resources to perform the function.

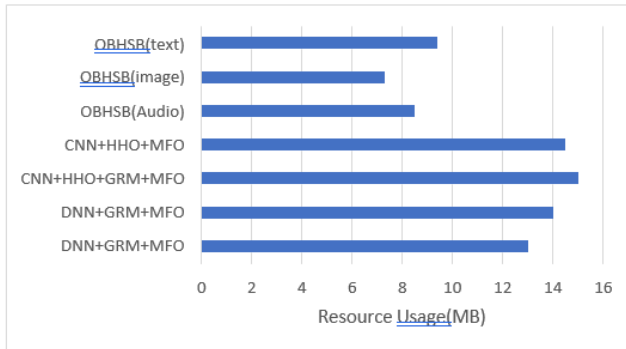


Fig. 7. Comparison of resource usage.

2) *Scalability*: Scalability refers to the overall capability to co-operate and perform well with data given to the model.

$$\sigma = R_u^* * \beta_t \tag{9}$$

Where σ defines the scalability function of the proposed model R_u^* was the resource usage function and β_t represented the model's throughput. Moreover, the scalability of the proposed model was about 153 MB. The scalability of the implemented model was comparing through the existing models like CNN, DCNN, RNN and DBN. Among them, the proposed model attains a better rate of scalability. The stability comparison of the proposed model is illustrated in Fig. 8.

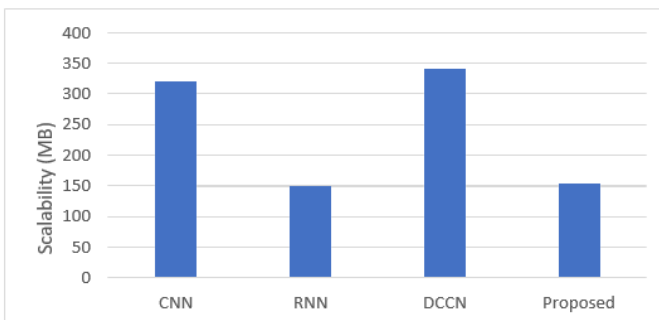


Fig. 8. Scalability comparison.

3) *Stability*: Stability refers to the steadiness of the system as well as the condition of the system. Subsequently, the Stability range of the developed model was comparing with the existing models such as CNN, RNN, DCNN, and DBN. However, the proposed model staining a better stability range was about 99%. Stability helps to find the men's performance within a particular time. For evaluation, the exact increment of performance stability will be used. The stability comparison of the proposed model was shown in Fig. 9.

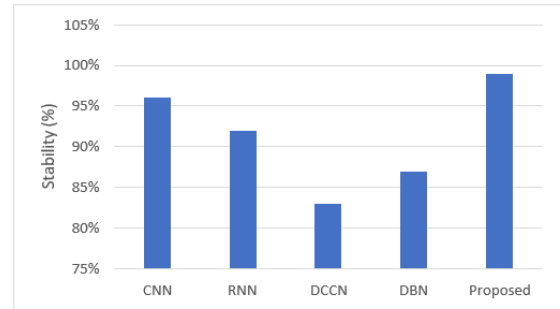


Fig. 9. Stability comparison.

C. Discussion

In this section, the performance parameters of the proposed model were discussed. In this research, the proposed model attained higher rate of throughput about lower rate of encryption time was achieved through the audio, text, and image data was about 10.35ms, 17.56ms, and 3.29ms. Moreover, the decryption time of the proposed model, also low through audio, image, and text data, was about 11.66ms, 28 2ms, and 6.233ms. A higher rate of confidential rate was achieved through the proposed model through the three different datasets, and the confidential rate was 100%. The proposed model used fewer number resources. The text data rate of resource usage was about 8.5MB, the image resource used was about 7.3MB, and 94MB resources were used through the text data. Moreover, the overall performance rate of the developed model was based on three different data sets were tabulated in Table II.

TABLE II. OVERALL PERFORMANCE OF THE IMPLEMENTED DESIGN

Parameters	Audio	Image	Text
Encryption time	10.35ms	17.ms	5.29ms
Decryption time	1.66ms	28.2ms	6.23ms
Confidential rate	100%	100%	100%
Throughput	94%	73%	85%
Data transfer rate	18.95ms	19.6ms	4.20ms
Resource usage	8.5MB	7.3MB	9.4MB

VI. CONCLUSION AND FUTURE SCOPE

This work was presented to provide security for file access. Moreover, the blockchain and homomorphism methods were used to secure the data from the unauthenticated node. Through this proposed model, more security was provided in the cloud environment. In this work, key matching and homomorphism were considered essential features. Due to

these two features, the data in the cloud was safe without accessing the unauthenticated user. In this model, the encrypted data was stored in the cloud environment for better security, and the percentage of improvement was also added in this section. This proposed model measured the output based on image, text, and the audio data set. Subsequently, through the audio, image, and text data, the proposed model needs a low encryption time was about 10.35ms, 17.6ms, and 5.29ms, and the decryption time of the proposed model is also low with three different datasets was about 11.66ms, 28.2ms and 6.23ms. The amount of resource usage of the proposed model with the audio, image, and text data was about 8.5MB, 7.3MB, and 9.4MB. On comparing with existing models, the developed design needs a lower rate of resources to perform the function. The system attains 94% throughput with the audio data set, 73% of throughput in the image data set, and 85% in the text data set. The data transfer rate of the implemented design along with audio, image, and text data was 18.9MB, 19.6MB, and 4.20MB. Subsequently, the proposed model attains 100% of the confidential rate while processing the audio, image, and text data set. Resource usage of the proposed model was 8.5 MB in the audio data set, 7.3 MB in the image data set, and 9.4 MB in the text data set. Among them, the proposed model developed by 4% in resource usage. The Stability of the system was about 99% comparing with the existing techniques; the implemented design improves 3% of stability rate. Consequently, the overall system scalability range obtained through the proposed model was about 153MB; compared with the existing models, the scalability of the proposed model was developed by 5%. Due to the high confidentiality rate, the system provides more security to the files presented in the cloud environment. In future, the model can be checked with other attacks also to check the stability of the model.

REFERENCES

- [1] Alazab, Mamoun, et al. "Federated Learning for Cybersecurity: Concepts, Challenges, and Future Directions." *IEEE Transactions on Industrial Informatics* 18.5 (2021): 3501-3509.
- [2] Huo, Weiwei, et al. "Performance prediction of proton-exchange membrane fuel cell based on convolutional neural network and random forest feature selection." *Energy Conversion and Management* 243 (2021): 114367.
- [3] Chen, Mingzhe, et al. "Distributed learning in wireless networks: Recent progress and future challenges." *IEEE Journal on Selected Areas in Communications* (2021).
- [4] Zhu, Hangyu, et al. "Federated learning on non-IID data: A survey." *Neurocomputing* 465 (2021): 371-390.
- [5] Wink, Tobias, and Zoltan Nocht. "An approach for peer-to-peer federated learning." *2021 51st Annual IEEE/IFIP International Conference on Dependable Systems and Networks Workshops (DSN-W)*. IEEE, 2021.
- [6] Long, Guodong, et al. "Federated learning for privacy-preserving open innovation future on digital health." *Humanity Driven AI*. Springer, Cham, 2022. 113-133.
- [7] Rezaee, Khosro, et al. "A survey on deep learning-based real-time crowd anomaly detection for secure distributed video surveillance." *Personal and Ubiquitous Computing* (2021): 1-17.
- [8] De, Suparna, et al. "Analysing environmental impact of large-scale events in public spaces with cross-domain multimodal data fusion." *Computing* 103.9 (2021): 1959- 1981.
- [9] Sahoo, Somya Ranjan, and Brij B. Gupta. "Multiple features based approach for automatic fake news detection on social networks using deep learning." *Applied Soft Computing* 100 (2021): 106983.
- [10] Hassan, Mohammad A. "Relational and NoSQL Databases: The Appropriate Database Model Choice." *2021 22nd International Arab Conference on Information Technology (ACIT)*. IEEE, 2021.
- [11] Komninos, Nicos, et al. "Towards high impact smart cities: A universal architecture based on connected intelligence spaces." *Journal of the Knowledge Economy* 13.2 (2022): 1169-1197.
- [12] Leite, Emilene. "Innovation networks for social impact: An empirical study on multi-actor collaboration in projects for smart cities." *Journal of Business Research* 139 (2022): 325-337.
- [13] Csukás, Máté S., and Roland Z. Szabó. "The many faces of the smart city: Differing value propositions in the activity portfolios of nine cities." *Cities* 112 (2021): 103116.
- [14] Corsi, Alana, et al. "Big data analytics as a tool for fighting pandemics: a systematic review of literature." *Journal of ambient intelligence and humanized computing* 12.10 (2021): 9163-9180.
- [15] Pika, Anastasiia, et al. "Using big data to improve safety performance: an application of process mining to enhance data visualisation." *Big Data Research* 25 (2021): 100210.
- [16] Iqbal, Naeem, et al. "A novel blockchain-based integrity and reliable veterinary clinic information management system using predictive analytics for provisioning of quality health services." *IEEE Access* 9 (2021): 8069-8098.
- [17] Naeem, Muhammad, et al. "Trends and future perspective challenges in big data." *Advances in intelligent data analysis and applications*. Springer, Singapore, 2022. 309-325.
- [18] Chen, Jie, L. Ramanathan, and Mamoun Alazab. "Holistic big data integrated artificial intelligent modeling to improve privacy and security in data management of smart cities." *Microprocessors and Microsystems* 81 (2021): 103722.
- [19] Ayaz, Ferheen, et al. "A blockchain based federated learning for message dissemination in vehicular networks." *IEEE Transactions on Vehicular Technology* 71.2 (2021): 1927-1940.
- [20] Cheng, Xu, et al. "A Blockchain-Empowered Cluster-based Federated Learning Model for Blade Icing Estimation on IoT-enabled Wind Turbine." *IEEE Transactions on Industrial Informatics* (2022).
- [21] Otoum, Safa, Ismael Al Ridhawi, and Hussein Mouftah. "Securing critical IoT infrastructures with blockchain-supported federated learning." *IEEE Internet of Things Journal* 9.4 (2021): 2592-2601.
- [22] Gao, Liang, et al. "FGFL: A blockchain-based fair incentive governor for Federated Learning." *Journal of Parallel and Distributed Computing* 163 (2022): 283-299.
- [23] Xu, Yajing, et al. "BESIFL: Blockchain Empowered Secure and Incentive Federated Learning Paradigm in IoT." *IEEE Internet of Things Journal* (2021).

AUTHORS' PROFILE



K. Prasanna Lakshmi is working as a Professor and Dean Academics in Information Technology Department in Gokaraju Rangaraju Institute of Engineering and Technology (GRIET), Hyderabad. She received the Bachelor's Degree in Mechanical Engineering (2000), Master's Degree in Computer Science (2002) and Ph.D in Computer Science (2016) in the area of Data Stream Mining. She has total 20 years of teaching and 13+ years of research experience. She is a reviewer for various conferences, journals and books, Editorial Board Member for IGI Global Publications. Her research interests include Data Science, Artificial Intelligence, Data Stream Mining, Web Mining, Big Data Analysts, Social Networking. Published many research articles in renowned national and international journals and conferences.



K. Swapnika pursuing Ph.D in Data Mining and Information Retrieval Systems stream at Jawaharlal Nehru Technological University Hyderabad. She completed M. Tech in Software Engineering from Jawaharlal Nehru Technological University Hyderabad and has 10 years of academic experience. Her Research Interest includes Information Retrieval Systems, Deep Learning, Cloud Computing and Blockchain Technology.

Hate Speech Detection in Social Networks using Machine Learning and Deep Learning Methods

Aigerim Toktarova¹, Dariga Syrlybay², Bayan Myrzakhmetova³, Gulzat Anuarbekova⁴, Gulbarshin Rakhimbayeva⁵,
Balkiya Zhylanbaeva⁶, Nabat Suieuoova⁷, Mukhtar Kerimbekov⁸

Khoja Akhmet Yassawi International Kazakh, Turkish University, Turkistan, Kazakhstan¹
Bachelor Student, Khoja Akhmet Yassawi International Kazakh, Turkish University, Turkistan, Kazakhstan²

M. Auezov South Kazakhstan Universtiy, Shymkent, Kazakhstan¹

South Kazakhstan State Pedagogical University, Shymkent, Kazakhstan³

Abai Kazakh National Pedagogical University, Almaty, Kazakhstan⁴

Asfendiyarov Kazakh National Medical University, Almaty, Kazakhstan^{5, 6}

Yessenov University, Aktau, Kazakhstan⁷

University of Friendship of People's Academician, A. Kuatbekov, Shymkent, Kazakhstan⁸

Abstract—Hate speech on social media platforms like Twitter is a growing concern that poses challenges to maintaining a healthy online environment and fostering constructive communication. Effective detection and monitoring of hate speech are crucial for mitigating its adverse impact on individuals and communities. In this paper, we propose a comprehensive approach for hate speech detection on Twitter using both traditional machine learning and deep learning techniques. Our research encompasses a thorough comparison of these techniques to determine their effectiveness in identifying hate speech on Twitter. We construct a robust dataset, gathered from diverse sources and annotated by experts, to ensure the reliability of our models. The dataset consists of tweets labeled as hate speech, offensive language, or neutral, providing a more nuanced representation of online discourse. We evaluate the performance of LSTM, BiLSTM, and CNN models against traditional shallow learning methods to establish a baseline for comparison. Our findings reveal that deep learning techniques outperform shallow learning methods, with BiLSTM emerging as the most accurate model for hate speech detection. The BiLSTM model demonstrates improved sensitivity to context, semantic nuances, and sequential patterns in tweets, making it adept at capturing the intricate nature of hate speech. Furthermore, we explore the integration of word embeddings, such as Word2Vec and GloVe, to enhance the performance of our models. The incorporation of these embeddings significantly improves the models' ability to discern between hate speech and other forms of online communication. This paper presents a comprehensive analysis of various machine learning methods for hate speech detection on Twitter, ultimately demonstrating the superiority of deep learning techniques, particularly BiLSTM, in addressing this critical issue. Our findings pave the way for further research into advanced methods of tackling hate speech and facilitating healthier online interactions.

Keywords—Machine learning; deep learning; hate speech; social network; classification

I. INTRODUCTION

Social media platforms like Twitter have become an essential communication tool in our digital age, enabling users worldwide to share their thoughts, opinions, and experiences with a vast audience [1]. However, the rapid growth of social

media has also given rise to undesirable content, including hate speech. Hate speech is a form of communication that is offensive, malicious, and discriminatory, targeting individuals or groups based on their race, ethnicity, gender, religion, or other attributes [2]. The proliferation of hate speech on social media is a critical issue, as it fosters animosity, threatens social cohesion, and undermines the principles of free expression and respectful discourse. Consequently, the need for effective hate speech detection and monitoring tools is more significant than ever.

In recent years, machine learning techniques have emerged as a promising avenue for addressing the challenge of detecting and mitigating hate speech on social media platforms [3-4]. Machine learning algorithms, both shallow and deep, have demonstrated potential in tackling various natural language processing (NLP) tasks, such as sentiment analysis, text classification, and named entity recognition [5]. This paper aims to investigate and compare the performance of various shallow and deep learning methods in detecting hate speech on Twitter.

Machine learning methods have shown effectiveness in various applications, including spam detection, sentiment analysis, and topic modeling [6]. However, shallow learning algorithms have limitations in capturing the complex semantics and context of natural language, which may hinder their ability to identify hate speech accurately.

Deep learning techniques, on the other hand, have exhibited promising results in multiple NLP tasks due to their capacity for modeling high-level abstractions and capturing intricate language patterns [7]. LSTM and BiLSTM are recurrent neural networks (RNNs) that excel at processing sequential data, making them suitable for analyzing the temporal structure of text. CNNs, originally designed for image classification, have also demonstrated their applicability in text classification tasks by identifying local and global patterns in text through convolutional filters.

To investigate the effectiveness of shallow and deep learning methods for hate speech detection on Twitter, we first compile a diverse and representative dataset of tweets, ensuring

that the dataset encompasses a broad spectrum of online discourse [8]. The dataset is annotated by experts, who label the tweets as hate speech, offensive language, or neutral, thus providing a nuanced classification of the content. By adopting a multi-class labeling approach, we aim to capture the complexity and subtlety of hate speech more accurately.

We then apply a range of shallow learning techniques to the dataset, evaluating their performance in identifying hate speech. We also explore the integration of feature selection techniques. Establishing a baseline performance for these methods allows us to gauge the potential advantages of deep learning techniques.

Next, we implement LSTM, BiLSTM, and CNN models and evaluate their performance against the established baseline [9]. By comparing the performance of deep learning techniques with that of shallow learning methods, we aim to identify the most effective approach for hate speech detection on Twitter. In addition to comparing the overall performance of the models, we also assess their ability to handle various challenges associated with the detection of hate speech, such as understanding context, sarcasm, and semantic nuances.

To further enhance the performance of the deep learning models, we incorporate word embeddings, such as Word2Vec and GloVe, which facilitate the representation of words in a continuous vector space [10]. These embeddings capture semantic and syntactic relationships between words, thus enriching the input features for our models. By leveraging word embeddings, we aim to improve the models' ability to discern between hate speech and other forms of online communication, thereby increasing their accuracy and reducing false positives.

Our results reveal that deep learning techniques, particularly BiLSTM, outperform the shallow learning methods in detecting hate speech on Twitter [11]. BiLSTM demonstrates a superior ability to capture the intricate nature of hate speech by understanding context, semantic nuances, and sequential patterns in tweets [12]. This finding underscores the potential of deep learning techniques in addressing the challenge of hate speech detection and monitoring on social media platforms.

Thus, this paper presents a comprehensive analysis of various machine learning methods for hate speech detection on Twitter. Our findings suggest that deep learning techniques, specifically BiLSTM, hold promise for tackling this critical issue more effectively than their shallow learning counterparts. By identifying the most accurate models for hate speech detection, we contribute to the ongoing effort to develop advanced tools and strategies to combat hate speech on social media and foster healthier online interactions.

Future research directions may include the exploration of additional deep learning architectures, such as transformers, to further enhance hate speech detection performance. Moreover, investigating the impact of transfer learning and pre-trained language models, like BERT or GPT, on the performance of the models may provide valuable insights. Lastly, the development of explainable AI techniques to provide interpretable and transparent predictions in hate speech

detection can improve user trust and facilitate better decision-making in content moderation.

II. RELATED WORKS

The problem of detecting hate speech on social media platforms has been extensively studied in recent years due to its increasing prevalence and the potential harm it can inflict on individuals and communities. In this section, we provide an overview of the related works in the field of hate speech detection, focusing on both shallow and deep learning approaches.

A. Shallow Learning Approaches

Several studies have utilized logistic regression, random forest, and decision tree algorithms for hate speech detection on social media. For instance, [13] employed logistic regression for hate speech detection in online communities, using bag-of-words and paragraph2vec features. Similarly, [14] proposed a multi-class classifier using logistic regression and random forest, which demonstrated improved performance over single classifiers. Study [15] employed decision trees to detect hate speech on Twitter, highlighting the importance of feature engineering in improving model performance.

Naïve Bayes and K-NN classifiers have also been employed for hate speech detection. Like [16] used a naïve bayes classifier to detect cyber hate on Twitter, while [17] proposed a K-NN-based approach for the same task. Both studies indicated the effectiveness of these classifiers in detecting hate speech when combined with appropriate feature extraction techniques, such as bag-of-words and TF-IDF.

SVMs have been widely used for hate speech detection, with several studies demonstrating their effectiveness. For example, [18] used SVM to detect cyberbullying and hate speech on Twitter, leveraging features such as character n-grams, sentiment scores, and syntactic patterns. Similarly, [19] employed SVM for hate speech detection, demonstrating that the inclusion of linguistic and semantic features improved the model's performance.

B. Deep Learning Approaches

LSTM and BiLSTM models have been increasingly employed for hate speech detection due to their ability to capture long-range dependencies in text. The authors in [20] proposed a deep learning approach using LSTM for detecting hate speech on Twitter, demonstrating superior performance compared to shallow learning techniques. On the other hand, [21] used BiLSTM models for the same task, illustrating the effectiveness of bidirectional RNNs in capturing the context and semantics of text. Additionally, [22] used both LSTM and BiLSTM models to detect hate speech on Twitter, finding that the BiLSTM model outperformed its unidirectional counterpart.

CNNs have also been applied for hate speech detection on social media platforms. As [23] proposed a CNN-based model for detecting hate speech on Twitter, leveraging character n-grams as input features. Their approach demonstrated improved performance compared to traditional shallow learning techniques. Similarly, [24] employed a CNN-based model for hate speech detection on Twitter, illustrating the

benefits of incorporating pre-trained word embeddings such as Word2Vec and GloVe.

C. Hybrid Approaches and Ensemble Models

Some studies have explored hybrid approaches and ensemble models for hate speech detection, combining both shallow and deep learning techniques to enhance model performance. The research [25] proposed a hybrid approach that combined CNN with LSTM for detecting abusive language on Twitter, demonstrating that the integrated model outperformed standalone CNN and LSTM models. Similarly, [26] developed an ensemble model combining SVM and LSTM for hate speech detection, which achieved better performance compared to individual models.

Recent studies have highlighted the importance of using word embeddings and pre-trained language models for improving hate speech detection performance. For instance, [27] investigated the impact of using different word embeddings. Their findings revealed that the choice of word embeddings could significantly impact model performance.

The use of pre-trained language models has also been explored for hate speech detection. Like [28] proposed a BERT-based model for detecting hate speech on social media platforms, demonstrating superior performance compared to traditional machine learning techniques. Similarly, [29] employed BERT for detecting hate speech on Twitter, highlighting the model's ability to capture the complex semantics of text and adapt to various linguistic contexts.

III. PROBLEM STATEMENT

It is possible that the problem of early identification of cyberbullying on social networking sites is separate from the difficulty of classifying different types of cyberbullying. In the circumstances presented here, there is a group of social media sessions that we will refer to collectively as "S." As a result, there is the chance that some of them are instances of cyberbullying. A sequence of sessions on a social network may be described using the equation (1), which is as follows:

$$S = \{s_1, s_2, \dots, s_{|S|}\} \quad (1)$$

Where S refers to the total number of sessions, "i" indicates the current session.

The sequence in which submissions are made during a specific session is subject to change at different points in time and is governed by a variety of factors

$$P_s = \left(\langle P_1^s, t_1^s \rangle, \langle P_2^s, t_2^s \rangle, \dots, \langle P_n^s, t_n^s \rangle \right) \quad (2)$$

where the tuple P represents the kth post for the social network session and s is the timestamp of when post P was published.

At the same time, a vector of features is utilized to identify each post in a manner that is completely unique:

$$P_k^S = [f_{k_1}^S, f_{k_2}^S, \dots, f_{k_n}^S] \quad k \in [1, n] \quad (3)$$

Therefore, the objective is to acquire the knowledge necessary to develop a function f that can classify whether or not a text is related to hate speech.

IV. MATERIALS AND METHODS

A. The Proposed Framework

A representation of the model that has been built for the purpose of identifying instances of cyberbullying may be shown in Fig. 1. The following are the steps that make up this model: the preprocessing stage, the feature extraction stage, the classification stage, and the assessment stage. In this part, a significant amount of focus is placed on doing a more in-depth analysis of each stage.

B. Feature Extraction

Term frequency-inverse document frequency: In the context of the paper on hate speech detection using shallow and deep learning methods, Term Frequency-Inverse Document Frequency (TF-IDF) plays an essential role as a feature extraction technique [30].

The product of TF and IDF yields the TF-IDF score, which reflects the importance of a term within a document and across the entire corpus. A high TF-IDF score suggests that the term is significant within the document and infrequent across the corpus, making it a valuable feature for classification tasks [31].

In the context of hate speech detection, TF-IDF can be employed to transform raw text data into a structured representation that captures the relative importance of words or terms [32]. The resulting feature vectors can be used as input for various shallow learning algorithms, to develop hate speech detection models. By incorporating TF-IDF, the models can effectively distinguish between hate speech and other types of communication based on the discriminative power of specific terms.

It is important to note that, while TF-IDF has been proven effective in various text classification tasks, it may not always capture the complex semantics and context inherent in natural language [33]. In such cases, advanced feature extraction techniques, such as word embeddings or pre-trained language models, may be employed to complement or replace TF-IDF in the development of more sophisticated hate speech detection models.

Word2Vec: In the context of the paper on hate speech detection using shallow and deep learning methods, Word2Vec is a significant technique for generating word embeddings. Word2Vec is an unsupervised learning algorithm that converts words into continuous vector representations, capturing semantic and syntactic relationships between words. The technique was introduced by [34] and has since become a widely used method in natural language processing (NLP) tasks, including text classification, sentiment analysis, and machine translation.

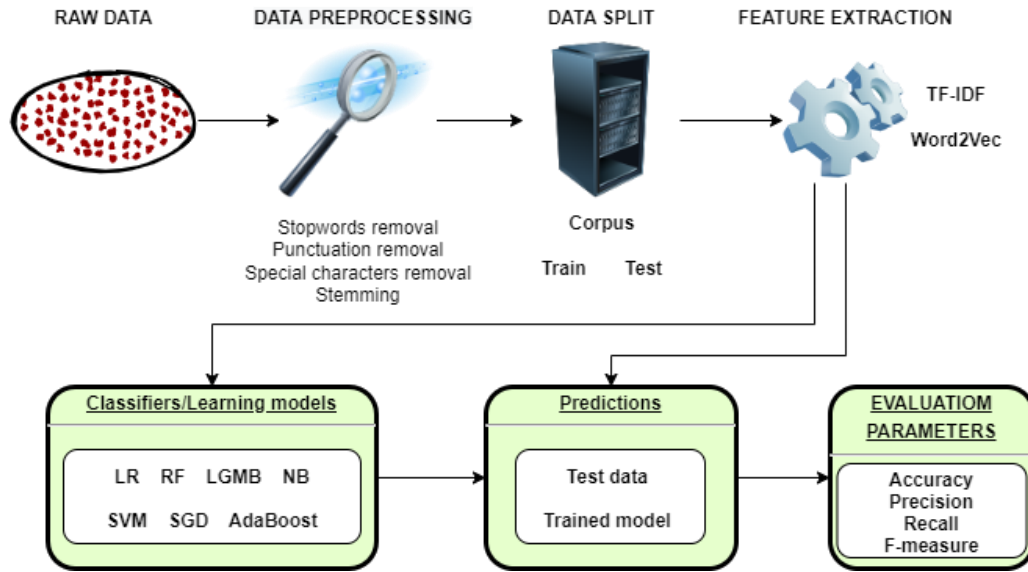


Fig. 1. Proposed framework.

In hate speech detection, Word2Vec embeddings can be employed to enrich the input features for both shallow and deep learning models [35]. By leveraging the semantic information captured in these embeddings, models can better discern between hate speech and other types of communication, resulting in improved classification performance. Word2Vec embeddings can be used in combination with other feature extraction techniques, such as TF-IDF or pre-trained language models, to further enhance the models' understanding of the complex semantics and context inherent in natural language.

In this specific piece of study, the weighting method that we make use of is the tf-idf system. For the purpose of calculating the tf-idf weight that corresponds to the i th word in the j th text, the following formula is used:

$$w_{i,j} = TF_{i,j} \times \log\left(\frac{N}{DF_i}\right) \quad (4)$$

Bag of Words: In the context of the paper on hate speech detection using shallow and deep learning methods, the Bag of Words (BoW) model serves as a fundamental text representation technique [36]. BoW is a widely used method in natural language processing (NLP) tasks, such as text classification, information retrieval, and sentiment analysis, as it provides a simple and efficient way to represent text data in a structured format.

In hate speech detection, BoW can be employed to transform raw text data into a structured representation that serves as input for various shallow learning algorithms. However, it is important to note that the BoW model lacks the ability to capture context, semantics, and word order, which may limit its effectiveness in some classification tasks. To address these limitations, more advanced feature extraction techniques, such as word embeddings (e.g., Word2Vec) or pre-trained language models, can be used in combination with or as

a replacement for the BoW model. The goal is to increase the likelihood that, given the following circumstances:

$$\arg \max_{\theta} \prod_{w \in T} \left[\prod_{c \in C} p(c | w; \theta) \right] \quad (5)$$

C. Machine Learning Methods

Decision Tree is a supervised learning algorithm that recursively splits the input space into regions based on feature values, forming a tree-like structure [37]. It is interpretable and handles non-linear relationships well. In hate speech detection, Decision Trees can be employed to make decisions based on extracted text features, such as word frequencies or presence of specific terms.

Naïve Bayes is a probabilistic classifier based on Bayes' theorem, which assumes feature independence [38]. Despite this simplifying assumption, it often performs well in text classification tasks. In hate speech detection, Naïve Bayes can be used to classify tweets by estimating the likelihood of a tweet being hate speech given the occurrence of certain words or phrases.

K-Nearest Neighbors is a non-parametric, instance-based learning algorithm that classifies instances based on the majority class of their K-nearest neighbors in the feature space [39]. In hate speech detection, K-NN can be employed to classify tweets by considering the similarity between their feature representations, such as word embeddings or TF-IDF vectors.

Support Vector Machine (SVM) is a supervised learning algorithm that aims to find the optimal hyperplane separating different classes in the feature space [40]. It is effective in handling high-dimensional data and can be used with various kernel functions. In the context of hate speech detection, SVM can be employed to classify tweets by learning the decision boundary based on the extracted features, such as word frequencies, n-grams, or sentiment scores.

D. Deep Learning Methods

1) *LSTM (Long Short-Term Memory)*: LSTM is a type of recurrent neural network (RNN) specifically designed to address the vanishing gradient problem common in standard RNNs [41]. LSTM networks have memory cells that can store information over long sequences, allowing them to capture long-range dependencies and context within text data. In the context of hate speech detection, LSTM models can be employed to process tweets as sequences of words or characters, enabling them to capture temporal patterns and dependencies that are crucial for understanding the semantics and intent of the text. By using LSTM networks, classification models can better distinguish between hate speech and non-hate speech based on the contextual information present in the tweets. Fig. 2 demonstrates architecture of LSTM network.

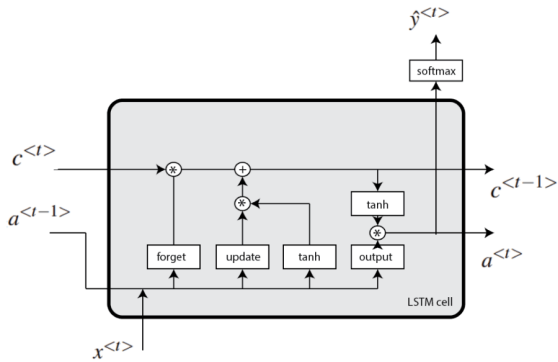


Fig. 2. LSTM network.

2) *BiLSTM (Bidirectional Long Short-Term Memory)*: BiLSTM is an extension of LSTM that processes the input data in both forward and backward directions, enabling it to capture both past and future context [42]. In the context of hate speech detection, BiLSTM models can process tweets in a bidirectional manner, capturing the context and dependencies present in the text more effectively. This improved contextual understanding leads to better classification performance compared to unidirectional LSTM models. BiLSTM networks can be combined with other deep learning architectures, such as convolutional neural networks (CNN), to further enhance the model's ability to capture both local and global contextual information in the text. Fig. 3 demonstrates architecture of BiLSTM network.

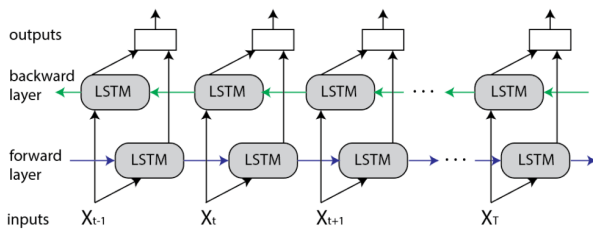


Fig. 3. BiLSTM network.

3) *CNN (Convolutional Neural Network)*: CNN is a deep learning architecture traditionally used for image processing

tasks but has also demonstrated effectiveness in various NLP tasks, including text classification [43]. CNNs employ convolutional layers to learn local patterns within input data through the application of filters or kernels. In the context of hate speech detection, CNN models can be used to process tweets by treating them as one-dimensional sequences of words or characters. These models can learn local patterns, such as n-grams or specific phrases that are indicative of hate speech. By combining CNNs with other deep learning architectures, such as LSTM or BiLSTM, models can capture both local patterns and long-range dependencies, leading to improved classification performance in hate speech detection tasks. Fig. 4 demonstrates architecture of the convolutional neural network.

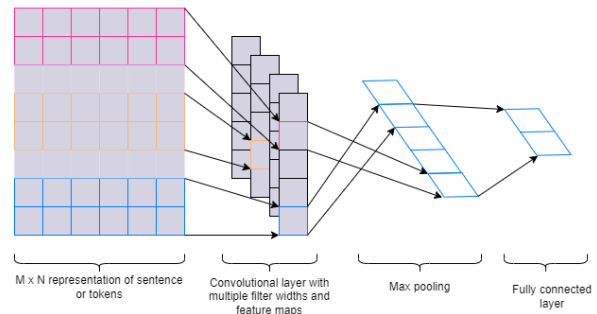


Fig. 4. CNN architecture.

V. EXPERIMENTAL SETUP

A. Evaluation Parameters

1) *Accuracy*: Accuracy is a common metric used to evaluate the performance of classification models. It is calculated as the ratio of the number of correct predictions to the total number of predictions [44]. Although accuracy provides a general overview of a model's performance, it may not be suitable for imbalanced datasets, where one class dominates the other(s), as it can yield misleading results.

$$accuracy = \frac{TP + TN}{P + N} \quad (6)$$

2) *Precision*: Precision is a metric that evaluates the proportion of true positive predictions among all positive predictions made by a classification model [45]. It is particularly useful for assessing the performance of models when the cost of false positives is high, such as in spam detection or medical diagnosis.

$$precision = \frac{TP}{TP + FP} \quad (7)$$

3) *Recall*: Recall, also known as sensitivity or true positive rate, measures the proportion of true positive predictions among all actual positive instances in the dataset [46]. Recall is crucial in situations where the cost of false negatives is high, such as in fraud detection or cancer diagnosis.

$$recall = \frac{TP}{TP + FN} \quad (8)$$

4) *F-score*: F-score, or F1-score, is the harmonic mean of precision and recall, and provides a balanced measure of a model's performance when both false positives and false negatives are important. The F-score ranges from 0 to 1, where a higher value indicates better performance [47]. It is particularly useful for evaluating models on imbalanced datasets, where accuracy may be misleading.

$$F1 = \frac{2 \times precision \times recall}{precision + recall} \quad (9)$$

5) *ROC curve*: The Receiver Operating Characteristic (ROC) curve is a graphical representation of a classifier's performance, plotting the true positive rate (recall) against the false positive rate for various decision thresholds. The area under the ROC curve (AUC-ROC) is a scalar measure of a model's performance, with a higher value (closer to 1) indicating better classification [48]. The ROC curve and AUC-ROC are especially useful for comparing different models and selecting the optimal decision threshold.

B. Experimental Results

Accuracy, Precision, Recall, F-measure, and Area under a Receiver Operating Characteristic (AUC-ROC) are all terms that are used in the field of cyberbullying detection research. The confusion matrices for each of the techniques used in this work and evaluated in the cyberbullying classification dataset are shown in Fig. 5. We are able to clearly show the actual amount of classification results in respect to other classes by using confusion matrices. In the research that we conducted, we found that there are three different classes: cyberbullying, which was given the score of 1, non-cyberbullying, which was given the score of 0, and neutral class, which was given the score of 2.

In Fig. 6, a comparison is made between the model that was suggested and all of the other machine learning and deep learning models that were used. The AUC performance evaluation in each classification is done by finding the area under the receiver operating characteristic curve that includes all extracted attributes. The AUC-ROC curves of all of the strategies that have been implemented as well as the suggested method are compared in Fig. 7. As has been pointed out, deep learning models have been shown to be more valuable than machine learning approaches. According to the figure, the suggested model, which consists of BiLSTM, displays the best AUC-ROC value from the very first iteration and all the way along the graph.

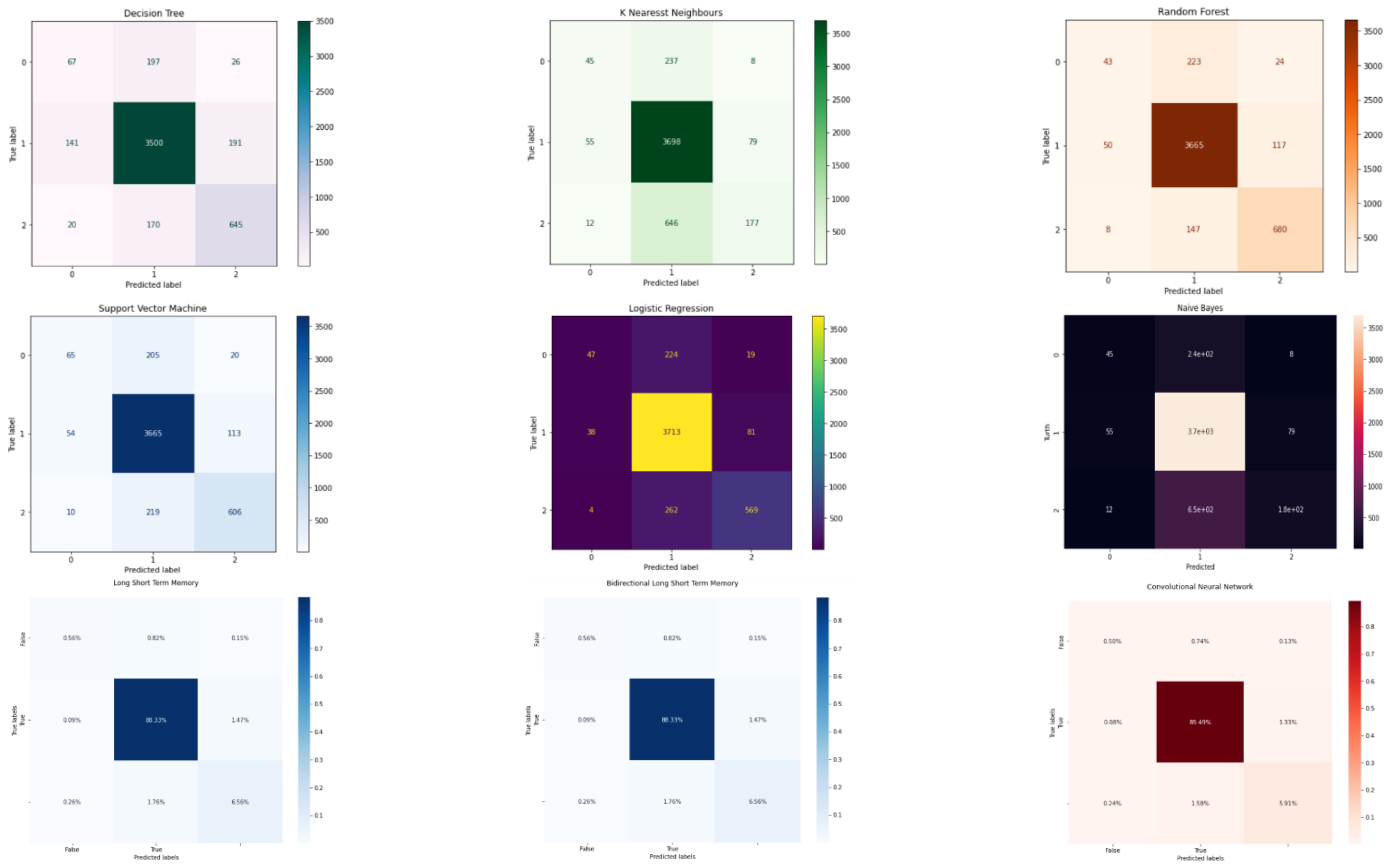


Fig. 5. Confusion matrices for hate speech detection.

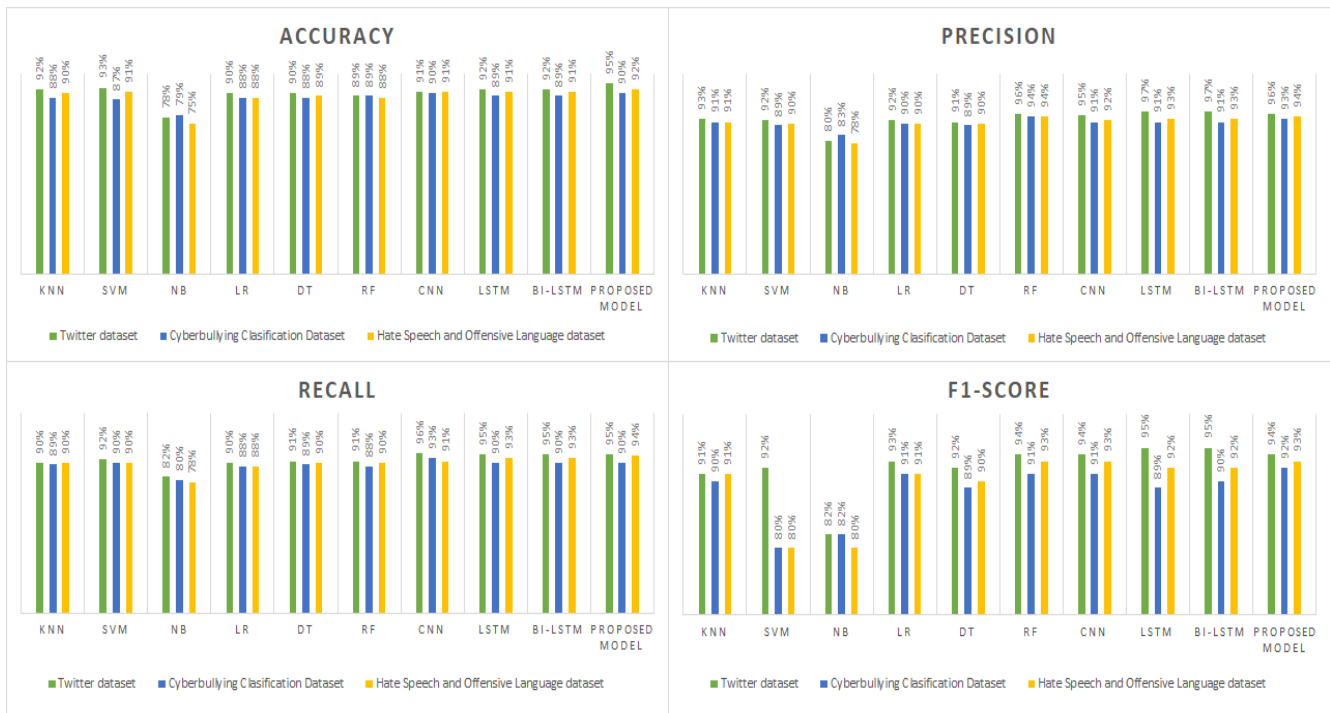


Fig. 6. Evaluation parameters for different datasets.

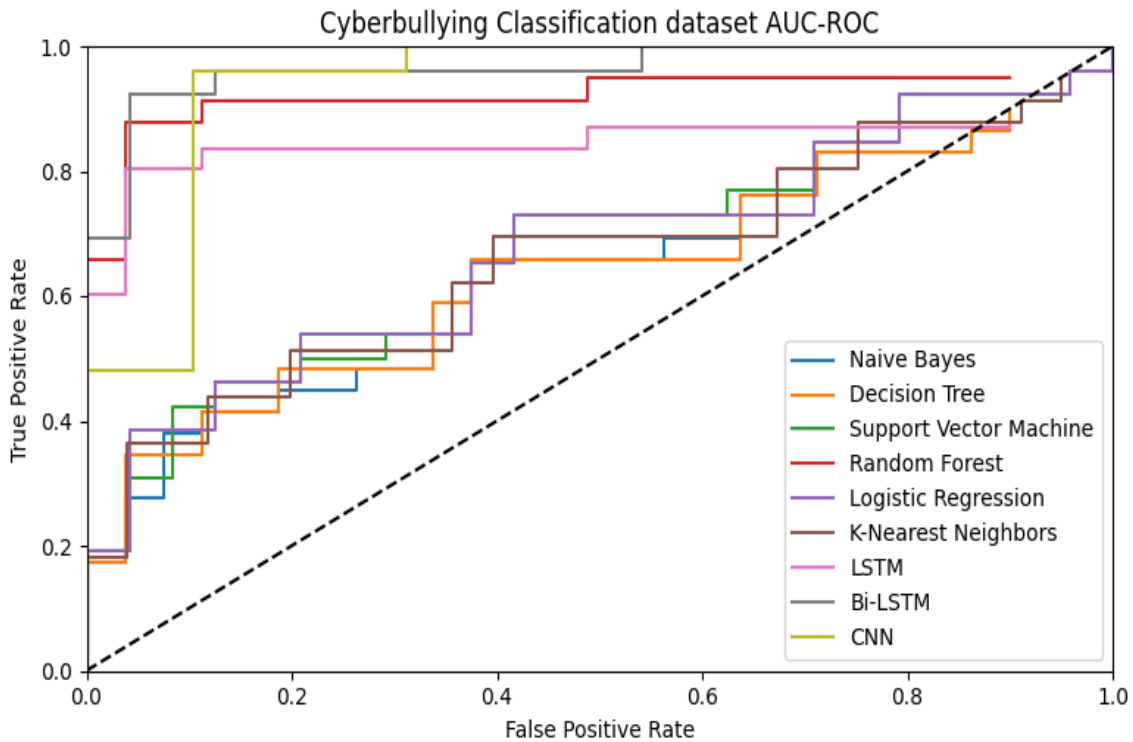


Fig. 7. ROC curve of applied machine learning and deep learning techniques for hate speech detection.

The categorization findings of cyberbullying are shown in Table I below. These results were achieved by using machine learning and deep learning techniques to three different

datasets. We employed assessment measures such as accuracy, precision, and recall, and F1-score [48-51] to evaluate the approaches of machine learning and deep learning.

TABLE I. COMPARISON OF THE OBTAINED RESULTS

Dataset	Approach	Model	Accuracy	Precision	Recall	F-score	ROC
Hate Speech and Offensive Language	Machine Learning Models	SVM	0.873	0.852	0.862	0.851	0.78
		KNN	0.856	0.839	0.831	0.837	0.92
		NB	0.874	0.832	0.863	0.851	0.80
		DT	0.602	0.524	0.585	0.642	0.65
		RF	0.851	0.854	0.822	0.856	0.77
		LR	0.862	0.853	0.837	0.858	0.78
	Deep Learning Models	CNN	0.892	0.895	0.898	0.896	0.93
		LSTM	0.901	0.896	0.91	0.898	0.93
		BiLSTM	0.902	0.916	0.904	0.899	0.94
Twitter Hate Speech	Machine Learning Models	SVM	0.873	0.852	0.862	0.851	0.75
		KNN	0.856	0.839	0.831	0.837	0.90
		NB	0.874	0.832	0.863	0.851	0.76
		DT	0.602	0.524	0.585	0.642	0.68
		RF	0.851	0.854	0.822	0.856	0.77
		LR	0.862	0.853	0.837	0.858	0.78
	Deep Learning Models	CNN	0.892	0.895	0.898	0.896	0.92
		LSTM	0.901	0.896	0.91	0.898	0.92
		BiLSTM	0.902	0.916	0.904	0.899	0.93
Cyberbullying	Machine Learning Models	SVM	0.873	0.852	0.862	0.851	0.75
		KNN	0.856	0.839	0.831	0.837	0.80
		NB	0.874	0.832	0.863	0.851	0.79
		DT	0.602	0.524	0.585	0.642	0.67
		RF	0.851	0.854	0.822	0.856	0.78
		LR	0.862	0.853	0.837	0.858	0.78
	Deep Learning Models	CNN	0.892	0.895	0.898	0.896	0.91
		LSTM	0.901	0.896	0.92	0.898	0.91
		BiLSTM	0.902	0.916	0.904	0.899	0.93

As a consequence of this, taking into consideration the success rates it has achieved, the suggested strategy may be accepted as a possible method for identifying instances of cyberbullying inside social networking sites. In addition, taking into account all of the criteria used for assessment, the deep neural network that was presented had the greatest performance when it comes to identifying cases of cyberbullying. The usage of the suggested deep neural network for modifying the weights and biases, in addition to a reduction in the amount of time spent training, resulted in favorable outcomes, which can be ascribed to the employment of the proposed technique. The results indicate that the suggested technique using deep neural networks may easily be modified to handle both short and lengthy texts as they are currently used.

VI. DISCUSSION

In this section, we will discuss the advantages, disadvantages, open issues, challenges, and future perspectives of the methods explored in this paper for hate speech detection in Twitter.

A. Advantages of Computational Intelligence in Hate Speech Detection

Shallow learning methods, such as logistic regression, random forest, decision tree, naïve bayes, K-NN, and SVM, offer several benefits, including simplicity, interpretability, and

computational efficiency. These algorithms can perform well on relatively small datasets and are less prone to overfitting compared to deep learning methods.

Deep learning methods, such as LSTM, BiLSTM, and CNN, have the ability to capture complex patterns and long-range dependencies in text data. These methods can learn hierarchical representations of the data, leading to improved classification performance in many NLP tasks, including hate speech detection.

Feature extraction techniques, such as Bag of Words, TF-IDF, and Word2Vec, allow for the transformation of raw text data into structured representations suitable for input to various classifiers. These techniques can capture different aspects of text data, such as word frequencies, term importance, and semantic relationships, providing valuable information for classification tasks.

B. Disadvantages of Computational Intelligence in Hate Speech Detection

Shallow learning methods may struggle to capture complex patterns and long-range dependencies in text data, which can lead to suboptimal classification performance in some cases.

Deep learning methods, despite their ability to capture complex patterns, may suffer from overfitting and require large amounts of labeled data for effective training. Additionally,

these models can be computationally expensive and less interpretable than shallow learning methods.

Feature extraction techniques, while providing valuable information for classification tasks, may not always capture the nuanced semantics and context present in natural language. This limitation can lead to misclassifications, particularly in complex tasks such as hate speech detection.

C. Open Issues and Challenges of Computational Intelligence in Hate Speech Detection

The development of robust and accurate classifiers for hate speech detection remains an open issue, as the nature of hate speech is constantly evolving. New forms of hate speech, including code words, slang, or non-textual elements (e.g., images or emojis), may not be effectively captured by existing models and feature extraction techniques.

The presence of imbalanced datasets, where the number of instances of one class significantly outweighs the other(s), is a common challenge in hate speech detection. Traditional performance metrics, such as accuracy, may be misleading in these situations, and alternative metrics or approaches (e.g., F-score, oversampling, or undersampling) may be necessary for effective model evaluation.

The issue of false positives and false negatives in hate speech detection presents a significant challenge, as the consequences of these misclassifications can be severe, leading to the suppression of free speech or the perpetuation of harmful content. Developing models that strike a balance between precision and recall remains a critical task.

D. Future Perspectives of Computational Intelligence in Hate Speech Detection

Investigating the integration of other deep learning architectures, such as transformers or attention mechanisms, may further enhance the models' ability to capture complex semantics and context, leading to improved classification performance.

The use of pre-trained language models, such as BERT or GPT, can be explored for their potential to leverage large-scale, pre-existing knowledge of language structure and semantics, leading to more accurate and robust hate speech detection systems.

Developing methods for effectively handling imbalanced datasets, such as advanced sampling techniques, cost-sensitive learning, or ensemble methods, may lead to improved model performance and more accurate classification of hate speech.

Exploring techniques for incorporating non-textual elements, such as images or emojis, into hate speech detection models can help address the evolving nature of hate speech and improve the overall effectiveness of classification systems.

Investigating methods for enhancing the interpretability of deep learning models, such as attention mechanisms or explainable AI techniques, can provide valuable insights into the decision-making process of these models, improving trust and adoption in real-world applications.

Collaborating with domain experts, such as sociologists or psychologists, can help in developing a more comprehensive understanding of the complex and evolving nature of hate speech. This interdisciplinary approach can lead to the development of more effective and contextually-aware classification models.

Exploring the potential of transfer learning and domain adaptation techniques can help in developing models that can be effectively applied to different languages, regions, or platforms, broadening the impact and applicability of hate speech detection systems.

In conclusion, the methods and techniques presented in this paper provide a foundation for the development of advanced, robust, and accurate hate speech detection systems. By addressing the open issues and challenges, and considering future perspectives, researchers can contribute to the ongoing effort to create a safer and more inclusive online environment on platforms like Twitter. The lessons learned from these investigations can also be applied to other social media platforms and domains, where hate speech and harmful content pose significant challenges to users and society at large.

VII. CONCLUSION

In conclusion, this paper has presented a comprehensive study of various shallow and deep learning methods for detecting hate speech on Twitter. Shallow learning algorithms, including logistic regression, random forest, decision tree, naïve bayes, K-NN, and SVM, have been explored as effective classifiers for identifying hate speech based on features extracted from text data, such as Bag of Words, TF-IDF, or word embeddings. Additionally, deep learning methods, such as LSTM, BiLSTM, and CNN, have been investigated for their ability to capture complex patterns and long-range dependencies in text, resulting in improved classification performance.

The paper has also discussed the importance of feature extraction techniques in transforming raw text data into structured representations that can be used as input for various classifiers. Techniques like Bag of Words, TF-IDF, and Word2Vec have been highlighted for their ability to capture different aspects of text data, including word frequencies, term importance, and semantic relationships.

In evaluating the performance of the various classifiers, metrics such as accuracy, precision, recall, F-score, and ROC curve have been employed to provide a comprehensive understanding of the models' effectiveness in detecting hate speech. These metrics are crucial in assessing the trade-offs between different models and selecting the most suitable approach for a particular task.

Future research in hate speech detection can explore the integration of other deep learning architectures, such as transformers or attention mechanisms, to further enhance the models' ability to capture complex semantics and context. Moreover, the use of pre-trained language models, such as BERT or GPT, can be investigated for their potential to improve classification performance by leveraging large-scale, pre-existing knowledge of language structure and semantics.

Ultimately, the detection of hate speech on social media platforms like Twitter is of paramount importance in fostering a safe and inclusive online environment. The methods and techniques presented in this paper provide valuable insights and serve as a foundation for the development of advanced, robust, and accurate hate speech detection systems.

REFERENCES

- [1] T. Alsubait and D. Alfageh, "Comparison of machine learning techniques for cyberbullying detection on youtube arabic comments," *International Journal of Computer Science and Network Security*, vol. 21, no. 1, pp. 1–5, 2021.
- [2] A. Dewani, M. Memon and S. Bhatti, "Cyberbullying detection: Advanced preprocessing techniques & deep learning architecture for roman urdu data," *Journal of Big Data*, vol. 8, no. 1, pp. 1–20, 2021.
- [3] D. Hall, Y. Silva, Y. Wheeler, L. Cheng and K. Baumel, "Harnessing the power of interdisciplinary research with psychology-informed cyberbullying detection models," *International Journal of Bullying Prevention*, vol. 4, no.1, pp. 47–54, 2021.
- [4] K. Arce-Ruelas, "Automatic cyberbullying detection: A Mexican case in high school and Higher Education Students," *IEEE Latin America Transactions*, vol. 20, no. 5, pp. 770–779, 2022.
- [5] T. Ahmed, M. Rahman, S. Nur, A. Islam and D. Das, "Natural language processing and machine learning based cyberbullying detection for Bangla and romanized bangla texts," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 20, no. 1 pp. 89–97, 2021.
- [6] B. Omarov, A. Tursynova, O. Postolache, K. Gamry, A. Batorybekov et al., "Modified UNet model for brain stroke lesion segmentation on computed tomography images," *CMC-Computers, Materials & Continua*, vol. 71, no. 3, pp. 4701–4717, 2022.
- [7] A. Al-Marghilani, "Artificial intelligence-enabled cyberbullying-free online social networks in smart cities," *International Journal of Computational Intelligence Systems*, vol. 15, no. 1, pp. 1–13, 2022.
- [8] C. Theng, N. Othman, R. Abdullah, S. Anawar, Z. Ayop et al., "Cyberbullying detection in twitter using sentiment analysis," *International Journal of Computer Science & Network Security*, vol. 21, no. 11, pp. 1-10, 2021.
- [9] S. Sadiq, A. Mehmood, S. Ullah, M. Ahmad, G. Choi et al., "Aggression detection through deep neural model on twitter," *Future Generation Computer Systems*, vol. 114, no. 1, pp. 120–129, 2021.
- [10] E. Sarac Essiz and M. Oturakci, "Artificial bee colony-based feature selection algorithm for cyberbullying," *The Computer Journal*, vol. 64, no. 3, pp. 305–313, 2021.
- [11] C. E. Gomez, M. O. Sztainberg and R. E. Trana, "Curating cyberbullying datasets: a human-AI collaborative approach," *International journal of bullying prevention*, vol. 4, no. 1, pp. 35-46, 2022.
- [12] S. Salawu, J. Lumsden and Y. He, "A mobile-based system for preventing online abuse and cyberbullying," *International Journal of Bullying Prevention*, vol. 4, no. 1, pp. 66–88, 2022.
- [13] M. Mladenović, V. Ošmjanski and S. V. Stanković, "Cyber-aggression, cyberbullying, and cyber-grooming: a survey and research challenges," *ACM Computing Surveys (CSUR)*, vol. 54, no.1, pp. 1–42, 2021.
- [14] S. R. Sangwan and M. P. S. Bhatia, "Denigrate comment detection in low-resource Hindi language using attention-based residual networks," *Transactions on Asian and Low-Resource Language Information Processing*, vol. 21, no. 1, pp. 1–14, 2021.
- [15] T. T. Aurpa, R. Sadik and M. S. Ahmed, "Abusive Bangla comments detection on Facebook using transformer-based deep learning models," *Social Network Analysis and Mining*, vol. 12, no.1, pp. 1–14, 2022.
- [16] R. Yan, Y. Li, D. Li, Y. Wang, Y. Zhu et al., "A Stochastic Algorithm Based on Reverse Sampling Technique to Fight Against the Cyberbullying," *ACM Transactions on Knowledge Discovery from Data (TKDD)*, vol. 15, no. 4, pp. 1–22, 2021.
- [17] C. J. Yin, Z. Ayop, S. Anawar, N. F. Othman and N. M. Zainudin, "Slangs and Short forms of Malay Twitter Sentiment Analysis using Supervised Machine Learning," *International Journal of Computer Science & Network Security*, vol. 21, no. 11, pp. 294–300, 2021.
- [18] G. Jacobs, C. Van Hee and V. Hoste, "Automatic classification of participant roles in cyberbullying: Can we detect victims, bullies, and bystanders in social media text?," *Natural Language Engineering*, vol. 28, no. 2, pp. 141–166, 2022.
- [19] A. Jevremovic, M. Veinovic, M. Cabarkapa, M. Krstic, I. Chorbev et al., "Keeping Children Safe Online With Limited Resources: Analyzing What is Seen and Heard," *IEEE Access*, vol. 9, no. 1, pp. 132723–132732, 2021.
- [20] K. Kumari, J. P. Singh, Y. K. Dwivedi and N. P. Rana, "Multi-modal aggression identification using convolutional neural network and binary particle swarm optimization," *Future Generation Computer Systems*, vol. 118, no. 1, pp. 187–197, 2021.
- [21] A. M. Abbas, "Social network analysis using deep learning: applications and schemes," *Social Network Analysis and Mining*, vol.11, no. 1, pp. 1–21, 2021.
- [22] S. Gupta, N. Mohan, P. Nayak, K. C. Nagaraju and M. Karanam, "Deep vision-based surveillance system to prevent train–elephant collisions," *Soft Computing*, vol. 26, no. 8, pp. 4005–4018, 2022.
- [23] S. Mohammed, W. C. Fang, A. E. Hassanien and T. H. Kim, "Advanced Data Mining Tools and Methods for Social Computing," *The Computer Journal*, vol. 64, no. 3, pp. 281–285, 2021.
- [24] B. Thuraisingham, "Trustworthy Machine Learning," *IEEE Intelligent Systems*, vol. 37, no.1, pp. 21–24, 2022.
- [25] V. Rupapara, F. Rustam, H. Shahzad, A. Mehmood, I. Ashraf et al., "Impact of SMOTE on imbalanced text features for toxic comments classification using RVVC model," *IEEE Access*, vol. 9, no. 1, pp. 78621–78634, 2021.
- [26] O. Sharif and M. M. Hoque, "Tackling cyber-aggression: Identification and fine-grained categorization of aggressive texts on social media using weighted ensemble of transformers," *Neurocomputing*, vol. 490, no. 1, pp. 462–481, 2022.
- [27] K. Kumari, J. P. Singh, Y. K. Dwivedi and N. P. Rana, "Bilingual Cyber-aggression detection on social media using LSTM autoencoder," *Soft Computing*, vol. 25, no. 14, pp. 8999–9012, 2021.
- [28] A. Mohamed, E. Amer, N. Eldin, M. Hossam, N. Elmasry et al., "The Impact of Data processing and Ensemble on Breast Cancer Detection Using Deep Learning," *Journal of Computing and Communication*, vol. 1, no.1, pp. 27–37, 2022.
- [29] A. Sheth, V. L. Shalin and U. Kursuncu, "Defining and detecting toxicity on social media: context and knowledge are key," *Neurocomputing*, vol. 490, no. 1, pp. 312–318, 2022.
- [30] U. Kursuncu, H. Purohit, N. Agarwal and A. Sheth, "When the bad is good and the good is bad: Understanding cyber social health through online behavioral change," *IEEE Internet Computing*, vol. 25, no.1, pp. 6–11, 2021.
- [31] A. M. Veiga Simão, P. Costa Ferreira, N. Pereira, S. Oliveira, P. Paulino et al., "Prosociality in cyberspace: Developing emotion and behavioral regulation to decrease aggressive communication," *Cognitive Computation*, vol. 13, no. 3, pp. 736–750, 2021.
- [32] G. Isaza, F. Muñoz, L. Castillo and F. Buitrago, "Classifying cybergrooming for child online protection using hybrid machine learning model," *Neurocomputing*, vol. 484, no. 1, pp. 250–259, 2022.
- [33] L. Cuoghi and L. Konopelko, "Cyberbullying Classification," [Online]. Available <https://www.kaggle.com/datasets/andrewmvd/cyberbullying-classification> (accessed on 25 June 2022). 2022.
- [34] D. Bruwaene, Q. Huang and D. Inkpen, "A multi-platform dataset for detecting cyberbullying in social media," [Online]. Available <https://dl.acm.org/doi/abs/10.1007/s10579-020-09488-3> (accessed on 25 June 2022). 2022.
- [35] A. Samoshyn, "Hate Speech and Offensive Language Dataset," [Online]. Available <https://www.kaggle.com/datasets/mrmorj/hate-speech-and-offensive-language-dataset> (accessed on 25 June 2022). 2020.
- [36] G. Perasso, N. Carone and L. Barone. "Written and visual cyberbullying victimization in adolescence: Shared and unique associated factors,"

- European Journal of Developmental Psychology, vol. 18, no. 5, pp. 658–677, 2021.
- [37] M. Amjad, N. Ashraf, A. Zhila, G. Sidorov, A. Zubiaga et al., “Threatening Language Detection and Target Identification in Urdu Tweets,” *IEEE Access*, vol. 9, no. 1, pp. 128302–128313, 2021.
- [38] Ö. Çoban, S. A. Özel and A. İnan, “Deep Learning-based Sentiment Analysis of Facebook Data: The Case of Turkish Users,” *The Computer Journal*, vol. 64, no. 3, pp. 473–499, 2021.
- [39] B. Omarov, N. Saparkhojayev, S. Shekerbekova, O. Akhmetova, M. Sakypbekova et al., “Artificial intelligence in medicine: Real time electronic stethoscope for heart diseases detection,” *CMC-Computers, Materials & Continua*, vol. 70, no. 2, pp. 2815–2833, 2022.
- [40] P. Parikh, H. Abburi, N. Chhaya, M. Gupta and V. Varma, “Categorizing Sexism and Misogyny through Neural Approaches,” *ACM Transactions on the Web (TWEB)*, vol. 15, no.4, pp. 1–31, 2021.
- [41] S. Kiritchenko, I. Nejadgholi and K. C. Fraser, “Confronting abusive language online: A survey from the ethical and human rights perspective,” *Journal of Artificial Intelligence Research*, vol. 71, no. 1, pp. 431–478, 2021.
- [42] J. A. García-Díaz, M. Cánovas-García, R. Colomo-Palacios and R. Valencia-García, “Detecting misogyny in Spanish tweets. An approach based on linguistics features and word embeddings,” *Future Generation Computer Systems*, vol. 114, no. 1, pp. 506–518, 2021.
- [43] A. Tontodimamma, E. Nissi, A. Sarra and L. Fontanella, “Thirty years of research into hate speech: topics of interest and their evolution,” *Scientometrics*, vol. 126, no.1, pp. 157–179, 2021.
- [44] X. Chen, H. Xie, G. Cheng and Z. Li, “A decade of sentic computing: topic modeling and bibliometric analysis,” *Cognitive Computation*, vol. 14, no.1, pp. 24–47, 2022.
- [45] A. S. Srinath, , H. Johnson, G. G. Dagher and M. Long, “BullyNet: Unmasking Cyberbullies on Social Networks,” *IEEE Transactions on Computational Social Systems*, vol. 8, no.2, pp. 332–344, 2021.
- [46] C. Kumar, T. S. Bharati and S. Prakash, “Online social network security: A comparative review using machine learning and deep learning,” *Neural Processing Letters*, vol. 53, no. 1, pp. 843–861, 2021.
- [47] M. Zhu, A. H. Anwar, Z. Wan, J. H. Cho, C. A. Kamhoua et al., “A survey of defensive deception: Approaches using game theory and machine learning,” *IEEE Communications Surveys & Tutorials*, vol. 23, no. 4, pp. 2460–2493, 2021.
- [48] H. Sun and R. Grishman, “Employing lexicalized dependency paths for active learning of relation extraction,” *Intelligent Automation & Soft Computing*, vol. 34, no. 3, pp. 1415–1423, 2022.
- [49] Altayeva, A., Omarov, B., & Im Cho, Y. (2018, January). Towards smart city platform intelligence: PI decoupling math model for temperature and humidity control. In 2018 IEEE International Conference on Big Data and Smart Computing (BigComp) (pp. 693-696). IEEE.
- [50] F. Bozyiğit, O. Doğan and D. Kiliç, “Categorization of Customer Complaints in Food Industry Using Machine Learning Approaches,” *Journal of Intelligent Systems: Theory and Applications*, vol. 5, no. 1, pp. 85–91, 2022.
- [51] B. Omarov, S. Narynov, Z. Zhumanov, A. Gumar and M. Khassanova, “A skeleton-based approach for campus violence detection,” *Computers, Materials & Continua*, vol. 72, no.1, pp. 315–331, 2022.

New Arabic Root Extraction Algorithm

Nisrean Jaber Thalji¹, Emran Aljarrah², Roqia Rateb³, Amaal Rateb Mohammad Al-Shorman⁴

Department of Artificial Intelligence and Robotics-Faculty of Science and Information Technology, Jadara University, Irbed, Jordan¹

Department of Internet of Things-Faculty of Science and Information Technology, Jadara University, Irbed, Jordan^{2,4}

Department of Computer Science-Faculty of Science and Information Technology, Jadara University, Irbed, Jordan³

Abstract—This research presents a new algorithm for Arabic root extraction, which aims to improve the accuracy of Arabic Natural Language Processing Algorithms by addressing the weaknesses and errors of existing algorithms. The proposed algorithm utilizes a database, that includes a collection of roots, patterns, and affixes, to generate potential derivation roots of a word without eliminating affixes initially. By matching the derived word with patterns to identify potential roots, the proposed algorithm avoids the inaccuracies caused by eliminating affixes based on expectation methods. The study conducted a comparison of the proposed algorithm with three commonly used Arabic root extraction algorithms. The evaluation process is performed on three corpora. Results showed that the proposed algorithm achieved an average accuracy rate of 96%, which is significantly higher than the others.

Keywords—Natural language processing; Arabic root extraction algorithm; Arabic applications; Arabic morphology; Text mining

I. INTRODUCTION

Arabic is a Semitic language with a rich history and culture, and it is spoken by over 420 million people worldwide. The Arabic language is characterized by a unique system of roots, where most words are derived from a three-letter root [1]. Therefore, the ability to accurately extract roots from Arabic words is crucial for understanding the language, conducting research, and developing natural language processing algorithms [2].

In recent years, there has been a growing interest in developing Arabic root extraction algorithms, particularly those based on datasets and rules. These algorithms rely on linguistic rules and datasets to extract the root of a given Arabic word. They have proven to be effective in extracting roots from a variety of Arabic texts, including classical literature, modern newspapers, and social media [3]. The importance of Arabic root extraction algorithms lies in their ability to improve natural languages processing tasks such as machine translation, text classification, and sentiment analysis. These algorithms also play a critical role in the development of Arabic language technologies, including spell checkers, search engines, and speech recognition systems [4]. Despite the challenges posed by the complexity of the Arabic language and its various dialects, researchers continue to explore new techniques and methods for Arabic root extraction. The development of these algorithms is essential for advancing the field of Arabic natural language processing and enhancing our understanding of the language [5].

To effectively extract the root from Arabic words, it is crucial to understand the fundamental concepts of root extraction in Arabic, which include roots, affixes, patterns, and derived words [6]. Until now, not all of the root words and affixes in the Arabic language have been identified. While Arabic scholars have discovered a significant number of them, there is still a need to uncover the remaining ones in order to obtain more precise outcomes when extracting the roots of Arabic words. Thalji et al. [7] have released an Arabic corpus containing 12,000 roots, 430 prefixes, 320 suffixes, 4,320 patterns, and 720,000 word-root pairs. One of the objectives of this paper is to thoroughly comprehend and examine the given corpus, and to extract significant information that can aid in the extraction of Arabic language roots.

This research introduces a new algorithm for Arabic root extraction in Natural Language Processing (NLP). The algorithm utilizes a database and pattern matching techniques to generate potential derivation roots without eliminating affixes initially, resulting in improved accuracy compared to existing algorithms. The evaluation conducted on three corpora demonstrates an average accuracy rate of 96%, highlighting the algorithm effectiveness in accurately extracting roots from Arabic words. This contribution has significant implications for Arabic NLP applications, enhancing the performance and reliability of tasks such as information retrieval, machine translation, and sentiment analysis. Overall, the paper presents a valuable addition to the field of Arabic language processing, advancing the accuracy and reliability of Arabic root extraction in NLP.

II. LITERATURE REVIEW

The literature review summarizes current techniques used in Arabic root extraction, highlighting their strengths and weaknesses, with the goal of identifying gaps in current approaches and proposing areas for future research.

Alfredaghi and Al-Anzi [8] propose a data-base-oriented method for identifying Arabic roots using patterns and root lists. The method is efficient and does not require individual word analysis, but has some limitations such as only returning one root when multiple patterns match, and a relatively short list of patterns.

Al-Serhan et al. [9] propose a statistical approach for extracting Arabic roots based on assigning weights to letters and using mathematical equations. The approach is efficient and doesn't require word analysis, but has limitations such as difficulty in handling the complexities of the Arabic language, and may not provide as accurate results as rule-based

approaches. Additionally, the lack of a clear explanation for root extraction makes it challenging to understand and improve the algorithm.

The Khoja and Garside algorithm [10] is a widely used rule-based approach to Arabic stemming that identifies and removes prefixes and suffixes from Arabic words to produce their root form. It follows a set of rules based on Arabic morphology to identify the prefixes and suffixes that can be stripped from a word to obtain its root. The algorithm is effective but has some limitations, such as mistakenly removing common prefixes and suffixes that are actually part of the root letters, missing certain rules, and providing only one solution for non-vocalized words.

Taghva, Elkhoury, and Coombs [11] developed a rule-based algorithm to extract roots, which aimed to improve Khoja and Garside's algorithm [10] by eliminating the need for a root list. The algorithm did not require a root list, which made the root extraction process faster, but it had limitations, such as ambiguity in affixes, providing only one solution for non-vocalized words, returning meaningless roots, and sometimes failing to extract roots for derived words that contain the "ابدال" rule. Cross-checking with the root list was necessary to minimize the number of erroneous roots.

Ghwanmeh et al. [12] developed a rule-based algorithm to extract the trilateral, quadrilateral, and pentaliteral roots of Arabic words. The algorithm removes affixes and matches the remaining word against a list of patterns. The algorithm still missed many roots, prefixes, suffixes, and patterns. It also faced challenges in dealing with affixes ambiguity problems and returned only one solution for non-vocalized words.

Alkabi [13] proposed a new algorithm for Arabic root extraction to improve the accuracy of Khoja and Garside's algorithm [10]. The new algorithm used additional patterns to supplement Khoja and Garside's patterns and was tested on MSA textual documents from Arabic newspapers websites. The results showed an increase in the accuracy of Khoja and Garside's algorithm from 71% to 76%. The study concluded that expanding the number of patterns can enhance the accuracy of root extraction algorithms.

The Word Substring Stemming Algorithm (WSS), proposed by Yaseen and Hmeidi [14], generates all possible substrings of a word and matches them with a list of known roots to extract Arabic roots. The algorithm achieved an accuracy of 83.9% when tested on the Holy Quran. The algorithm's main strength is its ability to extract all possible roots of derived words. However, it generates a large number of roots, most of which are not related to the original root, and it may mistakenly remove some prefixes and suffixes that are actually part of the root.

Boudchiche et al. [15] presented the second version of AlKhalil Morpho analyzer, a tool for Arabic text processing that analyzes the morphological and syntactic structure of the Arabic language, with improved accuracy and efficiency. The tool can be used for various natural language processing tasks and was evaluated using different methods such as coverage, speed, and an average number of suggested root forms and proposed word stems per word. However, the authors did not

evaluate the precision, recall, and F-measure of the tool due to the unavailability of a corpus with all possible features for each word.

Atta and Al-Hmouz [16] introduced a rule-based approach to extract Arabic roots using a set of rules and a dictionary containing stop words, affixes, and roots. The algorithm was tested on a set of 480 proverbs in Standard Arabic and achieved an accuracy of 74.11%. The algorithm's strength lies in its attempt to enhance existing algorithms by suggesting new rules and changing the order of rules. However, the algorithm has limitations, such as limited applicability of rules and decreased accuracy as word length increases.

Alnaied et al. [17] proposed a new method called Arabic Morphology Information Retrieval (AMIR) to generate Arabic word stems using a set of rules. AMIR outperformed other systems in terms of mean average precision, but it has some weaknesses, including its inability to extract the root of many words and its tendency to make errors in root extraction by removing some letters that are part of the root.

The research by R. Kanaan and G. Kanaan presents an improved algorithm for extracting trilateral Arabic roots [18]. In their work, Boudlal, Lakhouaja, Mazroui, and Meziane developed Alkhalil morpho sys1 [19], a morphosyntactic analysis system specifically designed for Arabic texts. The system provides detailed analysis and processing capabilities for Arabic linguistic features, aiding in various language processing tasks. In their research, Momani and Faraj proposed a novel algorithm for extracting tri-literal Arabic roots [20]. The algorithm introduces a new approach to accurately identify and extract the core tri-literal roots in Arabic words, contributing to Arabic language processing tasks. In the study by A. Belal [21], comprehensive processing techniques were developed for Arabic texts to extract their roots. The research focuses on providing robust methods for accurately identifying and extracting the roots of Arabic words, contributing to Arabic language analysis and processing tasks. Sonbol, Gheim, and Desouki introduced a new approach for Arabic morphological analysis [22]. The study presents innovative methods and techniques for analyzing the morphological structure of Arabic language, contributing to the field of Arabic language processing and related applications. Hamza, Ahmed, and Hilal provide an overview of Arabic root extraction algorithms in the field of text mining [23]. The study explores various algorithms and techniques used for extracting roots from Arabic texts, highlighting their strengths and limitations. The survey serves as a comprehensive resource for researchers and practitioners interested in Arabic language processing and text mining.

Various algorithms for Arabic root extraction have been proposed in the literature, which aims to suggest new rules, change the order of rules, or increase the dictionaries of data rules. However, these algorithms were tested on specific corpora, and their efficiency decreased when tested on another corpus.

III. METHODOLOGY

In this research paper, the methodology section describes the procedures and techniques employed to conduct the study,

providing a clear and concise explanation of the research dataset and methodology.

A. The Dataset

The research paper utilizes Thalji et al. dataset [7] and discusses the fundamental concepts of root extraction in Arabic. The dataset section is divided into three sections, namely roots, affixes, and patterns in Arabic known as "AWZAN".

1) *Arabic roots*: Arabic roots are the basic building blocks of words in the Arabic language [24]. The roots consist of two or more letters that combine to create a meaning. The roots can be sorted into categories based on their length and the type of letters they contain. The length-based roots are divided into five categories, and the second type of root is divided into two categories based on the type of letters they contain. This categorization helps provide insights into the morphology of the Arabic language and highlights the need for advanced root extraction algorithms to effectively handle the different types of roots. Upon examining Thalji et al.'s corpus [7], the roots can be sorted into categories based on their length and the type of letters they contain, as illustrated in Table I.

TABLE I. TYPES OF ARABIC ROOTS

Category	Sub Category	No of roots	Examples
Length-based root	2	480	(عَض, "add", pride)
	3	8000	(دَرس, drasa, study)
	4	3112	(جَمهر, jamher, mass)
	5	360	(عَظفِر, adanfer, glory)
	6	48	(عَنقَير, ankafeer, skillful)
Type of letters root	Vowel	3000	(يَوم, yawem, day)
	Non-vowel	9000	(دَفَع, dfaa, pay)

2) *Arabic affixes*: Arabic prefixes are added at the beginning of a root word to modify its meaning or function, and can indicate various aspects of meaning [25]. Thalji et al.'s corpus includes 430 prefixes, with lengths ranging from one to six letters, and Table II provides statistical information on a subset of these prefixes. Understanding Arabic prefixes is important for comprehending the language and literature.

TABLE II. TYPES OF ARABIC PREFIXES

Prefixes (length-based)	Number	Examples
1	13	(ي, "yaa", the present tense for the male/s)
2	103	(ال, al, the)
3	146	(وال, wal, and the)
4	103	(ليست, leyasta, the present tense).
5	52	(كالمِن, kaelmon, used for analogy)
6	13	(والاست, walest, used for noun)
Total	430	

The Arabic language has infixes, which are inserted within the root of a word to add more meaning. Thalji et al.'s corpus includes 11 Arabic infixes that are classified by length, ranging from one to two letters. It is important to note that a word may contain one or more of these infixes, or none at all. Table III shows a sample of these infixes and their corresponding statistics.

TABLE III. TYPES OF ARABIC INFIXES

Infixes Subcategory (length-based)	Number of prefixes	Prefixes
1	4	ا, و, ي, ت
2	7	وا, يا, او, يي, وي, يت, تا

Arabic suffixes are added to the end of a root word to modify its meaning or grammatical function. They can indicate various aspects, including tense, aspect, voice, gender, number, and case. The study identifies 320 suffixes in the Arabic language, and Table IV shows the number of suffixes in each length category, along with examples for each type. The identification and understanding of Arabic suffixes are crucial for studying the Arabic language and literature. According to the same table, the length of three letters has the highest number of suffixes, with a total of 183. The length of four letters comes next with 94, and both the length of two and five letters have the same number of 40. The length of one letter has a total of 6, and finally, the length of six letters has only 3 suffixes.

TABLE IV. TYPES OF ARABIC SUFFIXES

Suffixes length	Number	Examples
1	6	(ت, "taa", indicates that the subject of the verb is a singular female)
2	40	(ات, at, indicates that the object is plural female)
3	132	(هما, homa, indicates that the object is dual)
4	94	(ناهم, nahom, indicates that the subject of the verb is a plural and indicates that the object is plural male).
5	40	(كموها, kamoha, indicates that the first object is a male plural and indicates that the second object is singular female).
6	3	(انتان, entyan, indicates that the first object is a dual and indicates that the second object is dual also).
Total	320	

3) *Arabic patterns*: Arabic patterns are important for forming words in the Arabic language [26]. They consist of a sequence of letters added to a root to form a complete word with a specific meaning. The study identified 4320 Arabic patterns, ranging in length from three to twelve letters. The most common pattern length is seven letters, with 1296 patterns, followed by lengths of six and eight letters with almost equal numbers. The length of three letters has only one pattern, while the lengths of eleven and twelve letters have 43 patterns each, as shown in Table V. Understanding Arabic patterns is essential for mastering the language.

TABLE V. TYPES OF ARABIC PATTERNS

Pattern length	Number of patterns	Examples
3	1	(فعل) faal, indicates that one was doing something).
4	86	(يفعل) yafaal, indicates single male is doing something).
5	302	(فعلته) faalatho, indicates single female was doing something).
6	994	(الفعلة) alfealah, indicates singular noun).
7	1296	(يتفعلون) yatfaaloon, indicates plural male are doing something).
8	950	(يتفعلان) yattafaalan, indicates dual male are doing something).
9	475	(واستفعلها) estafalaha, indicates single male was doing something and the object is femal).
10	129	(المفعولتان) almafolatan, indicates the object is dual female and it is noun).
11	43	(واقفعلاتهن) waqfealatehem, indicates that it is noun and plural female).
12	43	(والفوعلايون) waltawalaneyoon, indicates that it is noun and plural male).
Total	4320	

B. Normalization

Before stemming, normalize the Arabic word by applying the following steps:

- 1) Remove diacritics punctuation and the Shadda.
- 2) Replace all distinct forms of Hamza with (أ).
- 3) Replace Madda (آ) with Hamza and Alef (أ).
- 4) Replace Alef Maksura (آ) with Alef (أ).

By applying these normalization steps, the algorithm ensures that all Arabic words are represented in a standardized form, which is essential for accurate and efficient root extraction.

C. Pattern Generation

Generate all possible patterns that match the word. The following template is used for the possible patterns: <prefix> <ف> <infix> <ع> <infix><ل1><ل3><ل2> <ل><suffix>. The format consists of different parts:

- <prefix>: This part represents the letters that come before the root of the word, like in the case of the pattern (المفعلات) for the word (المدرسات), the prefix is (الم). Also, the prefix part can be empty, like in the case of the pattern (فاعلات) for the word (دارسات).
- <ف>: This part corresponds to the first root letter, like in the case of the pattern (المفعلات) for the word (المدرسات), the <ف> letter is corresponding to the root letter (ف). If the root consists of only two letters, the first root letter may not exist, in the case of the pattern (عل) of the word (قف), the initial letter of the original word (وقف) was removed, and this led to the deletion of the letter (ف) from the pattern, resulting in (عل).
- <infix1>: This part represents the infix letters that can appear between the first root letter and the second root letter, like in the case of the pattern (مفتعلون) for the word (منتشرون), the < infix1> letter that appears between the first root letter and the second root letter is (ت). This part may be empty, like in the case of the pattern

(المفعلات) for the word (المدرسات), there is no infix letter between the first root letter and the second root letter.

- <ع>: This part represents the second letter of the root, like in the case of the pattern (المفعلات) for the word (المدرسات), the <ع> letter is corresponding to the root letter (ع). If the root consists of only two letters, the first root letter may not exist, in the case of the pattern (فل) of the word (قول), the second root letter of the original word (قول) was removed, and this led to the deletion of the letter (ع) from the pattern, resulting in (فل).
- <infix2>: This represents any infix letters that can appear between the second root letter and the third root letter, like in the case of the pattern (مفعول) for the word (منتشور), the < infix2> letter that appears between the second root letter and the third root letter is (و). This part may be empty, like in the case of the pattern (المفعلات) for the word (المدرسات), there is no infix letter between the second root letter and the third root letter.
- <ل1>: This represents the third letter of the root, like in the case of the pattern (المفعلات) for the word (المدرسات), the <ل1> letter is corresponding to the root letter (ل). If the root consists of only two letters, the third root letter may not exist, in the case of the pattern (افع) of the word (ارم), the third root letter of the original word (ارمي) was removed, and this led to the deletion of the letter (ل) from the pattern, resulting in (افع).
- <ل2>: This represents the fourth letter of the root, like in the case of the pattern (متفعل) for the word (متدحرج), the <ل2> letter is corresponding to the root letter (ج). If the root consists of three or two letters, the fourth root letter does not exist, in the case of the pattern (فاعل) of the word (دارس), the fourth root letter does not exist.
- <ل3>: This part represents the fifth letter of the root, like in the case of the pattern (فعللل) for the word (سفرجل), the <ل3> letter is corresponding to the root letter (ل). If the root consists of four or fewer letters, the fifth root letter does not exist, in the case of the pattern (فاعل) of the word (دارس), the fifth root letter does not exist.
- <ل4>: This part represents the sixth letter of the root, like in the case of the pattern (فعلللل) for the word (عنقير), the <ل3> letter is corresponding to the root letter (ر). If the root consists of five or fewer letters, the sixth root letter does not exist, in the case of the pattern (فاعل) of the word (دارس), the fifth root letter does not exist.
- <suffix>: This part represents the letters that come after the root of the word, like in the case of the pattern (المفعلات) for the word (المدرسات), the suffix is (ات). Also, the suffix part can be empty, like in the case of the pattern (مفاعل) for the word (مدارس).

D. Remove Non-Patterns

Note that this approach generates all possible patterns that match the word, but not all of them will actually be valid Arabic patterns. Some of the generated patterns may need to be

filtered. The identified patterns are matched against the set of patterns stored in the database. Any pattern that is not present in the database is eliminated.

E. Extract the Roots

Once the potential patterns of the word have been determined, the next step is to identify the root of the word, which can be done by following these instructions:

- The initial letter of the root is the one that corresponds to <ف>. Like in the case of the pattern (المفعلات) for the word (المدرسات), the <ف> letter is corresponding to the root letter(د).
- The second letter of the root is the one that corresponds to <ع>. Like in the case of the pattern (المفعلات) for the word (المدرسات), the <ع> letter is corresponding to the root letter(ر).
- The third letter of the root is the one that corresponds to <ل>. Like in the case of the pattern (المفعلات) for the word (المدرسات), the <ل> letter is corresponding to the root letter(س).
- The third letter of the root is the one that corresponds to <2ل>. Like in the case of the pattern (متفعل) for the word (متدرج), the <2ل> letter is corresponding to the root letter(ج).
- The third letter of the root is the one that corresponds to <3ل>. Like in the case of the pattern (فعلل) for the word (سفرجل), the <3ل> letter is corresponding to the root letter(ل).
- The third letter of the root is the one that corresponds to <4ل>. Like in the case of the pattern (فعللل) for the word (عنقير), the <3ل> letter is corresponding to the root letter(ر).

IV. RESULT AND DISCUSSION

This section presents the study findings by describing the testing and comparison of the algorithm with different algorithms on various datasets.

A. Testing the Algorithm in Different Datasets

The suggested algorithm is tested on three different corpora, and its effectiveness is evaluated using precision, recall, and F1 score metrics based on root length and type. Thalji et al. corpus, which includes 720,000 word-root pairings, is divided into five categories based on root length and two types based on letter type. Alshawakfa et al.'s corpus [27], comprises 27,628,821 word-root pairs. The corpus includes only trilateral roots and is divided into two types of roots based on root letter type: vowel roots (VR) and non-vowel roots (NVR). Alkabi et al.'s corpus [26], which includes 6081 word-root pairs. This corpus is distributed into two root types based on their length, namely TR and QR, and two types of roots based on their letter type: VR and NVR. Table VI summarizes the average results across all corpora and compares the performance of the algorithm on three different datasets. In cases where a particular root type is not listed in a corpus, such as BR in Alshawakfa et al.'s corpus, the column is marked with a "-". The table indicates that the proposed

algorithm consistently produces high values for precision, recall, and F1 score, regardless of the type of corpus used.

TABLE VI. SUMMARY OF THE SYSTEM EVALUATION USING THREE DIFFERENT CORPORA

Roots type	Precision			Recall			F-Measure		
	Thalji	Alshawakfa	Alkabi	Thalji	Alshawakfa	Alkabi	Thalji	Alshawakfa	Alkabi
2	82	-	-	-	-	-	84	-	-
3	81	88	82	93	100	95	87	94	88
4	87	-	86	92	-	88	89	-	87
5	90	-	-	92	-	-	91	-	-
6	93	-	-	85	-	-	89	-	-
Avg.	87	88	84	90	100	92	88	94	88
VR	70	77	71	90	100	82	79	87	76
NVR	90	97	85	94	100	97	92	99	90
Avg.	80	87	78	92	100	90	85	93	83

B. Comparing the Algorithm with other Root Extraction Algorithms

To evaluate the accuracy of the proposed algorithm, a comparison is made with three other Arabic root extraction algorithms, namely Khoja and Garside's algorithm [10], Sonbol et al.'s algorithm [22], and Alkabi et al.'s algorithm [26]. These algorithms are established and respected methods in Arabic language applications and have demonstrated high accuracy performance in their respective studies. The comparison is conducted on the Thalji et al.'s corpus, Alshawakfa et al.'s corpus, and Alkabi et al.'s corpus, and the results are presented in Table VII.

TABLE VII. ACCURACY PERFORMANCE OF THE FOUR ALGORITHMS

The algorithm	Corpus type			Average
	Thalji's corpus	Alshawakfa et al.'s corpus	Alkabi et al.'s corpus.	
Khoja and Garside's algorithm	63%	34%	74%	57%
Sonbol et al.'s algorithm	68%	24%	65%	52%
Alkabi et al.'s algorithm	70%	35%	76%	60%
The proposed algorithm	92%	100%	95%	96%

The proposed algorithm for Arabic root extraction outperformed previous algorithms in terms of accuracy according to Table VI and VII. The proposed algorithm returns all potential roots for non-vocalized words and includes all types of roots, not just one specific type. Previous algorithms returned only one root for non-vocalized words and ignored other possible solutions, resulting in a decrease in accuracy. Additionally, previous algorithms suffered from the reduction of the content of the lists used, ambiguity problems, and the inability to extract roots for words without any consonant letters. Overall, the proposed algorithm had the highest accuracy rate compared to previous algorithms.

The proposed algorithm has limitations in dealing with derived words that consist of only one letter, as they are not considered in the algorithm. These derived words originate from weak roots with three letters, wherein the weak letters are omitted during the derivation process. Moreover, the algorithm's tendency to generate all possible roots can result in confusion when attempting to identify the specific root required, as it primarily focuses on individual derived words rather than considering the context of complete meaningful sentences or paragraphs. Future work can address these limitations by enhancing the algorithm to handle one-letter derived words and incorporating techniques such as natural language processing or linguistic analysis to improve its contextual understanding and accuracy in root extraction.

V. CONCLUSION

This study examined the algorithms used to extract Arabic word roots and found that their accuracy is affected by the lack of comprehensive lists and essential rules. Previous research focused on trilateral roots and ignored other types, resulting in incorrect results for non-vowel roots, which make up 75% of all roots. Weak roots were also found to be a major cause of failure in previous Arabic root extraction algorithms due to their numerous irregular cases.

This study proposes a new algorithm for extracting Arabic word roots and compares its accuracy with three commonly used algorithms. The proposed algorithm generates all potential derivation roots of a word without eliminating affixes first, which is different from previous algorithms. The study uses Thalji et al.'s corpus to utilize the maximum amount of content available in the lists. The proposed algorithm achieves an average accuracy of 96%, which is significantly higher than the accuracy of the other three algorithms.

REFERENCES

- [1] N. Thalji and S. Alhakeem, "Developing an effective light stemmer for Arabic language information retrieval," *International Journal of Computer and Information Technology*, vol. 5, no. 1, pp. 55-59, 2016.
- [2] N. K. Masrei, "An innovative automatic indexing method for Arabic text," M.S. thesis, Dept. Comput. Sci., Lebanese Am. Univ., Lebanon, 2020.
- [3] N. Thalji, N. Hanin, W. Bani-Hani, S. Al-Hakeem and Z. Thalji, "A novel rule-based root extraction algorithm for Arabic language," *Int. J. Adv. Comput. Sci. Appl.*, vol. 9, no. 10, pp. 120-128, 2018.
- [4] M. S. S. Sawalha, *Open-source resources and standards for Arabic word structure analysis : Fine grained morphological analysis of Arabic text corpora*, Leeds, UK: University of Leeds, 2011.
- [5] N. Thalji, N. Hanin, Z. Thalji, W. Bani Hani and S. Al-Hakeem, "Towards improving rule-based Arabic root extraction algorithm for non-vocalized text," *Int. J. Comput. Inf. Technol.*, vol. 7, no. 6, pp. 235-242, 2018.
- [6] N. Thalji, N. Hanin, Z. Thalji and S. Al-Hakeem, "Enhancing the accuracy of Sonbol's Arabic root extraction algorithm," *Jordan. J. Comput. Inf. Technol.*, vol. 4, no. 3, pp. 159-174, 2018.
- [7] N. Thalji, A. Hanin, Y. Yacob and S. Al-Hakeem, "Corpus for test, compare and enhance Arabic root extraction algorithms," *Int. J. Adv. Comput. Sci. Appl.*, vol. 8, no. 5, pp. 229-236, 2017.
- [8] S. Al-Fedaghi and F. Al-Anzi, "A new algorithm to generate Arabic root-pattern forms," in in Proc. 11th Nat. Comput. Conf. Exhib., Dhahran, Saudi Arabia, 1989, pp. 04-07.
- [9] H. Al-Serhan, R. Al-Shalabi and G. Kannan, "New approach for extracting Arabic roots," in in Proc. 2003 Arab Conf. Inf. Technol., Egypt, 2003, pp. 42-59.
- [10] S. Khoja and R. Garside, "Stemming Arabic text," Ph.D. dissertation, Computing Department, Lancaster University, Lancaster, UK, 1999.
- [11] K. Taghva, R. Elkhoury and J. Coombs, "Arabic stemming without a root dictionary," in in Proc. Int. Conf. Inf. Technol.: Coding and Computing (ITCC'05) - Volume II, Las Vegas, NV, USA, 2005, pp. 152-157.
- [12] S. Ghwanmeh, S. Rabab'ah, R. Al-Shalabi and G. Kanaan, "Enhanced algorithm for extracting the root of Arabic words," in Proc. Sixth Int. Conf. Comput. Graphics, Imaging and Visualization, pp. 388-391, 2009.
- [13] M. Al-Kabi, "Towards improving Khoja rule-based Arabic stemmer," in IEEE Jordan Conference on Applied Electrical Engineering and Computing Technologies, Amman, 2013, pp. 1-6.
- [14] Q. Yaseen and I. Hmeidi, "Extracting the roots of Arabic words without removing affixes," *J. Inf. Sci.*, vol. 40, no. 3, pp. 376-385, 2014.
- [15] M. Boudchiche, A. Mazroui, M. Bebah, A. Lakhouaja and A. Boudlal, "AlKhalil morpho sys 2: A robust Arabic morpho-syntactic analyzer," *J. King Saud Univ. Comput. Inf. Sci.*, vol. 29, no. 2, pp. 141-146, 2017.
- [16] H. Atta and A. Al-Hmouz, "Enhanced Arabic root-based lemmatizer," M.S. thesis, Dept. Comput. Sci., Middle East University, Amman, 2020.
- [17] A. Alnaied, M. Elbendak and A. Bulbul, "An intelligent use of stemmer and morphology analysis for Arabic information retrieval," *Egypt. Inform. J.*, vol. 21, no. 4, pp. 209-217, 2020.
- [18] R. Kanaan and G. Kanaan, "An improved algorithm for the extraction of trilateral Arabic roots," *European Scientific Journal*, vol. 10, no. 3, pp. 346-355, 2014.
- [19] A. Boudlal, A. Lakhouaja, A. Mazroui and A. Meziane, "Alkhalil morpho sys1: A morphosyntactic analysis system for Arabic texts," in *International Arab Conference on Information Technology*, New York, 2010, pp. 1-6.
- [20] M. Momani and J. Faraj, "A novel algorithm to extract tri-literal Arabic roots," in *2007 IEEE/ACS International Conference on Computer Systems and Applications*, Amman, 2007, pp. 309-315.
- [21] A. Belal, "Comprehensive processing for Arabic texts to extract their roots," *Iraqi Journal of Science*, vol. 60, no. 6, pp. 1404-1411, 2019.
- [22] R. Sonbol, N. Ghneim and M. Desouki, "Arabic morphological analysis: A new approach," in *In 3rd International Conference on Information and Communication Technologies: From Theory to Application*, Damascus, Syria, 2008, pp. 1-6.
- [23] M. Hamza, T. Ahmed and A. Hilal, "Text mining: A survey of Arabic root extraction algorithms," *International Journal of Advanced and Applied Sciences*, vol. 8, no. 1, pp. 11-19, 2021.
- [24] K. Abainia, S. Ouamour and H. Sayoud, "A novel robust Arabic light stemmer," *Journal of Experimental and Theoretical Artificial Intelligence*, vol. 29, no. 3, pp. 557-573, 2017.
- [25] H. Alshalabi, S. Tiun, N. Omar, F. AL-Aswadi and K. Alezabi, "Arabic light-based stemmer using new rules," *Journal of King Saud University-Computer and Information Sciences*, vol. 34, no. 9, pp. 6635-6642, 2022.
- [26] M. Al-Kabi, S. Kazakzeh, B. Abu-Ata, S. Al-Rababah and I. Alsmadi, "A novel root based Arabic stemmer," *J. King Saud Univ. - Comput. Inf. Sci.*, vol. 27, no. 2, pp. 94-103, 2015.
- [27] E. Alshawakfa, A. Al-Badameh, S. Shatnawi, K. Al-Rabab'ah and B. Bani-Ismail, "A comparison study of some Arabic root finding," *J. Am. Soc. Inf. Sci. Technol.*, vol. 61, no. 5, pp. 1015-1024, 2010.

An Evolutive Knowledge Base for “AskBot” Toward Inclusive and Smart Learning-based NLP Techniques

Khadija El azhari¹, Imane Hilal², Najima Daoudi³, Rachida Ajhoun⁴, Ikram Belgas⁵

Smart Systems Laboratory-E.N.S.I.A.S, Mohammed V University, Rabat, Morocco^{1,4}

LyRica Labs, School of Information Sciences, Rabat, Morocco^{2,3}

École Nationale Supérieure des Arts et Métiers, Casablanca, Morocco⁵

Abstract—Artificial Intelligence chatbots have shown a growing interest in different domains including e-learning. They support learners by answering their repetitive and massive questions. In this paper, we develop a smart learning architecture for an inclusive chatbot handling both text and voice messages. Thus, disabled learners can easily use it. We automatically extract, preprocess, vectorize, and construct AskBot's Knowledge Base. The present work evaluates various vectorization techniques with similarity measures to answer learners' questions. The proposed architecture handles both Wh-Questions starting with Wh words and Non-Wh-Questions, beginning with unpredictable words. Regarding Wh-Questions, we develop a neural network model to classify intents. Our results show that the model's accuracy and the F1-Score are equal to 99,5%, and 97% respectively. With a similarity score of 0.6, our findings indicate that TF-IDF has performed well, correctly answering 90% of the tested Wh-Questions. Concerning No-Wh Questions, soft cosine measure, and fasttext successfully answered 72% of Non-Wh-Question.

Keywords—Knowledge base; KB; artificial intelligence; AI; chatbot; e-learning; cosine similarity; soft cosine similarity; TF-IDF; FastText; neural network

I. INTRODUCTION

The e-learning domain has shown impressive growth in applying AI technologies to enhance the quality of learning. e-Learning platforms are increasingly recognizing the importance of integrating AI to perform tasks effectively while saving time, energy, and cost. Based on AI technologies, the e-learning domain succeeds in (1) personalizing educational content according to each learner's needs and capabilities instead of proposing a standard approach to learning. Hence, the learning strategy becomes dynamic, customized, and individualized to encourage learners. (2) Providing specific information about each learner's progress, strengths, and weaknesses, and even attendance issues. Hence, data analysis on e-learning platforms enhances and improves learning experiences. (3) Developing multilanguage course content by integrating automatic translation tools that offer more speed and efficiency in translating huge amounts of content, thus saving time and offloading teachers from such tasks that consume time and energy. (4) Supporting learners by providing AI chatbots to answer learners' questions. Chatbots are available 24/7. Thus, learners are free to learn at their own pace through multiple devices.

Various chatbots have been created for use in multiple areas, including the e-learning domain. Especially, there is an

exponential interest in AI chatbots in the last few years, especially from 2016 until now [1]. AI chatbots have been used in the e-learning domain to satisfy several needs such as (1) Promoting learners' interaction with online courses. (2) Providing information about administration [2], courses, and exam regulations (3) Sharing exercises and tips/hints to solve them and assist students to master the course knowledge (4) Answering repetitive and massive questions about the course knowledge (5) Recommending learning materials and educational resources according to the learner's need (6) Assessing learners' knowledge by automating exams and assignments (Sreelakshmi et al., 2019) (5) Encourage collaborative learning between learners (El Azhari et al., 2022).

Therefore, e-learning chatbots address several issues facing the e-learning domain, especially since they have succeeded in: (1) Automating repetitive tasks by performing them efficiently. Thus, helping tutors to focus their energies on more complicated tasks rather than answering repetitive and massive questions (El Azhari et al., 2021). Hence, saving time, energy, and cost. (2) Capitalizing knowledge from several sources and storing them as the chatbot Knowledge Base (KB), Thus, assisting learners to quickly find the reliable information needed without wasting time searching in many information sources. (3) Encouraging learners to ask their questions (Moreno-Guerrero et al., 2023) without being afraid of attracting attention from others, being criticized, and having their opinions misinterpreted. (4) Supporting interaction between learners and the chatbot, hence, learners ask their questions at their own pace through multiple devices without waiting for the course session (El Azhari et al., 2022).

Despite the efforts made to integrate AI chatbots in the e-learning domain, there are some drawbacks related to the manual process of creating e-learning chatbots. Specifically, several researchers (M. Verleger and J. Pembridge, 2018; Herrera, Yaguachi and Piedra, 2019; El Janati, Maach and El Ghanami, 2020; H. C. B. Chan and T. T. Fung, 2020; Tamayo et al., 2020; Deepika, Bala and Kumar, 2021a; Nhut Lam, Nhat Le and Kalita, 2022; Singh and Singh, 2022) propose AI chatbots by manually creating pairs of Questions and Answers (Q&As) and storing them as the chatbot's local KB. They manually create learners' intents rather than automatically extracting them. Thus, consuming time, energy, and cost.

In this paper, we will address these issues by proposing an inclusive chatbot called « AskBot » able to automatically understand learners' requests in text and voice formats without the need for prebuilt services in online platforms. Thus, saving

time, energy, and cost. This work differs from existing chatbots by providing an automatic approach to construct the AskBot's KB using the web scraping tool without wasting time in manually collecting Q and As related to the chatbot's domain.

The remainder of this paper is structured as follows: The next section outlines the context and the problem statement of the study. The third section presents related works. The fourth section provides AskBot's architecture, and the implementation process and the last section provides the conclusion and future works.

II. CONTEXT AND PROBLEM STATEMENT

A. Overview of AI Chatbots and NLP Techniques

AI chatbots are based on NLP techniques, especially Natural Language Understanding (NLU) to understand what the user asks for and Natural Language Generation (NLG) to generate the appropriate response and answer correctly. AI chatbots recognize users' needs by applying the NLU technique. They extract two main elements: (1) The intent which means the user's intention behind asking a question or formulating a message. (2) Entities are values extracted from the user's input to understand the information needed. Fig. 1 demonstrates a use case of using AI chatbots to answer learners' questions.

Before understanding the user's request, it's highly recommended to transform it into a vector by applying the word embedding technique. Specifically, each word is converted into a single vector. It considers that a word is characterized by its context, i.e., by the words that surround it. Thus, words that share similar contexts also share similar meanings.

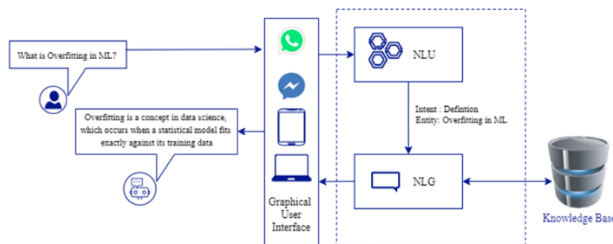


Fig. 1. Example of AI chatbot in an e-learning context.

In this paper, we test four well-known word embedding techniques:

1) *Term Frequency Inverse Document Frequency (TF-IDF)* is a text vectorizer method that aims to transform the text into vectors by combining three main concepts: (i) *Term Frequency (TF)*: It indicates the significance of a particular term by calculating the number of times it appears in a document. (ii) *Document Frequency (DF)*: It refers to the number of documents that include a particular term. It reveals how frequently a term is used. (iii) *Inverse Document Frequency (IDF)* determines the weight of a particular term. It aims to reduce the weight of a term if its occurrences are dispersed over all the documents.

2) *Word2Vec* is based on two-layer neural networks and seeks to learn the vector representations of the words

composing a text. Thus, words with similar contexts are represented by close numerical vectors.

3) *GloVe works based on two main methods*: (i) *Global matrix factorization* is the process of reducing huge term frequency matrices using matrix factorization techniques from linear algebra. (ii) *Local context window methods* are CBOW and Skip-Gram.

4) *FastText* encodes each word as an n-gram of characters rather than immediately learning word vectors. N-grams can be defined as continuous words, symbols, or token sequences in a document.

The chatbot uses the output of the vectorization step to answer given questions. Especially, it measures the similarity between the user's question and all stored questions, then, it returns the response of the most similar question to the user's question. To perform this process, the chatbot needs to measure similarities between questions by using techniques such as Cosine Similarity and Soft Cosine Measure. They are among the techniques widely used. Specifically, they have proven good results in different implementations :

1) *Cosine similarity*: It calculates the cosine of the angle formed by two vectors projected into a multidimensional space. The cosine similarity increases with decreasing angle.

2) *Soft cosine measure*: It assesses the similarity between two publications meaningfully even when they don't share any words. It has been demonstrated that it performs better than several cutting-edge techniques in determining semantic text similarity.

In this part, we introduced an overview of the main concepts used in our work to implement AskBot's architecture. The next part is dedicated to discussing the problem statement of the present work.

B. Problem Statement

The e-Learning domain suffers from a variety of issues, especially, managing learners' questions. Specifically, tutors spend considerable time and energy manually answering repetitive and massive learners' questions. They are unavailable to manually handle them and satisfy all learners' needs [3], [4]. Thus, learners are forced to seek the information they need from several materials: Books, online links, and search engines [5]. Thus, consuming time and energy in filtering relevant and reliable information [6]. Hiring additional tutors might be a solution to handle massive learners' queries. However, it leads to high costs. For that reason, automatically answering learners' questions is needed to offload tutors from repetitive tasks [7]. Thus, they can concentrate their energies on more complicated tasks.

AI chatbots are highly integrated into e-Learning platforms to automatically respond to learners' questions [8]. They automate handling learners' requests by giving the appropriate answers to given queries. Thus, saving time, energy, and cost. As demonstrated by [9], using an AI chatbot positively impacts learner retention. Specifically, they compared learning using AI chatbots and the Google search engine. Outcomes show that learning through the proposed AI chatbot has a positive impact on memory retention and learning outcomes compared to the

learning through Google search engine. Hence, a chatbot is considered an effective tool [10] to support learners and encourage them to freely ask their questions without being evaluated or misjudged.

Several works have been carried out to automatically handle learners' questions. Many researchers propose AI chatbots to automatically answer learners' questions and satisfy their needs by saving time, energy, and cost. However, results are still insufficient and additional efforts are required to enhance AI chatbots in the e-Learning domain [11]. As shown by [11], [12], educational chatbots in the instant messaging application are still limited and need additional AI features. Especially, chatbots in the E-learning domain suffer from manually creating the chatbot's KB. Many researchers construct the KB by manually collecting pairs of Q&As. Thus, consuming time and energy. For that reason, additional efforts are needed to automate the creation process of the chatbot's KB. In addition to that, researchers prefer using platforms such as Dialog flow, IBM Watson, Wit.ai, etc. They facilitate the creation of chatbots through trained AI models. However, they are expensive and lead to high costs.

In this paper, we will address these issues by proposing a smart architecture based on AI technologies. Especially, we will automatically construct the chatbot's KB by scraping reliable and relevant knowledge. Then, automatically classifying intents by using a neural network model rather than wasting time manually creating training phrases. Specifically, the proposed chatbot can automatically understand learners' needs and satisfy them. Thus, saving time, and energy, and reducing costs. To demonstrate the feasibility of the proposed architecture, we will test the chatbot in the Machine learning (ML) domain. Thus, the designed chatbot will answer questions related to the ML domain.

III. RELATED WORKS

Several works have been carried out to develop e-learning chatbots in different learning contexts to satisfy various needs. They support learners by giving them the information needed rapidly and efficiently. They understand learners' needs and respond correctly based on the local KB. In this section, we will present and discuss recent works focused on automatically constructing AI chatbots to assist learners.

Based on our review [11], most studies propose creating chatbots by manually feeding the KB. They propose constructing the chatbot's KB by manually creating a set of Q&As which is time- and energy-consuming [13]–[21]. On the other hand, some papers automate the process of creating e-learning chatbots by using recent technologies such as web scraping, Optical Character Recognition (OCR), and spider robots. The authors in [22] proposed an educational chatbot to answer questions related to the Data Science domain. They automatically extracted the chatbot KB by using the web scraping technique. Study [23] proposed a chatbot to deliver learning materials. They automatically collected relevant documents, indexed them by Elasticsearch, and stored them in Postgre Database. Researchers in [24] proposed an educational chatbot able to assess and evaluate students' knowledge. They used Apache PDFBox and an overgenerating system to automatically construct the local KB. Study [25] proposed a

generative chatbot able to predict answers based on deep learning models. They applied these models to learn from an existing dataset and train the chatbot.

After analyzing previous works, we conclude that few papers proposed automating the creation of the chatbot's KB. They propose the use of web scraping techniques, OCR, or spider robots to automatically collect pairs of Q&As. However, the proposed approaches are still insufficient, and more efforts are needed to automatically understand users' intents without manually creating them. Specifically, they propose using some online platforms such as DialogFlow, IBM Watson, Wit.ai, and Rasa. etc. to facilitate the chatbot's training process without the need for technical knowledge in advanced NLP techniques [26]–[33]. These platforms already integrate NLU and NLG techniques, they reduce the energy needed to understand users' requests and answer them. However, there are some limitations:

1) In these platforms, the integration of Q&As is done manually by adding intent for each question with training phrases (Q&As) to help the chatbot learn from them. The manual integration of intents is time and energy-consuming because AI chatbots require a lot of Q&As to function properly. Otherwise, the chatbot will be restricted to the few Q&As included in training phrases because it is challenging to manually gather a huge number of Q&As.

2) These platforms are expensive, and the number of queries available in their free editions is constrained.

3) These platforms limit the channels to incorporate the chatbot.

The research [34] proposed an approach based on deep learning algorithms, they address the problem of manually creating intents by proposing a generative chatbot. It answers automatically to a user's request by predicting the response via a deep learning model without the need of referring to the KB or classifying the user's intent. Thus, they reduce the time needed to classify Q&As. However, a large amount of data is needed to train generative chatbots. Otherwise, they can result in illogical responses or incorrect answers if the chatbot is trained using little or poor-quality datasets.

In this paper, we aim to automatically handle users' questions through AskBot's architecture. Specifically, we propose a smart architecture to automate the process of detecting intents and understanding the real needs of learners, then, answering correctly without wasting time in classifying intents. Hence, saving time, energy, and cost.

IV. PROPOSED ARCHITECTURE

A. Chatbot's Architecture

In this section, we will present AskBot's architecture, its implementation process, and the role of its main components. As demonstrated in Fig. 2 there are two main layers in AskBot's architecture: (1) the Back-End layer containing the core components of the architecture, namely: (1) Spell Correction, (2) Data Preprocessing, (3) Vectorization, (4) Similarity Measure, (5) Speech To Text, (6) Text To Speech, (7) Small Talk Verification (8) DialoGPT and (9) The knowledge base. They work together to produce the

appropriate answer for a given question. (2) the Front-End layer representing the graphical user interface (G.U.I). It facilitates the interaction between learners and AskBot. Thus, learners can directly ask their questions using its graphical interface.

AskBot's architecture addresses the problem of manually creating chatbots in the e-learning context either by manually constructing the local KB or by manually creating intents for training phrases in online platforms. Specifically, the present work proposes using the web scraping technique to automatically construct AskBot's KB. Hence, saving time and energy. Furthermore, based on our proposed python script, AskBot can detect users' needs without using prebuilt NLP models in online platforms, thus saving time, and energy, and reducing cost.

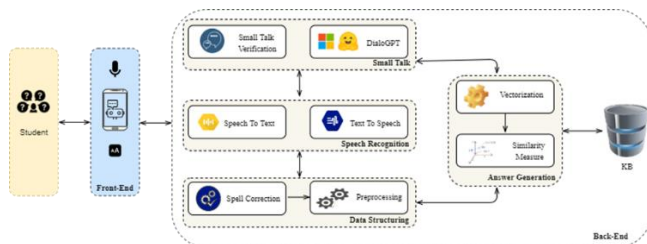


Fig. 2. Askbot's Architecture.

B. Implementation Process

In this part, we will present the implementation process of AskBot's architecture. To demonstrate the feasibility of our approach, we focused our work on the Machine Learning domain. Thus, we develop an inclusive chatbot able to handle repetitive and massive questions related to the Machine Learning domain. Furthermore, AskBot's architecture can easily perform in different contexts by applying the same implementation process.

In Fig. 3 we present the methodology adopted to train AskBot. As demonstrated in Fig. 3 there are seven main phases in the implementation process of AskBot, namely: (1) Data Collection, (2) Data Pre-processing, (3) Word embedding, (4) Data Splitting, (5) Intent Classification, (6) Similarity Measures and (7) Answer Generation. In this section, we will deeply outline each phase.

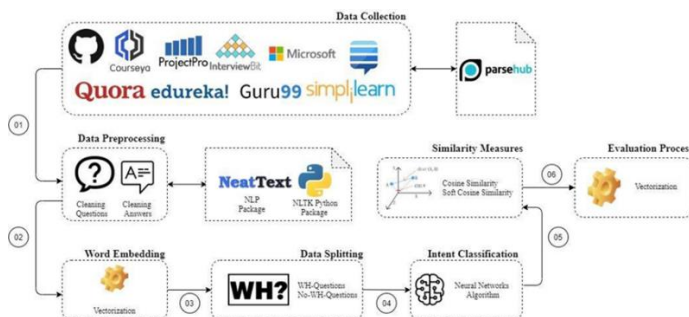


Fig. 3. Methodology adopted to develop AskBot.

1) *Data collection*: The proposed approach automatically collects pairs of Q&As from several online forums and educational sources providing reliable answers for ML

questions, including: Interview Bit¹, Simplilearn², Edureka³, Project Pro⁴, Guru99⁵, Coursera⁶, and Quora⁷. Specifically, the present work includes 10075 Q&As retrieved through the ParseHub data extraction tool. It scraps and handles large amounts of data from several sources. However, our solution excludes 8784 of the Quora retrieved Q&As since the chatbot requires direct and concise answers whereas most of Quora's answers are subjective (ideas, experiences, ...), too long, and indirect. Furthermore, this work includes Q&As shared in the Stack Exchange network, especially, 19876 pairs of Q&As are integrated from three reliable sources: Cross Validated, data science, and Artificial Intelligence. They enrich AskBot's KB to 21167 Q&As.

Besides ML questions, the present work integrates Q&As about general conversations (Small Talk) to improve the chatbot's ability to appropriately interact when it receives queries about topics other than technical ones. For that reason, the proposed chatbot integrates an open-source dataset, from the GitHub site. It contains general Q&As, regarding the following topics: greetings, AI, computers, emotion, food, gossip, health, history, humor, literature, money, movies, politics, psychology, science, sports, and stories. Thus, AskBot can imitate human capability to talk about general topics. Furthermore, the chatbot integrates DialogPT, a sizable pre-trained dialogue response-generating model, developed by MSR AI and the Microsoft Dynamics 365 AI Research team for small talk conversations. The model is created using 147M conversations from Reddit posts. The DialogPT project lays the groundwork for creating adaptable Open Domain chatbots, able to answer engagingly and naturally a wide range of conversational subjects, tasks, and information requests. Experience demonstrates that the response produced by DialogPT is comparable to the quality of human response (Zhang et al., 2019).

2) *Data preprocessing*: The present step focuses on applying a series of transformations to preprocess and clean the retrieved Q&As. Hence, successfully performing NLP models. As demonstrated in Fig. 4 there are six main steps in cleaning questions: (1) Remove duplicated rows (2) Delete numbers, and hashtags using the NeatText library (3) Replace punctuations with a space, except the dashes (- and _) since the dataset contains technical words separated by dashes such as the word "scikit-learn". In this case, replacing dashes leads to considering scikit and learn as two different words. The proposed solution is to concatenate these words rather than separate them (4) Remove stopwords: Many words in the English language, such as "I," "the," and "you," are used frequently in texts however they do not offer any significant

1 <https://www.interviewbit.com/>
2 <https://www.simplilearn.com/>
3 <https://www.edureka.co/>
4 <https://www.projectpro.io/>
5 <https://www.guru99.com/>
6 <https://www.coursera.org/>
7 <https://stackexchange.com/>

information for NLP operations and modeling. Since it is highly recommended to eliminate them, the proposed approach removes stopwords to increase the efficiency and robustness of the NLP model (5) Fix contractions: A contraction is a word or group of words that has had one or more letters removed and replaced with an apostrophe. The proposed solution replaces contractions with the complete version of the word; For example, “what’s” and “you’ve” become respectively “what is” and “you have”. (6) Lemmatization: in this step, the proposed solution consists of converting any kind of word to its base root mode. It is highly recommended to apply Lemmatization when the meaning of the word is important for the analysis.

The second part of the data processing step is to clean responses by removing special characters and HTML tags. In Fig. 5 we present the word cloud for all stored questions in the dataset. As shown in the word cloud, the word occurs in the text more frequently the bigger and bolder it is in the word cloud. Thus, we can ensure that all questions in the dataset are around the Machine Learning domain.

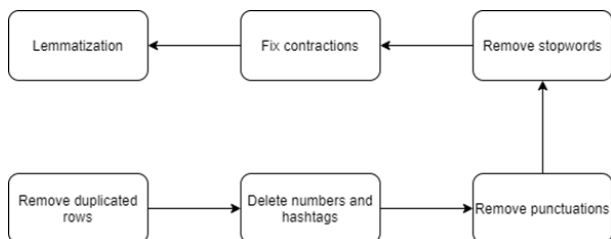


Fig. 4. Methodology adopted to preprocess the questions.

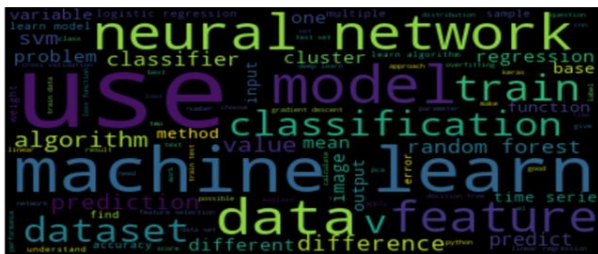


Fig. 5. Word cloud for all stored questions in the dataset.

3) *Word embedding*: The proposed approach focuses on four main word embedding techniques, especially:

- TF-IDF instead of Bag Of Words, because Bag of Words simply creates a set of vectors that contain the number of word occurrences in the document, while the TF-IDF model contains information about the most important and least important words as well. BOW vectors are easy to interpret. However, TF-IDF generally works better in machine-learning models (Pimpalkar and Raj, 2020).
- GloVe captures long-term interdependence by taking semantic meaning and word similarity into account during embedding (Chuah, 2022).

- Fasttext since it can consider the context in textual data and handle out-of-order words by n-gram models (Lestari and Setiawan, 2022).
- Word2vec has proven excellent performance in vectorizing words, and phrases, by producing one vector per word (Sharma and Kumar, 2023b).

Based on the Python Language, the proposed approach succeeds in (1) Developing the TF-IDF model able to vectorize Q&As in numerical vectors by following the TF-IDF process. (2) Developing the glove model by applying “Glove-wiki-Gigaword-50”: a pre-trained glove model with no casing, based on 2 billion tweets, 27 billion tokens, and 1.2 billion words. (3) Developing the Fasttext model through the pre-trained model called “Fasttext-wiki-news-subwords-300” which uses one million words vectors and is trained on the statmt.org news dataset, UMBC web-based corpus, and Wikipedia 2017 (16B tokens). (4) Applying the word2vec model by using the “word2vec-google-news-300” that was trained on 100 billion words. It includes three million words and phrases represented by 300-dimensional vectors.

4) *Data splitting*: In this step, the proposed approach automatically classifies questions' intents to group similar questions into the same class. The chatbot’s KB includes two types of questions: (1) WH-Questions starting with Wh words such as: what, how, when, why, which, who, and where. They represent almost 27.5% of the KB (2) “Non-Wh-Questions” beginning with different words, they represent almost 72.5% of the KB because most learners prefer asking their questions freely without starting with wh-words. Fig. 6 presents the distribution of WH-Questions and Non-WH-Questions in the KB.

Our work proposes a novel approach to analyze both Wh-Questions and Non-Wh-Questions. The chatbot’s KB is divided into two main parts, and each part will be analyzed separately: (1) Dataset for Wh-Questions to automatically classify their intents since all questions start with "WH-words" and (2) Dataset for "Non-Wh Questions": because it is challenging to automatically classify them since they begin with unpredictable words.

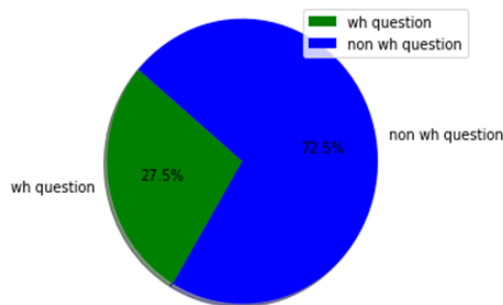


Fig. 6. Distribution of WH-questions and No-WH-questions in Q&As dataset.

5) *Intent classification*: Our proposed approach automatically classifies WH-Questions by developing a python script based on the following conditions:

- If the question starts with "what", the intent class will be: "Defintion_or_asking_for_information", since we noticed that the questions that start with "what", ask for either a definition or a piece of information. Example: what is supervised learning?
- If it starts with "why", the intent class will be "Reason". Example: Why does overfitting occur?
- If it starts with "How", the intent class will be "Method ". Example: How is the f1 score used?
- If it starts with "Who", the class will be "Person". Example: Who invented the concept of overfitting?
- If it starts with "Which ", the intent class will be "Choice ". Example: which is better lstm or gru?
- If it starts with "Where", the intent class will be "Source_or_case", since the questions that contain where ask for either a source or an explanation about a specific case. Example: Where do predictions depend on?
- If it starts with "When", the intent class will be "Situation_to_use_or_to_happen", since the questions start with when asking when to use a situation and when it occurs. Example: When to use graph Learning?

As demonstrated by the distribution of intent classes (Fig. 7) the dataset of WH-Questions is unbalanced. Histograms show that most questions fall into two classes: "Method" with 2944 questions and "Definition or asking for information" with 2092 questions. In addition to that, 260 questions refer to "Situation to use or to happen," 387 questions pertain to "Choice," and 873 questions refer to "Reason." However, just a few questions from the class "Source or case" with 51 questions and "Person" with four questions.

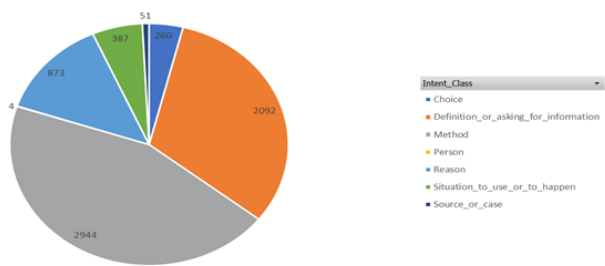


Fig. 7. Distribution of intent classes.

The intent classification step aims to predict the intent of new wh-questions. For that reason, our approach includes a predictive model to forecast the appropriate intent class for a given wh-question. Especially, there are various models to perform the intent classification task, such as K nearest neighbors, Naïve Bayes, Support Vector Machine, Decision Tree, Random Forest, etc. Our proposed architecture adopts Neural network algorithm (NN) because of two main reasons claimed by [35] : (1) it needs less formal statistical training (2)

it has a high capacity to detect complex nonlinear relationships between dependent and independent variables, in our case, independent variables refer to wh-questions and the intent class is the dependent variable. The first task is to vectorize wh-questions by using word embedding techniques. Then, develop the neural network (NNs) model that predicts the corresponding intent class in WH-Questions. For that reason, we divide the Wh-Question dataset into two parts: The first one is training data (80% of the dataset) to train the NNs model and the second one is testing data to test the pre-trained model and evaluate its accuracy (20% of the dataset). Then, we use the confusion matrix to evaluate the performance of the NNs model. As demonstrated in Fig. 8 the confusion matrix resumes the intents classification task. Predictions are distinguished by classes and contrasted with real values. Good predictions are presented in the diagonal of the matrix. For example [Method, Method] = 569 which means that 569 questions in the test data present the method intent class, and they were well classified by the NNs model. As demonstrated by Fig. 8 a few questions were badly classified: For example [Reason, Method] = 2 which means that just two questions that present method class, have been classified as Reason class. Thus, we can conclude that the NNs model fits well the Q&As in the test dataset.

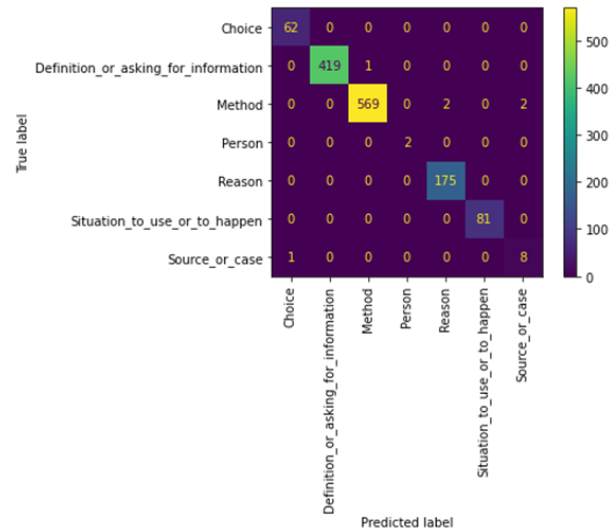


Fig. 8. Confusion matrix of NN model.

Additionally, we display the classification report as a performance evaluation metric to measure the model's performance. Especially, it presents the classification model's precision, recall, F1 score, and accuracy.

Recall for the class Definition = 1 (419 / 419). Only the classification of the definition intent is important for the recall of the class definition. This doesn't depend on how the other intents are classified. Even if the model mistakenly identified all other intents as definition, the recall will be 100% when it classifies all the definition intent questions as Definition. Precision for the class Definition = 0.9976 (419/420). Many incorrect (Or few correct) classifications for the Definition class lead to low precision. The precision for the Definition class shows how accurate the model is in identifying learners' questions related to the definition class.

Recall and precision are complementary; they measure the model's performance related to a specific intent. However, the model's performance related to all classes is measured through the accuracy or F1 score, they describe the model performance in forecasting questions' intents. Accuracy calculates the number of times the model was correct overall and (ii) F1 score assesses a model's performance by combining the model's precision and recall scores.

As demonstrated by Fig. 9 the classification report demonstrates that the model's accuracy and F1-Score are respectively equal to 0.995, 0.97. It means that our NNs model fits well the dataset of WH-Question, i.e., the model can distinguish well between the classes. Thus, we can conclude that the model is reliable; it is able to make good predictions.

		precision	recall	f1-score	support
	Choice	1.00	0.98	0.99	63
Definition_or_asking_for_information		1.00	1.00	1.00	419
	Method	0.99	1.00	1.00	570
	Person	1.00	1.00	1.00	2
	Reason	1.00	0.99	0.99	177
Situation_to_use_or_to_happen		1.00	1.00	1.00	81
	Source_or_case	0.89	0.80	0.84	10
	accuracy			1.00	1322
	macro avg	0.98	0.97	0.97	1322
	weighted avg	1.00	1.00	1.00	1322

accuracy: 0.9954614228877458

Fig. 9. Classification report of NN model.

6) *Similarity measures*: The proposed architecture calculates similarity measures to retrieve the most similar question. Then, send its response to the learner's question. In the case of WH-Question, AskBot vectorizes the learner's question through word embedding techniques, predicts the learner's intent, then applies cosine similarity. Regarding Non-Wh-Questions, it is difficult to classify the intent class because they start with unpredictable words. For that reason, the proposed solution uses the Soft Cosine Measure to find the appropriate answer directly without classifying their intentions. Soft Cosine Measure is most appropriate for Non-WH-Questions because it can find questions that are related even when they do not share any words. After evaluating several similarity scores, we find that the score of 0.6 has shown satisfactory results in extracting similar questions to the learners' questions. For that reason, we adopt that score as a threshold of similarity. When a user asks a question, we calculate the similarity between the user question and all questions in the local KB, if the similarity is greater than 0.6, then, we send the response of the similar question to the user. Specifically, we choose the question with the highest score of similarity.

7) *Evaluation process*: The proposed approach includes 100 pairs of Q&As related to the ML domain to evaluate each vectorization model. As presented in Fig. 10 for each question in the test dataset, we applied the preprocessing steps and the vectorization models. Then, there are two main cases: (1) Relating WH-question, the proposed solution is to predict the intent class by applying the NNs model, then applying cosine

similarity to retrieve the most similar question to the test question. And finally, retrieving the stored answer to the matched question. (2) Regarding the No-WH-Questions, the proposed approach is to apply the soft cosine similarity to retrieve the most similar question with its response.

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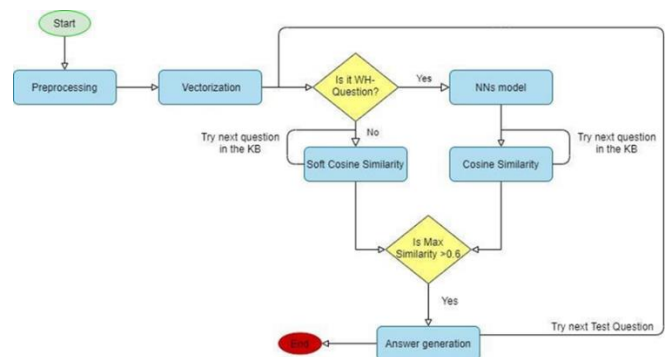


Fig. 10. Flowchart of the evaluation process.

In the evaluation process, we create a dataframe that summarizes the test results. Next, we evaluate the performance of the vectorization methods. Sometimes, even if the scores similarity is high, we find that questions are not very similar. Thus, we cannot automatically evaluate the test results based on the score similarity. Therefore, three team members examine the results to retrieve the number of correct answers in each vectorization method. Each member scores the generated answers by reporting 1 if the questions are similar and 0 otherwise. Since the dataset used in the evaluation process contains Wh and Non-Wh questions, we calculate the percentage of correctly answered questions for each type according to each vectorization technique.

As shown in Fig. 11 all vectorization techniques have demonstrated good results regarding WH-Questions. Specifically, TF-IDF succeeds in responding to 90% of WH-Questions. Based on Fig. 11 we considered TF-IDF as the most appropriate method for WH-Questions for two main reasons: (1) 90% of WH-Questions were well classified. (2) Just 10% of WH-Questions were badly classified, which demonstrates that there is a low chance to make bad classifications for new WH-Questions. Based on Fig. 12, both TF-IDF and Fasttext demonstrated good results in 70%, and 72% of questions respectively. Thus, we adopted Fasttext for Non-WH-Questions.

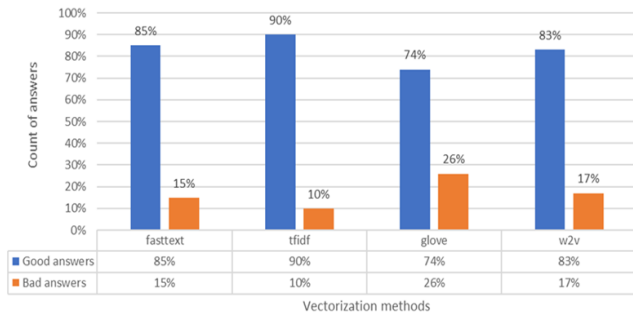


Fig. 11. Comparison between the performances of the vectorization methods in WH-Questions.

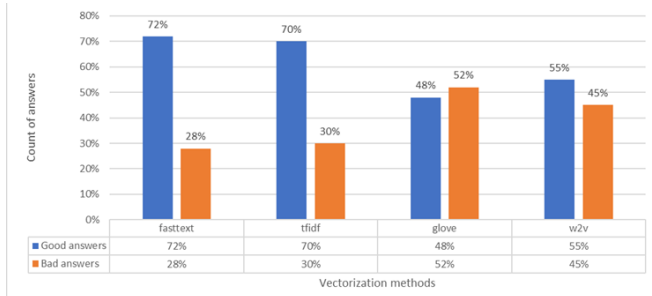


Fig. 12. Comparison between the performances of the vectorization methods in NO-WH-Questions.

C. Architecture's Components

In this section, we will present the main components of AskBot's architecture and the generated information flow to answer learners' questions. In Fig. 13 we present a flowchart that explains how the chatbot's components interact to answer a given question.

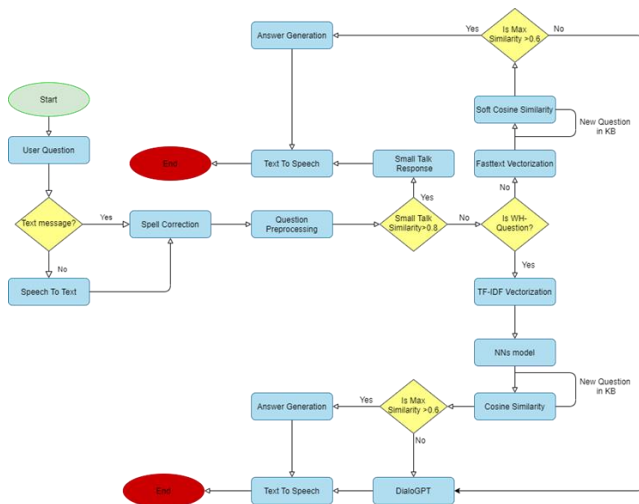


Fig. 13. Flowchart of the Askbot's architecture.

1) Back-end

a) *Spell Correction*: One common task in automatic NLP is spelling correction for many NLP applications, including Web search engines, text summarization, sentiment analysis, etc. When the user misspells search terms or the user's message differs from the spelling in the local KB, the Automatic Spelling Correction function enables search queries

to produce the intended results by correcting and rectifying misspelled words through a suggested set of terms that are the closest lexically to the incorrect ones (Hládek, Staš and Pleva, 2020). Python proposes a variety of modules and packages to carry out spell correction such as textblob, pyspellchecker, and JamSpell. However, these Python tools are not specifically designed for correcting technical words in the ML field. For that reason, our approach proposes the my_autocorrect Python function that takes a word as input and outputs a list of terms that are related to it.

First, we start by extracting 10068 keywords from Q&As in AskBot's KB, next, we store them in a python dictionary. Then, we check if a given word exists in the dictionary, thus, the word is correct. Otherwise, we calculated the similarity between the given word and all words in the dictionary. Specifically, after testing several similarity scores, we find that the score of 0.5 has shown good results in retrieving the most similar words. For that reason, we adopt that score as a threshold of similarity. We keep words with similarity scores higher than the threshold of 0.5. And finally, we replace the given word with the word that has the highest similarity score. In Fig. 14 we present two use cases of the developed function "my_autocorrect". In the first example: my_autocorrect('bagng'), the misspelled word 'bagng' will be replaced by the word "bagging" since it represents the highest score similarity (=0.571429). In the other example, the word 'classfer' will be replaced by "classifier" as the most similar word to 'classfer'.

my_autocorrect('bagng')				my_autocorrect('classfer')			
	Word	Prob	Similarity		Word	Prob	Similarity
2202	bagging	0.000133	0.571429	5525	classifier	0.000133	0.666667
3170	bag	0.000133	0.400000	6939	classifiers	0.000133	0.600000
67	laggy	0.000133	0.285714	420	class	0.000133	0.571429
187	bagof	0.000133	0.285714	953	classier	0.000133	0.555556
1104	engage	0.000133	0.250000	1307	perclass	0.000133	0.555556

Fig. 14. Spell correction function.

b) *Data Preprocessing*: It is the component responsible for cleaning the user's input to transform it into a structured format by applying the data preprocessing steps.

c) *Vectorization*: It is the component that vectorizes the user's input, it takes the output of the "Data Preprocessing component" and verifies if the user's question is a WH-Question, then, it applies TF-IDF to vectorize it. Otherwise, it applies Fasttext.

d) *Prediction Model NNs*: It is the model that predicts the intent class for WH-Questions asked by the user. It uses the output of the vectorization component to predict the user's intention.

e) *Similarity Measure*: It is the component responsible for generating the appropriate answer for a given question, it verifies the question's type. When the asked question is a WH-Question, then, it uses the intent class and the cosine similarity score to retrieve the most similar question to the user's

question, and finally, it sends the response of the similar question as the appropriate response. Otherwise, if the user's question is a NO-WH-Question, then, it applies the Soft Cosine Similarity to generate the answer.

f) *Small Talk Verification*: It is the component responsible for analyzing the user's message and verifying whether the message falls into small talk data or not. It aims to handle small talk conversation by applying the cosine similarity between the user and the small talk data. If the user's question is similar to a small talk question. (i.e the similarity between the user's question and questions in the small talk data is greater than 0.8). Then, the response will be extracted from small talk data (See Fig. 6) rather than searching in the local kb. We used a high score similarity to ensure that the user's question falls into general conversation and not a technical question.

g) *DialoGPT*: It is the component responsible for generating answers if the user's questions do not match with the stored Q&As in the local kb. After applying the similarity measures, if the similarity score between the user's question and the KB does not exceed the threshold of 0.6. Then, the answer is generated from the DialoGPT component. The small talk and DialoGPT components aim to make the chatbot richer and friendlier. It can interact with learners freely and respond to general questions beyond its local kb. Thus, enhancing the user experience.

h) *Speech Recognition*: It is the component responsible for interacting with voice messages. It aims to make the chatbot more inclusive. Thus, disabled learners can use it to find the information they need. There are two main tasks to perform speech recognition:(1) *Speech-To-Text (STT)*: It is an AI technology that converts voice content into text. It enables a computer program to take a human voice and convert it into text. (2) *Text-To-Speech (TTS)*: It is an AI technology that aims to convert text into voice. It provides the opposite of speech-to-text software's ability to turn voice content into text. The AskBot's architecture supports learners, especially those with disabilities, by efficiently handling their voice queries through *SpeechToText* and *TextToSpeech* techniques. Hence, our proposed chatbot is inclusive.

2) Front-end

a) *Graphical user Interface*: In order to facilitate the use of the chatbot, we developed a Graphical User Interface (G.U.I). Thus, learners can use it to interact with the chatbot by sending text/voice messages. We used the package "Tkinter" to develop the chatbot interface. It is a standard graphical library for Python to create a GUI-based application.

As demonstrated in Fig. 15 the interface includes a frame for conversation, an input field for the user to enter a message, and two buttons. The first one is labeled "send," to enable sending a message, and the second one enables the STT technology. Students can send messages through two methods: (1) Entering text messages in the input field. (2) Pressing on the "micro" icon to send voice messages.

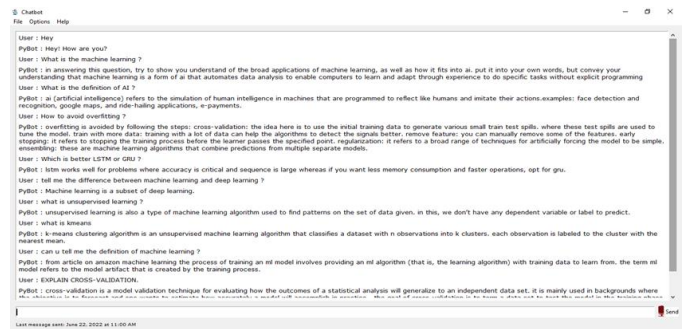


Fig. 15. Spell Use case of AskBot.

V. CONCLUSION

In this paper, we proposed an inclusive chatbot able to respond to users' questions about the Machine Learning field. It helps learners in their learning processes by providing reliable information the learners need without wasting time searching in many available sources. The present work proposes a smart learning architecture that supports various AI technologies and aims specially to automate answering massive and repetitive questions asked by learners. AskBot offloads tutors from doing repetitive tasks and helps them concentrate and focus their energies on tasks that need more concentration and effort. Furthermore, it converts text to speech and speech to text to facilitate the learning process. Thus, the designed chatbot is inclusive, it can be used by disabled students using speech recognition technology. Disabled students can easily ask their questions by sending vocal messages and receiving their responses in voice format. In addition to that, our chatbot can recognize small talk messages and handle general conversation by using small talk data and the DialoGPT model. Thus, the chatbot adapts its response according to the student's requests. Hence, it encourages learners to interact freely with it and makes them more engaged and motivated. Although this work provides valuable insights to save time and energy needed in chatbot's creation process, it is important to acknowledge some limitations that could be covered by other researchers. Especially, (1) the current version AskBot is not evolutive because the local KB is still limited to already stored knowledge. (2) More advanced models could be tested to all questions without separating them to Wh-Questions and No-Wh-Questions. In future works, we plan to address these limitations and add more advanced features such as (1) Sentiment analysis to recognize the learner's emotions and personalized the chatbot's responses. (2) Deep learning models to create generative chatbots and test their ability to answer students' questions. (3) Distributed storage for the chatbot kB to enhance the speed system and its performance (4) integrate AskBot in the existing Learning Management Systems (LMS).

REFERENCES

- [1] E. Adamopoulou and L. Moussiades, "Chatbots: History, technology, and applications," *Mach. Learn. Appl.*, vol. 2, p. 100006, Dec. 2020, doi: 10.1016/j.mlwa.2020.100006.
- [2] S. Meshram, N. Naik, V. Megha, T. More, and S. Kharche, "College enquiry chatbot using RASA framework," presented at the 2021 Asian Conference on Innovation in Technology (ASIANCON), IEEE, 2021, pp. 1-8.
- [3] H. T. Hien, P.-N. Cuong, L. N. H. Nam, H. L. T. K. Nhung, and L. D. Thang, "Intelligent assistants in higher-education environments: the FIT-

- EBot, a chatbot for administrative and learning support,” presented at the Proceedings of the 9th International Symposium on Information and Communication Technology, 2018, pp. 69–76.
- [4] E. V. Kuanishbaevna, “The Role of the Teacher in Teaching Students in Accordance with National Values,” *Eur. J. Bus. Startups Open Soc.*, vol. 2, no. 1, pp. 79–80, 2022.
- [5] W. Ahmed and B. Anto, “AN AUTOMATIC WEB-BASED QUESTION ANSWERING SYSTEM FOR E-LEARNING,” *Inf. Technol. Learn. TOOLS*, vol. 58, no. 2, pp. 1–10, 2017.
- [6] E. Kasthuri and S. Balaji, “A Chatbot for Changing Lifestyle in Education,” in 2021 Third International Conference on Intelligent Communication Technologies and Virtual Mobile Networks (ICICV), Feb. 2021, pp. 1317–1322. doi: 10.1109/ICICV50876.2021.9388633.
- [7] R. Andersen, A. I. Mørch, and K. T. Litherland, “Collaborative learning with block-based programming: investigating human-centered artificial intelligence in education,” *Behav. Inf. Technol.*, vol. 41, no. 9, pp. 1830–1847, 2022.
- [8] A.-J. Moreno-Guerrero, J.-A. Marín-Marín, P. Dúo-Terrón, and J. López-Belmonte, “Chatbots in Education: A Systematic Review of the Science Literature,” *Artif. Intell. High. Educ.*, pp. 81–94, 2023.
- [9] S. Abbasi and H. Kazi, “Measuring effectiveness of learning chatbot systems on student’s learning outcome and memory retention,” *Asian J. Appl. Sci. Eng.*, vol. 3, no. 2, pp. 251–260, 2014.
- [10] N. Mutovkina, “Digital Technologies in the Educational Process and the Effectiveness of Their Use,” in *Advances in Intelligent Systems, Computer Science and Digital Economics IV*, Springer, 2023, pp. 937–946.
- [11] K. El Azhari, I. Hilal, N. Daoudi, and R. Ajhoun, “Chatbots in E-learning: Advantages and Limitations,” presented at the Colloque sur les Objets et systèmes Connectés-COC’2021, 2021.
- [12] P. Smutny and P. Schreiberova, “Chatbots for learning: A review of educational chatbots for the Facebook Messenger,” *Comput. Educ.*, vol. 151, p. 103862, Jul. 2020, doi: 10.1016/j.compedu.2020.103862.
- [13] M. A. Calijorne Soares, W. Cardoso Brandão, and F. Silva Parreiras, “A Neural Question Answering System for Supporting Software Engineering Students,” in 2018 XIII Latin American Conference on Learning Technologies (LACLO), Oct. 2018, pp. 201–207. doi: 10.1109/LACLO.2018.00047.
- [14] M. Verleger and J. Pembridge, “A Pilot Study Integrating an AI-driven Chatbot in an Introductory Programming Course,” in 2018 IEEE Frontiers in Education Conference (FIE), Oct. 2018, pp. 1–4. doi: 10.1109/FIE.2018.8659282.
- [15] M. Kowsher, F. S. Tithi, M. Ashraful Alam, M. N. Huda, M. Md Moheuddin, and M. G. Rosul, “Doly: Bengali Chatbot for Bengali Education,” in 2019 1st International Conference on Advances in Science, Engineering and Robotics Technology (ICASERT), May 2019, pp. 1–6. doi: 10.1109/ICASERT.2019.8934592.
- [16] H. A. Rasheed, J. Zenkert, C. Weber, and M. Fathi, “Conversational chatbot system for student support in administrative exam information,” presented at the ICERI2019 Proceedings, IATED, 2019, pp. 8294–8301.
- [17] P. A. Tamayo, A. Herrero, J. Martín, C. Navarro, and J. M. Tránchez, “Design of a chatbot as a distance learning assistant,” *Open Prax.*, vol. 12, no. 1, pp. 145–153, 2020.
- [18] A. T. Neumann et al., “Chatbots as a tool to scale mentoring processes: Individually supporting self-study in higher education,” *Front. Artif. Intell.*, vol. 4, p. 668220, 2021.
- [19] Y. S. Li, C. S. N. Lam, and C. See, “Using a machine learning architecture to create an AI-powered chatbot for anatomy education,” *Med. Sci. Educ.*, vol. 31, pp. 1729–1730, 2021.
- [20] K. Nhut Lam, N. Nhat Le, and J. Kalita, “Building a Chatbot on a Closed Domain using RASA,” *ArXiv E-Prints*, p. arXiv-2208, 2022.
- [21] S. Singh and S. Singh, “Effective Analysis of Chatbot Frameworks: RASA and Dialogflow,” *EasyChair*, 2516–2314, 2022.
- [22] D. Carlander-Reuterfelt, A. Carrera, C. Iglesias, O. Araque, J. Sanchez-Rada, and S. Munoz, “JAICOB: A Data Science Chatbot,” *IEEE ACCESS*, vol. 8, pp. 180672–180680, 2020, doi: 10.1109/ACCESS.2020.3024795.
- [23] B. Göschlberger and C. Brandstetter, “Conversational AI for Corporate E-Learning,” in Proceedings of the 21st International Conference on Information Integration and Web-Based Applications & Services, in iiWAS2019. New York, NY, USA: Association for Computing Machinery, 2019, pp. 674–678. doi: 10.1145/3366030.3366115.
- [24] A. S. Sreelakshmi, S. B. Abhinaya, A. Nair, and S. Jaya Nirmala, “A Question Answering and Quiz Generation Chatbot for Education,” in 2019 Grace Hopper Celebration India (GHCI), Nov. 2019, pp. 1–6. doi: 10.1109/GHCI47972.2019.9071832.
- [25] Y. Sumikawa, M. Fujiyoshi, H. Hatakeyama, and M. Nagai, “An FAQ dataset for E-learning system used on a Japanese University,” *Data Brief*, vol. 25, p. 104001, Aug. 2019, doi: 10.1016/j.dib.2019.104001.
- [26] I. Bohomolova, N. Kushnir, and S. Moshkovska, “Using Chatbots to Approach Individual Learning Trajectories in Physics for Foreign Students,” in CEUR Workshop Proceedings, 2021, pp. 253–263. [Online]. Available: <https://www.scopus.com/inward/record.uri?eid=2-s2.0-85121650753&partnerID=40&md5=5a7f89df4f4b10e49c20c8df2e9cfcf5>
- [27] C. Chun Ho, H. L. Lee, W. K. Lo, and K. F. A. Lui, “Developing a Chatbot for College Student Programme Advisement,” in 2018 International Symposium on Educational Technology (ISET), Aug. 2018, pp. 52–56. doi: 10.1109/ISET.2018.00021.
- [28] D. Carlander-Reuterfelt, Á. Carrera, C. A. Iglesias, Ó. Araque, J. F. Sánchez Rada, and S. Muñoz, “JAICOB: A Data Science Chatbot,” *IEEE Access*, vol. 8, pp. 180672–180680, 2020, doi: 10.1109/ACCESS.2020.3024795.
- [29] N. M. Deepika, M. M. Bala, and R. Kumar, “Design and implementation of intelligent virtual laboratory using RASA framework,” *Mater. Today Proc.*, Feb. 2021, doi: 10.1016/j.matpr.2021.01.226.
- [30] D. E. Gonda and B. Chu, “Chatbot as a learning resource? Creating conversational bots as a supplement for teaching assistant training course,” presented at the 2019 IEEE International Conference on Engineering, Technology and Education (TALE), IEEE, 2019, pp. 1–5.
- [31] H. Steinbeck, T. E. I. Zobel, and C. Meinel, “Towards leveraging conversational agents for instructors and learners to find and access learning resources,” in 2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC), Nov. 2021, pp. 607–611. doi: 10.1109/WEEF/GEDC53299.2021.9657307.
- [32] S. Meshram, N. Naik, V. Megha, T. More, and S. Kharche, “College enquiry chatbot using RASA framework,” presented at the 2021 Asian Conference on Innovation in Technology (ASIANCON), IEEE, 2021, pp. 1–8.
- [33] A. T. Neumann et al., “Chatbots as a Tool to Scale Mentoring Processes: Individually Supporting Self-Study in Higher Education,” *Front. Artif. Intell.*, vol. 4, 2021, doi: 10.3389/frai.2021.668220.
- [34] L. Wang and W. Wang, “Research and Construction of Junior High School Subject Q&A System Model based on Deep Learning,” in 2018 International Conference on Information Systems and Computer Aided Education (ICISCAE), Jul. 2018, pp. 504–508. doi: 10.1109/ICISCAE.2018.8666853.
- [35] S. Liang and R. Srikant, “Why deep neural networks for function approximation?,” *ArXiv Prepr. ArXiv161004161*, 2016.

Knowledge Management Model for the Generation of Innovative Capacities in Organizations that Provide Services

Cristhian Ronceros¹, José Medina², Pedro León³, Alfredo Mendieta⁴, José Fernández⁵, Yuselys Martínez⁶
Faculty of Computer Engineering and Systems, Private University San Juan Bautista, Ica-Perú^{1, 2, 3, 4, 5}
Oriente Gas Compression Management, Petroleos de Venezuela S.A. Maturín, Venezuela⁶

Abstract—The research was oriented to the development of a knowledge management model for the generation of innovative capacities in the organizations that provide services. A systematic review of articles published in the Scopus, IEEE Explore and Google Scholar databases was carried out, where 67 articles and 24 models were selected, which were subsequently analyzed based on their theoretical foundation, strategies used for the generation and dissemination of knowledge, incorporation of the organizational culture and the use of Information and Communication Technology (ICT) in the generation and dissemination of knowledge. The proposed model, unlike the models evaluated, is oriented towards generating added value with a new strategic approach structured in the knowledge management and organizational memory macro-processes, which in turn are divided into 29 and 11 macro-activities respectively, which incorporate the organizational culture and allows guiding the organization to improve its functions through the incorporation of innovation and use of ICT in all processes of the organization and in each stage of the generation and management of knowledge; establishing the essential parameters for the generation of innovative capacities, generation of knowledge, intellectual capital and transfer of information to knowledge, which can be used within the organization. The proposed model, unlike the models evaluated, is aimed at directly strengthening interpersonal relationships between members of the organization and between them and their clients. In the same way, it incorporates a maturity model made up of five levels to measure the state in which the organization is in relation to knowledge management.

Keywords—Component; model; knowledge management; intellectual capital; information and communication technologies

I. INTRODUCTION

In a competitive world like today, marked by globalization and constant changes in the environment, it has generated the obligation in organizations not only to produce but also to innovate their processes and improve their products and/or services through the incorporation of new technologies, knowledge and information management, among other strategies. [1,2] In these new innovations impregnated with radical changes, knowledge-based work prevails [3,4]. From this point of view, it is proposed that those companies that offer products and services based on knowledge and that put the generation of added value through innovation first will become an intelligent company with a competitive advantage over its competitors. [5]. Under this context, the knowledge and

reflective capacity of people is the driving force for business and organizational performance [6,7], positioning itself as the essential element of an organization to achieve a competitive advantage over its competitors [8,9]. It is an element of high differential value in organizations, used as a competitive strategy to maximize the productivity of organizations [10].

Knowledge is recognized as a fundamental resource for modern society and organizations as it has unlimited potential for business growth [11], becoming the main source of competitive advantage for organizations [12,13]. In this sense, organizations in their search to stay current in competitive environments, must ensure continuous improvement in all their processes and make use of those concepts, tools, and models that make them faster than their competitors; one of these concepts is knowledge management [14]. Knowledge management has the purpose of collecting, organizing, distributing, sharing and using the intangible assets of an organization [15]. Knowledge management has emerged as the strategy companies need to adopt to manage and use organizational knowledge. [16,17], that is, it allows information to be managed among its stakeholders, to advance its process of wealth creation and value addition [18] positively impacting organizational innovation [19]

In this context, organizations are oriented to form high-performance work teams in such a way that it allows them to synchronize the knowledge applied in the available resources to be used optimally. In this same-dimensional scheme, knowledge, information, and communications are extremely key factors in the production or service generation processes. In this sense, managing knowledge in organizations will not be anything other than the process of creating, storing and applying knowledge in solving problems related to the processes that are part of the value chain. To achieve this task, it is necessary to have quality information technology services, which include highly qualified human capital, as well as financial and technological resources through planning, direction, and control.

In this order of ideas, the following research questions emerged: What are the theoretical and practical elements that should be considered as base descriptors in the construction of a knowledge management model? What are the knowledge management models that facilitate the generation of innovative capacities in organizations? In this sense, the present investigation was oriented to the development of a knowledge

management model that allows service provider organizations to manage the knowledge inherent to the activities carried out by the personnel that work in the organization. The established objectives were as follows: a) Establish the theoretical and practical elements of knowledge management b) Compare the knowledge management according to the established theoretical and practical elements and c) develop a knowledge management model for the generation of innovative capacities in service provider organizations.

This research is structured as follows: Section II highlights a brief theoretical description of the issue raised. Section III describes the methodology used to address the research and develop the proposal of the knowledge management model. Section IV provides the development of the knowledge management model proposal for the generation of innovative capacities and the detailed description of each of the macro activities that comprise it. Section V includes the comparison of the models studied and the discussion of the most outstanding findings of the investigation. Section VI concludes the paper and highlights future work.

II. THEORY

A. Knowledge

The triumph of new companies is based on learning, where the most important capital is man [20,21,22], who owns the most precious asset of this era and has the power to transform it through learning, its socialization and application [23]. In this regard [24] point out that the best source for obtaining lasting competitive advantages is knowledge. Knowledge is a flow in which experiences, important values, contextual information, and expert points of view are mixed [25, 18], which provide a framework for the evaluation and incorporation of new experiences and information [26, 27].

B. Knowledge Management and Innovation

Knowledge management is the ability of a company to generate knowledge for its subsequent dissemination and incorporation into its products or services [28]. It is the relationship between the employee and the company aimed at managing information; that is, identify it, select it, organize it and give it a use to generate competitive advantage. [29, 30, 31, 32]. Knowledge management is more than a process of accumulation of information, since the most important objective is to create new knowledge that contributes value and is a source of competitive advantages [33, 34, 35]. Through knowledge management, organizations manage to capture, preserve, generate, and transmit the knowledge necessary to obtain a competitive advantage, through the generation of value and the innovation of their processes [36, 37, 38, 39]. In this sense, we can affirm that knowledge management is one of the most important assets of the organization, being the engine of organizational innovation [31, 32, 40, 41].

III. METHODS

A systematic review of articles published in the Scopus, IEEE Explore, and Google Scholar databases was carried out applying criteria to filter information such as the definition of keywords, aimed at obtaining the information according to the intention of the analysis of the present investigation. The first

step was to select the knowledge management models present in scientific databases and scientific indexing services such as Scopus, IEEE Explore, and Google Scholar, where 46 knowledge management models were selected. In the second step, the models that did not meet the criteria were discarded and only 24 were selected that clearly established the foundation bases and the strategies used for knowledge management. The third step was to perform a search for articles related to knowledge management, and 625 related articles were reviewed. In the fourth step, articles that did not meet the requirements were discarded and 67 articles that fall within the knowledge areas of this study were selected. In the following, Fig. 1 shows the flow chart for the selection of models and reviewed articles.

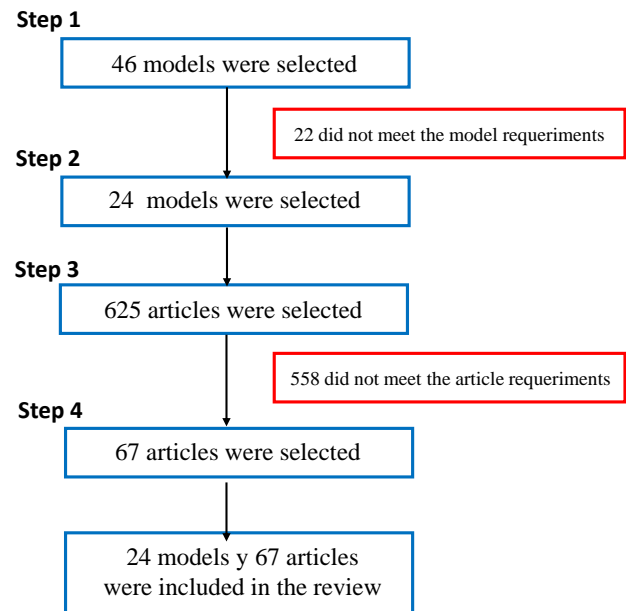


Fig. 1. Flow chart for the selection of models and reviewed articles.

The knowledge management models that were analyzed and that were the pillars of the proposed knowledge management model were: Wiig's knowledge management model. (Wiig, 1993), Nonaka and Takeuchi (1995), Technology Broker Model (Brooking, 1996), Canadian Imperial Bank Model (Hubert Saint-Onge, 1996), West Notary University Model (Bontis, 1996), Skandia Navigator Model (Leif and Malone, 1997), Intangible Assets Model (Sveiby, 1997), Intellect Model (Euroforum, 1998), Dow Chemical Model (Dow, 1998), Competitive Strategic Management Model: Intangible Capital (Bueno, 1998), Knowledge Practices Management Model (Tejedor and Aguirre, 1998), Nova Model. (Nova Care, 1999), Andersen model (Andersen, 1999), Knowledge Management Assessment Tool Model (Andersen and APQC, 1999), Cities Intellectual Capital Benchmarking System Model (CICBS, 2001), Operations Intellectual Capital Benchmarking System Model. (OICBS Viedma, 2001), Kerschberg technology integration model. (Kerschberg, 2001), Bustelo and Amarilla's knowledge management model (Bustelo and Amarilla, 2001), and Riesco's situational integrated model. (Riesco, 2004), Knowledge management model from a "humanist" vision (De Tena, 2004), Design of a knowledge management system in a school organization

(Durán, 2004), Paniagua technological knowledge management model and López (Paniagua and López, 2007), Holistic Model for knowledge management. (Angulo and Negrón, 2008), Knowledge management model for productivity and innovation centers. (Rivera, 2021); where fundamental aspects that give the nature of knowledge management models were evaluated, such as: the bases that support the models, intervention strategies for the generation, sharing, dissemination and internalization of knowledge, organizational culture and the role of technologies in knowledge management.

IV. RESULTS

A. Construction of the Knowledge Management Model

Based on the results obtained from the analysis of the 24 knowledge management models mentioned above and the analysis of the 67 articles related to the research topic that were selected as input for this research, a knowledge management

model was developed for the generation of innovative capacities in organizations that provide technological services, supported by various strategic actions that are in turn grouped according to the processes considered important for the correct generation and dissemination of knowledge.

In the model that is going to be presented, there are two macro processes such as Knowledge Management and Corporate Memory. In turn, from the Knowledge Management macro-process, two processes emerge, such as: Knowledge Management and Organizational Culture with their respective subprocesses: Intellectual Capital, Knowledge Transfer, Organizational Development, Organizational Learning, Organizational Commitment, and Competency Development. Each thread has its respective strategic actions to guarantee the harmonious functioning of the processes. Next, in Fig. 2, the Knowledge Management Model for the Generation of Innovation Capabilities in organizations that provide services.

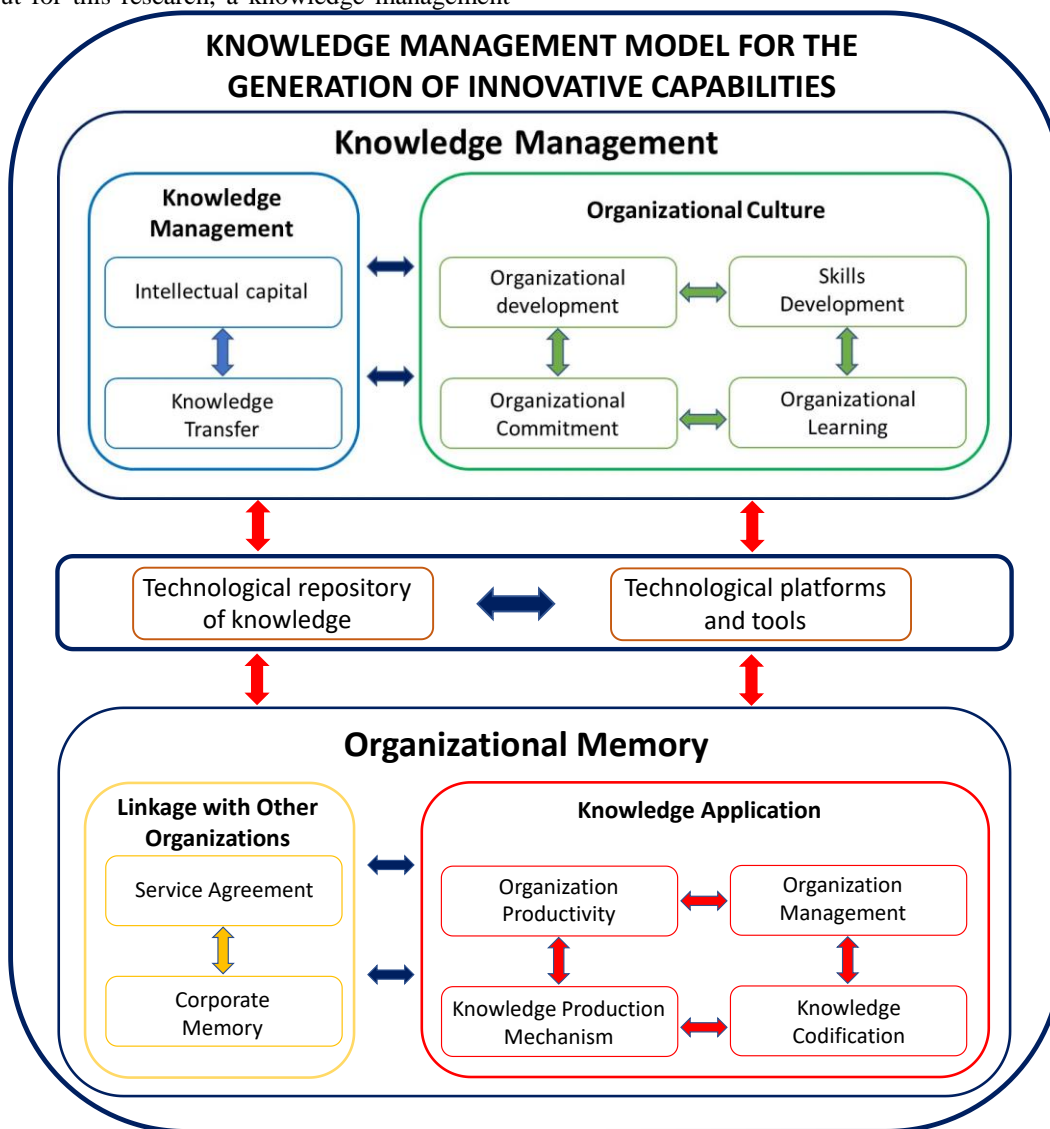


Fig. 2. Knowledge management model for the generation of innovation capabilities in organizations that provide technological service.

Each of the processes with their respective sub-processes is described below:

- 1) Knowledge management macroprocess
 - a) *Process: Knowledge Management*

Sub-process: Intellectual Capital

The strategic actions required for this subprocess are mentioned below:

- 1) Increase individual capacities through the encouragement and support of their staff to carry out post-graduate studies and/or updates
- 2) Guide the generation of knowledge to the needs of the environment.
- 3) Use the investigations carried out by the personnel who work within the organization.
- 4) Guide the production of knowledge to the solution of customer problems.
- 5) Establish knowledge-exchange relationships with other institutions in the area.
- 6) Establish policies for knowledge management.
- 7) Relate knowledge management to the organization's exchange strategies.
- 8) Guide the generation of tacit and explicit knowledge in the creation and capture of the same.
- 9) Establish the generation of knowledge due to the functions of the personnel that make it up .
- 10) Establish the order of knowledge in the organization that generates it.
- 11) Classify knowledge according to its content.

Sub-process: Knowledge Transfer

The strategic actions required for this sub-process are mentioned below:

- 1) Spread knowledge both internally and externally.
- 2) Share the knowledge produced to improve professional practice.
- 3) Establish the dissemination of knowledge generated by the staff working in the organization.

b) *Process: Organizational Culture*

Sub-process: Organizational Development

- 1) Relate the shared values with the management philosophy of your clients.
- 2) Operationalize shared values through productivity.
- 3) Guide the self-development of workers in relation to the needs of their clients.
- 4) Guide the self-development of workers in relation to personal skills.

Sub-process: Organizational learning

- 1) Link competencies related to knowing how to know with individual expectations.
- 2) Recognize the importance of organizational learning for knowledge management.

- 3) Spread knowledge and share best practices through workers

- 4) Relate the exchange strategies of the organization with knowledge management.

Sub-process: Corporate commitment

- 1) Develop a training plan aimed at organizational development and knowledge management.
- 2) Establish common protocols and standards for the production of knowledge
- 3) Evidence the organizational commitments in the production of knowledge.
- 4) Show individual commitments in the production of knowledge.

Sub-process: Competence development

- 1) Link the competences related to know-how with the capacities of the personnel, for the correct generation of knowledge.
- 2) Orient the competences related to know-how towards the ideal performance.
- 3) Link the competencies related to knowing how to know with the requirements of a particular situation.

Likewise, from the organizational memory macroprocess, two (2) processes emerge, such as: Application of knowledge and Linkage with Other Organizations. The Knowledge Application Process through the Management of the organization under study, was made up of the sub-processes (with their respective strategic actions): Productivity, Organization Management, Knowledge Production Mechanism, and Knowledge Codification. The Linkage process with other organizations was made up of the sub-process: Services agreement and Corporate Memory. Each of the strategic actions grouped into the corresponding sub-processes is described below:

- 2) Organizational memory macroprocess

a) *Process: Application of Knowledge*

Sub-process: Productivity of the Organization

- 1) Guide operational processes through the management responsible for knowledge management.
- 2) Include knowledge delivery mechanisms in the organization responsible for knowledge generation.

Sub-process: Organization Management

- 1) Add value to processes and results through the generation of innovative knowledge.
- 2) Promote and maintain cooperation with public and private institutions involved in national development.

Sub-process: Knowledge Production Mechanism

- 1) Establish an administrative structure for the registration of knowledge production.
- 2) Include knowledge production mechanisms in the different processes that make up the organization.

Sub-process: Codification of Knowledge

1) Codify the knowledge generated based on each product or service provided.

Sub-process: Investigation

1) Develop an adequate inventory of the knowledge production of the different processes that make up the organization.

2) Establish a human resource training process for Management based on the priorities of its clients.

b) Process: Linkage with Other Organizations

Sub-process: Acuerdo de Servicios

1) Establish cooperation agreements for the transfer of knowledge

Sub-process: Memoria Corporativa

1) Incorporate ICT for the storage and management of knowledge

The model embodied considers the technological platform as a fundamental pillar for the correct management of knowledge. The model is part of the contribution of IT in each process that makes up the organization under study, which will allow knowledge to be generated due to the functions of the members of the organization under study, for which standard processes are required for their management, which is specified in: capturing and creating knowledge; classify, order and encode to transfer, disseminate, and share it in a common language; thus, it is possible to objectify it, separate it and group it according to common characteristics of the organization.

In relation to the Organizational Culture for knowledge management, priority should be given to the characteristics of people and organizations such as: self-development, values, learning and sharing skills, as well as knowing, knowing how to do, and organizational exchange strategies; likewise, to the human asset, organizational development and organizational learning.

The Knowledge Management and Organizational Culture components are derived from the proposed Knowledge Management model, and both components interact with the possibility of being improved and affected. This is because knowledge management is an organizational process of intellectual capital, which is made up of human, structural, and referential capital.

The effectiveness of the knowledge put into action by the Management of the organization under study must be oriented by reason of the organization's mission. For the quality of knowledge, emphasis should be placed on the following: staff training regarding the social reality of the industry and the country and thus achieve a rational use of knowledge, have a standard structure and a system of indicators to measure and evaluate the added value of the knowledge managed by the Management.

B. Proposed Knowledge Management Maturity Model

For the implementation of the proposed model, a maturity model for knowledge management was developed, which is made up of five levels, as can be seen in Fig. 3. Each level reflects the state in which the organization is with related to knowledge management.

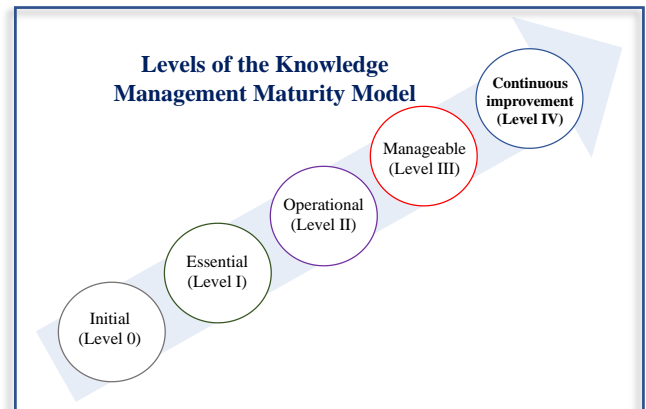


Fig. 3. Levels of the proposed maturity model for knowledge management. Adapted from Ronceros and Arias (2022).

Each stage reflects a state of maturity that is manifested through a set of characteristics (see Table I), which define the scale of the organization, which is visible through a process of evaluation and feedback as progress is made in its implementation.

TABLE I. MATURITY LEVELS

Maturity levels		
Level	Name	Features
I	Initial	There are no defined standard processes or methodologies for knowledge management.
		Knowledge management processes are not used or are used very little.
II	Essential	Fundamental processes for knowledge management defined and implemented.
		Tools implemented for the generation and dissemination of knowledge.
		Defined Roles and Responsibilities.
III	Operational	Establishment of a standard communication scheme.
		Defined, documented and integrated standard processes for knowledge management.
		Establishment of methodologies for the generation of knowledge
		Using the standard communication scheme.
		Quality Assurance in the generation and dissemination of knowledge.
		Processes for the generation of knowledge used by most of the organization's personnel.
IV	Manageable	Training process based on the career plan
		Particular management for corrective actions.
		Standardized and configured processes for the generation of knowledge.
		Historical database structure with

Maturity levels		
Level	Name	Features
		information on the different processes, lessons learned and metrics available to the entire organization.
		Evaluation of the processes involved in the generation and management of knowledge.
		Knowledge management tools integrated with corporate systems
		Identification, definition and documentation of critical success factors known by all members of the organization
V	Continuous improvement	Permanent evaluations and improvements in knowledge management
		Review and update of staff training plans
		Improvement of the instrument for measuring the maturity of knowledge management
		Evaluations and implementation of improvements to the methods and tools used for the generation and management of knowledge

V. DISCUSSION

The selected models were compared on the basis of their operation, intervention strategies for the generation, sharing, dissemination and internalization of knowledge. The comparative analysis of the knowledge management models and the selected learning models was carried out based on the descriptors base or foundation, Strategies for the generation and dissemination of knowledge, Organizational culture, participants and use of technologies; on which the following findings were obtained:

- **Base or foundation:** some models are based on the conversion of tacit knowledge and organizational knowledge on individual knowledge; others establish their operation in the culture of the organization and the commitment of the people who are part of it; another model is based on understanding different learning strategies by planning learning strategies to achieve learning conditions and objectives, in order to apply their knowledge and conceptual understanding to organizational problems.
- **Strategies for the generation and dissemination of knowledge:** the intervention strategies used in the different models for the generation, sharing, dissemination, and internalization of knowledge were evaluated. Saint-Onge (1996), bases his strategy on the fulfillment of corporate objectives through intellectual capital. Leif and Malone (1997) propose the creation of knowledge from the integration of human capital, structural capital, and client capital. Sveiby (1997) focuses on the cause and effect relationships between human capital, structural capital and relational capital. Bueno (1998), focuses on aligning the intellectual capital of the organization with the company's strategy. Tejedor and Aguirre (1998), the model guides its strategies in the strategic direction through competencies. Andersen (1999), the model establishes its strategies aimed at the measurement and

management of intellectual capital in organizations. Andersen and APQC (1999) are based on facilitating the flow of knowledge from individuals to the organization and back to individuals. Nonaka and Takeuchi (1999) proposed the creation of knowledge maps for the generation of tacit knowledge. Molina (2002), establishes learning communities and good practices for the generation of knowledge, assistance meetings, and help among the participants. Duran (2004) established the creation of forums for debates, meetings, and seminars among the participants to facilitate the generation of knowledge. Stallis and Jones (2002) and De Tena (2004) are based on the generation of knowledge maps for the creation of knowledge based on knowledge communities. Arciénaga et al. (2018) propose the creation of combined knowledge, through cooperative, learning, and work-based strategies.

- **Organizational culture:** Participation of the organizational culture in the processes of knowledge creation and management. The models proposed by Saint-Onge (1996), Leif and Malone (1997), Sveiby (1997), Bueno (1998), Tejedor and Aguirre (1998), Andersen (1999), and Andersen and APQC (1999), Stallis and Jones (2002), do not consider organizational culture in their model. Nonaka and Takeuchi (1995), De Tena (2004), Molina (2002), and Duran (2004), require for their operation that the culture of the organization pro-motes the sharing of knowledge among its members. Arciénaga et al. (2018) consider culture as a central point and a systemic factor in any discussion about the development of new knowledge or innovation.
- **Participants:** The different models consider the members of the organization responsible for the generation and development of knowledge creation and management systems.
- **Use of Technologies:** the role of technology in each of the evaluated models is slightly present in management, but is not present in the generation of knowledge. The Arciénaga et al. (2018) model establishes the use of ICTs for the generation and transfer of knowledge that allows innovation.

The models analyzed above mention that they use strategies for knowledge management, one group uses strategies that are oriented towards the identification and location of organizational knowledge, and another group uses strategies aimed at generating, disseminating and internalizing the knowledge that exists within the organization. each individual who works in the organization, however none of the models detail the strategies used or indicate the activities that involve these strategies, that is, they do not have a detailed scheme for the execution of the model unlike the proposed model where it is proposed a strategic structure that includes an execution scheme of the macro activities that make up each sub-process which in turn make up the macro processes of the model, in which 40 macro activities are involved.

Less than 30% of the models analyzed consider organizational culture as a fundamental basis for knowledge

management. However, it is not reflected in the model schematic. The organizational culture is a fundamental basis in the generation and management of knowledge, which is why in the proposed model it is considered as a process made up of four macro activities, being a main link of the model. In order to guarantee the alignment of the organizational culture to the proposal of knowledge management, the proposal of the maturity model of knowledge management composed of five levels was developed, in order to obtain a diagnosis of the state or level in which the organization is located. organization in relation to knowledge management in order to make the corresponding adjustments to the organizational culture to facilitate the success of the implementation of the knowledge management model. In this order of ideas, less than 40% of the models analyzed mention information technology for the transfer of knowledge and less than a third of this percentage indicates it in their scheme. However, the use of information technologies is not considered in the stages prior to the transfer of knowledge, which could be considered a weakness of these models. The proposed model considers the use of technologies in each of the phases of knowledge generation and management in organizations.

VI. CONCLUSION

Knowledge Management should be understood as the process within the organization aimed at creating a culture of sharing knowledge that has been acquired outside of it or that has been generated within it, with the purpose of being used by all members of the organization. organization, in order to encourage it to be more competitive through the generation of innovative processes, products and/or services. In this context, the proposed model:

- Generates value through knowledge management in all processes that are part of the organization, supported by communication as a process where the receiver is of great importance in the development of knowledge and its dissemination to its collaborators and clients.
- It is supported by concepts such as intellectual capital, knowledge management and organizational culture. Therefore, it translates into the need to develop the intellectual capital of the organization under study.
- It is a strategic process since it contributes to the generation, recruitment, organization, dissemination and use of intellectual capital, which allows the creation of a sustainable competitive advantage in organizations.
- Provides a new approach to guide the organization to improve its function; establishing the essential parameters for the generation, treatment and transfer of knowledge, which can later be used within the organization.
- It allows establishing the framework on which the organization can improve the work performance of the workers, as well as safeguard all the necessary knowledge for the full operation of the organization, strengthening the work groups that are in charge of solving problems and preserving the information.

- It allows contributing to the constitution of teams or working groups for the transfer of information and problem solving, directly strengthening the interpersonal relationships between the members of the organization and between them and their clients.
- It allows organizations to improve organizational performance, since its application directly contributes to the performance of the organization, which translates into more efficient employees and therefore a more profitable company.
- It provides a maturity model made up of five levels that allow measuring the relationship level of knowledge management within the organization, important information for the application of any knowledge management model.
- The proposed model is oriented to organizations that provide services; however, it could be considered to be implemented in other types of organizations. In this sense, the authors consider its implementation in a production organization for further studies to measure its level of effectiveness and its impact on knowledge management.

REFERENCES

- [1] A. Hayfa, A. Abdullah, and A. Blaqees. "The Impact of Knowledge Management on Organizational Performance" International Journal of Advanced Computer Science and Applications(ijacsa), 9(4), 2018. <http://dx.doi.org/10.14569/IJACSA.2018.090432>
- [2] K. North and R. Rivas. Gestión del conocimiento. Una guía práctica hacia la empresa inteligente, Libros en red, 2008. México.
- [3] P. Drucker. La gerencia en la sociedad futura. Grupo Editorial Norma, 2002. Bogotá.
- [4] R. Ngah, T. Tai, and N. Bontis. Knowledge management capabilities and organizational performance in roads and transport authority of Dubai: the mediating role of learning organization. Knowl. Process Manag. 2016. 23, 184–193. <https://doi.org/10.1002/kpm.1504>
- [5] F. Liu, D. Dutta, and K. Park. From external knowledge to competitive advantage: absorptive capacity, firm performance, and the mediating role of labour productivity. Technol. Anal. Strateg. Manag. 2020. 1–13. doi: 10.1080/09537325.2020.1787373
- [6] H. Zaim, S. Muhammed, and M. Tarim. Relationship between knowledge management processes and performance: critical role of knowledge utilization in organizations. Knowl. Manag. 2019. Res. Pract. 17, 24–38. <https://doi.org/10.1080/14778238.2018.1538669>
- [7] Wahda. "Mediating effect of knowledge management on organizational learning culture in the context of organizational performance", Journal of Management Development, 2017. Vol. 36 No. 7, pp. 846-858. <https://doi.org/10.1108/JMD-11-2016-0252>
- [8] L. Namdarian, A. Sajedinejad & S. Bahanesteh (2020). The impact of knowledge management on organizational performance: a structural equation modeling study. ad-minister
- [9] M. Zabaleta, L. Brito, & M. Garzón. Knowledge management model in the ICT area for a Colombian Caribbean university. Lasallian Research Magazine, 2016. 13(2), 136-150. <https://doi.org/10.22507/rli.v13n2a13>
- [10] D. Rubier. The incidence of knowledge management in the success of organizations. Cooperativism and Development, 7(3), 392-405. Epub 2019. Retrieved on May 14, 2022, de http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S2310-340X2019000300392&lng=es&tng=es.
- [11] D. Valdés. The incidence of knowledge management in the success of organizations. Cooperativism and Development, 2019. 7(3), 392–405. <http://coodes.upr.edu.cu/index.php/coodes/article/view/269>

- [12] E. Agudelo, y A. Valencia. Knowledge management, an organizational policy for today's company. I will engineer. Chilean engineering magazine, 2018. 26 (4), Chile. (Pp. 673-684). <http://dx.doi.org/10.4067/S0718-33052018000400673>
- [13] V. Pérez, and M. Flores. Theoretical models of knowledge management: descriptors, conceptualizations and approaches. Entreciencias: dialogues in the Knowledge Society, 2016. 4 (10), México. (Pp. 201-227). <https://doi.org/10.21933/J.EDSC.2016.10.181>
- [14] F. Muñoz. Knowledge management, need or added value? Science and Air Power, 2017. 12(1), 276-286. <https://doi.org/10.18667/cienciaypoderareo.578>
- [15] Á. Fidalgo-Blanco, M. L. Sein-Echaluce, & F. J. García-Peñalvo. Knowledge Spirals in Higher Education Teaching Innovation. International Journal of Knowledge Management, 2014.10(4), 16-37. <https://doi.org/10.4018/ijkm.2014100102>
- [16] C. Pons, O. Molina, L. Ruiz, V. Medero, & S. Rodríguez. Use of ICT for knowledge management and its contribution to agri-food development. Cuban Journal of Informatics Sciences, 2017. 11(3), 114-125. Retrieved on August 30, 2022, from http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S2227-18992017000300010&lng=es&tlng=es.
- [17] N. Silva, & D. Torres. Knowledge Audits and strategic knowledge management. Scope, 2018. 7(18), 138-152. Epub 27 de junio de 2019. Retrieved on August 30, 2022, http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S2411-99702018000300138&lng=es&tlng=es.
- [18] K. Asma and M. Abdellatif. A New Model for the Impact of Knowledge Management on University Performance. Journal of Information & Knowledge Management. 2016. Vol. 15 N° 4, pp. 1650041. <https://doi.org/10.1142/S0219649216500416>
- [19] E. Byukusenge, & J. C. Munene. Knowledge management and business performance: Does innovation matter Cogent Business & Management, 2017. 4(1), 1-18. <https://doi.org/10.1080/23311975.2017.1368434>
- [20] L. Pedraja, E. Rodríguez, & J. Rodríguez. The influence of knowledge management on organizational effectiveness: A study in public institutions and private companies. Magazine of the Faculty of Engineering University of Antioquia. 2009. 47, 218-227
- [21] L. Afshari, A. Nasab, and G. Dickson. Organizational culture, social capital, and knowledge management: An integrated model. International Journal of Knowledge Management. Volume 16, Issue 2, April-June 2020, Pages 52-66, doi: 10.4018/IJKM.2020040104.
- [22] J. González Millán, and L. Álvarez Castañón. Knowledge management and open innovation: Towards the formation of a theoretical relational model. Revista Venezolana de Gerencia. Volume 24, Issue 88, 2019, doi: 13159984.
- [23] D. Rubier. The incidence of knowledge management in the success of organizations. Cooperativism and Development, 7(3), 392-405. Epub 2019. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S2310-340X2019000300392&lng=es&tlng=es
- [24] I. Nonaka, H. Takeuchi. Knowledge creation process. 2004. Available Online at: http://www.gestiondelconocimiento.com/modelo_nonaka.htm.
- [25] M. Guerrero. Knowledge management in companies, its importance and dependence on the leadership style of senior management. INNOVA Research Journal, 2016. 1(1), 1-7. <https://doi.org/10.33890/innova.v1n1.2016.2>
- [26] C. Li, S. Ashraf, F. Shahzad, I. Bashir, M. Murad, N. Syed, and M. Riaz. Influence of Knowledge Management Practices on Entrepreneurial and Organizational Performance: A Mediated-Moderation Model. Frontiers in Psychology. Volume 11, 3 December 2020, Article number 577106.
- [27] F. Alhamdi. Impact of Knowledge Management Models on Entrepreneurial Organizations and Mediating Role of Strategic Entrepreneurship: An Exploratory Study of Asiaccell Mobile Communications, Iraq. Eurasian Journal of Educational Research. Volume 2022, Issue 98, 2022, Pages 147-164, doi: 10.14689/ejer.2022.98.010.
- [28] I. Nonaka y H. Takeuchi. The Knowledge-Creating Company. 1995. New York Oxford. Oxford University Press.
- [29] R. Bustelo and I. Amarilla. Knowledge management and information management. 2001. Retrieved from http://www.intercontact.com.ar/comunidad/archivos/Gestion_del_Conocimiento-BusteloRuesta-AmarillaIglesias.pdf
- [30] E. Agudelo, and A. Valencia. La gestión del conocimiento, una política organizacional para la empresa de hoy. Ingeniare. Revista chilena de ingeniería, 26(4),673-684. 2018. <https://dx.doi.org/10.4067/S0718-33052018000400673>
- [31] R. Kumar. Assessing The impacto of knowledge management on innovation: An empirical study. Prestige International Journal of Management & IT-Sanchayan, 8(1), 1-14. 2019.
- [32] N. Nguyen, A. Pham, & T. Thang. Knowledge acquisition, knowledge management strategy and innovation: An empirical study of vietnamese firms. 2020. Cogent Business & Management, 7(1), 1-14.
- [33] L. Giraldo, and D. Montoya. Aplicación de la metodología Commonkads en la Gestión del Conocimiento. Revista CEA, 2015. 1(2), 99-108. doi: <https://doi.org/10.22430/24223182.133>
- [34] M. Abubakar and H. Elrehail. Knowledge management, decision-making style and organizational performance. Journal of Innovation & Knowledge, 4 (2), 2019. España. (Pp.104-114). <https://doi.org/10.1016/j.jik.2017.07.003>
- [35] A. Alfaro-Ramos, and J. Ferreras-Méndez. Knowledge management and intellectual capital in the business model innovation of Costa Rican manufacturing firms. Tec Empresarial. Volume 16, Issue 2, 2022, Pages 18-33, doi: 10.18845/te.v16i2.6168
- [36] M. Wang, and T. Yang. Investigating the success of knowledge management: An empirical study of smalland medium-sized enterprises. Asia Pacific Management Review, 2016. Vol. 21. No 2, pp: 79-91. Disponible: <http://dx.doi.org/10.1016/j.apm-rv.2015.12.003>.
- [37] A. Calvo-Mora, A. Navarro-García, M. Rey-Moreno, and R. Periañez-Cristobal. Excellence management practices, knowledge management and key business results in large organizations and SMEs: A multi-group analysis, European Management Journal, 2016. Vol. 34. No 6, December, pp: 661-673. Disponible: <http://dx.doi.org/10.1016/j.emj.2016.06.005>.
- [38] L. P. Vargas, C. V. Durán, and J. C. Méndez. Innovation and Knowledge Management for the Increase of Business Productivity. Memories (0124-4361), 2016. Vol. 14. No 26, pp: 1-41. Disponible: doi:10.16925/me.v14i26.1571.
- [39] J. Acosta, and A. Fischer. Conditions of knowledge management, capacity for innovation and business results. An explanatory model. Thinking & Management, 2013. Vol. 35, pp: 25-63.
- [40] C. Cvitanovic, A.J. McDonald, A.J. Hobday. From science to action: Principles for undertaking environmental research that enables knowledge exchange and evidence-based decision-making, Journal of Environmental Management, 2016. Vol. 183, Part 3, pp: 864-874. Disponible: <https://doi.org/10.1016/j.jenvman.2016.09.038>.
- [41] L. Gómez-Bayona, E. Londoño-Montoya, & B. Mora-González,. Intellectual capital models at the business level and their contribution to the creation of value. Revista CEA, 2020. 6(11), 165-184. <https://doi.org/10.22430/24223182.1434>

Recognition of Lung Nodules in Computerized Tomography Lung Images using a Hybrid Method with Class Imbalance Reduction

Yingqiang Wang, Honggang Wang, Erqiang Dong*

School of Electronic Information Engineering, Xi'an Siyuan University
Xi'an 710038, Shaanxi, China

Abstract—Lung cancer is among the deadly diseases affecting millions globally every year. Physicians' and radiologists' manual detection of lung nodules has low efficiency due to the variety of shapes and nodule locations. The paper aims to recognize the lung nodules in computerized tomography (CT) lung images utilizing a hybrid method to reduce the problem space at every step. First, the suggested method uses the fast and robust fuzzy c-means clustering method (FRFCM) algorithm to segment CT images and extract two lungs, followed by a convolutional neural network (CNN) to identify the sick lung for use in the next step. Then, the adaptive thresholding method detects the suspected regions of interest (ROIs) among all available objects in the sick lung. Next, some statistical features are selected from every ROI, and then a restricted Boltzmann machine (RBM) is considered a feature extractor that extracts rich features among the selected features. After that, an artificial neural network (ANN) is employed to classify ROIs and determine whether the ROI includes nodules or non-nodules. Finally, cancerous ROIs are localized by the Otsu thresholding algorithm. Naturally, sick ROIs are more than healthy ones, leading to a class imbalance that substantially decreases ANN ability. To solve this problem, a reinforcement learning (RL)-based algorithm is used, in which the states are sampled. The agent receives a larger reward/penalty for correct/incorrect classification of the examples related to the minority class. The proposed model is compared with state-of-the-art methods on the lung image database consortium image collection (LIDC-IDRI) dataset and standard performance metrics. The results of the experiments demonstrate that the proposed model outperforms its rivals.

Keywords—Lung cancer; artificial neural network; fuzzy c-means clustering method; reinforcement learning; restricted boltzmann machine

I. INTRODUCTION

Lung cancer is a dangerous and deadly disease, causing millions of deaths worldwide each year. The chances of surviving for five years with lung cancer are only 14% [1, 2]. CT imaging is the most popular method for screening lung nodules and has reduced lung cancer mortality by 20% [3]. CT provides valuable information for the diagnosis of lung cancer, but as the number of images increases, accurate evaluation becomes more challenging and poses risks to radiologists [4]. Therefore, it has become necessary to assist physicians in making faster and more accurate decisions than CT images [5].

Various methods are used for lung segmentation, including supervised, unsupervised, and semi-supervised learning

approaches. Supervised learning techniques such as ANN require training data to provide good performance for segmentation [6]. Deep neural networks are becoming popular but require large training datasets and huge computational costs [7]. Unsupervised learning approaches, such as clustering-based methods, rely on the entire image and operate based on the acquired pixel distances. Partitional and hierarchical clustering techniques are primary examples of cluster analysis, with crisp and fuzzy clustering procedures as subcategories [8]. The fuzzy c-means (FCM) algorithm is superior to other clustering algorithms because it is more tolerant of ambiguity and retains more of the image, but it struggles to segment images containing complex textures and backgrounds. Boosted clustering algorithms have been employed to segment lung nodules, but they suffer from sensitivity to noise and require a lot of repetition for convergence. The FRFCM segmentation algorithm [9] is suggested to segment nodules from lung CT images with strategic views of robustness against noise and more rapid but precise segmentation performance. The FRFCM algorithm defines a spatial function by combining the similarity of the gray pixel value and the membership to update the membership function in each iteration. The FRFCM algorithm can provide suitable segmentation results for all images with low computational cost and high accuracy.

Esfandiari et al. [10] conducted a systematic review of medical studies and found that categorization is the most time-consuming aspect of data mining approaches in medical fields such as diagnosis, therapy, and screening. Meanwhile, Lee et al. [11] studied methods for identifying lung nodules and found that most of them relied on the classification of nodule candidates, which reduces workload by removing undesirable portions from CT images. Adaptive thresholding-based methods are considered the most effective for identifying lung nodule candidates, although various other methods have been utilized [12]. The most successful image classification models, including medical ones, are CNNs. However, using CNNs for nodule candidate classification cannot achieve high performance since they are not suitable for extracting features from images with low dimensions [13].

RBMs [14] are a variety of neural networks with stochastic processing units coupled bi-directionally. Two classes of neurons are visible and hidden in an RBM. A group of neurons has no connection between its nodes, yet it must nonetheless form a bipartite network with symmetric connections between

*Corresponding Author.

its visible and hidden units. RBMs can be trained using more effective algorithms than unrestricted Boltzmann machines. In classification applications, RBMs are frequently used for feature extraction [15].

Data imbalance, which can significantly reduce performance, is a major challenge to medical image classification, as negative instances are much smaller than positive ones. Measures that could be implemented to contend with class imbalance are separated into algorithm-level and data-level methods. The data-level strategy uses under-sampling, over-sampling, or a combination of the two to lessen the negative consequences of imbalanced classification [16]. Algorithm-level approaches increase the weight of the minority class [17]. Furthermore, deep-learning approaches could be employed to address the issue of imbalanced classification [18]. Over recent years, various domains, such as computer games, robots' control, and recommendation systems, have successfully employed deep reinforcement learning (DRL). DRL enhances the performance of classification problems by eliminating noisy data and discovering better features. Notwithstanding, few works have applied DRL to classify imbalanced data. DRL is eminently suitable for classifying imbalanced data because of its learning approach. It employs a reward function that discriminates between classes by imposing heavier penalties on minority classes or giving higher rewards to them.

The paper presents a hierarchical lung nodule detection model established on the FRFCM clustering algorithm, an RBM, and an ANN boosted by a RL-based algorithm. The proposed model includes five steps, which is shown in Fig. 1: 1) Patient lung extractor: The FRFCM algorithm is used to segment CT images into two right and left lungs, followed by the utilization of a CNN to identify sick lungs. 2) Nodule candidate detection: In this step, an adaptive thresholding algorithm is employed to recognize the suspected region of interest (ROI). 3) Feature extraction: Some standard features are selected from every ROI, and then the RBM is considered as a feature extractor that extracts rich features among the standard features. 4) Classification: The features extracted by RBM are entered into an ANN to classify ROIs as healthy or sick areas. Due to many healthy areas than sick ones, ANN becomes imbalanced. RL is used to solve this issue and describe classification as a guessing game with sequential decision-making steps. At each stage, the agent uses a training instance to represent the environmental state and then, guided by a policy, performs a three-class classification operation. The classifier will accept a positive reward if the operation is completed; a negative reward will be given. The minority class receives higher compensation than the majority class. The agent's objective is to categorize the samples as precisely as possible to earn the most cumulative rewards, and 5) Localization of nodules: The Otsu thresholding algorithm is used to localize the nodule.

The contributions of the suggested model can be summed up as follows: 1) A hybrid model is presented that contains some steps that try to decrease the problem space in every step, 2) The FRFCM algorithm is considered for segmentation, which is one developed model with low computational cost and high accuracy, 3) A DRL model is offered for the classification

problem of ROIs to address imbalanced classification, and 4) The effectiveness of each component, including lung segmentation, classification, and nodule identification, is examined through studies, and its performance is evaluated in comparison to other approaches.

The remaining sections of the article are structured as follows: In Section II, a review of the literature for analyzing the lung nodule is provided. In Section III, the suggested approach is presented in further depth. Section IV presents the experimental findings and necessary analyses. Section V presents the discussion. Finally, the conclusion of the paper is presented in Section VI.

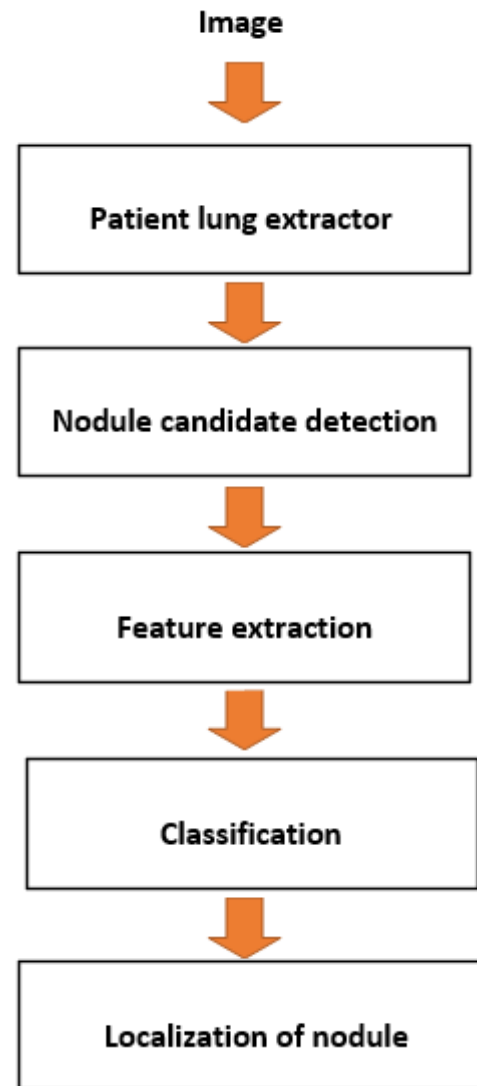


Fig. 1. Steps of the proposed algorithm.

II. RELATED WORK

Due to the small size of nodules, interpreting the CT images by the radiologist becomes difficult, so the task of accurate diagnosis is in trouble [19]. On the other hand, early detection of nodules is essential to achieve the best treatment plan and increase the survivability rate [20]. So far, many types of machine learning and deep learning approaches have been

introduced, focusing on detecting and localizing lung nodules, some of which are reviewed in this section.

A. Machine Learning

Ozekes and Camurcu [21] presented an automatic approach for pulmonary nodule detection using traditional machine learning methods like template matching. Wu, Sun, Wang, Li, Wang, Huo, Lv, He, Wang and Guo [22] designed an ANN architecture to distinguish malignant from benign samples. Texture and radiologist features were extracted and combined for classification in this work. Kuruvilla and Gunavathi [23] presented a computer-aided design (CAD) system comprising segmentation and classification stages for CT images. First, segmentation was done, then extracting features from the segmented area. Finally, an ANN was hired for classification. This work considered conventional features such as mean, SD, and skewness. Farahani, Ahmadi and Zarandi [24] founded a CAD system to diagnose pulmonary nodules in CT images. Their algorithm included three steps. First, a new segmentation algorithm was proposed based on FCM and KFCM algorithms that achieved acceptable results for lung segmentation. Second, they manually analyzed features and selected the best one for nodules classification. Finally, an ensemble of classifiers was applied for classification. Khan, Rubab, Kashif, Sharif, Muhammad, Shah, Zhang and Satapathy [25] combined pre-processing step with an ensemble approach for localized lung cancer. They showed that contrast stretching integrated with the discriminative classical features and the ensemble classifier could achieve high performance.

The inflexibility of feature extraction strategy is a major challenge in machine learning, particularly in deep learning. The lack of flexibility makes it difficult to learn high-level representations that generalize well to new and unseen data. This is particularly problematic when working with complex and heterogeneous datasets, where feature extraction is often a time-consuming and computationally expensive process. In addition, inflexible feature extraction strategies can also lead to overfitting, where the model becomes too specialized to the training data and performs poorly on new data.

B. Deep Learning

With the advent of deep learning algorithms in many applications [26-38], many researchers used them for nodule detection tasks [39, 40]. With its layered structure, deep learning can learn high-level features with high accuracy [41, 42]. Zhang, Yang, Gong, Jiang and Wang [43] introduced fusion feature vectors that integrated CNN, LBP, and HOG features to characterize the nodule area better. They used deep learning as a feature extraction module, in which the final feature vector was passed to a GBM classifier. The proposed method employed hybrid features for lung nodule classification. Hu et al. [61] combined the K-means algorithm kernel with the Mask R-CNN deep segmentation technique. This study had the greatest results, with a segmentation accuracy of 97% and an average runtime of 11s. Blanc et al. [44] offered a method to classify pulmonary nodules into two classes depending on whether their volume is greater than 100 mm³ or not. Zhang et al. [45] presented a multi-level CNN method to extract the essential features of any image. They optimize the values of meta-parameters using a non-stationary

kernel-based Gaussian surrogate model. Mobiny and Van Nguyen [46] developed an algorithm based on capsule networks for 3D lung nodules. The authors have shown that their algorithm performs well when a small dataset size. However, the prediction accuracy decreases when the dataset becomes too large. Kim et al. [47] designed a method based on the multi-scale gradual integration CNN, which used multi-scale inputs with different levels for classification. The proposed classification method suffers from data imbalance. Ozdemir et al. [48] suggested a two-step Bayesian CNN structure to take advantage of the segmentation predictions and uncertainties. In the first one, segmentation algorithms were performed on 2D axial CT slices. The original image combines segmentation predictive mean and standard deviation maps to create a 3-channel composite image fed into a 3D Bayesian CNN for nodule detection. Zhu et al. [49] combined expectation maximization (EM) to make a new 3D CNN method, whose purpose was to extract poorly supervised labels for nodule detection. In this algorithm, the Faster RCNN algorithm completed the nodule suggestion generation. Moreover, Logistic regression and the Half-Gaussian model were used for the central lobe location slice. Dou et al. [50] incorporated a group of 3D CNNs with diverse receptive field sizes to use multi-level contextual data around nodules. There are three different 3D CNNs designed for different-sized cropped cubes. Jiang et al. [51] suggested employing multi-group patches extracted from lung scans as a method for lung nodule detection. Frangi-filters were first utilized to remove the vessel-like formations. A slope analysis method was created to remove the nodules from the lung by enhancing the juxta-pleural nodules. Eventually, a CNN using multi-crop (MC) pooling was created to understand the specifics of radiologists using original CT images and their binarization. Dodia et al. [52] developed a new deep-learning-based method to detect lung nodules with decreased false positives. Their work employs a receptive regularization on the convolution and deconvolution layers of a decoder block in the V-Net. Huang et al. [53] proposed a CAD-based method that utilizes a 3D CNN [54] to detect lung nodules in low-dose CTs. The proposed method merges a priori intensity and geometrical knowledge about nodules and complicates anatomical structures with features and classifiers. Wu et al. [55] presented an interpretable method for pulmonary nodule segmentation, which supplies high-level semantic attributes and the areas of detected nodules. Huang et al. [56] introduced a fast and fully-automated end-to-end approach that automatically segments the exact nodule contours from the raw CT images with few FPs. Maqsood et al. [57] conducted a segmentation method using U-Net for lung nodule segmentation. Their technique increased the view of filters without reducing the loss and scope of data by integrating compactly and densely linked useful convolutional blocks with Atrous convolution blocks. Shen et al. [58] proposed a methodology called MC-CNN, which automatically obtains important nodule information by employing a multi-crop pooling strategy, cropping different regions from convolutional feature maps, and then repeatedly utilizing max-pooling.

Although deep models benefit from some properties, including extracting automatic features, they suffer from several difficulties. In the case of lung segmentation, an

extensive training dataset and huge computational costs are required for deep learning models. In nodule detection, they extract some suspicious ROIs and then classify them using CNN-based methods. Even though CNN can extract rich features, they fail in extracting features from small areas, i.e., ROIs.

III. ARCHITECTURE OF THE PROPOSED APPROACH

The paper offers a hybrid model containing steps that decrease problem space at every step. The proposed model consists of five steps: Patient lung extractor, Nodule candidate detection, Feature extraction, Classification, and Extraction of nodule area. First, CT images are segmented by the FRFCM algorithm that extracts two lungs, and then the lung containing the nodule for the next steps is identified by a CNN. In the second step, the adaptive thresholding method is hired to recognize ROIs from the suspicious lung. In the third step, some standard features from every ROI are selected, and then an RBM is considered to extract rich features from the standard ones. After that, the features extracted by RBM into an ANN to classify ROIs as healthy or sick areas. The proposed ANN benefits from an RL-based algorithm to handle class imbalance. Finally, the Otsu thresholding algorithm is used to localize the nodule. The overall architecture of the suggested model is given in Fig. 2; the next section provides further specifics.

A. Patient Lung Extractor

This step aims to segment the lungs of a CT image to reduce the search space by removing backgrounds and noises. The literature survey has proposed many preliminary segmentation methods for lung segmentation, but most fail to remove the noise from the image and segmentation quickly. To improve the weakness of the FCM-related algorithms, which are sensitive to noise, the FRFCM algorithm was proposed by combining local spatial data into the FCM algorithm to get better precision results. The objective function of the FCM algorithm with local information is provided by

$$J_m = \sum_{i=1}^N \sum_{k=1}^c u_{ki}^m ||x_i - v_k||^2 + \sum_{i=1}^N \sum_{j=1}^c G_{ki} \quad (1)$$

where $f = \{x_1, x_2, \dots, x_N\}$ illustrates a grayscale image, where x_i stands for the gray level of the i -th pixel. N shows the total number of pixels in image f , and c displays the number of clusters. m indicates a weighting exponent on each fuzzy membership, determining the amount of fuzziness of the resultant classification. $U = [u_{ki}]$ and G_{ki} denote the membership partition matrix and fuzzy factor provided as

$$G_{ki} = \sum_{\substack{r \in N_i \\ i \neq r}} \frac{1}{d_{ir} + 1} (1 - u_{kr})^m ||x_r - v_k||^2 \quad (2)$$

$$u_{ki} = \frac{1}{\sum_{j=1}^c \left(\frac{||x_i - v_k||^2 + G_{ki}}{||x_i - v_j||^2 + G_{ji}} \right)^{\frac{1}{m-1}}} \quad (3)$$

where v_k describes the prototype value of the k -th cluster, computed as

$$v_k = \frac{\sum_{i=1}^N u_{ki}^m x_i}{\sum_{i=1}^N u_{ki}^m} \quad (4)$$

Additionally, regarding morphological reconstruction (MR), the reconstruction of an image is shown as d and provided by

$$\varepsilon_p = R_e^c(f) \quad (5)$$

where $R_e^c(\cdot)$ is the morphological closing reconstruction, which is calculated as

$$R_e^c(f) = R_{R_f^\beta(\tau(f))}^\tau(\beta(R_f^\beta(\tau(f)))) \quad (6)$$

where τ and β stand for the erosion and dilation operation, respectively. Finally, considering morphological closing reconstruction, the objective function of FRFCM is computed as

$$J_m = \sum_{k=1}^c \sum_{p=1}^q [u_{kp}^m (||\varepsilon_p - v_k||)^2] + \sum_{k=1}^c \sum_{p=1}^q G_{kp} \quad (7)$$

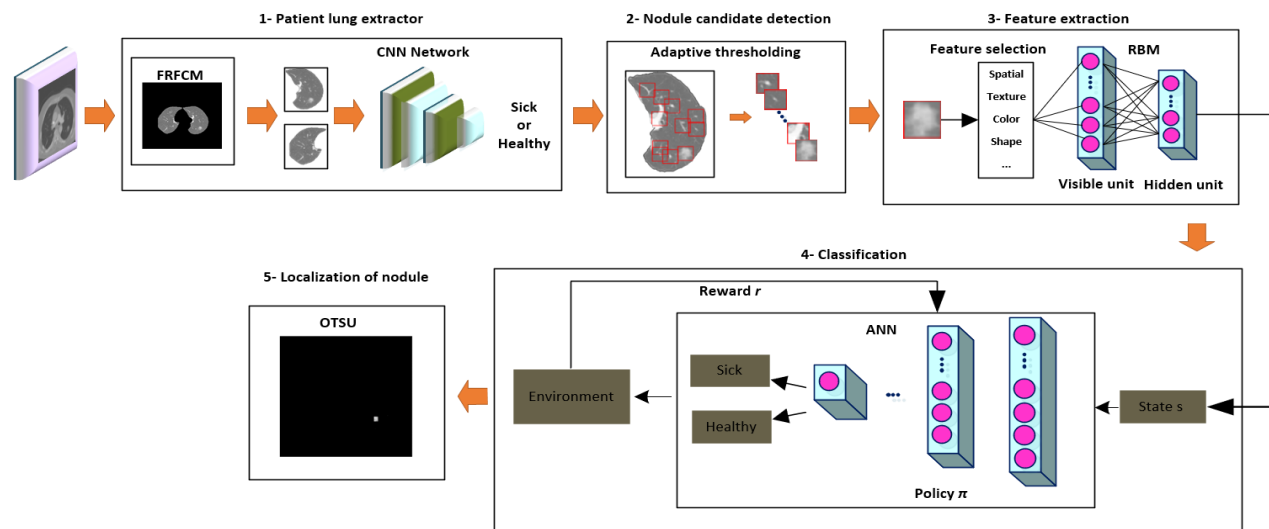


Fig. 2. Overall architecture of the proposed model.

A CNN is used to identify the lung containing nodules to decrease the search space further. Specifically, the only purpose of using CNN is to determine which lung in the CT image has the nodule, regardless of the nodule position.

B. Nodule Candidate Detection

The presence of any pulmonary nodules must be determined after the ill lung has been located using CT scans. However, finding nodules is difficult because pulmonary nodules are predominantly linked to the pleura or blood vessels. Moreover, various structural structures, such as blood arteries, airways, bronchioles, and alveoli, are present in both lungs and may have a comparable gray level to the nodules. Therefore, a transition step is needed to avoid missing nodules in CT images to specify a set of possible nodule candidates from ROIs [59]. This paper applies the adaptive thresholding method [61], one of the most valuable and efficient thresholding techniques, to select pulmonary nodule candidates for segmented lung images. This algorithm selects pixels less than a threshold value (TV) as the background, and those higher than the TV are chosen as the nodule candidate areas. In this method, the TV of each pixel is established on the values of the adjacent pixel intensity. The output of this step is different regions where the nodule is likely to be present. In this article, the bounding box, which has the most intersection of union (IOU) [60] with the actual location of the nodule, is identified as the patient area. Furthermore, two bounding boxes with IoU = 0 are randomly selected as non-nodule regions.

C. Feature Extraction

After detecting the nodule candidates from the sick lungs, the following stage selects a comprehensive feature vector for

each ROI to distinguish them as nodule or non-nodule. Indeed, ROIs and other structures are classified on such feature vectors. Although CNNs can select and extract automatically, they suffer from the classification of low dimensions, i.e., ROIs [61]. In this study, six classes of statistical features are used [62]: 1) Spatial including Entropy, Mean, Kurtosis, Skewness, Histogram of Oriented Gradients (Hog), 2) Texture including Haralick, Local Binary Pattern (LBP), Gray Level Co-occurrence Matrix (GLCM), Oriented FAST and Rotated BRIEF (ORB), 3) Color including Min Intensity, Max Intensity, Mean Intensity, Weighted Intensity, 4) Shape containing Area, Perimeter, Extent, Solidity, 5) Transform including Orientation, and 6) Edge including Corner Harries. These features are the most important ones that paraphrase an area appropriately. Fig. 3 shows the placement of these features in a vector for the next step.

It is possible that some features selected may be irrelevant and redundant, so a feature extraction step seems necessary. Many medical applications, particularly classification, depend on feature extraction [63]. It extracts the most relevant features and preserves the important information of the original image by removing unrelated and repetitious information [64]. An RBM is used that extracts efficient features and reduces the feature vector for this goal. Structurally, RBM is a deep architecture consisting of two layers of stochastic units called visible and hidden. Each element in the unit is connected indirectly with all pairs of another unit. There are no connections from visible to visible or hidden to hidden nodes in an RBM.

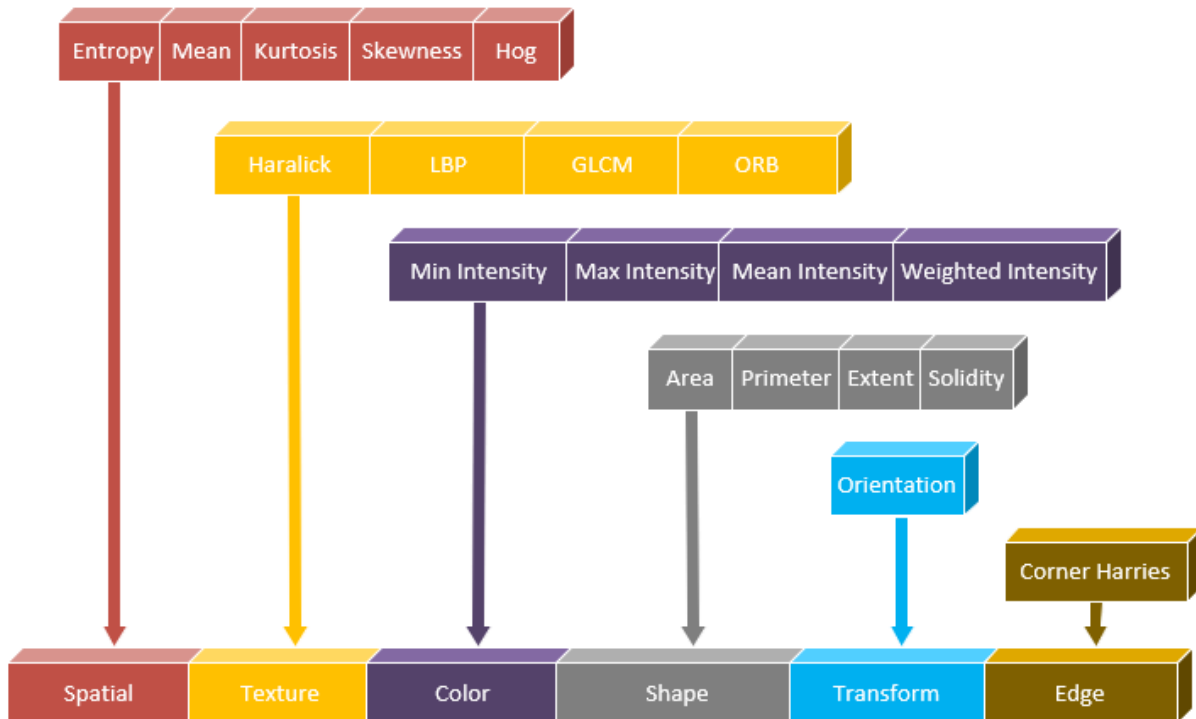


Fig. 3. Placement of features in a vector.

D. Classification

This step employs an ANN to classify ROIs as nodules or non-nodule areas. A classification imbalance issue exists due to the difference in the amount of data between non-nodule areas and nodule ones. The imbalanced classification Markov decision process (ICMDP) method is utilized to formulate a decision-making process that is sequential in nature, in order to deal with the problem of imbalanced classification. RL involves an agent attempting to achieve a high score by taking actions within an environment that lead to an optimal policy. For the suggested model, the agent receives a dataset sample and performs a classification task at each time step. Then, the agent receives the instant feedback from the environment. A correct classification results in a positive score, while an incorrect classification yields a negative score. The optimal policy can be achieved by maximizing the cumulative rewards in the algorithm of RL. Let a set of N samples with corresponding labels be given, denoted as $D = \{(x_1, y_1), (x_2, y_2), (x_3, y_3), \dots, (x_N, y_N)\}$, where x_i is the i -th sample and y_i is its label. The following describes the intended configurations:

- Policy π_θ : Policy π is a function that maps states (S) to actions (A), where $\pi_\theta(s_t)$ represents the action performed in a state s_t . The classifier model with weights θ is referred to as π_θ .
- State s_t : A sample x_t from the dataset D is mapped to each state s_t . The initial state s_1 is represented by the first data x_1 . In order to prevent the model from learning a specific sequence, D is randomized in each episode.
- Action a_t : The action a_t is executed to make a prediction about the label x_t , where the classification is binary, and the possible values of a_t are either 0 or 1. Here, 0 denotes the minority class, while 1 represents the majority class.
- Reward r_t : The reward is based on the performance of the action taken. If the agent performs the correct classification, it receives a positive reward; otherwise, it receives a negative reward. The bonus amount should differ for each class. Calibrated rewards can greatly enhance the model's performance by ensuring that the level of reward is aligned with the action taken. This work specifies the prize for an action using the subsequent formula:

$$r(s_t, a_t, l_t) = \begin{cases} +1, a_t = l_t \text{ and } s_t \in D_P \\ -1, a_t \neq l_t \text{ and } s_t \in D_P \\ \lambda, a_t = l_t \text{ and } s_t \in D_N \\ -\lambda, a_t \neq l_t \text{ and } s_t \in D_N \end{cases} \quad (8)$$

where D_P and D_N show the majority class and minority class. Correctly/incorrectly classifying a sample from the majority class yields a reward of $+\lambda/-\lambda$, where $0 < \lambda < 1$.

- Terminal E: In each training episode, the training process ends at various terminal states. A sequence of state-action pairs $\{(s_1, a_1, y_1), (s_2, a_2, y_2), (s_3, a_3, y_3), \dots, (s_t, a_t, y_t)\}$ from an initial state to a final state is

referred to as an episode. In the suggested model, the end of an episode is determined by either classifying all the training data or by incorrectly classifying a sample from the minority class.

- Transition probability P: The next state, s_{t+1} , is reached by the agent from the current state, s_t , according to the sequence of the data read. The probability of transition is represented as $p(s_{t+1}|s_t, a_t)$.

In deep Q-learning, the agent aims to choose actions to maximize the expected future rewards. Future rewards are worth γ times less in each subsequent time step:

$$R_t = \sum_{t'=t}^T \gamma^{t'-t} r_{t'} \quad (9)$$

where T shows the last time-step of the episode. An episode ends when either all the samples have been classified. Q values, measures of state-action quality, are defined as the expected return of the following strategy π , after seeing state s and taking action a :

$$Q^\pi(s, a) = E[R_t | s_t = s, a_t = a, \pi] \quad (10)$$

The maximum expected reward across all strategies after observing state s and taking action a is the best action-value function:

$$Q^*(s, a) = \max_{\pi} E[R_t | s_t = s, a_t = a, \pi] \quad (11)$$

This function satisfies the Bellman equation, which expresses that the optimal expected return for a given action is equal to the sum of the rewards from the current action and the maximum expected return from future actions at the following time:

$$Q^*(s, a) = E[r + \gamma \max_{a'} Q^*(s', a') | s_t = s, a_t = a] \quad (12)$$

The best action-value function is estimated iteratively utilizing the Bellman equation:

$$Q_{i+1}(s, a) = E[r + \gamma \max_{a'} Q_i(s', a') | s_t = s, a_t = a] \quad (13)$$

During training, after a state s is shown to the network, the network outputs an action a for that state while the environment returns a reward r , and the next state becomes s' . These parameters are embodied in a tuple (s, a, r, s') that is saved into the replay memory, M . Minibatches B of these tuples are selected from the replay memory to perform gradient descent. The loss function is expressed as:

$$L_i(\theta_i) = \sum_{(s, a, r, s') \in B} (y - Q(s, a; \theta_i))^2 \quad (14)$$

where θ indicates the model's weight, and y , shows the estimated target for the Q function. The latter is equal to the reward for the state-action combination plus the discounted maximum future Q value:

$$y = r + \gamma \max_{a'} Q(s', a'; \theta_{k-1}) \quad (15)$$

Of note, the Q value for the terminal state equals zero. The gradient value for the loss function at step i is calculated as follows:

$$\nabla_{\theta_i} L(\theta_i) = -2 \sum_{(s,a,r,s') \in B} (y - Q(s, a; \theta_i)) \nabla_{\theta_i} Q(s, a; \theta_i) \quad (16)$$

By performing a gradient descent step on the loss function, the model weights must be updated to minimize the error:

$$\theta_{i+1} = \theta_i + \alpha \nabla_{\theta_i} Q(s, a; \theta_i) \quad (17)$$

where α represents the learning rate.

E. Localization of Nodule

In the proposed method, sick ROIs, which ANN identifies, are localized by the Otsu thresholding algorithm [65]. Otsu is generally used for segmentation and localization applications [66, 67]. Otsu calculates and evaluates their between-class variation to determine the optimal threshold value. The Otsu shows that maximizing the between-class variance of the segmented classes is equivalent to minimizing the within-class variance. The Otsu segmentation level is acquired by reducing intra-class pixel power or gradually increasing inter-class variance. The inter-class variable specifies the mean between the pixels or classes of pixels [68].

IV. RESULTS AND DISCUSSION

A. Dataset

The Lung Image Database Consortium image collection (LIDC-IDRI) [69] was made by the Foundation for the National Institutes of Health (FNIH) and the Food and Drug Administration (FDA). In this dataset, a thoracic CT scan and a corresponding XML file, including the annotated results done by four radiologists, are included in 1,018 CT scans of 1,010 patients registered. The annotation procedure comprises two stages and seeks to recall all nodules in every CT scan as accurately as possible. In the first step, called the blinded-read step, every radiologist examined scans alone and observed lesions, including “nodule <3 mm” and “non-nodule ≥ 3 mm”. In the second unblinded-read stage, each radiologist checked their marks and decided to be aware of the anonymous marks of different radiologists. In the dataset, 7,371 lesions have been classified as nodules by at least one radiologist; 2,669 of these lesions received at least one “nodule 3 mm” designation from four radiologists, and 928 received four. These 2,669 lesions were given intellectual nodule characteristic ratings and nodule outlines.

B. Results

For this project, Python and the PyTorch framework were used, and the codes were written in a Jupyter notebook. The best model for the LIDC-IDRI dataset was obtained after 50 epochs, and the entire training process lasted for 3.5 hours. The optimal performance of the proposed model hinges on determining the best values for its hyperparameters. This task is not a straightforward one, as it entails exploring a vast search space of potential hyperparameter combinations and conducting numerous experiments to assess their efficacy. It demands significant effort and expertise in designing an

effective search strategy to identify the optimal values for each parameter. To achieve the optimal values, we conducted multiple experiments. A list of the most important parameters used in suggested model is shown in Table I.

The suggested algorithm effectiveness can be determined by comparing the suspicious areas that ANN identified with the real bounding box. For this goal, five algorithms are selected, namely 3D CNN [53], PN-SAMP-M [55], R-CNN [56], DA-Net [57], and MC-CNN [58], for comparison. The evaluation results obtained for the Intersection over Union (IoU) [60] and Hausdorff distance (HD) [70] criteria for the LIDC-IDRI dataset are depicted in Table II. According to the analysis, much research has improved nodule detection performance and achieved relatively excellent results. The IoU value of the MC-CNN model was 0.682, and the 3D CNN model later significantly enhanced it. The offered PN-SAMP-M model achieved an IoU score of 0.711, about 18% better than the previous model. Recent work was on the DA-Net model, which got an IoU score of 0.759. However, the proposed model outperformed the leading algorithm, DA-Net, with an IoU score of 0.825, or by around 20%. Fig. 4 shows examples of nodule detection by these methods. From the figure, the mask bounding box in the proposed model is more matched to that of the ground truth bounding box.

TABLE I. PARAMETER SETTING

Parameter	Value
Number of convolution layers	3
Convolution filters	32, 16, 8
Convolution padding	3 * 3
Convolution stride	2 * 2
Convolution kernel Size	1 * 1
Max-pooling size	2 * 2
Epochs	50
Early stopping	Yes (with patience=5)
Dropout probability	0.4
Batch size	64
Image pixel intensity range	[0, 1]
Image size	100 * 100

TABLE II. COMPARISON OF THE SUGGESTED MODEL WITH OTHER WORKS

Algorithm	IoU	HD
3D CNN [53]	0.683	0.875
PN-SAMP-M [55]	0.711	0.894
R-CNN [56]	0.727	1.136
DA-Net [57]	0.754	1.055
MC-CNN [58]	0.770	1.472
Proposed	0.826	1.618

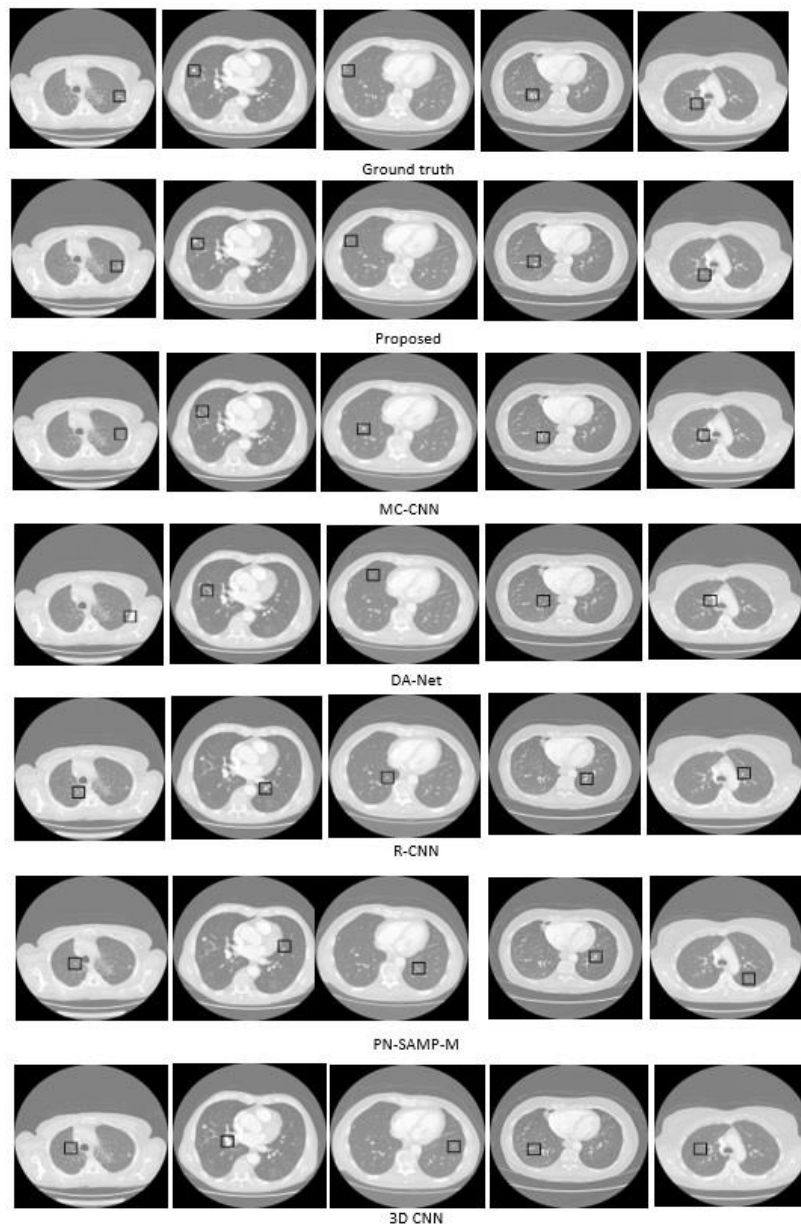


Fig. 4. Examples of nodule detection for methods.

1) *Examples of localizing nodules:* In the proposed algorithm, the suspicious regions detected by the ANN network are given to the Otsu algorithm to extract the localized nodule. Table III shows the results of ten samples of test images with the main images of the lung, single lungs, and localized nodules. Considering all these results shows that the Otsu algorithm localized the nodules well.

2) *Analyze of classifier:* The proposed ANN classifies nodule candidate areas and is a key element in the proposed model's performance. To investigate ANN performance, four models, namely HOUSES-UCB [45], CapsNet [46], MGI-CNN [47], and RFR V-Net [52], were employed for comparison on the LIDC-IDRI dataset. The evaluation criteria utilized are Accuracy, Sensitivity, Precision, F-measure,

Specificity, and G-mean. G-mean and F-measure are valuable metrics for evaluating the effectiveness of imbalanced classification algorithms [71]. G-mean is the geometric mean of sensitivity and precision, and F-measure represents a harmonic mean between recall and precision. As the G-mean and F-measure get a higher score, better performance of the algorithm would be reached. The performance of the proposed ANN, along with RL and the three-deep learning-based models, are compared in Table IV. The ANN model is a classifier that does not use RL for classification, and CNN is a model used instead of ANN. As the results reveal, the ANN+RL model has a more acceptable performance than the rest, which reduces errors by more than 45% in all criteria.

TABLE III. EXAMPLES OF NODULES LOCALIZED BY THE OTSU ALGORITHM

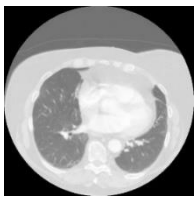
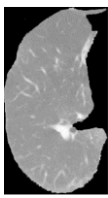

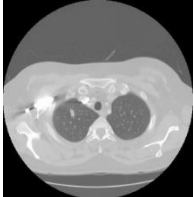
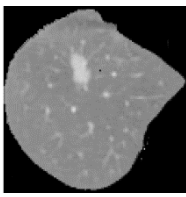
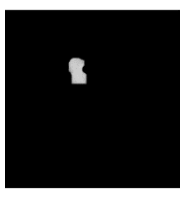

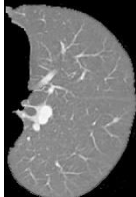


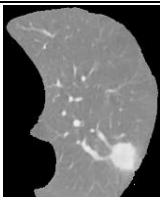
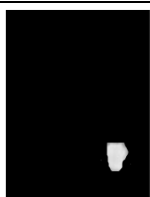
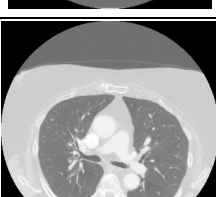
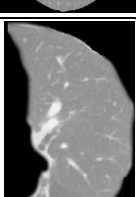
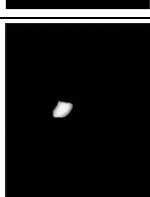
Original Image	Single Lung	localized nodule
		
		
		
		
		

TABLE IV. PERFORMANCE OF VARIOUS CLASSIFIERS

Method	Accuracy	Sensitivity	Precision	F-measure	Specificity	G-mean
HOUSES-UCB	79.11	80.85	90.72	91.52	87.26	82.75
CapsNet	83.00	83.63	91.33	92.35	88.45	83.40
MGI-CNN	85.33	85.71	92.49	93.40	90.02	84.45
RFR V-Net	89.40	90.28	94.72	95.50	91.02	88.48
CNN	84.12	86.23	91.03	91.25	89.15	85.47
ANN	88.13	93.61	95.65	94.61	92.15	86.53
ANN+RL	94.94	96.82	97.91	96.89	95.15	92.90

TABLE V. RESULTS OBTAINED FOR FUZZY ALGORITHMS

Method	IoU	HD
FCM	0.67	1.02
KFCM	0.76	1.56
SAFCM	0.72	1.81
FLICM	0.78	2.01
FRFCM	0.88	2.65

Furthermore, the maximum value of all measures in deep models is relatively different from ANN+RL. For example, by comparing ANN+RL and the second-best model, i.e., RFR V-Net, the difference is about 11% and 10% for the two criteria of F-measure and Recall. The comparison of ANN with ANN+RL shows that the RL trick improved the model by approximately 50%.

3) *Comparison of segmentation methods:* In this section, a comparison of the FRFCM algorithm with other fuzzy-based algorithms is intended. For this purpose, four algorithms, namely FCM [72], KFCM [73], SAFCM [74], and FLICM [75], were selected. The metrics IoU and HD, which are the most widely used for segmentation tasks, were used for evaluation. Table V shows the evaluation results of these methods. FCM had the weakest performance with values of 0.67 and 1.02 for IoU and HD, respectively. The developed algorithms, KFCM and SAFCM, had more power than FCM. Overall, fuzzy methods performed weaker than FRFCM, which outperformed the second-best algorithm, FLICM, with an improvement of roughly 36% for the IoU metric.

To investigate the execution time of algorithms, 20 test data samples were selected and the time spent on them was measured. Table VI shows the average time for these 20 samples. As expected, the time average of the FRFCM algorithm is less than others. Fig. 5 indicates a sample of CT images to highlight the superiority of FRFCM over others. As can be seen, the FCM algorithm did not correctly extract the nodule areas inside the lungs, which severely reduces the system performance since the proposed model's next steps depend on correctly extracting nodules in the segmentation step. Although KFCM performs better, they are unable to extract nodules. FRFCM is the most robust algorithm among the rest.

4) *Exploration of the loss function:* Data imbalances can also be handled using conventional methods, including tweaking data augmentation and loss functions. Among these techniques, the loss function is more important as it can emphasize the minority class. Five functions Balanced Cross-Entropy (BCE), Weighted Cross-Entropy (WCE), Dice Loss (DL), Tversky Loss (TL), and Focal Loss (FL) [76] were chosen to test the effectiveness of the loss functions in the proposed model. In the BCE and WCE loss functions, the positive and negative examples are given equal weight. The FL function can benefit applications using unbalanced data, which helps the model concentrate more on learning complex samples by underweighting the contribution of simple

examples [139]. Table VII displays the evaluation outcomes of these loss functions for the datasets. The FL function outperforms the others as expected, and as a result, it is around 51.16% better than the other loss functions. However, the FL function performs 34% worse than reinforcement learning.

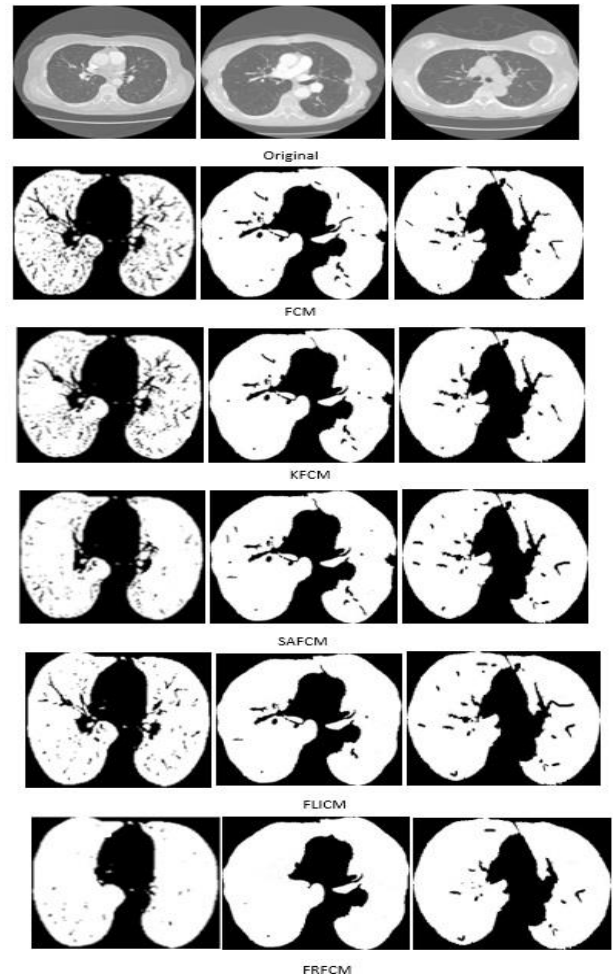


Fig. 5. Examples of lung segmentation by fuzzy algorithms.

TABLE VI. COMPARISON OF EXECUTION TIMES OF METHODS (IN MILLISECOND)

Method	Time
FCM	810
KFCM	405
SAFCM	374
FLICM	328
FRFCM	219

TABLE VII. EFFECTIVENESS OF THE SUGGESTED ANN FOR VARIOUS LOSS FUNCTIONS

Method	Accuracy	Sensitivity	Precision	F-measure	Specificity	G-mean
WCE	83.78	84.25	86.48	86.40	85.03	82.79
BCE	84.47	85.85	87.02	87.79	86.14	83.71
DL	87.09	90.74	90.82	89.63	88.10	85.89
TL	88.25	91.43	92.79	90.20	90.96	87.06
FL	90.55	93.15	94.09	93.19	92.48	89.79

5) *Impact of the reward function:* In the proposed model, rewards of +1 /-1, and $+λ/-λ$ are assigned for correct/incorrect classifications to the majority and minority classes, respectively. $λ$ depends on the relative proportions of the majority to minority samples: the optimal value of $λ$ is expected to decrease as the ratio increases. To investigate the impact of $λ$, the model performance is evaluated with $λ$ initialized using a value from incremental values $\{0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1\}$, while keeping the majority class bonus constant (Fig. 6). At $λ = 0$, the impact of the majority class becomes zeroized; and at $λ = 1$, the relative impacts of both majority and minor classes are equal. Model performance across all metrics peaks at a $λ$ value of 0.3 (increasing from 0 to 0.4, and decreasing from 0.3 to 1. As such, while the effect of the majority class needs to be attenuated by adjusting $λ$, the overall model performance can be degraded by using too low of a value.

6) *Analysis of features extracted by RBM:* The hidden unit in the RBM network fed to ANN is a practical tool containing the compressed data of nodule candidate areas. The additional information is entered into the ANN by increasing the hidden size, which is practically useless. On the other hand, a small hidden size may not be able to hold all the information. To check the effect of the hidden size on the proposed model, six values $\{50, 80, 120, 150, 180, 210\}$ were tried as the hidden size on the model. Fig. 7 displays the results for these metrics. For all metrics, when the hidden size takes the values from the interval $[50, 120]$, the chart moves upward, and from $(120, 210]$, it has a descending movement. Accordingly, the best value for the hidden size is found to be 120.

C. Discussion

This section looks at why the suggested approach produces superior outcomes to other approaches. First of all, suggested model inherits from the hierarchical structure. Although these models may increase the time of diagnosis, they are relatively accurate as they provide each section's analysis process separately.

The proposed model consisted of several parts, each designed for a specific purpose. Two lungs needed to be extracted to reduce the entrance space, and despite the many segmentation methods available, FRFCM was found to be the best option. FRFCM was selected due to its short implementation time and acceptable results obtained in other articles, and its superiority over other algorithms was confirmed in Tables V and VI. Additionally, unlike different algorithms, FRFCM completely extracted all the holes in terms of schematic output, demonstrating its stability against various noise and other image disturbances (see Fig. 5). In the following steps, it was unnecessary to utilize a lung that did not include a nodule. Among deep learning structures for classification, CNN was the best architecture, which required little pre-processing compared to others. Whereas, in previous designs, filters were typically hand-engineered, CNN learned these filters firmly. Therefore, the first stage alone could diagnose lung diseases that might be hidden from the physician.

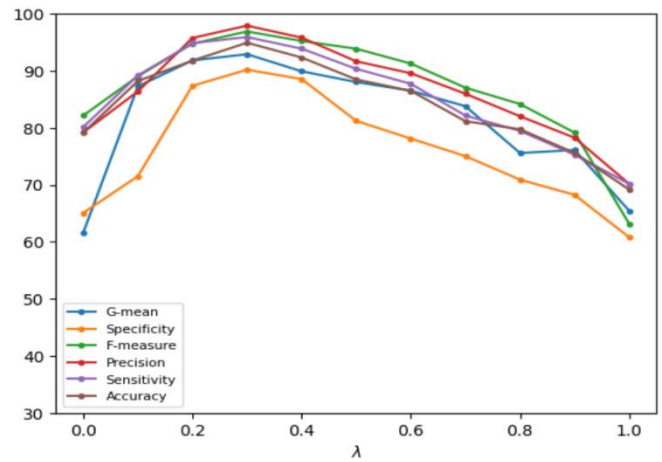


Fig. 6. Performance metrics plotted vs. the value of $λ$ in the reward function.

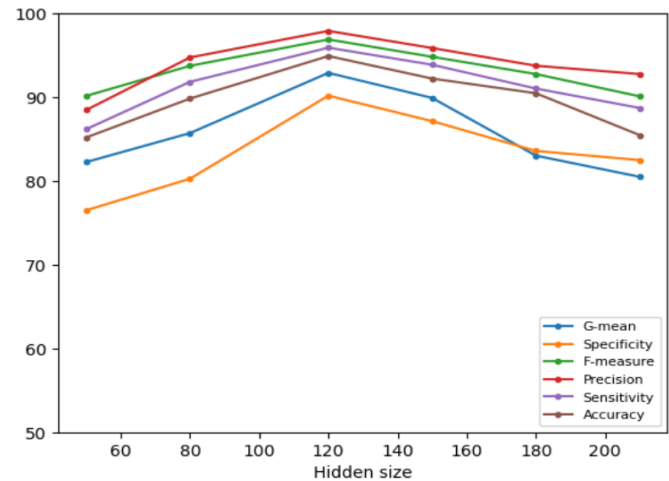


Fig. 7. Performance metrics plotted vs. the hidden size in RBM.

To reduce the input space further, the adaptive thresholding method was chosen as the best algorithm to select ROIs that are more likely to be nodules. This algorithm works well because it compares a pixel with the pixels around the contrast lines and prevents soft gradient changes. Moreover, another advantage is that only one image pass is needed.

One of the proposed algorithm's steps was selecting and extracting ROIs for classification. Although CNNs are one of the best models for classification, they cannot be helpful for tiny areas. In the experiments, CNN is used with various architectures as a classifier and reported the best result in Table IV. As can be seen, it works weaker than ANN. On the other hand, due to the nature of deep learning, the leading network is multi-layered, so some features are lost during the extraction and transfer process to the lower layer. In particular, overfitting may occur due to the extraction of many features. These problems are exacerbated if the amount of data is small. Therefore, the traditional feature selection process can be one of the critical options for selecting basic features with little data and achieving high accuracy. But the presence of unrelated and redundant features reduces the performance of machine learning models. For this purpose, an RBM that can encode any distribution and is computationally efficient was applied. Moreover, activations of the hidden layer can be used as input

in deeper models. The performance of the model is also affected by the size of the hidden layer, for which there is generally no rule for the number of hidden layers and accuracy. As shown in Fig. 7, better performance was obtained by setting the size to 120.

But the most important and innovative part of the proposed method was the classification of ROIs with ANN, which was an imbalanced problem due to a large amount of majority class data. From the results, it was confirmed that reinforcement learning applied to the classification could essentially solve it. On the other hand, it is hypothesized that the reinforcement learning method used in this study can be utilized by all classifiers experiencing imbalance to address this issue.

One potential limitation of the proposed model is its computational intensity, which may be due to the use of multiple algorithms, such as FRFCM, CNN, adaptive thresholding, RBM, ANN, and Otsu thresholding. As a result, the processing time required for analyzing a large number of CT images may increase. Another limitation is the possibility of class imbalance, as sick ROIs are less common than healthy ones, which may decrease the performance of the ANN. Although the reinforcement learning-based algorithm is used to address this issue, it may not always be fully effective. Furthermore, the accuracy of the proposed model may be dependent on the quality of the CT images used for analysis. The model's accuracy may decrease if the images have poor resolution or are affected by image artifacts or noise. Lastly, the proposed model was evaluated using the LIDC-IDRI dataset, and its performance may vary when applied to other datasets or in clinical settings. Therefore, further testing and validation are necessary to determine the model's robustness and generalizability.

V. CONCLUSION

This paper presented a hybrid method to recognize the pulmonary nodules in CT lung images. The proposed method's structure was composed of five different steps. First, the FRFCM algorithm is applied, which developed fast and robust to segment CT images, followed by a CNN to identify the sick lung. Then, the adaptive thresholding algorithm is performed to detect suspected ROIs from sick lungs identified by CNN. Next, some statistical features are determined from every ROI, and then an RBM is hired as a feature extractor that extracts wealthy features. After that, an ANN is utilized to classify ROIs as nodule or non-nodule areas. Finally, sick ROIs are localized by the Otsu thresholding algorithm. Naturally, sick ROIs are less than healthy ones, resulting in an imbalanced classification that reduces ANN performance. To shield this problem, RL is applied, which frames the training process as a sequential decision-making step. At each stage, the agent gets an example and categorizes it. The agent gets a reward from the environment for each categorization act in which the minority class receives a larger reward than the majority class. Finally, the agent discovers an optimal policy with a specific reward function and a supportive learning environment. Several experiments are designed to investigate the parts of the suggested model on the LIDC-IDRI dataset and standard performance metrics. Experimental findings showed that the suggested model performs better than other competitors.

In future work, it is planned to use 3D processing instead of 2D, which may increase the effectiveness of the proposed solution. Additionally, focus will be given to feature selection or extraction to improve the speed and accuracy of the suggested method.

REFERENCES

- [1] K.-J. Wang, J.-L. Chen, K.-M. Wang, Medical expenditure estimation by Bayesian network for lung cancer patients at different severity stages, *Computers in biology and medicine*, 106, pp. 97-105, 2019.
- [2] S. Afaghi, F.E. Tarki, F.S. Rahimi, S. Besharat, S. Mirhaidari, A. Karimi, N.M. Alamdari, Prevalence and clinical outcomes of vitamin D deficiency in COVID-19 hospitalized patients: a retrospective single-center analysis, *The Tohoku Journal of Experimental Medicine*, 255, pp. 127-134, 2021.
- [3] N. Khosravan, H. Celik, B. Turkbey, E.C. Jones, B. Wood, U. Bagci, A collaborative computer aided diagnosis (C-CAD) system with eye-tracking, sparse attentional model, and deep learning, *Medical image analysis*, 51, pp. 101-115, 2019.
- [4] M.S. Hakemi, A.A. Nassiri, A. Nobakht, M. Mardani, I.A. Darazam, M. Parsa, M.M. Miri, R. Shahrami, A.A. Koomleh, K. Entezarmahdi, Benefit of hemoadsorption therapy in patients suffering sepsis-associated acute kidney injury: a case series, *Blood Purification*, 51, pp. 823-830, 2022.
- [5] D. Riquelme, M.A. Akhloufi, Deep learning for lung cancer nodules detection and classification in CT scans, *AI*, 1, pp. 28-67, 2020.
- [6] A.Q. Al-Faris, U.K. Ngah, N.A.M. Isa, I.L. Shuaib, Breast MRI tumour segmentation using modified automatic seeded region growing based on particle swarm optimization image clustering, *Soft Computing in Industrial Applications*, Springer, 2014, pp. 49-60.
- [7] J.C. Bezdek, Pattern recognition with fuzzy objective function algorithms, Springer Science & Business Media 2013.
- [8] A.K. Jain, Data clustering: 50 years beyond K-means, *Pattern recognition letters*, 31, pp. 651-666, 2010.
- [9] T. Lei, X. Jia, Y. Zhang, L. He, H. Meng, A.K. Nandi, Significantly fast and robust fuzzy c-means clustering algorithm based on morphological reconstruction and membership filtering, *IEEE Transactions on Fuzzy Systems*, 26, pp. 3027-3041, 2018.
- [10] N. Esfandiari, M.R. Babavalian, A.-M.E. Moghadam, V.K. Tabar, Knowledge discovery in medicine: Current issue and future trend, *Expert Systems with Applications*, 41, pp. 4434-4463, 2014.
- [11] S.L.A. Lee, A.Z. Kouzani, E.J. Hu, Automated detection of lung nodules in computed tomography images: a review, *Machine vision and applications*, 23, pp. 151-163, 2012.
- [12] F. Shaukat, G. Raja, A.F. Frangi, Computer-aided detection of lung nodules: a review, *Journal of Medical Imaging*, 6, p. 020901, 2019.
- [13] A. Nibali, Z. He, D. Wollersheim, Pulmonary nodule classification with deep residual networks, *International journal of computer assisted radiology and surgery*, 12, pp. 1799-1808, 2017.
- [14] N. Zhang, S. Ding, J. Zhang, Y. Xue, An overview on restricted Boltzmann machines, *Neurocomputing*, 275, pp. 1186-1199, 2018.
- [15] M. Moradi, M. Samwald, Deep Learning, Natural Language Processing, and Explainable Artificial Intelligence in the Biomedical Domain, arXiv preprint arXiv:2202.12678, 2022.
- [16] H. Han, W.-Y. Wang, B.-H. Mao, Borderline-SMOTE: a new over-sampling method in imbalanced data sets learning, *International conference on intelligent computing*, Springer, pp. 878-887, 2005.
- [17] J. Chen, C.-A. Tsai, H. Moon, H. Ahn, J. Young, C.-H. Chen, Decision threshold adjustment in class prediction, SAR and QSAR in Environmental Research, 17, pp. 337-352, 2006.
- [18] C. Huang, Y. Li, C.C. Loy, X. Tang, Learning deep representation for imbalanced classification, *Proceedings of the IEEE conference on computer vision and pattern recognition*, pp. 5375-5384, 2016.
- [19] A. Naik, D.R. Edla, Lung Nodule Classification on Computed Tomography Images Using Deep Learning, *Wireless Personal Communications*, 116, pp. 655-690, 2021.

- [20] E. Dandil, A computer-aided pipeline for automatic lung cancer classification on computed tomography scans, *Journal of healthcare engineering*, 2018, 2018.
- [21] S. Ozekes, A.Y. Camurcu, Automatic lung nodule detection using template matching, *International Conference on Advances in Information Systems*, Springer, pp. 247-253, 2006.
- [22] H. Wu, T. Sun, J. Wang, X. Li, W. Wang, D. Huo, P. Lv, W. He, K. Wang, X. Guo, Combination of radiological and gray level co-occurrence matrix textural features used to distinguish solitary pulmonary nodules by computed tomography, *Journal of digital imaging*, 26, pp. 797-802, 2013.
- [23] J. Kuruvilla, K. Gunavathi, Lung cancer classification using neural networks for CT images, *Computer methods and programs in biomedicine*, 113, pp. 202-209, 2014.
- [24] F.V. Farahani, A. Ahmadi, M.H.F. Zarandi, Hybrid intelligent approach for diagnosis of the lung nodule from CT images using spatial kernelized fuzzy c-means and ensemble learning, *Mathematics Computers in Simulation*, 149, pp. 48-68, 2018.
- [25] M.A. Khan, S. Rubab, A. Kashif, M.I. Sharif, N. Muhammad, J.H. Shah, Y.-D. Zhang, S.C. Satapathy, Lung cancer classification from CT images: An integrated design of contrast based classical features fusion and selection, *Pattern Recognition Letters*, 129, pp. 77-85, 2020.
- [26] M.S. Sartakhti, M.J.M. Kahaki, S.V. Moravvej, M. javadi Joortani, A. Bagheri, Persian language model based on BiLSTM model on COVID-19 corpus, *2021 5th International Conference on Pattern Recognition and Image Analysis (IPRIA)*, IEEE, pp. 1-5, 2021.
- [27] S.V. Moravvej, A. Mirzaei, M. Safayani, Biomedical text summarization using Conditional Generative Adversarial Network (CGAN), *arXiv preprint arXiv:2110.11870*, 2021.
- [28] S.V. Moravvej, M.J.M. Kahaki, M.S. Sartakhti, A. Mirzaei, A method based on attention mechanism using bidirectional long-short term memory (BLSTM) for question answering, *2021 29th Iranian Conference on Electrical Engineering (ICEE)*, IEEE, pp. 460-464, 2021.
- [29] Z. SobhaniNia, N. Karimi, P. Khadivi, R. Roshandel, S. Samavi, Brain Tumor Classification Using Medial Residual Encoder Layers, *arXiv preprint arXiv:2011.00628*, 2020.
- [30] Z. Sobhaninia, N. Karimi, P. Khadivi, S. Samavi, Brain Tumor Classification by Cascaded Multiscale Multitask Learning Framework Based on Feature Aggregation, *arXiv preprint arXiv:2112.14320*, 2021.
- [31] G. Peeters, G. Richard, *Deep Learning for Audio and Music*, Springer, 2021.
- [32] S.V. Moravvej, M. Joodaki, M.J.M. Kahaki, M.S. Sartakhti, A method Based on an Attention Mechanism to Measure the Similarity of two Sentences, *2021 7th International Conference on Web Research (ICWR)*, IEEE, pp. 238-242, 2021.
- [33] T. Iqbal, S. Qureshi, The survey: Text generation models in deep learning, *Journal of King Saud University-Computer and Information Sciences*, 2020.
- [34] S. Moravvej, M. Maleki Kahaki, M. Salimi Sartakhti, M. Joodaki, Efficient GAN-based Method for Extractive Summarization, *Journal of Electrical and Computer Engineering Innovations (JECEI)*, 2021.
- [35] S.V. Moravvej, S.J. Mousavirad, M.H. Moghadam, M. Saadatmand, An LSTM-Based Plagiarism Detection via Attention Mechanism and a Population-Based Approach for Pre-training Parameters with Imbalanced Classes, *International Conference on Neural Information Processing*, Springer, pp. 690-701, 2021.
- [36] S.V. Moravvej, S.J. Mousavirad, D. Oliva, G. Schaefer, Z. Sobhaninia, An Improved DE Algorithm to Optimise the Learning Process of a BERT-based Plagiarism Detection Model, *2022 IEEE Congress on Evolutionary Computation (CEC)*, IEEE, pp. 1-7, 2022.
- [37] S.V. Moravvej, R. Alizadehsani, S. Khanam, Z. Sobhaninia, A. Shoeibi, F. Khozeimeh, Z.A. Sani, R.-S. Tan, A. Khosravi, S. Nahavandi, RLMD-PA: a reinforcement learning-based myocarditis diagnosis combined with a population-based algorithm for pretraining weights, *Contrast Media & Molecular Imaging*, 2022, 2022.
- [38] S. Danaei, A. Bostani, S.V. Moravvej, F. Mohammadi, R. Alizadehsani, A. Shoeibi, H. Alinejad-Rokny, S. Nahavandi, Myocarditis Diagnosis: A Method using Mutual Learning-Based ABC and Reinforcement Learning, *2022 IEEE 22nd International Symposium on Computational Intelligence and Informatics and 8th IEEE International Conference on Recent Achievements in Mechatronics, Automation, Computer Science and Robotics (CINTI-MACRo)*, IEEE, pp. 000265-000270, 2022.
- [39] H. Cao, H. Liu, E. Song, G. Ma, X. Xu, R. Jin, T. Liu, C.-C. Hung, A two-stage convolutional neural networks for lung nodule detection, *IEEE journal of biomedical and health informatics*, 24, pp. 2006-2015, 2020.
- [40] Z. Ali, A. Irtaza, M. Maqsood, An efficient U-Net framework for lung nodule detection using densely connected dilated convolutions, *The Journal of Supercomputing*, 78, pp. 1602-1623, 2022.
- [41] S. Vakilian, S.V. Moravvej, A. Fanián, Using the artificial bee colony (ABC) algorithm in collaboration with the fog nodes in the Internet of Things three-layer architecture, *2021 29th Iranian Conference on Electrical Engineering (ICEE)*, IEEE, pp. 509-513, 2021.
- [42] S. Vakilian, S.V. Moravvej, A. Fanián, Using the cuckoo algorithm to optimizing the response time and energy consumption cost of fog nodes by considering collaboration in the fog layer, *2021 5th International Conference on Internet of Things and Applications (IoT)*, IEEE, pp. 1-5, 2021.
- [43] G. Zhang, Z. Yang, L. Gong, S. Jiang, L. Wang, Classification of benign and malignant lung nodules from CT images based on hybrid features, *Physics in Medicine and Biology*, 64, p. 125011, 2019.
- [44] D. Blanc, V. Racine, A. Khalil, M. Deloche, J.-A. Broyelle, I. Hammouamri, E. Sinitambirivoutin, M. Fiammante, E. Verdier, T. Besson, Artificial intelligence solution to classify pulmonary nodules on CT, *Diagnostic interventional imaging*, 101, pp. 803-810, 2020.
- [45] M. Zhang, H. Li, J. Lyu, S.H. Ling, S. Su, Multi-level CNN for lung nodule classification with Gaussian Process assisted hyperparameter optimization, *arXiv preprint arXiv:00276*, 2019.
- [46] A. Mobiny, H. Van Nguyen, Fast capsnet for lung cancer screening, *International Conference on Medical Image Computing and Computer-Assisted Intervention*, Springer, pp. 741-749, 2018.
- [47] B.-C. Kim, J.S. Yoon, J.-S. Choi, H.-I. Suk, Multi-scale gradual integration CNN for false positive reduction in pulmonary nodule detection, *Neural Networks*, 115, pp. 1-10, 2019.
- [48] O. Ozdemir, B. Woodward, A.A. Berlin, Propagating uncertainty in multi-stage bayesian convolutional neural networks with application to pulmonary nodule detection, *arXiv preprint arXiv:1712.00497*, 2017.
- [49] W. Zhu, Y.S. Vang, Y. Huang, X. Xie, Deepem: Deep 3d convnets with em for weakly supervised pulmonary nodule detection, *International Conference on Medical Image Computing and Computer-Assisted Intervention*, Springer, pp. 812-820, 2018.
- [50] Q. Dou, H. Chen, L. Yu, J. Qin, P.-A. Heng, Multilevel contextual 3-D CNNs for false positive reduction in pulmonary nodule detection, *IEEE Transactions on Biomedical Engineering*, 64, pp. 1558-1567, 2016.
- [51] H. Jiang, H. Ma, W. Qian, M. Gao, Y. Li, An automatic detection system of lung nodule based on multigroup patch-based deep learning network, *IEEE journal of biomedical and health informatics*, 22, pp. 1227-1237, 2017.
- [52] S. Dodia, A. Basava, M. Padukudru Anand, A novel receptive field-regularized V-net and nodule classification network for lung nodule detection, *International Journal of Imaging Systems and Technology*, 2022.
- [53] X. Huang, J. Shan, V. Vaidya, Lung nodule detection in CT using 3D convolutional neural networks, *2017 IEEE 14th International Symposium on Biomedical Imaging (ISBI 2017)*, IEEE, pp. 379-383, 2017.
- [54] S.M. Ganji, M. Tehranchi, A. Ehterami, H. Semyari, F. Taleghani, M. Habibzadeh, M.H. Tayeed, N. Mehrnia, A. Karimi, M. Salehi, Bone tissue engineering via application of a PCL/Gelatin/Nanoclay/Hesperetin 3D nanocomposite scaffold, *Journal of Drug Delivery Science and Technology*, 76, p. 103704, 2022.
- [55] B. Wu, Z. Zhou, J. Wang, Y. Wang, Joint learning for pulmonary nodule segmentation, attributes and malignancy prediction, *2018 IEEE 15th International Symposium on Biomedical Imaging (ISBI 2018)*, IEEE, pp. 1109-1113, 2018.
- [56] X. Huang, W. Sun, T.-L.B. Tseng, C. Li, W. Qian, Fast and fully-automated detection and segmentation of pulmonary nodules in thoracic

- CT scans using deep convolutional neural networks, *Computerized Medical Imaging and Graphics*, 74, pp. 25-36, 2019.
- [57] M. Maqsood, S. Yasmin, I. Mehmood, M. Bukhari, M. Kim, An Efficient DA-Net Architecture for Lung Nodule Segmentation, *Mathematics*, 9, p. 1457, 2021.
- [58] W. Shen, M. Zhou, F. Yang, D. Yu, D. Dong, C. Yang, Y. Zang, J. Tian, Multi-crop convolutional neural networks for lung nodule malignancy suspiciousness classification, *Pattern Recognition*, 61, pp. 663-673, 2017.
- [59] M.N. Mughal, W. Ikram, Early lung cancer detection by classifying chest CT images: a survey, 8th International Multitopic Conference, 2004. Proceedings of INMIC 2004., IEEE, pp. 67-72, 2004.
- [60] H. Rezatofghi, N. Tsoi, J. Gwak, A. Sadeghian, I. Reid, S. Savarese, Generalized intersection over union: A metric and a loss for bounding box regression, *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 658-666, 2019.
- [61] F.V. Farahani, A. Ahmadi, M.H.F. Zarandi, Hybrid intelligent approach for diagnosis of the lung nodule from CT images using spatial kernelized fuzzy c-means and ensemble learning, *Mathematics and Computers in Simulation*, 149, pp. 48-68, 2018.
- [62] C. Fuchs, S. Heuel, Feature extraction, *Second Course in Digital Photogrammetry*, pp. 3-1, 1995.
- [63] F. Afza, M.A. Khan, M. Sharif, A. Rehman, Microscopic skin laceration segmentation and classification: A framework of statistical normal distribution and optimal feature selection, *Microscopy research technique*, 82, pp. 1471-1488, 2019.
- [64] B. Remeseiro, V. Bolon-Canedo, A review of feature selection methods in medical applications, *Computers in biology and medicine*, 112, p. 103375, 2019.
- [65] M. Sharif, M.A. Khan, M. Faisal, M. Yasmin, S.L. Fernandes, A framework for offline signature verification system: Best features selection approach, *Pattern Recognition Letters*, 2018.
- [66] Y. Tan, K. Lu, J. Xue, An Automated Lung Nodule Segmentation Method Based On Nodule Detection Network and Region Growing, *Proceedings of the ACM Multimedia Asia*, 2019, pp. 1-6.
- [67] R. Mastouri, H. Neji, S. Hantous-Zannad, N. Khelifa, A morphological operation-based approach for Sub-pleural lung nodule detection from CT images, 2018 IEEE 4th Middle East Conference on Biomedical Engineering (MECBME), IEEE, pp. 84-89, 2018.
- [68] W. Abbas, K.B. Khan, M. Aqeel, M.A. Azam, M.H. Ghouri, F.H. Jaskani, Lungs Nodule Cancer Detection Using Statistical Techniques, 2020 IEEE 23rd International Multitopic Conference (INMIC), IEEE, pp. 1-6, 2020.
- [69] L.M. Pehrson, M.B. Nielsen, C. Ammitzbøl Lauridsen, Automatic pulmonary nodule detection applying deep learning or machine learning algorithms to the LIDC-IDRI database: a systematic review, *Diagnostics*, 9, p. 29, 2019.
- [70] D.P. Huttenlocher, G.A. Klanderman, W.J. Rucklidge, Comparing images using the Hausdorff distance, *IEEE Transactions on pattern analysis and machine intelligence*, 15, pp. 850-863, 1993.
- [71] Q. Gu, L. Zhu, Z. Cai, Evaluation measures of the classification performance of imbalanced data sets, *International symposium on intelligence computation and applications*, Springer, pp. 461-471, 2009.
- [72] J.C. Bezdek, R. Ehrlich, W. Full, FCM: The fuzzy c-means clustering algorithm, *Computers & geosciences*, 10, pp. 191-203, 1984.
- [73] Y. Ding, X. Fu, Kernel-based fuzzy c-means clustering algorithm based on genetic algorithm, *Neurocomputing*, 188, pp. 233-238, 2016.
- [74] K.-S. Chuang, H.-L. Tzeng, S. Chen, J. Wu, T.-J. Chen, Fuzzy c-means clustering with spatial information for image segmentation, *computerized medical imaging and graphics*, 30, pp. 9-15, 2006.
- [75] M. Lavanya, P.M. Kannan, Lung lesion detection in CT scan images using the fuzzy local information cluster means (FLICM) automatic segmentation algorithm and back propagation network classification, *Asian Pacific journal of cancer prevention: APJCP*, 18, p. 3395, 2017.
- [76] S. Jadon, A survey of loss functions for semantic segmentation, 2020 IEEE Conference on Computational Intelligence in Bioinformatics and Computational Biology (CIBCB), IEEE, pp. 1-7, 2020.

A Theoretical Framework for Creating Folk Dance Motion Templates using Motion Capture

Amir Irfan Mazian¹, Wan Rizhan², Normala Rahim³, Azrul Amri Jamal⁴, Ismahafezi Ismail⁵, Syed Abdullah Fadzli⁶
Faculty of Informatics and Computing, Universiti Sultan Zainal Abidin, 22200 Besut, Terengganu, Malaysia^{1, 2, 3, 4, 5}
Faculty of Ocean Engineering Technology and Informatics, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia⁶

Abstract—Folk dance (FD) is a type of traditional dance that has been handed down through a culture or group from generation to generation. It is crucial to preserve and safeguard this type of cultural legacy since it can reflect the history and identity of particular nations. However, due to ineffective preservation and conservation techniques, the survival of FDs is being negatively impacted more and more. Its extinction may be caused by ignorance about and disregard for preservation and conservation efforts. The most efficient method for digitizing intangible cultural property, including FDs, is motion capture (MoCap). MoCap enables the conversion of real-time movement into digital performance to produce motion templates. This paper aims to provide suggestions and guidelines in conducting research to generate motion templates of FDs. Several key approaches are presented and discussed in detail, including acquaintance meetings, procedures and approval, interviews and experiments, and the framework. The proposed framework includes models for MoCap, skeleton generation, skeleton refinement, and evaluation. By implementing the proposed framework, the motion templates for FDs can be created. The generated motion templates will preserve and conserve FDs and guarantee their originality and authenticity.

Keywords—Motion capture; folk dance; motion template

I. INTRODUCTION

Since cultural heritage reflects the history and identity of certain countries, it is important to preserve and conserve it. Cultural heritage refers to the inherited beliefs, values, customs, practices, and artifacts that define a group or society [1]. It includes both tangible and intangible elements that have been passed down from generation to generation. The National Heritage Act of 2016 defines intangible cultural heritage as a human action or movement that can be observed, felt, tasted, smelled, or heard when performed or present, but cannot be appreciated when lost or disappeared [2]. This includes performing arts, customs and culture, oral traditions, fine arts or crafts, knowledge and practice, and living heritage.

Folk dance (FD) is considered a ritual among people that is a characteristic of the common inhabitants of a country or region that is passed down from generation to generation [3]. By performing such rituals for many years, people have gathered and performed such rituals to develop bonds with each other and connect with the space where they spend or spent their daily lives [2]. Dance is a performing art and consists of various movement sequences [4]. It can have different messages depending on the context due to their close relation to the culture and heritage of a place or nation [5].

Moreover, each dance creates a meaning, a story with the help of music, costumes, and dance movements [6]. In Malaysia, FD has been registered and categorized as performing arts under Intangible Cultural Heritage. Performing arts is a form of stage performance that is performed directly or immediately for the audience or spectators and involves four basic elements, namely time, space, and the relationship between performer and audience [2]. Examples of the most popular FDs in Malaysia are Tarian Gamelan, Tarian Piring, Tarian Zapin, Tarian Mak Yong, Tarian Sumazau, Tarian Ngajat, Tarian Kipas, Tarian Kathak, Tarian Kuda Kepang and others [7,8].

However, this kind of heritage can easily die out over time if it is not a tangible heritage. This is because the younger generation is not interested in passing on the cultural heritage and because of the changes in traditions (the transition to modernity) [2]. These reasons have significant impacts in the form of loss, neglect, extinction, and destruction. In addition, current methods for teaching, learning, and assessing FDs focus on human demonstration, text documentation, and video [9]. Human instructors such as teachers and coaches are usually involved to give commands or demonstrations about the dance movement [10]. Santos [11] described three limitations when a person attempts to provide feedback: The person cannot maintain the same level of attention and concentration for an extended period of time; they are unable to observe all the important physiological and biomechanical variables that characterise the movement, either at the same time or with high precision; and they are unlikely to provide extended simultaneous feedback. The use of text documents is suitable for presenting information about dance and its cultural significance, but it cannot present movements and different dance styles accurately [10]. When using videos, the movements of dances can be easily presented, but it is static (2D) and difficult to present additional information about each dance [10]. The existing framework from previous research is not sufficient to create the motion templates of FDs from scratch. Therefore, there must be a stable mechanism to preserve and maintain this kind of valuable intangible cultural heritage.

Digitization and visualization of FDs is an increasingly active research area in computer science. With the advent of rapidly advancing technologies, new ways of learning folk dances are being explored that enable the digitization and visualization of various FDs for learning purposes using different tools [10]. One of the methods for such purposes is

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motion capture. Motion capture (MoCap) is one of the most effective methods for digitizing intangible cultural heritage, including FDs [6]. This is because MoCap enables the translation of live motion into a digital performance [12,13,14]. Mocap can also be used to recreate dances in three dimensions and display them in a 3D environment [15]. In other words, MoCap can be used to create motion templates. The use of motion templates in FDs has gained popularity in recent years due to the numerous advantages they offer. Motion templates are predefined movements or poses that are captured using motion capture technology and can serve as a reference for dancers to learn and perform choreography [16].

In this paper, a theoretical framework for creating motion templates of FDs using MoCap is proposed and presented. Different techniques and approaches for data acquisition and analysis are discussed in detail. In addition, the importance and processes of digitizing FDs with MoCap are highlighted to preserve and maintain folk dances by creating movement templates. This paper covers materials and methods in Section II, data collection and analysis in Section III, expected results and discussion in Section IV, and the last Section touches on the conclusion.

II. MATERIALS AND METHODS

To ensure the success of preserving and conserving FDs through digitization, various formal and informal research approaches can be used. These approaches include conducting acquaintance meetings, procedures and approval, interviews, and conducting experiments. The results of these approaches are important in obtaining the needed information and proposing the framework shown in Fig. 1. The framework includes the acquaintance meetings, procedures and approvals, interviews, experiments, and workflows.

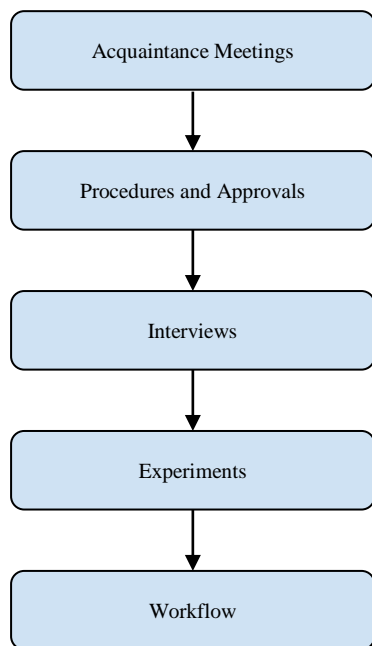


Fig. 1. Proposed framework for creating motion templates of FDs using MoCap.

A. Acquaintance Meeting

The main purpose of acquaintance meetings is to gather information about the FD present in certain areas. Therefore, meetings with FD experts from the State Tourism Department and the Centre for Arts and Heritage at the local Institute of Higher Learning (IHL) are crucial to gather the information. The results of the acquaintance meetings can take the form of the following:

- Documentation of local FDs such as forms, articles, journals, policies, and guidelines.
- Identification of experts/founders of the local FDs
- Clarification of history and background of local FDs
- Explaining the movement styles and types of FDs

The knowledge gained from the acquaintance meetings can be used for the next steps; procedures and approval.

B. Procedures and Approval

To further investigate the local FDs, the procedures and approval related to laws and their procedures can be applied and implemented. These are listed below:

1) *Letter of intent for conducting the research at the potential sites/locations:* The potential sites/locations usually result from the previous acquaintance meetings. This letter is important to obtain the consent and cooperation of the potential sites for the study of the corresponding FDs. The content of this letter must address the need and importance of researching the local FDs, in addition to explaining the research team and the use of current technology to digitise the FDs. The need for teachers, experts or trainers to participate should also be mentioned in this letter.

2) *Invitation letter for conducting the fieldwork:* Once the consent and cooperation of the potential sites have been obtained, this letter should indicate the need for recording the movements of the masters, teachers, experts or trainers in the target sites. This fieldwork typically involves recording the movements of teachers or trainers using specific MoCap devices. The recorded movement data can be used as motion templates. The content of the letter should include an explanation of the type of MoCap devices used in the fieldwork and the results obtained when using the recorded movement data to create the movement templates.

3) *Request for Verification of Motion Templates:* The purpose of this letter is to request expert assistance in verifying the motion templates developed using the captured motion data. This step is important to ensure the authenticity of the local FDs under investigation. The letter must include the need for multiple experts among the masters, teachers, or instructors to be present at a specific date, time, and location.

4) *Application for copyright:* Copyright may be requested for any movement template created by FDs. The rights that creators have over their literary and artistic creations are critical to describing the copyrights in the created movement templates. The letter can be forwarded to potential

parties that can assist in funding and managing the publication of copyrights, such as the Intellectual Properties Corporation, the Division of Research and Development in certain IHLs.

These procedures and approvals step must occur in order for the research to be conducted effectively, especially when laws and confidential issues are involved.

C. Interviews

Interviewing is one of the most important methods to obtain and collect information about the FD under study and to verify the validity of the information. The interview can be conducted in a variety of formats including structured, semi-structured, and unstructured interviews [17] to meet the experts on FDs such as masters, teachers, trainers, etc. The frequency of interviews depends on whether the information collected is satisfactory and sufficient.

The results of the interviews are usually overviews of the type of FDs under study such as background, history, founders, and types of movements. In addition, the experts can be educated about the purpose of the study and the experiments to be conducted.

D. Experiments

The experiments are proposed to implement the methods planned in the research such as the proposed workflow and the collection of data from MoCap. The experiments usually involve the FDs experts and trainees in two different phases (development and evaluation), especially in collecting and recording their movements with MoCap devices. The development phase focuses on creating motion templates for FDs to use as benchmarks and reference sources. FD experts among teachers and trainers are involved in this phase. Later, the motion templates produced will be used as benchmarks in the dance evaluation phase by comparing the dancers' physical movements with the recorded movements in the motion template.

Therefore, explaining the experimental procedure is crucial to achieve the desired results. This includes the frequency of repetitions of the movements to be performed during recording with MoCap, the position and distance between the dancers and the MoCap device, the types of FDs to be implemented, and the types of actions to start and stop the movements.

E. Proposed Workflow

To generate the motion templates of FDs, the workflow in Fig. 2 is proposed. The workflow includes MoCap, skeleton generation, refined skeleton, and evaluation models. This workflow is used in the development phase.

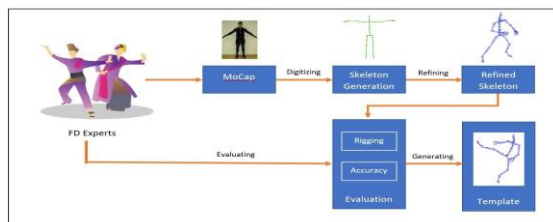


Fig. 2. Proposed workflow for creating motion templates of FDs using MoCap.

1) *MoCap*: The MoCap model is used to capture motion data using specific MoCap techniques. MoCap techniques can be divided into marker-based and markerless MoCap. Both techniques have their own advantage in terms of performance, accuracy and cost. Examples of marker-based MoCap devices Optical Motion Capture System Qualisys, Vicon, Peak Performance Motion Capture System, Optoelectronic Motion Analyser, Eagle-Hawk System, and MAC3D Motion Capture System, while markerless MoCap devices are Kinect, PrimeSense Sensor, Sony PlayStation Eye, and Intel's Creative Camera [18].

The selection and use of these sensor devices usually depends on the provision of research funding and the complexity of the captured motion [19]. The marker-based MoCap techniques can guarantee high accuracy in capturing and tracking the human movements. However, attaching markers to a performer's body can restrict the performer's movements, which may affect the quality of the performance [20]. Moreover, marker-based MoCap techniques are usually developed in specialised and static studios. The cost of developing such studios is high. In contrast, the markerless MoCap techniques offer more freedom in movements and performance, as well as affordable prices, since no markers are attached to the performer's body, and no specialised studios are needed.

2) *Skeleton generation*: The skeleton generation model is used to project the skeleton for body movements. The data obtained from the motion recording is considered accurate. The skeleton is a set of systematically linked joints. The skeleton data is converted to specific file formats such as SKL, FBX, BVH, and CSV so that it can be used to enhance the data.

The skeleton file format (SKL) contains motion capture information, i.e., the spatial locations of points on the human body called joints. The SKL file format can be used and supported in Kinect Studio, Gesture Description Language Studio (GDL), and OpenNI [21,22]. In addition, the SKL file format can be found in the documentation for the 3D modeling software MilkShape 3D. According to the documentation, SKL files are "skeleton files that contain the bone hierarchy of the model and the positions and orientations of the bones in each frame of the animation" [23]. This file format is also used to capture motion data from human subjects during various exercises [24].

The FBX file format is created using the Autodesk FBX program. This file format can be created and modified in a variety of modeling programs such as Maya, 3ds Max, and Blender. FBX files can contain a variety of data types, including mesh, material, texture, and skeletal motion information. Animation data in FBX files is typically stored in keyframe format, with the position, rotation, and scale of each joint stored for each frame of animation [25]. They are therefore ideal for use in video games and computer graphics. In addition, FBX files can be imported into other software programs that accept the FBX format from Autodesk software programs [26].

Biovision Hierarchy (BVH) file format a file format commonly used in motion capture to store skeletal data [27]. This file format consists of ASCII text with a time-framed sequence of different specifications for subsequent poses. The first part of the ASCII text specifies the initial pose of a human skeleton. The hip joint is designated as ROOT in the first section of a BVH file, preceded by the keyword HIERARCHY, indicating that it has no progenitor joints. It serves as the parent joint and as the child joint of a nested construction [28,29].

Comma-Separated Values (CSV) is a file format used to store tabular data [30]. In the context of motion capture, CSV files can be used to store motion data in a format that can be easily imported into 3D animation software. CSV files typically contain a series of rows, with each row representing a frame of the animation and each column representing the position, rotation, or scale of a particular joint in the skeletal structure. The data in each row of the file contain three columns (X, Y and Z coordinates) separated by commas. The name of this file format is derived from the fact that the fields are separated by commas. In most cases, the data is simply entered into a text file as ASCII numeric values separated by commas [31].

3) *Refined skeleton*: The refined skeleton model is used to correct or refine certain minor motion errors by adjusting the keyframes for each joint in the skeleton. This process can be done using certain 3D programs such as Autodesk Maya, Blender, 3D Studio Max, ZBrush, Adobe Dimension, Cinema 4D, Sense, Houdini etc.

Knowledge of human anatomy is crucial in this process so that the joints of the skeleton can be adjusted as desired. Moreover, keyframing, graph editor for animation and rigging techniques like Euler filter, Butterworth and noise reduction are also important to minimize the anomalies in the skeleton.

Maya is a 3D modeling, animation, and rendering software developed by Autodesk [32]. It is widely used in the film and television industry for creating complex visual effects and character animation. Maya provides a wide range of tools and features for modeling, animation, texturing, and rendering, including support for advanced shading and lighting techniques such as physically based rendering (PBR) and high dynamic range (HDR) imaging.

Blender is a free and open source 3D software known for its versatility and ease of use [33]. It offers a similar range of tools and features as Maya, including support for advanced shading and lighting techniques. Blender is widely used in the gaming industry for asset and environment creation, and in the film and television industry for visual effects and animation.

3D Studio Max is a 3D modeling, animation, and rendering software developed by Autodesk [34]. It is similar to Maya in terms of tool selection and features, but is more focused on architectural and engineering visualization, as well as product design and prototyping. 3D Studio Max also provides support for advanced shading and lighting techniques and is commonly used in the architecture and engineering industries to create 3D visualizations of buildings and other structures.

Other popular 3D software packages include Cinema 4D, Houdini, and ZBrush, all of which have their own strengths and weaknesses depending on the specific needs of the user. In conclusion, the choice of 3D software largely depends on the specific requirements of the project and the skill level of the user. Maya, Blender and 3D Studio Max are all popular programs with their own unique features and capabilities.

4) *Evaluation*: a heuristic evaluation is proposed to evaluate the review of the created motion templates. Heuristic evaluation is one of the usability engineering techniques used to identify usability problems in user interface design so that they can be fixed during an iterative design process. The goal of heuristic evaluation is to identify usability problems in a user interface design so that they can be fixed during an iterative design process. It is the most widely used inspection method; it is inexpensive, intuitive, and easy to use compared to other evaluation methods, and it does not require pre-planning [35]. In heuristic evaluation, the interface is examined by a small group of evaluators and checked for compliance with established usability guidelines. According to Nielsen [36], the recommendation for a heuristic evaluation is three to five people. A heuristic evaluation session for a single evaluator typically takes one to two hours. For larger or more complex interfaces with a significant number of dialogue pieces, longer evaluation sessions may be required; however, it would be preferable to break the evaluation into numerous smaller sessions, each focusing on a different aspect of the interface. The main goal of heuristic evaluation is to identify usability problems in user interface design using ten (10) established heuristic principles [37].

Heuristic evaluation is a testing method based on the characteristics of reusability of the system in terms of user interface design, which enables fast and effective problem solving and decision making. Heuristic evaluation is an approach used in this case to identify a set of usability criteria of the motion templates and 3D model for FDs, for example, in cases where the criteria do not meet user requirements. The heuristic evaluation is used to successfully improve the design. By having the design perform a series of activities, the evaluator can assess how well it meets the standards for each stage [38]. In the testing in this application, heuristic evaluation is performed in accordance with the ten Nielsen principles, which include visibility of system state, consistency with the real world, user control and freedom, consistency and standards, error prevention, recognition, flexibility and efficiency of use, aesthetic and minimalist design, helping users detect, diagnose, and fix errors, and help and documentation. The authors plan to evaluate the application using heuristics, which is supported by the above description.

The goal of the heuristic evaluation is to identify as many usability issues as possible in the development of the motion templates and 3D model character for FDs. The feedback from the experts is important to design and develop good motion templates and 3D model characters for FDs. To achieve this, a heuristic evaluation procedure is performed in this step:

a) Distribute an online questionnaire and video clip via email before conducting a testing session.

b) Schedule a 2-hour appointment with the experts to conduct the assessment.

c) The experts provide their feedback via online questionnaires.

d) The results obtained are analysed and used to develop a framework and prototype.

In summary, heuristic evaluation is the most widely used inspection methodology; it is inexpensive, intuitive, and easy to use compared to other evaluation methods, and does not require advance planning [35].

III. DATA COLLECTION AND ANALYSIS

MoCap can generate raw FD motion data based on expert movements. The trajectories of the motion data can be collected and analyzed in a variety of file formats such as FBX, SKL, BVH, CSV, etc., which can be used in 3D software. Observing the keyframes for each motion is critical to ensure that the motion data is rendered as accurately as possible with few anomalies. Having the correct and accurate motion data is important for creating motion templates that can be used in a variety of areas.

Once the motion templates are created, the verification analysis of the created motion templates can be performed to maintain the level of efficiency, accuracy and satisfaction. The appropriate tool or procedure to verify the created motion templates is heuristic evaluation. The data collected by the FDs experts can be analyzed to verify the created motion templates.

In order to use the motion templates in certain platforms such as virtual reality, augmented reality, animation, simulation, games, etc., verification analysis must be performed for FDs motion templates with 3D characters.

The evaluation of VR, AR, animation, simulation, and game platforms can also be tested using the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT). TAM and UTAUT are both widely used models in the field of technology acceptance and adoption.

TAM is a theoretical model that explains how users perceive and adopt new technologies [39]. The model was originally proposed by Davis in 1989 and later modified by Venkatesh and Davis in 2000. According to TAM, two main factors influence user acceptance of technology: perceived usefulness (PU) and perceived ease of use (PEOU) [40]. PU refers to the extent to which a user believes that using the technology will improve his/her job performance, while PEOU refers to the extent to which a user believes that using the technology will be easy and effortless. The model suggests that PU and PEOU are the most important determinants of a user's attitude toward technology, which in turn affects his or her intention to use it [41].

UTAUT is a model that explains the factors that influence user acceptance and use of technologies [39]. The model was developed by Venkatesh et al. in 2003 [42] and is based on

four key factors: performance expectancy (PE), effort expectancy (EE), social influence (SI), and facilitating conditions (FC). PE refers to the extent to which a user believes that using the technology will improve his or her job performance, while EE refers to the extent to which a user believes that using the technology will be easy and effortless. SI refers to the extent to which a user believes that influential people in his or her life believe that he or she should use the technology, while FC refers to the extent to which a user believes that he/ she has the resources and support necessary to use the technology [42].

IV. EXPECTED RESULTS AND DISCUSSION

By implementing the approaches proposed in this research, the expected results can be presented and discussed in detail.

Using the proposed framework, the digitization of different types of FDs can be implemented using MoCap. MoCap technology captures movements with high precision, allowing detailed analysis of the specific body movements and gestures characteristic of FDs. This information can be used to create templates for movement patterns that can be used as references by dancers, choreographers, and researchers [16]. The proposed framework provides suggestions and guidelines for conducting research to create movement templates for FDs.

Moreover, the creation of motion templates for FDs is very important for the future generation. With the motion templates, this kind of valuable intangible cultural heritage can be preserved, conserved, and bequeathed to future generations [43]. Preservation, conservation, and inheritance can be done through various platforms such as virtual reality, augmented reality, simulation, film, animation, games, e-learning, etc. The representation of FDs on these platforms may be able to attract people and introduce them to FDs.

The movement templates can also be used to standardize the teaching and performance of folk dances. By creating movement templates that represent the correct movements and gestures, dancers can learn the dances more efficiently and accurately. This can also help maintain consistency in performances by ensuring that the dances are presented in the same way each time they are performed [16].

At the same time, the movement templates of local FDs can be copyrighted to formally register them as local intangible cultural heritage. This is because the appearance of the motion templates shows their uniqueness and innovativeness compared to the existing local FDs.

It may also be associated with collaboration and cooperation with other third parties. In many cases of local FDs, the experts are outsiders or come from different organizations. In addition, the movement templates created may themselves attract the creative content industry. This may provide an opportunity for commercialization of the created movement templates.

V. CONCLUSION

This paper presents and discusses in detail the framework proposed in this study for the creation of movement templates

of FDs with MoCap for the preservation and conservation of intangible cultural heritage. This framework includes conducting acquaintance meetings, procedures and approval, interviews and implementing experiments and proposed workflow. The findings from this framework are important and inter-relevant to obtaining the desired information.

The acquaintance meetings can be in the form of documentation and identification of experts that are important to gather the information about the local FDs present in certain areas. Letter of intent for conducting the research at the potential sites/locations, Invitation letter for conducting the fieldwork, Request for Verification of Motion Templates and Application for copyright are important to ensure the eligibility of the research conducted especially when law and confidential issues are involved. Meanwhile, the interviews are also important to get an overview of the types of FDs studied such as background, history, founders, and types of movements. Clarification of the purpose of the study and the experiments to be conducted can also be discussed with the experts. The workflow proposed in this study includes MoCap, skeleton generation, refined skeleton, and evaluation models.

For future work, this study is willing to apply the research approaches proposed in this paper to build the motion templates for local FDs in Malaysia. In Malaysia, FD has been registered and categorized as a performing art under Intangible Cultural Heritage. There are many FDs in Malaysia such as Tarian Gamelan, Tarian Piring, Tarian Zapin, Tarian Mak Yong, Tarian Sumazau, Tarian Ngajat, Tarian Kipas, Tarian Kathak, Tarian Kuda Kepang and others. It is expected that the implementation of the familiarization meetings, procedures and approval, interviews, experiments, and framework will fulfill the goals of facilitating the digitization of FDs and the preservation and conservation of this type of valuable intangible cultural heritage.

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REFERENCES

- [1] Smith, L. (2006). *Uses of heritage*. Routledge.
- [2] Solihah Mustafa & Yazid Saleh, An Overview on Intangible Cultural Heritage in Malaysia, *International Journal of Academic Research in Business and Social Sciences*, 2017, Vol. 7, No. 4, pp. 1053-1059.
- [3] Giannoulakis S., Tsapatoulis N. and Grammalidis N., Metadata for Intangible Cultural Heritage-The Case of Folk Dances. In *Proceedings of the 13th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications, Funchal, Madeira, 27–29 January 2018*, pp. 534–545.
- [4] Iris Kico and Fotis Liarokapis, Investigating the Learning Process of Folk Dances Using Mobile Augmented Reality, *Applied Science*, 2020, Vol. 10, No. 599, pp. 1-15.
- [5] Iqbal, J.; Singh-Sidhu, M. A Framework for Correcting Human Motion Alignment for Traditional Dance Training Using Augmented Reality. In *Proceedings of the Knowledge Management International Conference (KMICe)*, Chiang Mai, Thailand, 29–30 August 2016; pp. 59–63.
- [6] Min Li, Zhenjiang Miao And Cong Ma, Dance Movement Learning for Labanotation Generation based on Motion-captured Data, *IEEE Access*, Vol. 0, 2019, pp. 1-12.
- [7] Portal Rasmi Jabatan Warisan Negara, <http://www.heritage.gov.my/tarian.html>, 31 MEI 2021.
- [8] JKKN Pemetaan Budaya, <https://pemetaanbudaya.jkkn.gov.my/category/culture/144>, accessed on 31 Mac 2023.
- [9] Elmedin Selmanović, Selma Rizvic, Carlo Harvey, Dusanka Boskovic, Vedad Hulusic, Malek Chahin, and Sanda Sljivo. 2019. Improving Accessibility to Intangible Cultural Heritage Preservation using Virtual Reality. *ACM J. Comput. Cult. Herit.* 1, 1, Article 1 (January 2019), 20 pages. <https://doi.org/10.1145/3377143>.
- [10] Iris Kico, Nikos Grammalidis, Yiannis Christidis and Fotis Liarokapis, Digitization and Visualization of Folk Dances in Cultural Heritage: A Review, *Inventions* 2018, Vol. 3, No. 72, pp. 1-23.
- [11] Santos O.C. (2016). Training the Body: The Potential of AIED to Support Personalized Motor Skills Learning, *International Journal Artificial Intelligence In Education Society* (2016), Vol.26, pp. 730–755.
- [12] Idris, W. M. R. W., Rafi, A., Bidin, A., & Jamal, A. A. (2018). A theoretical framework of extrinsic feedback based-automated evaluation system for martial arts. *International Journal of Engineering & Technology*, 7(2.14), 74-79. 12
- [13] Idris, W. M. R. W., Rafi, A., Bidin, A., & Jamal, A. A. (2019). Developing new robust motion templates of martial art techniques using R-GDL approach: a case study of SSCM. *International Journal of Arts and Technology*, 11(1), 36-79.
- [14] Hisham, N. F. Z., Jamal, A. A., & Idris, W. M. R. W. Lower Limb Walking Gait Profiling Using Marker-less Motion Capture with GDL and R-GDL methods to Assist Physiotherapy Treatment.
- [15] Magnenat Thalmann, N.; Protopsaltou, D.; Kavakli, E. Learning How to Dance Using a Web 3D Platform. In *Proceedings of the 6th International Conference Edinburgh, Revised Papers, UK, 15–17 August 2007*; Leung, H., Li, F., Lau, R., Li, Q., Eds.; Springer: Berlin/Heidelberg, Germany, 2008; pp. 1–12. [Google Scholar]
- [16] Chin, C. K., Cheong, V. S., & Fu, C. W. (2018). A motion template-based approach for analyzing the performance of traditional Chinese dance. *Journal of Visual Languages & Computing*, 47, 1-10.
- [17] Rubin, H. J., & Rubin, I. S. (2012). *Qualitative interviewing: The art of hearing data*. Sage publications.
- [18] Wan Idris, W.M.R., Rafi, A., Bidin, A. et al. A systematic survey of martial art using motion capture technologies: the importance of extrinsic feedback. *Multimed Tools Appl* 78, 10113–10140 (2019). <https://doi.org/10.1007/s11042-018-6624-y>
- [19] Sharma A., Agarwal M., Sharma A. and Dhuria P. (2013). Motion Capture Process, Techniques and Applications, *International Journal on Recent and Innovation Trends in Computing and Communication*, 1(4), 251–257.
- [20] Chye C., Sakamoto M. and Nakajima T. (2014). An Exergame for Encouraging Martial Arts, *Human-Computer Interaction*. In Kurosu M. (Eds.), *Human-Computer Interaction. Applications and Services. HCI 2014*. Vol. 8512. *Lecture Notes in Computer Science*. (pp. 221-232). Cham: Springer.
- [21] Hachaj, T., Ogiela, M.R. Human actions recognition on multimedia hardware using angle-based and coordinate-based features and multivariate continuous hidden Markov model classifier. *Multimed Tools Appl* 75, 16265–16285 (2016). <https://doi.org/10.1007/s11042-015-2928-3>.
- [22] CCI Research Group, access on April 3, 2023, <https://cci.up.krakow.pl/gdl/>
- [23] MilkShape 3D Documentation. (2002). Retrieved from https://www.milkshape3d.com/onlinehelp.php?version=1.8.2.0&page=Skeletal_Animation#skeletons, Accessed on 31 Mac 2023.
- [24] Kwon, O., Kim, K., Lim, S., & Kim, S. (2019). Deep learning-based human exercise recognition using skeletal data. *Sensors*, 19(4), 847. <https://doi.org/10.3390/s19040847>

- [25] Autodesk. (n.d.). FBX. Retrieved from <https://www.autodesk.com/products/fbx/overview>, Accessed 31 Mac 2023
- [26] Vection Technology, access on April 3, 2023, <https://vection-technologies.com/blog/Everything-You-Need-to-Know-About-FBX-Files-A-Comprehensive-Guide/>
- [27] Ratner, A., & Ratner, M. (2007). Biovision Hierarchy (BVH) format. In *The Computer Science and Engineering Handbook* (pp. 92-1 to 92-11). CRC Press.
- [28] Meredith, M. & Maddock, S. (2001) Motion Capture File Formats Explained.
- [29] BVH Motion Capture Data Animated, access on April 3, 2023, <https://www.cs.cityu.edu.hk/~howard/Teaching/CS4185-5185-2007-SemA/Group12/BVH.html>
- [30] DataCamp. (n.d.). What is CSV file format? Retrieved from <https://www.datacamp.com/community/tutorials/importing-data-into-r-part-two>, Accessed on 31 Mac 2023.
- [31] How to make a C3D file from ASCII data, access on April 3, 2023, <https://motionlabsystems.com/wp-content/uploads/2020/07/appnote-Creating-a-C3D-file-from-a-CSV-file.pdf>.
- [32] Autodesk. (n.d.). Autodesk Maya. Retrieved from <https://www.autodesk.com/products/maya/overview>, Accessed on 31 Mac 2023.
- [33] Blender Foundation. (n.d.). Blender. Retrieved from <https://www.blender.org/>, Accessed on 31 Mac 2023
- [34] Autodesk. (n.d.). 3D Studio Max. Retrieved from <https://www.autodesk.com/products/3ds-max/overview>, Accessed on 31 Mac 2023.
- [35] Nielsen, J. and Molich, R. (1990). "Heuristic evaluation of user interfaces", *Proceedings of ACM CHI90 Conference*, ACM, Seattle, WA, pp. 249-56.
- [36] Nielsen, J. (1994). Heuristic evaluation. In Nielsen, J., and Mack, R.L. (Eds.), *Usability Inspection Methods*. John Wiley & Sons, New York, NY.
- [37] Nielsen, J. How to Conduct a Heuristic Evaluation, 1995, [online] Available: <https://www.nngroup.com/articles/howto-conduct-a-heuristic-evaluation/>.
- [38] A Paz, Pow-Sang Freddy and A. J, "Usability Evaluation Methods for Software Development: A Systematic Mapping Review", *IEEE*, 2015.
- [39] Nurul Amara Muhamad Nazmi, Wan Rizhan, Normala Rahim, "Developing and Evaluating AR for Food Ordering System based on Technological Acceptance Evaluation Approach: A Case Study of Restaurant's Menu Item Selection," *International Journal of Engineering Trends and Technology*, vol. 70, no. 5, pp. 1-8, 2022. Crossref, <https://doi.org/10.14445/22315381/IJETT-V70I5P204>
- [40] Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS quarterly*, 13(3), 319-340.
- [41] Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: four longitudinal field studies. *Management science*, 46(2), 186-204.
- [42] Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS quarterly*, 425-478.
- [43] Lai, Y. H., Lu, C. L., Su, M. H., & Huang, C. C. (2020). Applications of motion capture technology in the study and preservation of traditional dance. *Journal of Information Hiding and Multimedia Signal Processing*, 11(1), 1-14.

Development of a New Lightweight Encryption Algorithm

Ardabek Khompysh¹, Nursulu Kapalova², Oleg Lizunov^{3*}, Dilmukhanbet Dyusenbayev⁴, Kairat Sakan⁵
Information Security Laboratory, Institute of Information and Computational Technologies, Almaty, Kazakhstan^{1,2,3,4,5}
Department of Information Technology, Al-Farabi Kazakh National University, Almaty, Kazakhstan^{1,5}

Abstract—Due to the growing need to use devices with low hardware resources in everyday life, the likelihood of their susceptibility to various cyber-attacks increases. In this regard, one of the methods to ensure the security of information circulating in these devices is encryption. For devices with small hardware resources, the most applicable is low-resource (lightweight) cryptography. This article introduces a new lightweight encryption algorithm, ISL-LWS (Information Security Laboratory – lightweight system), designed to protect data on resource-constrained devices. The encryption algorithm is implemented in the C++ programming language. The paper presents the statistical properties of ciphertexts obtained using the developed algorithm. For the experimental testing for statistical security, the sets of statistical tests by NIST and D. Knuth were used. Separately, the ISL-LWS algorithm was tested for avalanche effect properties. The obtained results of statistical tests were compared with the Present and Speck modern lightweight algorithms. The study and comparative analysis of the speed of encryption and key generation of the three algorithms were carried out on the Arduino Uno R3 board.

Keywords—Lightweight block cipher; S-box; linear transformation; avalanche effect; IoT devices; RFID tags; null hypothesis; NIST tests; D. knuth tests

I. INTRODUCTION

The main directions of the development of cryptography are largely associated with the development of communications and information technology. It is the progress in these areas that has made possible the widespread use of compact devices with low computing power that have access to the Internet and implement the concept of the Internet of Things (IoT) [1][2]. Examples of such devices are radio frequency tags (RFID), automated process control systems (SCADA), wireless sensors, electronic personal identification tools, etc. [3].

Lightweight ciphers are often less secure than traditional ciphers such as AES. This is because lightweight ciphers are optimized for high speed and low power consumption, not maximum security.

As defined by the US National Institute of Standards and Technology (NIST), lightweight cryptography is a subcategory of cryptography that aims to provide solutions for high-growth applications that make extensive use of low-power smart devices [4][5]. Modern cryptographic algorithms can work well on computers, servers, and some mobile phones, but IoT devices, smart cards, and RFID tags require the use of lightweight cryptographic algorithms [6].

When building lightweight block encryption algorithms, the following architectural solutions are used [7]:

- Reduction of the block size from 128 bits to 64 bits;
- Use of keys 64, 80, and 128 bits long;
- Use of 4-bit S-boxes instead of 8-bit ones;
- Use of a simplified key schedule.

Designing algorithms based on well-studied and widely used operations that perform elementary linear/nonlinear transformations.

When creating lightweight block ciphers, the following structures are used [8]:

- Feistel network;
- Substitution-permutation network (SP-network) using substitution boxes of small length;
- LRX-structure (logical operations, rotate left (right) shift, and addition modulo 2);
- ARX-structure (addition modulo 2^n , rotate left (right) shift, and addition modulo 2).

One of the main issues in lightweight cryptography is achieving a balance between security, efficiency, and cost. Obviously, optimizing a lightweight cipher to achieve high speed can weaken some of its security properties, and the algorithm will be more vulnerable to some attacks. Therefore, when developing a lightweight cipher, the first step is to determine the requirements for its security and limited resources, taking into account the scope of its application. When developing the encryption algorithm, the authors tried to balance security and speed.

This article presents a new lightweight symmetric block cipher algorithm ISL-LWS and its statistical analysis. The scientific novelty of the proposed algorithm is the SP transformation, which is performed in parallel by linear (P-box) and non-linear (S-box) cryptographic primitives, where two S-boxes are used simultaneously. This procedure makes it possible to increase the degree of non-linearity and data confusion in fewer rounds. An overview of related work is presented in the next Section II. Section III presents the developed algorithm, which is designed according to the Feistel network and includes linear and non-linear transformations that provide a high level of diffusion and confusion. The round key schedule algorithm is also presented

here. The results and discussion of the statistical tests are presented in Section IV. In addition, this section describes data on the hardware-software implementation of the algorithm and comparative performance analysis. Section V presents the conclusion, where the results of the work are indicated.

II. RELATED WORK

To date, a fairly large number of lightweight block encryption algorithms based on SP networks and Feistel networks are known [9]. Both approaches have their advantages and disadvantages in the context of constructing algorithms in conditions of limited resources. Lightweight block ciphers are represented by the following algorithms: Present [10][11], Clefia [12], Katan [13], Simon [14], Speck [15], Secure IoT (SIT) [16], etc.

A study by Xinxin Fan et al. (Fan et al. 2013) introduced a lightweight WG-8 encryption algorithm of the Welch-Gong family of stream ciphers, adapted for devices with low hardware resources [17]. Typically, some of them have been improved and developed by simplifying block ciphers to improve their performance. For example, DESL which is also known as lightweight DES, is a variant of classic DES. The main difference between the DESL cipher and the DES algorithm is that the former uses one S-box instead of eight ones, which reduces the ROM requirements for storing tables by eight times.

The lightweight encryption algorithm Present [18] is described in the article by L.K. Babenko, D.A. Bespalov, O.B. Makarevich, R.D. Chesnokov, and Ya.A. Trubnikov. The authors of this article have developed a software implementation and synthesized it into a hardware unit for a system on a chip within the framework of the requirements for low-resource cryptography, having obtained a sufficiently effective solution for its application in devices. In 2012, the ISO and IEC organizations included the Present algorithm in the international standard for lightweight encryption ISO/IEC 29192-2:2012.

Speck is a block lightweight encryption algorithm developed by the US National Security Agency. Speck is one of the fastest in lightweight cipher benchmarks, but its performance is highly dependent on architecture. Speck supports several block and key sizes. The block length can be 32, 48, 64, 96, and 128 bits. The key length depends on the block size. The range of key sizes is 64, 72, 96, 128, 144, 192, and 256 bits. The number of encryption rounds depends on the block size and the key. The range of rounds is 22, 23, 26, 27, 28, 29, 32, 33, and 34. Speck is standardized by ISO within the RFID air interface standard [15].

In a study by Muhammad Usman et al. 64-bit block lightweight encryption algorithm SIT [16] with a key length of 64 bits is considered. The architecture of the algorithm is a mixture of a Feistel network and an SP network. Conducted studies show that the algorithm provides significant security after five rounds of encryption.

Thus, R&D on the development and study of lightweight encryption algorithms is relevant.

III. LIGHTWEIGHT ENCRYPTION ALGORITHM ISL-LWC

The block diagram of the proposed ISL-LWC lightweight block encryption algorithm is shown in Fig. 1.

The main parameters of the algorithm:

- block length – 64 bits;
- key length – 80 bits;
- number of encryption rounds - 16.

The algorithm uses SP transformation, modulo 2 addition (XOR operation), rotate shift, and non-linear transformations in the form of S-boxes (S).

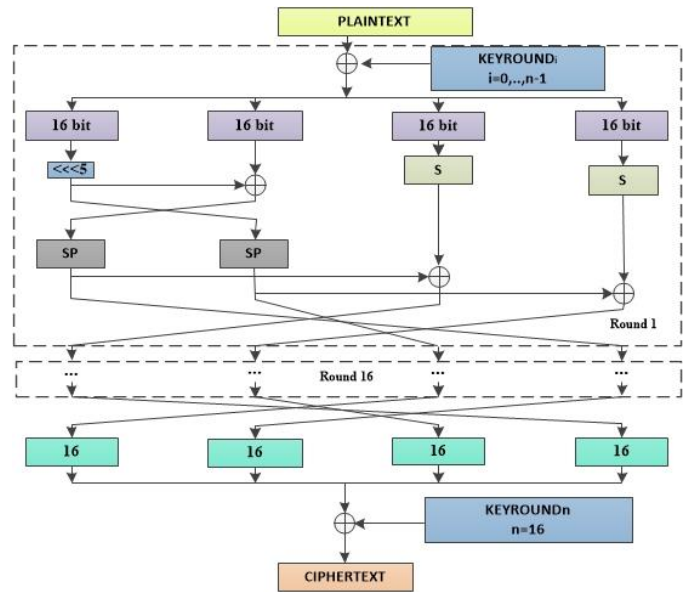


Fig. 1 Scheme of the encryption algorithm.

The encryption process consists of 4 stages:

Stage 1. A 64-bit plaintext block is added to the round key modulo 2 (XOR operation). Next, the resulting 64-bit block is divided into 4 subblocks of 16 bits each (the subblocks are numbered from left to right).

Stage 2. The 1st input subblock is rotated by 5, then the obtained value of the 1st input block is summed (XOR operation) with the 2nd subblock, and the resulting values are swapped in accordance with the scheme and go through SP transformations.

Stage 3. The 3rd and 4th sub-blocks go through the transformation S and then are added (XOR operation) with the results obtained at Stage 2 according to the scheme.

Stage 4. The results of Stages 2 and 3 are swapped according to the scheme of the encryption algorithm.

1) *SP transformation*: The SP transformation (Fig. 2) consists of non-linear 4-bit substitutions S-box1 and S-box2 (Tables I, II) and a linear bit permutation P-box (Table III). The methods for obtaining S-box1 and S-box2 are shown in [19]. The transformations above make it possible to perform confusion and diffusion.

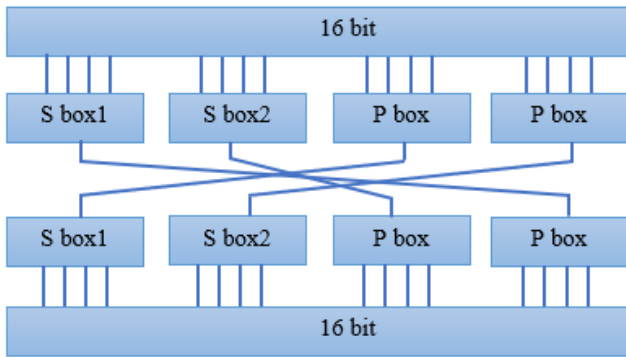


Fig. 2 SP transformation scheme.

TABLE I S-BOX1 SUBSTITUTION

0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
2	E	D	6	8	A	B	1	5	3	4	9	0	F	7	C

TABLE II S-BOX2 SUBSTITUTION

0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
F	5	D	8	C	2	4	7	0	9	6	A	1	3	E	B

TABLE III P-BOX BIT PERMUTATION

i	0	1	2	3
P(i)	3	2	0	1

2) *S transformation*; Input 16 bits are represented as $a_0a_1a_2a_3a_4a_5a_6a_7a_8a_9a_{10}a_{11}a_{12}a_{13}a_{14}a_{15}$ of which every sequential 4 bits are represented as $m_i, i = 0, 3$. $m_0 = a_0a_1a_2a_3$, $m_1 = a_4a_5a_6a_7$, $m_2 = a_8a_9a_{10}a_{11}$, $m_3 = a_{12}a_{13}a_{14}a_{15}$. The values m_0, m_2 and m_1, m_3 are passed through 4-bit S-box1 and S-box2 and then swapped according to Fig. 3.

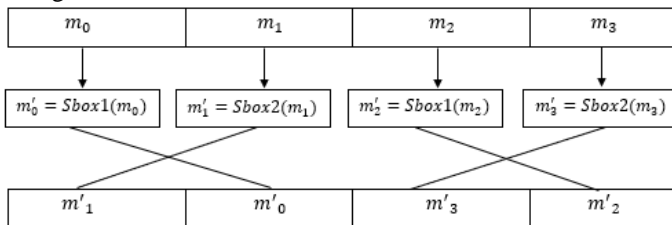


Fig. 3 S-box transformation process.

Round subkeys are generated on the basis of an 80-bit base key, which is divided into five sub-blocks of 16 bits each (sub-blocks are numbered from left to right) (Fig. 4). The cryptographic transformations used are the 4-bit S-box and addition modulo 2 raised to the power of the word length.

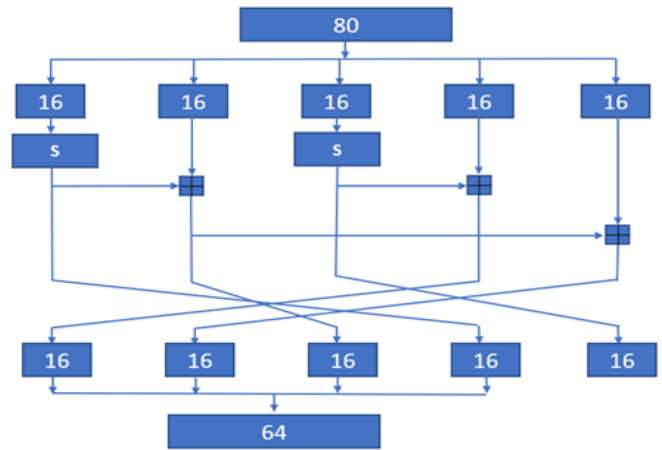


Fig. 4 Algorithm for generating round keys.

IV. STATISTICAL ANALYSIS OF CIPHERTEXTS

One of the main ways to test a block encryption algorithm for security is to conduct statistical analysis since most cryptographic attacks are based on the search for statistical vulnerabilities in the ciphertext.

To test sequences for randomness, there are a large number of algorithms, and for the convenience of checking sequences, software products have already been implemented that contain some sets of tests. Among them, the most common are the tests proposed by NIST, DIEHARD, CRYPT-X, D. Knuth, and others [20].

For statistical analysis of ciphertexts obtained using the ISL-LWC, Present, and Speck encryption algorithms, the NIST and D. Knuth test sets were used.

1) *NIST statistical tests*: NIST has developed a number of statistical tests which are based on the task of calculating a statistic that characterizes a certain property of a sequence compared with a reference statistic. Reference statistics are obtained mathematically, which is the subject of many theorems and scientific papers on cryptography, probability theory, and number theory. NIST tests have already been used to study the output sequences of cryptographic systems [21]. The tests are based on the concept of the null hypothesis. The null hypothesis is the assumption that there is some relationship between the occurrence of numbers. In other words, the null hypothesis is the assumption that the sequence is truly random (the symbols of which appear equally likely and independently of each other). Therefore, if such a hypothesis is true, then the encryption algorithm will perform well statistically.

To obtain the results of testing ciphers 15 NIST statistical tests were used: frequency bit test, frequency block test, test for a sequence of identical bits, test for the longest sequence of ones in a block, test for binary matrix ranks, spectral test, test for matching non-overlapping patterns, overlapping pattern matching test, Maurer's universal statistical test, linear complexity test, periodicity test, approximate entropy test, cumulative sums test, arbitrary variance test, and another arbitrary variance test [22].

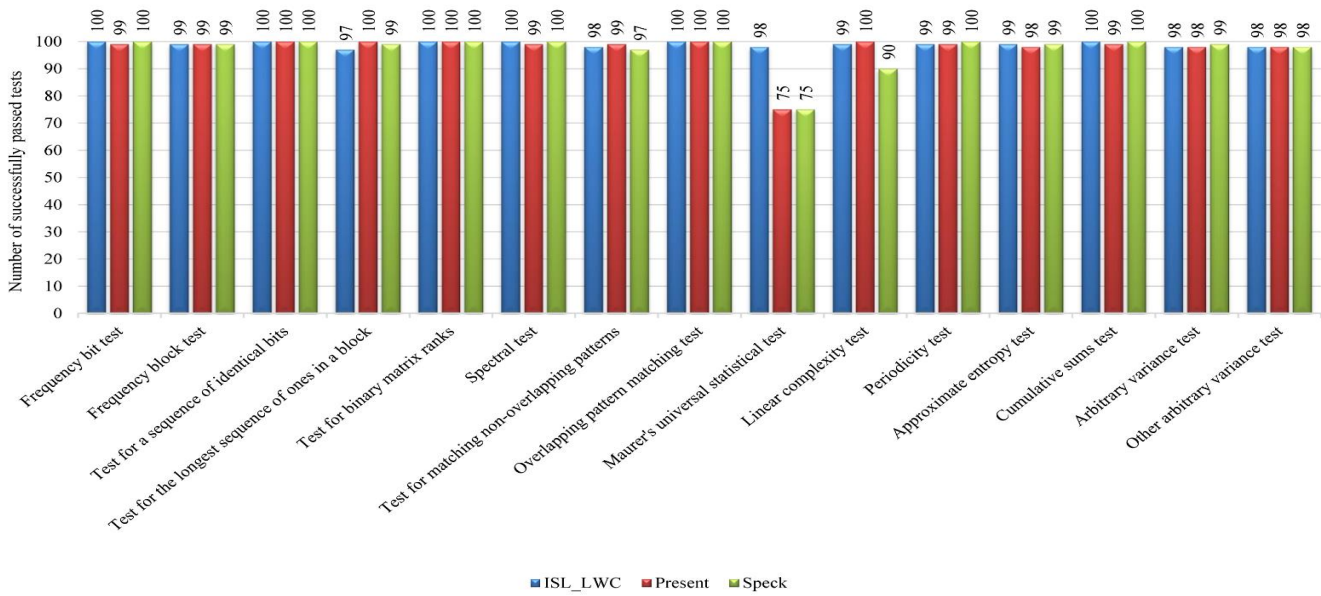


Fig. 5 Comparative analysis of successfully passed NIST tests.

To study the statistical security of the ISL-LWC, Present, and Speck encryption algorithms using NIST tests, each algorithm encrypted 20 files, differing in size, on five different keys. As a result, 100 files were encrypted with each algorithm. The number of successfully passed NIST tests and a comparative analysis of the ISL-LWC, Present, and Speck encryption algorithms are shown in Fig. 5.

In each test, a so-called P-value is calculated, which indicates the level of randomness. If the P-value = 1, then the sequence is perfectly random, and if it is zero, then the sequence is completely predictable. Next, the P-value is compared with the threshold level of randomness α , and if it is greater than α , then the null hypothesis is accepted and the sequence is recognized as random, otherwise, it is recognized as non-random.

In the tests, $\alpha = 0.01$ is assumed. Therefore:

- If the P-value ≥ 0.01 , then the sequence is considered random with a confidence level of 99%;
- If the P-value < 0.01 , then the sequence is considered non-random with a confidence level of 99%.

As a result of the study and comparative analysis of the three encryption algorithms according to NIST tests, it was found that the percentage of successfully passed tests by algorithms is: ISL-LWC – 99%, Present – 97.5%, Speck – 97%. From the obtained results, we can conclude that the ISL-LWC algorithm satisfies the statistical security criteria.

2) *Statistical tests by D. Knuth*: One of the first sets of statistical tests was proposed by D. Knuth in 1969 and described in his classic work "The Art of Computer Programming". D. Knuth's set contains such tests as the serial test, gap test, poker test, coupon collector test, permutation test, monotonicity test, and correlation test. The tests are based on the chi-square (χ^2) statistical test. The calculated value of the χ^2 statistic is compared with the tabular results and, depending on the probability of occurrence of such a statistic, a conclusion is made about its quality [23]. Among the advantages of these tests are their small number and the existence of fast execution algorithms. The disadvantage is the uncertainty in the interpretation of the results [24].

To study the statistical security of the ISL-LWC, Present, and Speck encryption algorithms using the D. Knuth tests, we encrypted with each algorithm the same 100 files that were checked using the NIST tests. The number of successfully passed tests by D. Knuth and a comparative analysis of the ISL-LWC, Present, and Speck encryption algorithms are shown in Fig. 6.

As a result of the study on the tests of D. Knuth and a comparative analysis of the three encryption algorithms, it was found that the percentage of successfully passed tests by the algorithms is 93.5% for ISL-LWC, 99% for Present, and 99% for Speck. From the obtained results, we can conclude that the ISL-LWC algorithm satisfies the statistical security criteria.

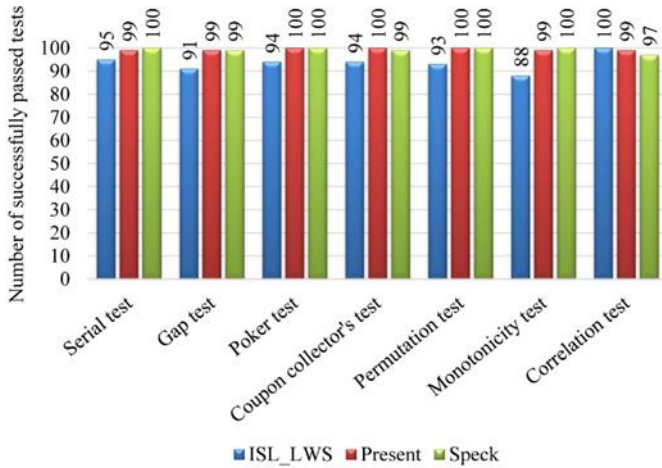


Fig. 6 Comparative analysis of successfully passed tests by D. Knuth.

3) Study of statistical security indicators: For the study of statistical security, the following indicators were considered:

- average number of output bits that change when one input bit changes (avalanche effect);
- degree of completeness (d_c);
- degree of avalanche effect (d_a);
- degree of strict avalanche criterion (d_{sa}).

They are considered for various numbers of cycles and randomly taken encryption keys. The definition of the above indicators is presented in [25].

The essence of the experiment is to evaluate the depth of the avalanche effect of the ISL-LWC encryption algorithm, which is determined by the number of encryption rounds. The experiment was carried out on 100, 1000, and 10,000 blocks of ciphertext obtained using the ISL-LWC algorithm. Table IV presents the results of the assessment of the statistical security indicators of the ISL-LWC cipher.

TABLE IV RESULTS OF THE ASSESSMENT OF STATISTICAL SECURITY INDICATORS OF THE ISL-LWC CIPHER

Round number	D_{min}	D_{max}	d_w	M_{min}	M_{max}	m_w	d_c	d_a	d_{sa}
ISL-LWC (100 blocks)									
1	9.00 20	10.8 636	9.93 28	3.074 85	5.70 76	4.3912	0.125	0.1372	0.0867
2	50.6 934	52.5 550	51.6 242	11.30 266	13.9 354	12.61906	0.4682	0.3943	0.3314
3	64.6 894	66.5 510	65.6 202	20.81 73	23.4 501	22.1337	0.8593	0.6916	0.6345
4	43.9 609	45.8 226	44.8 918	27.31 95	29.9 523	28.6359	0.9843	0.8939	0.8350
5	20.9 659	22.8 276	21.8 968	30.14 76	32.7 804	31.4640	1	0.9776	0.9114
6	15.5 450	17.4 067	16.4 759	30.57 96	33.2 124	31.8960	1	0.9898	0.9194
7	14.8 608	16.7 225	15.7 916	30.74 11	33.3 739	32.0575	1	0.9887	0.9219
8	14.4	16.2	15.3	30.62	33.2	31.9418	1	0.9894	0.9203

Round number	D_{min}	D_{max}	d_w	M_{min}	M_{max}	m_w	d_c	d_a	d_{sa}
	042	658	350	54	582				
9	14.7 902	16.6 519	15.7 211	30.58 53	33.2 181	31.9017	1	0.9905	0.9176
10	15.1 740	17.0 357	16.1 049	30.61 01	33.2 429	31.9265	1	0.9902	0.9218
11	15.4 715	17.3 332	16.4 024	30.67 45	33.3 073	31.9909	1	0.9911	0.9196
12	15.1 822	17.0 439	16.1 131	30.73 21	33.3 649	32.0485	1	0.9926	0.9216
13	14.9 554	16.8 170	15.8 862	30.66 18	33.2 946	31.9782	1	0.9903	0.9211
14	15.0 505	16.9 122	15.9 813	30.59 75	33.2 003	31.8839	1	0.989086	0.9199
15	14.6 191	16.4 812	15.5 504	30.62 61	33.2 589	31.9425	1	0.9898	0.9224
16	14.8 984	16.7 601	15.8 292	30.64 67	33.2 795	31.9631	1	0.9893	0.9201
ISL-LWC (1000 blocks)									
1	9,00 20	10,8 637	9,93 29	3,074 9	5,70 77	4,3913	0,1250	0,1372	0,0867
2	50,6 934	52,5 551	51,6 243	11,3 027	13,9 355	12,6	0,46	0,39	0,33
3	64,6 894	66,5 511	65,6 202	20,8 174	23,4 502	22,1	0,85	0,69	0,63
4	43,9 610	45,8 227	44,8 918	27,3 195	29,9 523	28,6	0,98	0,89	0,83
5	20,9 660	22,8 277	21,8 968	30,1 477	32,7 805	31,4	1	0,97	0,91
6	15,5 451	17,4 068	16,4 759	30,5 797	33,2 125	31,8	1	0,98	0,91
7	14,8 609	16,7 225	15,7 917	30,7 411	33,3 739	32,0	1	0,98	0,92
8	14,4 042	16,2 659	15,3 351	30,6 255	33,2 583	31,9	1	0,98	0,92
9	14,7 903	16,6 520	15,7 211	30,5 853	33,2 181	31,9	1	0,99	0,91
10	15,1 741	17,0 358	16,1 049	30,6 102	33,2 430	31,9	1	0,99	0,92
11	15,4 716	17,3 333	16,4 024	30,6 745	33,3 073	31,9	1	0,99	0,91
12	15,1 823	17,0 439	16,1 131	30,7 322	33,3 650	32,0	1	0,99	0,92
13	14,9 554	16,8 171	15,8 862	30,6 619	33,2 947	31,9	1	0,99	0,92
14	15,0 505	16,9 122	15,9 814	30,5 975	33,2 003	31,8	1	0,98	0,92
15	14,6 191	16,4 813	15,5 504	30,6 261	33,2 589	31,9	1	0,98	0,92
16	14,8 984	16,7 601	15,8 293	30,6 467	33,2 795	31,9	1	0,98	0,92
ISL-LWC (10000 blocks)									
1	9,00 20	10,8 637	9,93 29	3,07 49	5,70 77	4,39	0,12	0,13	0,08
2	50,6 934	52,5 551	51,6 243	11,3 027	13,9 355	12,6	0,46	0,39	0,33
3	64,6 894	66,5 511	65,6 202	20,8 174	23,4 502	22,1	0,85	0,69	0,63
4	43,9 610	45,8 227	44,8 918	27,3 195	29,9 523	28,6	0,98	0,89	0,83
5	20,9 660	22,8 277	21,8 968	30,1 477	32,7 805	31,4	1	0,97	0,91
6	15,5 451	17,4 068	16,4 759	30,5 797	33,2 125	31,8	1	0,98	0,91

Round number	D_{min}	D_{max}	d_w	M_{min}	M_{max}	m_w	d_c	d_a	d_{sa}
7	14,8609	16,7225	15,7917	30,7411	33,3739	32,0575	1	0,9888	0,9219
8	14,4042	16,2659	15,3351	30,6255	33,2583	31,9419	1	0,9895	0,9204
9	14,7903	16,6520	15,7211	30,5853	33,2181	31,9017	1	0,9906	0,9177
10	15,1741	17,0358	16,1049	30,6102	33,2430	31,9266	1	0,9902	0,9218
11	15,4716	17,3333	16,4024	30,6745	33,3073	31,9909	1	0,9911	0,9197
12	15,1823	17,0439	16,1131	30,7322	33,3650	32,0486	1	0,9927	0,9217
13	14,9554	16,8171	15,8862	30,6619	33,2947	31,9783	1	0,9904	0,9212
14	15,0505	16,9122	15,9814	30,5975	33,2003	31,8839	1	0,9891	0,9200
15	14,6191	16,4813	15,5504	30,6261	33,2589	31,9425	1	0,9899	0,9225
16	14,8984	16,7601	15,8293	30,6467	33,2795	31,9631	1	0,9894	0,9202

In Table IV, the following designations are used:

- M_{min} is the minimum value of the mathematical expectation of the number of changed bits for some bit at the input;
- M_{max} is the maximum value of the mathematical expectation of the number of changed bits for some bit at the input;
- D_{min} and D_{max} are the variances of the number of changed bits in the bitwise estimation of the minima and maxima of the mean values;

m_w is the average number of changed bits:

$$m_w = \frac{M_{min} + M_{max}}{2} \quad (1)$$

Analyzing the data obtained in Table IV, we can conclude that with an increase in the number of blocks for encryption, more accurate values of d_a and d_{sa} , are obtained, i.e. they approach value 1 faster in the fourth and subsequent rounds. As a result of the study, it was found that at the 4th round of encryption of the ISL-LWC algorithm, the input sequence is completely confused.

Results of the study and comparative analysis of the time of encryption and key generation on the Arduino Uno R3 board.

Encryption time testing for three encryption algorithms Speck, Present, and ISL-LWC was carried out on the Arduino Uno R3 board (Fig. 7).

- main features of Arduino Uno R3;
- microcontroller - ATmega328;
- clock frequency - 16 MHz;
- operating voltage - 5 V;
- flash memory - 32 MB;
- RAM - 2 Kb.



Fig. 7 Arduino Uno R3 board.

In [25] Arduino IDE version 2.0.0-rc3 was used to compile and upload the source code of lightweight encryption algorithms to the Arduino Uno R3 board (Fig. 8).

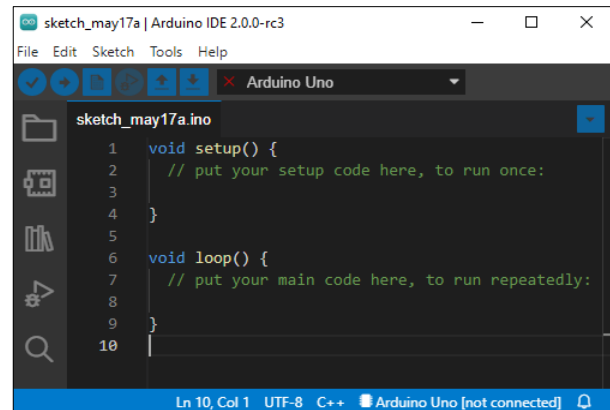


Fig. 8 Arduino IDE.

The three encryption algorithms (Speck, Present, and ISL-LWC) were implemented by the staff of the Information Security Laboratory of the Institute of Information and Computational Technologies of the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (RK MSHE CS ICT ISL) in the high-level programming language C++.

The tests were carried out on open-source software platforms developed by the US National Institute of Standards and Technology in order to unify, simplify, and speed up the testing of lightweight cryptographic algorithms.

The results of the study and comparative analysis of the Present, Speck, and ISL-LWC algorithms are shown in Table V.

TABLE V COMPARATIVE ANALYSIS OF THE ALGORITHMS BY THE TIME OF ENCRYPTION AND KEY GENERATION

Encryption algorithm	Key size, bits	Plaintext block size, bits	Encryption time, μ s	Key setting time, μ s
Present	80	64	2111.56	1541.31
Speck	96		16.90	1320.69
ISL-LWC	80		108.59	275.12

As a result of a comparative analysis of Table V, it was found that the proposed encryption algorithm works faster than Present, and when scheduling round keys, it is 6 and 5 times faster than the algorithms under consideration, respectively.

V. CONCLUSION

Lightweight encryption algorithms are considered a relatively new direction in the development of symmetric cryptography. This need arose as a result of the emergence of a large number of devices with little computing power and memory. Therefore, there was a need to develop algorithms that can provide a sufficient level of security with minimal use of resources.

This paper provides a brief literature review of existing lightweight encryption algorithms. A new lightweight block encryption algorithm ISL-LWC, developed by the staff of the RK MSHE CS IICT ISL, is presented.

The cryptographic properties of the developed algorithm were studied using the evaluation of the "avalanche effect" and statistical tests. Based on the work carried out, it was found that the proposed encryption algorithm is effective in providing a good avalanche effect, and the encrypted data is close to random and is statistically safe.

The developed algorithm is implemented in software and hardware on the Arduino Uno R3 board. A study and comparative analysis of the encryption and key generation time with the well-known lightweight algorithms Present and Speck have been carried out.

The obtained test results allow us to conclude that the ISL-LWC cipher is generally not inferior to these two well-known lightweight algorithms. Further study of the cryptographic properties of this algorithm by other methods, such as linear and differential cryptanalysis, etc., will be continued. The results will be presented in subsequent papers and used to improve the proposed algorithm.

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REFERENCES

- [1] V. A. Dovgal, and D. V. Dovgal, "Internet of Things: Concept, Applications, and Tasks," Bulletin of the Adyghe State University, Series 4: Natural-Mathematical and Technical Sciences, vol. 1, no. 212, pp. 129-135, 2018.
- [2] F. Chetouane, "An Overview on RFID Technology Instruction and Application," IFAC-PapersOnLine, vol. 48, no. 3, pp. 382-387, 2015, <https://doi.org/10.1016/j.ifacol.2015.06.111>.
- [3] H. Hasan, G. Ali, W. Elmedany, and C. Balakrishna, "Lightweight Encryption Algorithms for Internet of Things: A Review on Security and Performance Aspects," Int. Con. on Innov. and Intel. for Inf, Com. and Tech (3ICT), pp. 239-244, 2022, doi: 10.1109/3ICT56508.2022.9990859.
- [4] P. K. Dhillon, and S. Kalra, "A lightweight biometrics based remote user authentication scheme for IoT services," Jour. Inf. Sec. and Appl, vol. 34, pp. 255-270.
- [5] T. Eisenbarth, and S. Kumar, "A Survey of Lightweight-Cryptography Implementations," IEEE Des Test Com., vol. 24, no. 6, pp. 522-533, 2007.
- [6] I. Bhardwaj, A. Kumar, and M. Bansal, "A review on lightweight cryptography algorithms for data security and authentication in IoTs, " 2017 4th Int. Conf. on Sig. Proc., Com. and Cont., (ISPPCC), India, pp. 504-509, 2017, doi: 10.1109/ISPPCC.2017.8269731.
- [7] A. E. Zhukov, "Lightweight Cryptography [Part 1. Cybersecurity Issues]," vol. 1, no. 9, pp. 26-43, 2015. A. S. Soskov, and B. Ya. Ryabko, "The distinguishing attack on ARX-based lightweight block ciphers," Comp. Tech. vol. 24, no. 3, pp. 106-116, 2019. DOI: 10.25743/ICT.2019.24.3.008.
- [8] E. A. Ischukova, and E. A. Tolomanenko, "Analysis of the algorithms for encryption of lightweight cryptography in the context of the Internet of Things," Mod. High Tech., vol. 3, no. 2, pp. 182-186, 2019, URL: <https://top-technologies.ru/article/view?id=37462>.
- [9] Zh. Tang, J. Cui, H. Zhong, and M. Yu, "A Random PRESENT Encryption Algorithm Based on Dynamic S-box International," Jour. of Sec. and Its Appl., vol. 10, no. 3, pp. 383-392, 2016, <http://dx.doi.org/10.14257/ijasia.2016.10.3.33>.
- [10] A. Suhail, N. Mir, A. Mehvish, S. Ishfaq, and B. M. Tariq, "FPGA Implementation of PRESENT Block Cypher with Optimised Substitution Box," 2022 Smart Tech., Com. and Robot. STCR, pp. 1-6, 2022, doi: 10.1109/STCR55312.2022.10009366.
- [11] T. Shirai, T. Shibutani, and K. Akishita, "The 128-bit block cipher CLEFIA," FSE 2007. LNCS, vol. 4593, pp. 181-195, 2007.
- [12] F. M. Qatan, and I. W. Damaj, "High-speed KATAN ciphers on-a-chip," Comp. sys. and Ind. Inf. ICCSII, 2012 Inter. Conf, IEEE, pp. 1-6, 2012.
- [13] E. Aysu, and P. Gulcan, "Schaumont. SIMON says: Break area records of block ciphers on FPGAs," IEEE Emb. Syst Lett, vol. 6, pp. 37-40, 2014, <https://doi.org/10.1109/les.2014.2314961>.
- [14] R. Beaulieu, S. D. Treatman-Clark, B. Shors, J. Weeks, Smith, and L. Wingers, "The SIMON and SPECK lightweight block ciphers," 2015 52nd ACM/EDAC/IEEE Des. Auto. Conf DAC, San Francisco, USA, 2015, pp. 1-6, doi: 10.1145/2744769.2747946.
- [15] U. Muhammad, A. Irfan, M. Imran, Kh. Shujaat, and A. Sh. Usman, "SIT. A Lightweight Encryption Algorithm for Secure Internet of Things," IJACSA Inter. Jour. of Adv. Comp. Sci. and Appl, vol. 8, no. 1, pp. 402-411, 2017.
- [16] F. Xinxin, M. Kalikinkar, and G. Guang, "WG-8: A Lightweight Stream Cipher for Resource-Constrained Smart Devices Quality, Reliability, Security and Robustness in Heterogeneous Networks," vol. 115, pp. 617-632, 2013, https://doi.org/10.1007/978-3-642-37949-9_54.
- [17] A. Bogdanov, L. Knudsen, G. Leander, and et al, "PRESENT: An ultra-lightweight block cipher," CHES 2007. LNCS, vol. 4727, pp. 450-466, 2007.
- [18] A. Khompysh, N. Kapalova, K. Algazy, D. Dyusenbayev, and K. Sakan, "Design of substitution nodes (S-Boxes) of a block cipher intended for preliminary encryption of confidential information," Cogent Engineering, vol. 9, no. 1, pp. 1-14, 2022, DOI: 10.1080/23311916.2022.2080623.
- [19] A. A. Perov, "Using NIST statistical tests for the analysis of the output sequences of block ciphers," Sci. Bull. of NSTU, vol. 3, no. 76, pp. 87-96, 2019. doi:10.17212/1814-1196-2019-3-87-96.
- [20] F. Sulak, M. Uğuz, O. Koçak, and A. Doğanaksoy, "On the independence of statistical randomness tests included in the NIST test suite," Turk. Jour. of Elec. Engin. & Comp. Scien. vol. 25, no.5, pp. 3673-3683, 2017. doi:10.3906/elk-1605-212.
- [21] M. O. Pikuza, and S. Yu. Mikhnevich, "Testing a hardware random number generator using NIST statistical test suite," BSUIR Reports, vol. 19, no. 4, pp. 37-42, 2021. <https://doi.org/10.35596/1729-7648-2021-19-4-37-42>.
- [22] K. Sakan, S. Nyssanbayeva, N. Kapalova, K. Algazy, A. Khompysh, and D. Dyusenbayev, "Development and analysis of the new hashing algorithm based on a block cipher," Easter-Euro. Jour. of Enter. Techn. vol. 2, no. 9 (116), pp. 60-73, 2022. <https://doi.org/10.15587/1729-4061.2022.252060>
- [23] N. A. Kapalova, A. Khompysh, A. Müslüm, and K. Algazy, "A block encryption algorithm based on exponentiation transform [Cogent

- Engineering], 2020, Vol.7, no. 1, pp.1-12, <https://doi.org/10.1080/23311916.2020.1788292>
- [24] I. V. Lisitskaya, A. A. Nastenko, K. E. Lissitzky, “Large ciphers - random substitutions. Comparison of statistical security indicators of block symmetric ciphers submitted to the Ukrainian competition,” East. Euro. Jour. of Adv. Tech. ISSN 1729-3774 vol. 6, no.9 (60), pp. 1-11, 2012.
- [25] M. Simon, “Programming Arduino: Getting Started with Sketches,” Third Edition, McGraw Hill LLC, p.176, 2022.

An Investigation of Asthma Experiences in Arabic Communities Through Twitter Discourse

Mohammed Alotaibi^{1*}, Ahmed Omar²

Artificial Intelligence and Sensing Technologies (AIST) Research Center, University of Tabuk, Tabuk 71491, Saudi Arabia¹
Department of Computer Science-Faculty of Science, Minia University, Minia, Egypt, University Street, El-Minia 1666, Egypt²

Abstract—Artificial intelligence technologies can effectively analyze the public opinions from social-media platforms like twitter. This study aims to employ the AI technology and big data to explore and discuss the common issues of asthma that patients share on Twitter platform in Arabic communities. The data was acquired using the Twitter API version 2. Latent Dirichlet Allocation was used for grouping data into two clusters which provide information and tips about the treatment and prevention of asthma and personal experiences with asthma, including symptoms, diagnosis, and the negative impact of asthma on the quality of life. Sentiment analysis and data frequency distribution techniques were used to analyze the data in both clusters. The data analysis of first indicated that individuals are interested in learning about different ways to treat asthma and potentially finding a permanent solution. The data analysis of second cluster indicated the existence of negative sentiments about asthma, which also included religious expressions for improving the condition. The study also discussed the differences in expressions among Arabic communities and other communities.

Keywords—Asthma; twitter; semantic analysis; LDA; Arab; communities

I. INTRODUCTION

More than 350 million people worldwide suffer from asthma, which is one of the serious public health concerns [1]. Due to changes in the environment and in people's lifestyles, its prevalence and consequences are growing in urban areas and increasing around the world. It is the most prevalent chronic childhood condition as well as one of the most expensive healthcare expenditures.

One of the most prevalent forms of reactive airway disease is asthma, which is also associated with a higher risk of death and permanent impairment [1]. Atopic dermatitis and genetic predisposition mix with eosinophilic inflammation and ongoing exposure to environmental factors, particularly molds and pollution can cause progressive lung dysfunction. Also, due to greater understanding of the biology of the disease and therapeutic advancements, asthma-related mortality has decreased over the past few decades; nonetheless, more research and efforts are required to lower asthma-related death and disability. Also, it's estimated that asthma killed more than 1000 individuals worldwide [1].

The design and delivery of healthcare systems for the management and understanding of various chronic diseases like obesity [2-4], diabetes [5-8], and asthma have been accelerated by the rapid growth of technologies, smart mobile

devices, robotics, and social networks in telecommunications and the internet. A new virtual world was created as a result of the technological revolution; social networks now allow users to contact with friends and other people regardless of where they are in the world (geographically, politically, or economically). Globally, over 4.7 billion people use social networks, according to Statista [9], and this number is only anticipated to grow as mobile device use and mobile social networks gain popularity.

Twitter is one of the most commonly used social networks worldwide. It currently ranks as one of the leading social networks worldwide based on active users, according to recent social media industry statistics [9]. Twitter had 347.3 million monetizable daily active users worldwide as of the fourth quarter of 2020 [9]. Registered users can read and post tweets via the update feed, as well as follow other users [9]. This huge volume of posts on twitter platform provides billions of raw data that can be used for many purposes like research and business.

Big data is a term used to describe the enormous volume of both structured and unstructured data that regularly inundates a business [10]. Social networks in general are known as the most well-liked sources of big data. For example, each tweet posted on by a Twitter account includes multitude data input [Twitter account Id, Number of followers, Number of retweets, and Number of favorites etc.], all of which could be collected for each tweet, generating a huge volume of data in short time as the stream of data increase rapidly within seconds. Recently, artificial intelligence [AI] technology that uses huge volume of raw data has become one of the useful sources of information regarding people impressions/opinions about many events such as politics, social developments, pandemic etc.

AI technologies aid in the analysis of huge data, assisting decision-makers in their commercial decisions or governments in gaining insight into the views of the populace in their nation regarding a social, political, or economic issues. Sentiment analysis is a type of contextual text mining that can identify and extract subjective knowledge from various sources of information [11]. By monitoring online conversations, it assists a business in understanding the social perceptions of its brand, product, or service. As a result, the health sector participates in this virtual society as some patients share their experiences with the diseases they have and as some doctors have social media accounts and share clinical information with the public.

Using AI technologies for analyzing twitter conversations can be observed in healthcare research in different contexts.

For instance, twitter data was analyzed in [12] to understand the Covid-19 vaccine hesitancy; and the results revealed that potential side effects and vaccine safety were identified to be the major concerns among the public. Similarly, BERT-based supervised learning approach was used for analyzing over 31 million Covid-19 related tweets for self-disclosure in [13]. The study [13] found that users intentionally self-disclose and associate with similarly disclosing users for social rewards. Similarly, by analyzing HIV-related tweets [14] and diabetes-related tweets [15], recent research indicated that twitter discussions analysis can help in understanding nuanced public opinions, beliefs, and sentiments; and therefore, the decision-makers need to proactively use Twitter and other social media for understanding public health concerns. This is evident from a study conducted in Australia in 2019 [16]. A thunderstorm asthma outbreak in Melbourne, Australia, in 2016 led to over 8,000 hospital admissions in a matter of hours, which is a typical acute illness occurrence. A strategy based on the amount of time between events was suggested in this study since the time to respond to acute disease events is limited. Out of 18 experiment combinations, the results showed that three were able to identify the thunderstorm asthma outbreak up to nine hours ahead of the time specified in the official report, and five were able to identify it before the initial news report. The results of these studies [12-18] show the significance of Twitter monitoring and discuss conversational trends and prevailing attitudes that predominate in online social networks during a health crisis. In relation to twitter analysis of Asthma, previous studies [19-21] suggested the need for extensive research on using big data the asthma's contents in different contexts. To the best of authors' knowledge, there is no study about asthma issues in Arabic communities. Therefore, this study aims to employ the AI technology and big data to explore and discuss the common issues of asthma that patients share on Twitter platform in Arabic communities.

The remainder of the paper is organized as follows. Section II includes a review of related work. Section III describes the used methodology to develop the study. Section IV illustrates the outcomes and studies the results; and Section V discusses the results achieved while Section VI summarizes findings and outlines direction for future work.

II. RELATED WORKS

Asthma is one of the most common chronic health problems that have a significant negative influence on both society and an individual's well-being [1]. To create an epidemiological framework that can depict the condition's prevalence and patients' perceptions of that condition across multiple geographies, it is essential to integrate various large-scale data sources. Moreover, the number of social media applications has substantially increased over the last decade [20]. Twitter is a critical interactive venue for research information because statistics show that more than 80% of internet users look for health information online [9]. Social media is now being used by both patients and carers for support and information. They rely on social media for information and feedback from others to get the latest news and information on medications and treatments. Some even create and join online groups to provide support to each other.

In the contemporary era, Twitter was utilized in the health sectors, for example, to track and predict the spread of influenza [23-26]. It's also used to keep track of pharmaceutical side effects and understand the well-being of military populations [27], as well as to monitor the side effects of pharmaceuticals [28, 29]. These studies indicate the importance of social media data in public health, refining the target hypothesis' query lexicon and lowering the amount of noise in the extracted data. Despite the potential benefits, it is believed the following challenges explain why prior social media sensing experiments in public health have been short-lived or limited in scope. For example, [24] and [25] track influenza throughout a one- and two-month period, respectively. Moreover, the study in [27] investigates the harmful effects of medication over a six-month period. In terms of geographical coverage, just a few cities are examined in [24], and the transmission of influenza is studied at the national level rather than at the state or county level in [25]. Moreover, a study developed in 2013 [19] aimed to present Natural Language Processing-based Content Analysis research to aid with Asthma syndromic surveillance on Twitter. They used the Twitter API to get a big number of Tweets. Asthma and various misspellings of that word were among the search results, as were phrases for common medical devices linked with Asthma, such as "inhaler" and "nebulizer," as well as names of prescription medicines used to treat the illness, such as "albuterol" and "Singulair". Annotating the content of a randomly selected subset of these Tweets [N=3511] was done using an annotation scheme that coded for the following elements: the Asthma Symptom Experiencer [Self, Family, Friend, Named Other, Unidentified, and All-Non-Self, which was the union of these last four categories]; aspects of the type of information being conveyed by each Tweet [Medication, Triggers, Physical Activity, Contacting of a Medical Practitioner]. With the unigram model, SVM with 10-fold cross-validation achieved the highest prediction accuracy. Non-English, Self, All-Non-Self, Medication, Symptoms, and Spam were the categories with the highest reduction in classification error when utilizing the unigram model. For the unigram model, most of these categories demonstrated very high Precision and very high Recall. Surprisingly, the Unigram model performed significantly better than the bigram model, implying that individual words in these Tweets were more reliably predictive of content than pairs of words, which were less common. Authors concluded that using social media, such as Twitter, to undertake surveillance for chronic illnesses like Asthma is a promising method.

Moreover, another recent study [20] looked at the digital footprints [or "sociomes"] of asthma stakeholders on Twitter to see how they communicated online. Symplur Signals were used to collect tweets containing the word "asthma" and the hashtag #asthma. The characteristics of usage and tweets were examined between the words "asthma" and the hashtag #asthma, and then between four stakeholder groups: clinicians, patients, healthcare organizations, and industry. Authors found that with fewer people and tweets each month, the #asthma sociome was substantially smaller than the "asthma" sociome. The #asthma sociome, on the other hand, had a better correlation with asthma seasons and was less vulnerable to profanity and viral memes. Consequently, between April 2015

and November 2018, 308,370 individuals tweeted 695,980 times for the #asthma sociome. Clinicians accounted for 16% of tweets, patients for 9%, healthcare organizations for 22%, and industry for 0.3 percent. However, authors recommended that further research could aid in improving health-care communication and guiding patient and provide education.

In a different context, a recent study [21] focused on analyzing the most popular tweets and the quality of the links posted, and to determine what factors influence the debate about asthma on Twitter. The authors used Symplur Signals to extract data from Twitter, analyzing the top 100 most shared tweets and the top 50 most shared links with the hashtag #asthma. Each website's content was evaluated using an Asthma Content score, as well as validated DISCERN ratings and HONCode standards. They found out that the top 100 asthma-related tweets received 16,044 likes and were shared 10,169 times. Non-healthcare individuals accounted for 20 of the top 100 tweets, non-healthcare organizations accounted for 16, and doctors accounted for 14. There were 62 educational tweets among the top 100, 11 research-related tweets, ten political tweets, and 15 promotional tweets among the top 100. Moreover, the top 50 links were shared a total of 6009 times [median number of shares 92 (range 60-710)]. The most prevalent type of link was found to be instructional content (42%), followed by research papers (24%), promotional websites (22%), and political websites (12%). The Asthma Content ratings of educational links were higher than those of other links ($p=0.005$, $p<.05$). For all sorts of linkages, all three scores were poor. Only 34% of sites passed the HONCode criteria, and only 14% were found to be of good quality by the DISCERN score. The authors concluded that majority of tweets with the hashtag #asthma was educational. However, most top Twitter links rated low in terms of asthma content, quality, and trustworthiness.

A recent study [30] the impact of socio-cognitive factors on adherence to asthma medication using traditional mixed methods (interviews and twitter content analysis) and machine learning, found that some perceptions are more freely expressed on social media such as Twitter, than in the laboratory setting. Therefore, twitter data may be more reliable for understanding of public perceptions of asthma and its relevant factors compared to laboratory/hospital data in few instances. It should be noted that all studies refer to main role of tweets contents on understanding more about asthma while some studies recommend to do more search about the tweets contents towards asthma. However, this study is an attempt to contribute in adding a value to the understanding of tweets contents about asthma in Arabic communities.

III. METHODS

The study method occurred in the following phases, as shown in Fig. 1: data collection, data preprocessing (cleaning), sentiment analysis, and frequency distribution.

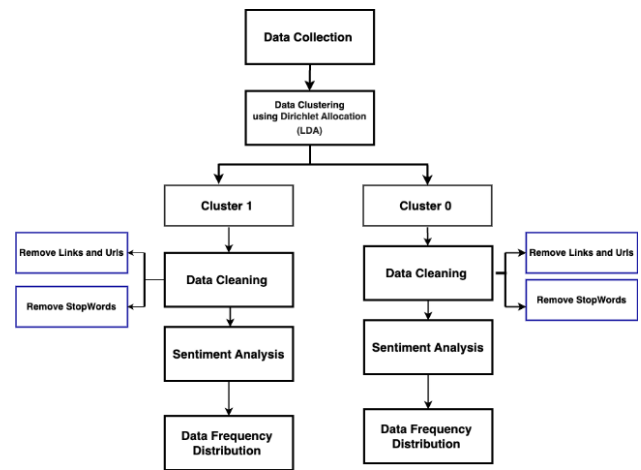


Fig. 1. Study methodology flowchart.

A. Data Collections

The data was acquired using the Twitter API version 2, premium version, which offers several additional features above the regular API version. The premium version of the Twitter API allows users to collect data from the previous 30 days. However, to enable the collection of data in excel sheet format, a python script was created. As search keywords, two separate terms [Asthma, asthmatic] were utilized. These hashtags were picked because they are popular on Twitter. User ID, user location, tweets, account followers, favorites, and retweets are all collected and kept in an excel sheet for further statistical research. One hundred thirty thousand (130,000) tweets including words asthma or asthmatic have been collected.

B. Data Clustering using Latent Dirichlet Allocation [LDA]

A statistical modeling technique called topic modeling can be used to identify the general "themes" that appear in a group of texts. A topic model such as Latent Dirichlet Allocation [LDA] is used to categorize text in a document to a certain topic. It creates a topic per document model and a words per topic model using Dirichlet distributions as the modeling framework.

C. Data Processing and Cleaning

In order to make the data clear, the following steps are followed: (1) personal interview, authors review all tweets and remove tweets that have no relation to asthma. (2) Python scripts were used to remove all tweets that include links or URLs because some of those tweets refer to another reference or for advertisement of a product etc. (3) another Python script was used to remove the stopwords in Arabic language from the tweets' contents. (4) a python script was used to tokenize tweets. Tokenization is one of the most fundamental yet crucial procedures in text analysis. Tokenization divides a stream of text into smaller pieces called tokens, which are frequently words or sentences. While this is a well-known issue with various ready-to-use solutions from popular libraries, Twitter data presents significant issues due to the language's nature.

E. Sentiment Analysis

One of the most beneficial applications of natural language processing is sentiment analysis (SA). We used "Mazajak" which is an Arabic SA system on the internet. The system is built on a deep learning model that produces cutting-edge results on a variety of datasets for Arabic dialects, including SemEval 2017 and ASTD. The existence of such a system ought to be helpful for numerous applications and fields of study that use sentiment analysis as a tool [31].

F. Data Frequency Distribution

As it is known in every language, some words are widespread. Notably, their use in the language is crucial; they don't usually convey a particular meaning, especially if taken out of context. Therefore, in this case of data frequency distribution, stop words were removed from each tweet using python scripts; also, removing the URL was performed.

G. Anonymity and Privacy

The data (preferred as tweets) utilized in this research is freely available on the internet. However, we decided to respect the privacy of the tweet senders. As a result, the User ID of all records were removed. Perceptions were defined as socio-cognitive elements such as opinions, beliefs, and feelings in this study, and this was also the definition of perceptions employed.

IV. RESULTS

We used LDA topic modeling to group the collected tweets into two clusters. The first cluster [cluster 0] contains tweets that provide information and tips about the treatment and prevention of asthma, including natural remedies, inhalation therapy, and the use of specific products. In contrast, the second cluster [cluster 1] contains tweets that discuss personal experiences with asthma, including symptoms, diagnosis, and the negative impact of asthma on the quality of life. There are also some tweets in this cluster that express frustration and negative feelings about asthma. In the following section we will presents and display some distributions of each cluster.

A. Cluster 0

Fig. 2 shows the distribution of sentiment in the first cluster. We can see that most of the tweets are labeled as neutral [62,366], followed by negative [32,913] and positive [6,412].

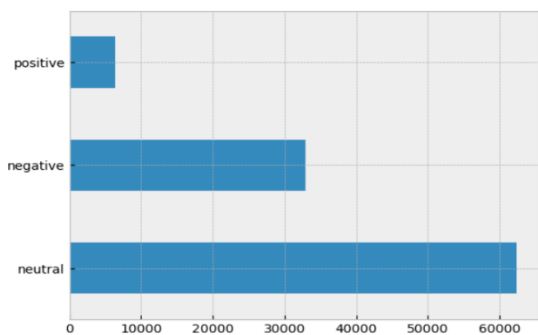


Fig. 2. Sentiment distribution in Cluster 0.

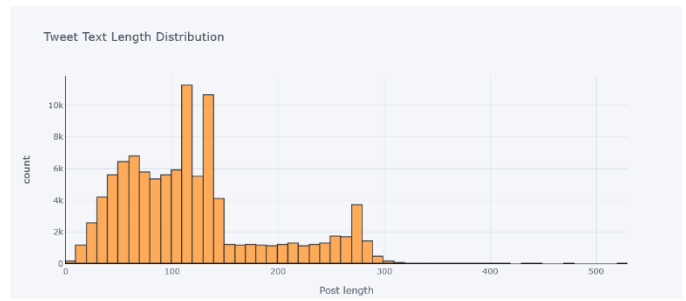


Fig. 3. Shows tweets length [number of characters] distribution.

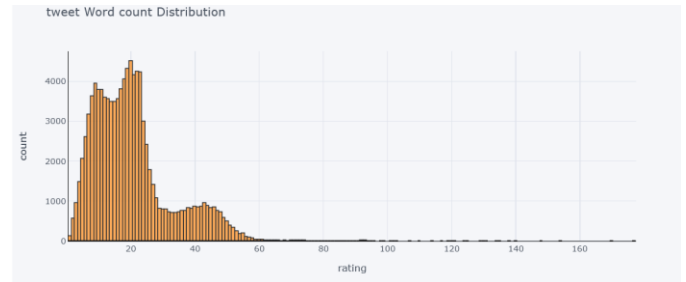


Fig. 4. Shows word count tweets distribution.

Fig. 3 shows tweets length [number of characters] distribution while Fig. 4 shows the word count tweets distribution. Top 20 words [including stop words] frequency distribution before removing stop words is shown in Fig. 5.

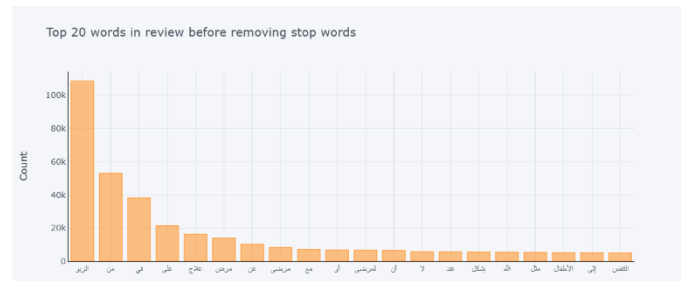


Fig. 5. Frequency distribution of top 20 words in Cluster 0 before removing stop words.

The data shows that the word "الربو" [asthma] has the highest frequency with 108450 occurrences, followed by "من" [from] with 52865 occurrences, and "في" [in] with 38052 occurrences.

Further analysis of the distribution reveals that the words "علاج" [treatment], "مرض" [disease], and "مرضى" [patients] are also highly frequent, which suggests that the text or corpus is likely related to medical or health topics.

It is important to note that the distribution includes some common prepositions such as "على" [on] and "مع" [with], which may not carry significant meaning on their own but contribute to the overall frequency count.

Fig. 6 represents top 20 words frequency distribution after removing stop words. In the new distribution, the word "الربو" [asthma] still has the highest frequency with 109379 occurrences, but the words "علاج" [treatment] and "مرض" [disease] have increased in frequency, suggesting that the text or corpus may be more focused on medical treatments and

conditions. Additionally, words such as " لمرضى " [for patients] and " للاطفال " [children] have been replaced with " لمرضاي " [for my patients] and " للأطفال " [kids], respectively, indicating a slight difference in phrasing.

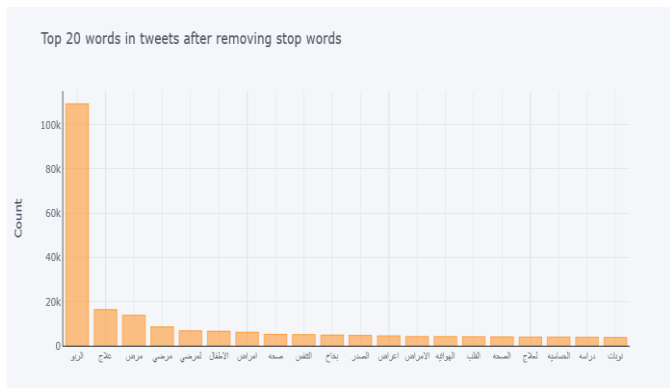


Fig. 6. Frequency distribution of top 20 words in Cluster 0 after removing stop words.

Fig. 7 shows the top 20 bigrams frequency distribution before removing stop words.

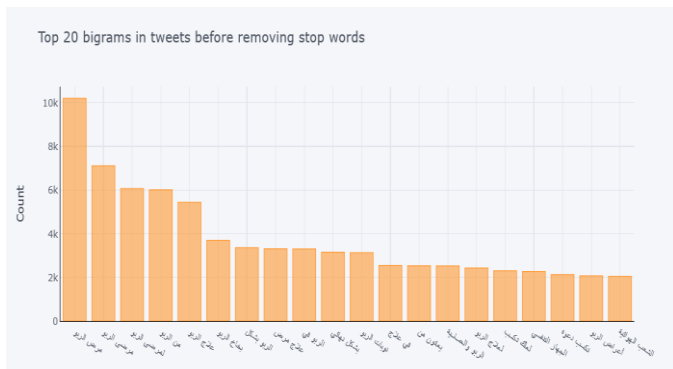


Fig. 7. Frequency distribution of top 20 bigrams in Cluster 0 before removing stop words.

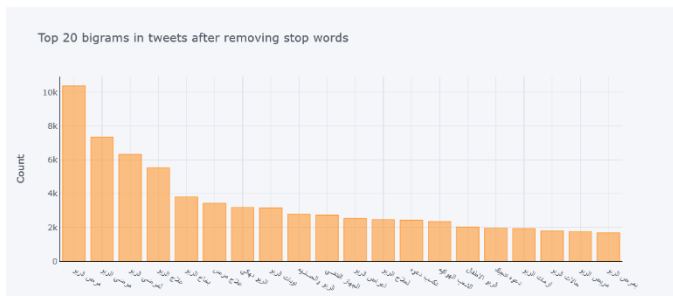


Fig. 8. Frequency distribution of top 20 bigrams in Cluster 0 after removing stop words.

The provided data is a bigram frequency distribution, which lists the frequency of two-word phrases occurring in the text or corpus. In this case, the bigrams are not filtered for stop words. The most frequent bigram is " و " [asthma disease] with 10200 occurrences, followed by " مرضى الربو " [asthma patients] with 7110 occurrences, and " لمرضى الربو " [for asthma patients] with 6067 occurrences.

When compared to the previous distribution with stop words, it is evident that the bigrams in the current distribution are more specific and related to the topic of asthma and its treatment. The bigrams also provide more context and information about the text or corpus, such as the prevalence of asthma patients and the use of inhalers as a treatment.

However, it is important to note that the inclusion of stop words in the bigrams may result in some noise and redundancy, as some common phrases that do not carry significant meaning may also appear frequently. Therefore, filtering for stop words may help to reduce noise and highlight the most meaningful bigrams which is presented in Fig. 8.

After removing stop words (Fig. 8), the bigram frequency distribution shows that " مرض الربو " [asthma disease] is still the most frequent bigram with 10366 occurrences, followed by " مرضى الربو " [asthma patients] with 7330 occurrences, and " لمرضى الربو " [for asthma patients] with 6315 occurrences.

Compared to the distribution with stop words, the current distribution has fewer occurrences of bigrams, indicating that filtering for stop words has removed noise and redundancy. The bigrams in the current distribution are more specific and related to asthma and its treatment, such as " علاج الربو " [asthma treatment] and " بخاخ الربو " [asthma inhaler].

Fig. 9 shows the top 20 trigrams frequency distribution before removing stop words.

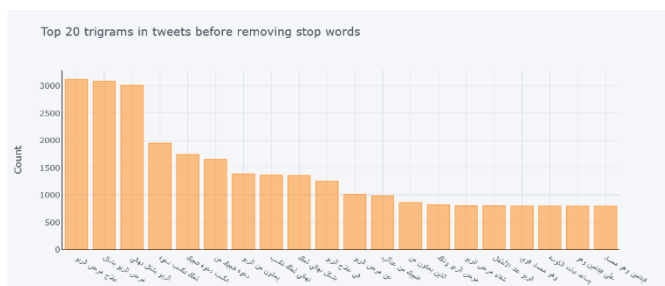


Fig. 9. Frequency distribution of top 20 trigrams in Cluster 0 before removing stop words.

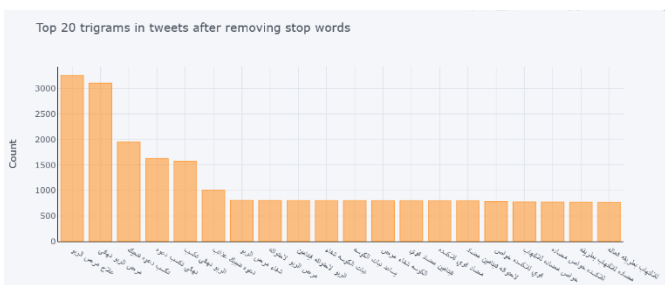


Fig. 10. Frequency distribution of top 20 triigrams in Cluster 0 after removing stop words.

The previous distribution is a frequency distribution of the top 20 trigrams related to the topic of asthma treatment. It appears that the most frequent trigrams are those related to the treatment of asthma, with " علاج مرض الربو " [treatment of asthma] being the most frequent trigram, followed closely by " الربو بشكل نهائي " [asthma permanently]. This indicates that individuals are interested in learning about different ways to treat asthma and

potentially finding a permanent solution. Other trigrams in the list include " في علاج الربو " [in the treatment of asthma], " عن " [about asthma], and " شفاء مرض الربو " [cure of asthma]. These trigrams suggest that people are looking for information on various aspects of asthma treatment, including the effectiveness of different treatments, information on the condition itself, and potential cures.

Furthermore, the frequency of " يعانون من الربو " [suffer from asthma] indicates that many individuals are affected by this condition and are actively seeking ways to manage or treat it. Overall, the distribution provides insights into what people are interested in learning about regarding asthma treatment, with a particular emphasis on finding effective treatments and potentially a cure. In contrast, the trigram distribution focuses more on treatments for asthma, with " علاج مرض الربو " [treatment of asthma] being the most frequent trigram, and " علاج الربو " [asthma treatment] and " لعلاج مرض الربو " [for asthma treatment] also appearing in the list.

The distribution of the top 20 trigrams after removing stop words (Fig. 10) is different from the one without removing stop words. In this distribution, the trigrams related to asthma treatment are still present, with " علاج مرض الربو " [treatment of asthma] being the most frequent trigram. However, " مرض الربو " [asthma in a way] and " مرض الربو بشكل " [asthma permanently] are replaced by " الربو نهائيًا " [asthma final] and " الربو لاحتوائه " [asthma for containing]. This suggests that people are interested in learning about the final stage of asthma and its contents.

The trigrams related to " تكسب دعوة تتجيك " [winning a prayer saves you] and " تكسب دعوة نهائي " [final, you win a prayer] indicate that most of the target population are believers and they are looking for a prayer that God [Allah] will help them and be cures from asthma. The trigrams related to " تساعد نبتة الكوسة " [helps zucchini plant] and " الكوسة شفاء مرض " [zucchini is a cure for asthma] suggest that people may be looking for natural remedies or alternative forms of treatment for asthma. The trigrams related to " مضاد قوي للأكسدة " [powerful antioxidant] and " مضاد خاص للالتهاب " [anti-inflammatory properties] indicate that people may be interested in learning about the potential benefits of antioxidants and anti-inflammatory substances in managing or treating asthma.

Overall, the distribution after removing stop words provides a different perspective on what people are interested in learning about regarding asthma treatment. While the focus on finding effective treatments and potentially a cure remains, there is also interest in the final stage of asthma, natural remedies, and potential benefits of antioxidants and anti-inflammatory substances. The word cloud for the cluster 0 is presented in Fig. 11.



Fig. 11. Word cloud for Cluster 0.

B. Cluster 1

Fig. 12 shows the distribution of sentiment in the second cluster. We can see that a majority of negative sentiment [68945] followed by neutral sentiment [23815], and a minority of positive sentiment [19013]. Compared to the first cluster, this cluster has a significantly higher proportion of negative sentiment, while the proportion of positive sentiment is also higher than the previous clusters. The majority of the sentiment being negative suggests that the text in this cluster contains a lot of negative or critical opinions, about personal experiences with asthma.

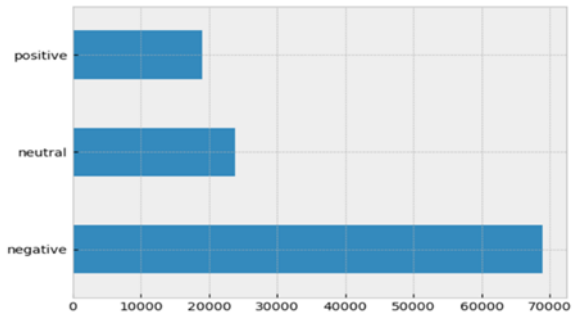


Fig. 12. Sentiment distribution in Cluster 1.

Fig. 13 shows tweets length [number of characters] distribution.

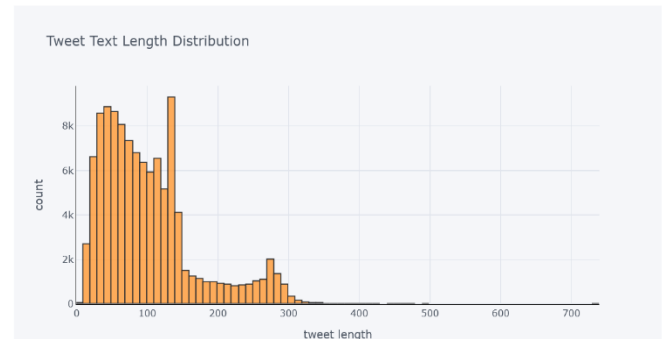


Fig. 13. Tweets length in Cluster 1.

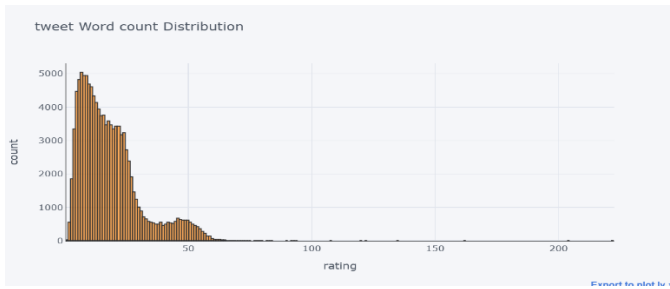


Fig. 14. Tweets distribution in Cluster 1.

Fig. 14 depicts the tweets distribution in cluster 1. Top 20 words [including stop words] frequency distribution before removing stop words is shown in Fig. 15.



Fig. 15. Frequency distribution of top 20 words in Cluster 1 before removing stop words.

The data shows that the most frequent word in the text is "الربو" [asthma] with a count of 112579, followed by The words "من" [from], "الله" [God], "في" [in], and "على" [on] with 52701, 27797, 21798, 11715 occurrences respectively. The word "ما" [what] appears in the list with a count of 11285, which suggests that the text may contain questions or inquiries related to asthma.

In the new distribution, the word "الربو" [asthma] still has the highest frequency with 109379 occurrences, but the words "علاج" [treatment] and "مرض" [disease] have increased in frequency, suggesting that the text or corpus may be more focused on medical treatments and conditions. Additionally, words such as "لمرضى" [for patients] and "الأطفال" [children] have been replaced with "لمرضائي" [for my patients] and "الأطفال" [kids], respectively, indicating a slight difference in phrasing.

Fig. 16 shows the top 20 words frequency distribution after removing stop words. The most frequent word in the text is still "الربو" [asthma], The word "لمرضي" [my illness] appears in the list with a count of 9408, which suggests that the tweets may include personal experiences of people with asthma. The word "الغبار" [dust] appears in the list with a count of 5667, which confirms that the text may be discussing asthma triggers, including environmental triggers like dust. The words "يا رب" [Oh God] and "اللهم" [O Allah] appear in the list with counts of 4724 and 4356, respectively, which suggests that some of the tweets may contain expressions of religious faith or appeals to a higher power for help with asthma management.

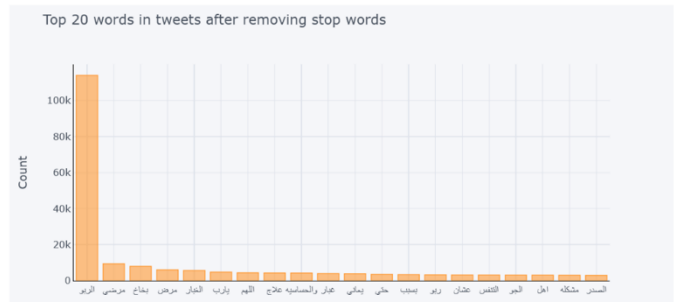


Fig. 16. Frequency distribution of top 20 words in Cluster 1 after removing stop words.

Fig. 17 shows the top 20 bigrams frequency distribution before removing stop words.

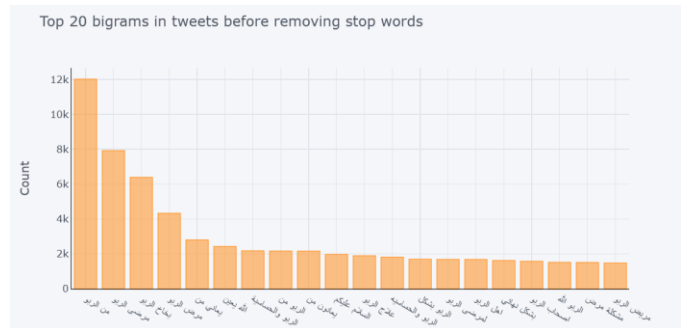


Fig. 17. Frequency distribution of top 20 bigrams in Cluster 1 before removing stop words.

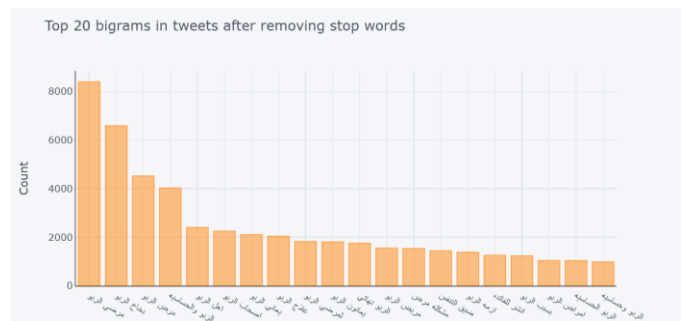


Fig. 18. Frequency distribution of top 20 bigrams in Cluster 1 after removing stop words.

The most frequent bigram is "من الربو" [because of asthma] with a count of 12014, followed by the bigram "مرضى الربو" [asthmatic patients] that appears in the list with a count of 7919, which confirms that the text is discussing asthma and may contain personal experiences of people with asthma. The bigram "يعاني من" [suffers from] appears in the list with a count of 2803, which suggests that the tweets may include discussions about the challenges and difficulties of living with asthma. The bigram "يعين الله" [God help] appears in the list with a count of 2428, which suggests that some of the tweets may contain expressions of religious faith or appeals to a higher power for help with asthma management. filtering for stop words may help to reduce noise and highlight the most meaningful bigrams which is presented in Fig. 18.

After removing stop words (Fig. 18), looking at the distribution, we can see that the most frequent bigram is "مرضى" [asthmatic patients]

الربو " ["my asthma" in English] with a frequency of 8394, followed by "بخاخ الربو" ["asthma inhaler"] with a frequency of 6590. These two bigrams are related to managing the symptoms of asthma and suggest that people are sharing their personal experiences with using inhalers to control their symptoms. The third most frequent bigram is "مرض الربو" ["asthma disease"] with a frequency of 4521, followed by "الربو والحساسية" ["asthma and allergy"] with a frequency of 4029. These bigrams suggest that people are sharing their personal experiences with the diagnosis of asthma and its relationship to allergies.

Other common bigrams in the distribution include "يعاني الربو" ["suffers from asthma"], "ضيق التنفس" ["shortness of breath"], and "مشكلة مرض" ["disease problem"]. These bigrams indicate that people are sharing their personal experiences with the negative impact of asthma on their quality of life and the challenges they face in managing their symptoms.

Overall, the distribution indicates that people are sharing their personal experiences with asthma, including symptoms, diagnosis, and the negative impact of the disease on their lives. This information can be useful for healthcare providers and researchers in understanding the lived experiences of people with asthma and developing interventions to improve their quality of life.

Fig. 19 shows the top 20 trigrams frequency distribution before removing stop words.

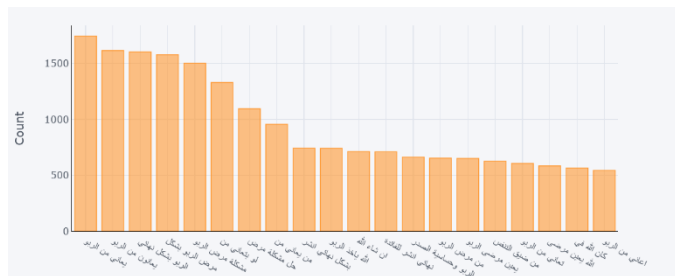


Fig. 19. Frequency distribution of top 20 trigrams in Cluster 1 before removing stop words.

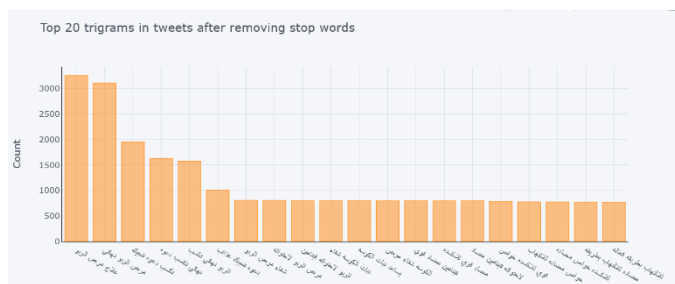


Fig. 20. Frequency distribution of top 20 trigrams in Cluster 1 after removing stop words.

Looking at the trigram distribution, we can see that the most frequent trigram is "يعاني من الربو" ["suffers from asthma"] with a frequency of 1746, followed closely by "يعانون من الربو" ["they suffer from asthma"] with a frequency of 1616. These trigrams suggest that people are sharing their personal experiences with asthma and the challenges they face in managing their symptoms.

The third most frequent trigram is "الربو بشكل نهائي" ["asthma finally"] with a frequency of 1603, followed by "مرض الربو بشكل" ["asthma disease in the form of"] with a frequency of 1579. These trigrams suggest that people are discussing the long-term impact of asthma on their lives and the challenges they face in managing the disease.

Other common trigrams in the distribution include "مشكلة" ["asthma disease problem"], "لو تعاني من" ["if you suffer from"], and "حل مشكلة المرض" ["solve the problem of disease"]. These trigrams suggest that people are sharing their personal experiences with the negative impact of asthma on their quality of life and seeking solutions to manage the disease.

Interestingly, the trigram "الله يأخذ الربو" ["God takes away asthma"] appears in the distribution with a frequency of 741. This trigram reflects a religious or cultural belief that asthma can be cured through divine intervention.

After removing the stop words (Fig. 20), the trigram distribution seems to be more focused on specific topics related to asthma. The most common trigrams are "مرض الربو نهائيا" [asthma is final], "مشكلة مرض الربو" [the problem of asthma], and "الربو وحساسية الصدر" [asthma and chest allergy]. These trigrams indicate that this cluster is more focused on discussing the negative impact of asthma on patients' lives and the difficulties associated with managing the disease.

The trigram "بخاخ الربو يفطر" [asthma inhaler breaks the fast] appears in the distribution, indicating that this cluster includes discussions related to religious practices during the month of Ramadan. This suggests that this cluster may include personal experiences and discussions from individuals living in Islamic countries where Ramadan is observed.

Overall, the trigram distribution after removing stop words indicates that the cluster focuses on discussing the negative impact of asthma on patients' lives, including the challenges associated with managing the disease and the impact on religious practices during the month of Ramadan. The word cloud for the first cluster is viewed in the Fig. 21.



Fig. 21. Word cloud for Cluster 1.

It is clear that this cluster focuses on personal experiences with asthma, including symptoms, diagnosis, and the negative impact of asthma on the quality of life.

V. DISCUSSION

LDA topic modeling was utilized to group tweets related to asthma into two clusters. The first cluster contained tweets that provided information and tips about the treatment and prevention of asthma. The second cluster contained tweets that discussed personal experiences with asthma and the negative impact on quality of life. Further analysis revealed that the text or corpus is related to medical or health topics, with the most frequent word being "asthma." Filtering stop words resulted in more specific and related bigrams and trigrams to asthma and its treatment. The data analysis of cluster 0 indicates that individuals are interested in learning about different ways to treat asthma and potentially finding a permanent solution. It is evident that most used phrases referred to the information on asthma, its treatments for patients and kids; with a focus on natural therapy and inhalation therapy. Similar results can be observed from [19], where it was found that most referred tweets reflected inhalation, use of nebulizer, and self-medication/ management procedures, indicating the informational content. In [20,21], it was identified that most of the tweets belonged to physicians and healthcare organizations presenting the educational and awareness information. Therefore, in similar other studies [19,20,21], the analysis of data from cluster 0 indicated that the social media platforms like twitter could be a useful platform for disseminating health information for creating awareness about asthma treatment and prevention practices, especially self-management procedures. Overall, the findings from cluster 0 could provide insights for healthcare professionals and researchers to develop better strategies and interventions for creating awareness in order to manage asthma.

In regard to cluster 1, the analysis of the sentiment, length, word count, and n-gram frequency distributions of the tweets related to asthma reveals important insights into the experiences and perceptions of people with asthma. Most of the sentiment in the second cluster is negative, indicating that this cluster contains a lot of critical opinions about personal experiences with asthma. The top words and bigrams suggest that people are sharing their personal experiences with asthma symptoms, diagnosis, and the negative impact of the disease on their lives. Filtering out stop words helps to identify the most meaningful bigrams and trigrams related to managing asthma symptoms and personal experiences of people with asthma. The analysis also highlights the prevalence of religious expressions by referring to God in the tweets related to asthma.

These findings indicate that people openly express negative sentiments about asthma and place significance importance on religion, indicating the impact of socio-cultural and religious factors among Arabic communities. However, analyzing the tweets in similar studies but in geographically different locations in previous studies [12-16,30], there were no references to the religion or god in asthma related tweets. Therefore, it is important to consider cultures in using the tweets for analyzing public perceptions related to healthcare services and disease management in order to formulate effective strategies for managing various conditions. In addition, analyzing twitter data can also be useful for assessing the public opinions related to the treatments, as in [12] vaccine hesitancy was highlighted for Covid-19. Similarly, the

reactions to asthma treatment and prevention procedures can be assessed from tweets analysis among the public in order to effectively manage the condition. In [30], it was observed that public can more freely express their opinions on social media platforms than on DHP's in relation to their health conditions. Furthermore, in [13], it was observed that public express their opinions on social media to gain social rewards. This is evident from the results from cluster 1 analysis, where people in Arabic communities openly expressed their religious references and beliefs; and also, the negative impacts on their quality of life. These openly expressed views can be an important source of information for healthcare decision-makers and governments during health crisis, where an outbreak can be effectively monitored, tracked, and controlled within the time as suggested in [16]. Furthermore, the twitter data analysis can also be effectively used in other critical conditions by analyzing disease specific tweets [14,15]. Furthermore, the studies [13-25,30] discussed in this article reflected varying results at different geographical locations, while few results are similar and few contrasted with the findings in this study. Therefore, the public perceptions related to asthma challenges, its management, treatment and prevention practices may differ across the regions, and it is also to be highlighted that there could be a cultural impact on these factors as observed in this study. Therefore, it is necessary for research practitioners to frequently analyze public perceptions about asthma at regular intervals at different locations to better manage the disease. Overall, the findings from cluster 1 analysis can be useful for healthcare providers and researchers in understanding the lived experiences of people with asthma and developing interventions to improve their quality of life.

VI. CONCLUSION

This study has addressed the research gaps by discussing the public opinions of asthma in Arabic communities, thus contributing to the knowledge, which can have various practical and theoretical implications. These findings can support healthcare decision-makers in Arabic communities to better understand the asthma patients' opinions about their conditions and aid them in formulating patient-centered strategies for managing asthma. Furthermore, this study acts as a foundation or reference for future researchers in using AI technologies for analyzing public health data, especially in Arabic communities.

In conclusion, it can be observed that neutral sentiment existed in relation to asthma related information, its prevention and treatment; and negative sentiments existed on its impact on the quality of life among the Arabic communities. Although, religious/cultural influence existed in expressing the opinions and managing the conditions, it is also observed that twitter could be an effective platform for not only monitoring and controlling the disease but also to educate and create awareness among the asthma patients.

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REFERENCES

- [1] EAACI Global Atlas of Asthma [Internet].; 2021 [updated Accessed: 18/10/22;]. Available from: <https://www.eaaci.org/newsfeed/4790-globalatlasofasthma>.
- [2] Alloghani M, Hussain A, Al-Jumeily D, Fergus P, Abuelma'Atti O, Hamden H. A mobile health monitoring application for obesity management and control using the internet-of-things. 2016 Sixth International Conference on Digital Information Processing and Communications [ICDIPC]; IEEE; 2016.
- [3] O'Malley G, Dowdall G, Burls A, Perry JJ, Curran N. Exploring the usability of a mobile app for adolescent obesity management. *JMIR mHealth and uHealth*. 2014;2[2]:e3262.
- [4] Wang Y, Min J, Khuri J, Xue H, Xie B, Kaminsky LA, et al. Effectiveness of mobile health interventions on diabetes and obesity treatment and management: systematic review of systematic reviews. *JMIR mHealth and uHealth*. 2020;8[4]:e15400.
- [5] Chavez S, Fedele D, Guo Y, Bernier A, Smith M, Warnick J, et al. Mobile apps for the management of diabetes. *Diabetes Care*. 2017;40[10]:e145-6.
- [6] Quinn CC, Clough SS, Minor JM, Lender D, Okafor MC, Gruber-Baldini A. WellDoc™ mobile diabetes management randomized controlled trial: change in clinical and behavioral outcomes and patient and physician satisfaction. *Diabetes technology & therapeutics*. 2008;10[3]:160-8.
- [7] Rodríguez AQ, Wägner AM. Mobile phone applications for diabetes management: A systematic review. *Endocrinología, diabetes y nutrición*. 2019;66[5]:330-7.
- [8] Alotaibi MM, Istepanian R, Philip N. A mobile diabetes management and educational system for type-2 diabetics in Saudi Arabia [SAED]. *Mhealth*. 2016;2.
- [9] Number of social network users of select social media platforms worldwide in 2019 and 2023 Most popular social networks worldwide as of October 2021, ranked by number of active users [Internet].; 2023 [Accessed: 28/3/23 updated October 10;]. Available from: <https://www.statista.com/statistics/1109866/number-social-media-users-worldwide-select-platforms/><https://www.statista.com/statistics/272014/global-social-networks-ranked-by-number-of-users/>.
- [10] Buyya R, Calheiros RN, Dastjerdi AV. *Big data: principles and paradigms*. Morgan Kaufmann; 2016.
- [11] Pozzi F, Fersini E, Messina E, Liu B. *Sentiment analysis in social networks*. Morgan Kaufmann; 2016.
- [12] Malova E. Understanding online conversations about COVID-19 vaccine on Twitter: Vaccine hesitancy amid the Public Health Crisis. *Communication Research Reports*. 2021;38(5):346–56.
- [13] Umar P, Akiti C, Squicciarini A, Rajtmajer S. Self-disclosure on Twitter during the COVID-19 pandemic: A network perspective. *Machine Learning and Knowledge Discovery in Databases Applied Data Science Track*. 2021;:271–86.
- [14] Malik A, Antonino A, Khan ML, Nieminen M. Characterizing HIV discussions and engagement on Twitter. *Health and Technology*. 2021;11(6):1237–45.
- [15] Akhila AM, Gayathri C, Srinivas B, Devi BSK. A review on sentiment analysis of Twitter data for diabetes classification and prediction. 2022 Seventh International Conference on Parallel, Distributed and Grid Computing (PDGC). 2022;
- [16] Joshi A, Sparks R, McHugh J, Karimi S, Paris C, MacIntyre CR. Harnessing Tweets for Early Detection of an Acute Disease Event. *Epidemiology*. 2020;31(1):90-97. doi:10.1097/EDE.0000000000001133
- [17] Ainley E, Witwicki C, Tallett A, Graham C. Using Twitter comments to understand people's experiences of UK health care during the COVID-19 pandemic: Thematic and sentiment analysis. *Journal of Medical Internet Research*. 2021;23(10).
- [18] Shah SHH, Noor S, Butt AS, Halepoto H. Twitter Research Synthesis for Health Promotion: A Bibliometric Analysis. *Iran J Public Health*. 2021;50(11):2283-2291. doi:10.18502/ijph.v50i11.7584.
- [19] Gillingham G, Conway MA, Chapman WW, Casale MB, Pettigrew KB. # wheezing: A Content Analysis of Asthma-Related Tweets. *Online Journal of Public Health Informatics*. 2013;5[1].
- [20] Carroll CL, Kaul V, Sala KA, Dangayach NS. Describing the digital footprints or "sociomes" of asthma for stakeholder groups on Twitter. *ATS scholar*. 2020;1[1]:55-66.
- [21] Kaul V, Szakmany T, Peters JJ, Stukus D, Sala KA, Dangayach N, et al. Quality of the discussion of asthma on twitter. *Journal of Asthma*. 2020:1-8.
- [22] Social media - Statistics & Facts [Internet].; 2021 [updated Feb 25;]. Available from: <https://www.statista.com/topics/1164/social-networks/>.
- [23] Cambria E, Das D, Bandyopadhyay S, Feraco A. Affective computing and sentiment analysis. In: *A practical guide to sentiment analysis*. Springer; 2017. p. 1-10.
- [24] Byrd K, Mansurov A, Baysal O. Mining twitter data for influenza detection and surveillance. *Proceedings of the International Workshop on Software Engineering in Healthcare Systems*; 2016.
- [25] Song S, Miled ZB. Digital immunization surveillance: monitoring flu vaccination rates using online social networks. 2017 IEEE 14th International Conference on Mobile Ad Hoc and Sensor Systems [MASS]; IEEE; 2017.
- [26] Culotta A. Towards detecting influenza epidemics by analyzing Twitter messages. *Proceedings of the first workshop on social media analytics*; 2010.
- [27] Freifeld CC, Brownstein JS, Menone CM, Bao W, Filice R, Kass-Hout T, et al. Digital drug safety surveillance: monitoring pharmaceutical products in twitter. *Drug safety*. 2014;37[5]:343-50.
- [28] Tutubalina E, Nikolenko S. Exploring convolutional neural networks and topic models for user profiling from drug reviews. *Multimedia Tools Appl*. 2018;77[4]:4791-809.
- [29] Klein A, Sarker A, Rouhizadeh M, O'Connor K, Gonzalez G. Detecting personal medication intake in Twitter: an annotated corpus and baseline classification system. *BioNLP 2017*; 2017.
- [30] Abu Farha, I. and Magdy, W. [2019] "Mazajak: An online Arabic sentiment analyser," *Proceedings of the Fourth Arabic Natural Language Processing Workshop* [Preprint]. Available at: <https://doi.org/10.18653/v1/w19-4621>.
- [31] Ljevar, V. Exploring the impact of socio-cognitive factors on adherence to asthma medication using traditional mixed methods and machine learning. PhD thesis, University of Nottingham, 2022.

Predicting Drug Response on Multi-Omics Data Using a Hybrid of Bayesian Ridge Regression with Deep Forest

Talal Almutiri¹, Khalid Alomar², Nofe Alganmi³

Department of Information Systems^{1,2}, Department of Computer Science³

Faculty of Computing and Information Technology, King Abdulaziz University, Jeddah, Saudi Arabia^{1,2,3}

Abstract—An accurate drug response prediction for each patient is critical in personalized medicine. However, numerous studies that relied on single-omics datasets continue to have limitations. In addition, the curse of dimensionality considers a challenge to drug response prediction. Deep learning has remarkable prediction effectiveness compared to traditional machine learning, but it requires enormous amounts of training data which is a limitation because the nature of most biological data is small-scale. This paper presents an approach that combines Bayesian Ridge Regression with Deep Forest. BRR relies on the Bayesian approach, in which linear model estimation occurs based on probability distributions rather than point estimates. It was utilized to integrate multi-omics, a feature selection that calculates the coefficient as the feature importance. DF reduces the computational cost and hyper-parameter tuning cost. The Cancer Cell Line Encyclopedia CCLE was used as a dataset to integrate the gene expression, copy number variant, and single nucleotide variant. Root Mean Square Error, Pearson Correlation Coefficient, and the coefficient of determination were used as the evaluation metrics. The obtained findings show that the proposed model outperforms Random Forest and Convolutional Neural Network regarding regression performance; it achieved 0.175 for RMSE, 0.842 for PCC, and 0.708 for R2.

Keywords—Bayesian ridge regression; deep forest; deep learning; drug response prediction; machine learning; multi-omics data

I. INTRODUCTION

Personalized medicine is a cancer therapy method that aims to find the most effective therapeutic solutions for each patient. The combination of genetic and drug-sensitivity data and the subsequent creation of drug-response associations allows for this discovery [1]. While personalized medicine is not yet utilized as a regular treatment, it is possible for most cancer patients due to the progress made in multi-omics features and drug-sensitivity testing [2]. Personalized treatment regimens based on genetics are one of the primary aims of systems medicine [3]. For the development of individualized cancer therapy treatments with a projected efficacy much above existing standard-of-care methods, the inferred models' ability to correctly forecast a tumor's responsiveness to a medicine or drug combination might benefit that process [3]. However, there has been a lack of progress in cancer treatment based on single-omics datasets such as those generated by the Human Genome Project and the early genomic profiling of the Cancer Genome Atlas (TCGA) projects [4]. The multi-omics analysis that has gained prominence in cancer research over the last several decades

may be the only way to get a comprehensive view of cancer behavior and uncover new therapeutic vulnerabilities [5].

Moreover, the "curse of dimensionality" or large p , small n , is one of the most challenging issues in drug response prediction and when dealing with omics data in general [6] in other words, having many features p . However, only a few available data instances n create a particular barrier to using early concatenation in multi-omics integration. For instance, the human genome has more than 20,000 protein-coding genes, a significant number. As a result of this integration, multi-omics datasets may easily contain more than 50,000 attributes when the genome, proteome, and transcriptome are all included. Regarding cancer data, the number of available tumor samples in a dataset is usually restricted, with cancer cohorts typically consisting of only a few hundred patient samples [5]. As a result, the features must be reduced through feature selection [7]. Feature selection works to identify the relevance of features and selects a collection of features or attributes based on a particular assessment criterion [8].

Despite the power of deep neural networks power, it appears to have drawbacks [9]. To begin with, it is noted that deep neural networks require enormous amounts (large-scale data) of training data are often needed, making them inapplicable to jobs having only small-scale data. Due to the high cost of class annotation, many real-world tasks currently lack adequate labeled data [9], [10], resulting in the poor effectiveness of deep neural networks in relation to those tasks [11]. Additionally, the success of deep learning is strongly dependent on carefully tuning several hyper-parameters [12]. Consequently, Zhou [11] introduced gcForest or Deep Forest (DF), which integrates multi-Grained and Cascade Forest as a deep learning alternative. gcForest is a new decision tree ensemble technique approach that outperforms deep learning across various applications.

This paper introduced a method that combines Bayesian Ridge Regression (BRR) with Deep Forest (DF) called (BRR-DF). BRR was used to integrate multi-omics which was utilized as a feature selection method that calculates the coefficient to determine the feature importance score. BRR relies on the Bayesian approach, in which linear model estimation occurs based on probability distributions rather than point estimates. In addition to the model parameters also coming from the distribution, the response is also generated from the probability distribution. The training inputs and outputs affect the posterior probability of the model parameters.

Furthermore, Ridge was embedded with Bayesian regression to reduce model complexity and multicollinearity by shrinking the coefficients. Most omics data is considered to be small-scale data; therefore, Bayesian is suitable for these cases. It integrates the prior knowledge of the parameter (prior parameter distribution) with the observed data. DF integrates Multi-Grained and Cascade Forest, which effectively capture the local features. The cascade forests utilize a network structure inspired by a multi-layer artificial neural network to continuously improve results. DF was suggested as a deep learning alternative to reduce complexity time in hyper-parameter tuning that otherwise causes a computational cost in deep learning models.

The contribution of the proposed method can be summarized in the following two points:

- Using BRR as a feature selection method for integrating gene expression, copy number variant, and single nucleotide variant to improve drug response prediction. BRR can handle inadequate data or skewed distributed data by modeling linear regression models using probability distributions. By utilizing BRR, we aim to identify the most informative features from multiple genomic data sources and improve the accuracy of drug response prediction.
- Using DF to reduce the computational cost of hyper-parameter tuning; also, when the inputs have a high degree of complexity or dimensionality, DF can boost its representational learning capabilities to improve prediction.

The rest of this paper is organized as follows. Section 2 introduced the related work. Section 3 presented the methods and materials used in this study including datasets, framework of BBR-DP, and evaluation metrics. Section 4 elaborated results and discussion. In Section 5, the conclusion and future work were presented.

II. RELATED WORK

The current studies have introduced various machine learning techniques for predicting drug sensitivity and discovering biomarkers affecting drug response. Examples of these techniques are Support Vector Machines (SVMs) [13], Graph Networks [14], [15], Bayesian multitask multiple kernel learning [16], [17], Random Forest (RF) [19–22], and Neural Network [22] models. However, there is still a significant opportunity to improve prediction effectiveness and model generalizability regarding these computational models. Deep Learning (DL) has also been employed successfully in other drug discovery-related tasks. The prediction effectiveness of Deep Learning algorithms is comparable to, if not better, than that of the approaches for the bulk of these tasks [23]. Numerous deep learning-based techniques for drug response prediction have been proven to be successful, including DeepProfile [24], CDRscan [25], DeepCDR [14], DeepDSC [26], and GraphDPR [15].

A Bayesian ridge regression-based approach (B-GEX) was developed by Wenjian et al. [27] to infer the gene expression profiles of various organs from blood gene expression

profiles. A low-dimensional feature vector was derived from the complete blood gene expression profile using feature selection for each gene in a tissue. To train the inference models to capture the cross-tissue expression correlations between each target gene in tissue and its preselected feature genes in peripheral blood, they used The Genotype-Tissue Expression (GTEx) RNA sequencing (RNA-seq) data of 16 tissues.

Velten and Huber [28] proposed a method for guiding penalization in regression using information from external covariates. Their method penalizes the feature groups defined by the covariates differentially and adjusts the relative power of penalization according to the information content of each group. Their procedure combines shrinkage with feature selection and provides a scalable optimization scheme using techniques from the Bayesian tool set. The method accurately retrieves each feature group's accurate effect sizes and sparsity patterns in simulations. They evaluated the performance of their method for drug response prediction using leukemia data. Prediction performance improves when the groups' dynamic ranges differ significantly.

Sharifi-Noghabi et al. [29] utilized deep learning to develop a method called MOLI (multi-omics late integration). MOLI integrates gene expression data, copy number alterations, and somatic mutation. Their model learns features for each omics data type by encoding subnetworks particular to it. MOLI is the first end-to-end late integration approach using deep learning that combines a "triplet loss function" and a "binary cross-entropy" to improve this representation. Responder cell lines are more comparable and distinct from non-responder cell lines, while the half maximal inhibitory concentration (IC50) values predicted by this depiction are more accurate.

Malik et al. [30] proposed a late multi-omics integration framework for robustly quantifying survival and drug response in breast cancer patients, emphasizing the relative predictive ability of the available omics datatypes. A supervised feature selection algorithm, neighborhood component analysis (NCA), was used to select the relevant features from the multi-omics datasets retrieved from The Cancer Genome Atlas (TCGA) and Genomics of Drug Sensitivity in Cancer (GDSC) databases.

A Deep Forest architecture, first presented by Zhou [31], was used by Su et al. [32] to develop the Deep-Resp-Forest anti-cancer drug response prediction model, which classifies the anti-cancer drug response as either sensitive or resistant. In Zhou et al.'s work, the Deep Forest, known as gcForest, was a cascade of forests. Su et al. achieved remarkable results when their model was tested against the Cancer Cell Line Encyclopedia (CCLE) and the Genomics of Drug Sensitivity in Cancer (GDSC). As they mentioned, regression is preferred for more accurate results.

Table I shows some recent studies that were focused on applying ML and DL methods in drug response prediction by focusing on methods/techniques, contributions/advantages, and limitations/disadvantages.

TABLE I. SUMMARY OF SOME RECENT STUDIES IN DRUG RESPONSE PREDICTION AND THEIR CONTRIBUTIONS AND LIMITATIONS

Resource and Year	Methods/Techniques	Merits, Contribution Advantages	Demerits and limitations Disadvantages	Datasets
Sharifi-Noghabi et al. [29], 2019	DNN Ridge regression	They indicated that MOLI outperforms early integration multi-omics and single-omics techniques. They mentioned it was the first strategy to employ pan-drug transfer learning for targeted drugs, and it improved prediction effectiveness relative to drug-specific inputs.	Although their research only employed DNA mutation, CNA, and gene expression profile, MOLI may be expanded to include other omics information and drug chemical structure. While they only explored the triplet loss for improving the concatenated representation, they observed that similar losses such as the contrastive loss function employed in the Siamese network [33] can be utilized instead. All utilized datasets have substantially skewed or imbalanced class distributions due to the few number of respondents' vs non-responders. They solved that by oversampling minorities. However, this method typically leads to overfitting, especially for deep neural networks.	GDSC PDX TCGA
Liu et al. [14], 2020	UGCN CNN	Insufficient or imbalanced training examples can be supplemented with the proposed UGCN by random selection of multiple complementary graphs for each medication. In the classification task, they randomized the feature matrix, connected complementary networks at random, and positive training examples were augmented five times. DeepCDR may be utilized with molecular generation processes. Existing chemical generation models based on the Recurrent neural network (RNN) technique[66], generative adversarial networks (GANs) [34] and deep reinforcement learning [35] Concentrate on broad chemicals while ignoring the characteristics of specific cancer cells. Methods for cancer-specific or disease-specific innovative drug design may be presented by employing DeepCDR predicted CDR as prior knowledge or a reward score for driving chemical production.	Top DL algorithms like DeepCDR and GraphDPR [15] perform better. For a drug-blind test, the examined deep learning approaches do not act as well as the SRMF, a matrix factorization-based method. To improve DL methods for predicting drug reactions, obtaining differentiating information from drug profiles is critical. Either create novel drug target fingerprint systems or use sophisticated "graph neural networks" to extract latent properties from drug data [36]. In future work, researchers can use huge amounts of omics data analyzed before and after treatment to determine how the tested drugs affect their molecular profiles.	GDSC CCLE TCGA
Jia et al. [37], 2021	VAE Elastic Net PCC PCA	Accurate drug sensitivity data prediction in cancer samples would allow recapitalization of recognized and new biomarkers, which are commonly missing owing to cell line methods or limitation of sample size. Their categorization of chemicals by reaction profiles showed distinct groupings and signatures. Using TCGA data, they discovered a link between medicines and TMB that was previously infeasible using cell line models. To find pan-cancer genomic markers, they explored DNA mutations, CNVs, and gene expression. The positive correlations between AZD6244 and the earlier published 18-gene signature demonstrated how their results are robust.	For some drugs, including LBW242, couldn't enhance prediction accuracy by fitting models. The model-fitting parameters of VAE-based models could not compete with PCA methods for several drugs (in-sample PCC and holdout R2). However, given insufficient data, the PCA-based model for paclitaxel failed to distinguish between pCR and non-pCR patients. So future validation is necessary to validate these prediction models. Moreover, while certain drugs had good prediction results in the cell line method, their response in cancer examples was variable. So studying drug response in cancer samples is substantially more difficult and involves various contexts and variables.	GDSC CCLE TCGA
Pouryahya et al. [38], 2022	Wasserstein distance Spearman's correlation PCC Hierarchical clustering Random forest regression	Using the optimal mass transport (OMT) theory and unsupervised and supervised ML models in conjunction with the CDCN model, they were able to show that random forest approaches in the consequent distinct pairs of cell-line and drug clusters can deliver more satisfactory predictive ability than the CDCN model used in previous studies. Using Wasserstein distances, which are calculated between invariant measurements of gene expression patterns, the researchers discovered that cell lines that were comparable in terms of Wasserstein distances responded similarly to (structurally identical) medicines.	In the clustering of drugs, unsupervised removal of strongly correlated cheminformatic features while maintaining non-redundant informative features. Despite the elimination of this feature, their strategy outperformed other approaches in terms of predictive power. Using mutation, CNV, and hyper-methylation data may enhance prediction results or provide new findings.	GDSC HPRD CCLP PubChem OncoKB
Wang et al. [39] 2023	GCNs AEs	In order to overcome some of the shortcomings of recent studies, including ignoring the correlation between drug cell line pairs (DCPs), the GADRP was developed. Additionally, the issue of over-smoothing, in which the representation of each node becomes more similar as the number of layers grows, was not considered in recent research that used GCNs. So they built a sparse drug cell line pair (DCP) network incorporating data on drug, cell line, and DCP similarity before using a stacked deep AE to extract low-dimensional representations from cell line attributes. Later, to learn DCP features, initial residual and layer attention based GCN (ILGCN), which can resolve over-smoothing issues, was used. Finally, the prediction was performed using a fully connected network.	First, ILGCN can only be regulated within five levels due to the scale of the DCP network and the constraints of computer storage capacity. Second, the GADRP deep learning model lacks biological entities like targets and disorders, which contribute to its level of inexplicability. Consideration should be given to including more entities and associations in cancer medication response prediction. Additionally, despite GADRP's potent prediction capabilities, its use in the clinic remains a significant issue because it is trained using in vitro data.	PubChem PRISM CCLE

GDSC: Genomics in Drug Sensitivity in Cancer

UGCN: Uniform Graph Convolutional Network

PDX: Patient-Derived tumor Xenograft

CNN: Convolutional Neural Network

CCLE: Cancer Cell Line Encyclopedia

VAE: Variational Autoencoder

TCGA: The Cancer Genome Atlas

PCC: Pearson Correlation Coefficient

CCLP: COSMIC Cell Line Project

PCA: Principal Component Analysis

HPRD: Protein Reference Database (HPRD)

GCN: Graph Convolutional Network

OncoKB: Precision Oncology Knowledge Base (OncoKB)

AE: Autoencoder

DNN: Deep Neural Network

Therefore, the drug response methods showed remarkable results when multi-omics were integrated. However, integration causes a curse of dimensionality which negatively affects prediction. In addition, multi-omics data is small-scale data, which needs a method to handle inadequate data or skewed distribution.

III. METHODS AND MATERIALS

The proposed solution works to reduce dimensionality and integrate the three omics, before using Deep Forest to improve the drug response prediction. The solution consists of four phases: datasets preparation, integrating multi-omics using Bayesian Ridge Regression, the Deep Forest phase, and the evaluation phase. The general framework is shown in Fig. 1; more details for each phase are discussed in the following points. Each single omics was processed independently; Bayesian Ridge Regression was utilized for each single data type.

A. Datasets

More than 1000 human cancer cell lines were gathered and molecularly described in the Cancer Cell Line Encyclopedia (CCLE) project [40] that has acquired and molecularly characterized over 1000 human cancer cell lines. The investigation discovered 24 anti-cancer drug sensitivity profiles among 504 cell lines. The CCEL [21], [40] dataset was used in this research. The half-maximal inhibitory concentration IC50 was used as the drug response for cell lines across the drugs (denoted by $y_{res,c}$) c for a cell line. Three omics were used, including single-nucleotide mutation (denoted by $x_{snv,g}$) g for gene, gene expression (denoted by $x_{exp,g}$), and copy number alteration/variation (denoted by

$x_{cnv,g}$) Gene expression and copy number alteration are real values, the single-nucleotide mutation use binary values, "1" used for mutation and "0" for wild type. There are no missing values in the gene expression data. For copy number alteration and single-nucleotide mutation, rows with more than half of the cells missing values were removed. The mean weight approach was used to compensate for the missing values for the remaining cell lines.

The distance was calculated to select the nearest k , which was used to impute the gene expression missing value, defined as follows:

$$dis(c, k) = \|x_{exp,c} - x_{exp,k}\|_2^2 \quad (1)$$

where c is the cell line, k is the nearest cell line, and x is the gene expression value for each cell line.

The mean value of the nearest cell lines was used to impute the missing value of cell line c in copy number alteration of genes g .

$$misCNV(c, g) = \sum_{k=1}^K \frac{dis(c, c_k)}{\sum_{k=1}^K dis(c, c_k)} misCNV(c_k, g) \quad (2)$$

The values of the single-nucleotide mutation features are binary, with 1 indicating mutation and 0 indicating wild type. The mean feature value for cell line c among the k -nearest cell lines was used to compensate for the missing SNV (single-nucleotide mutation or variation) value of gene g as follows:

$$\begin{cases} misSNV(c, g) = 1 & \text{if } (\sum_{k=1}^K misSNV(c_k, g) > \sum_{k=1}^K (1 - misSNV(c_k, g))) \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

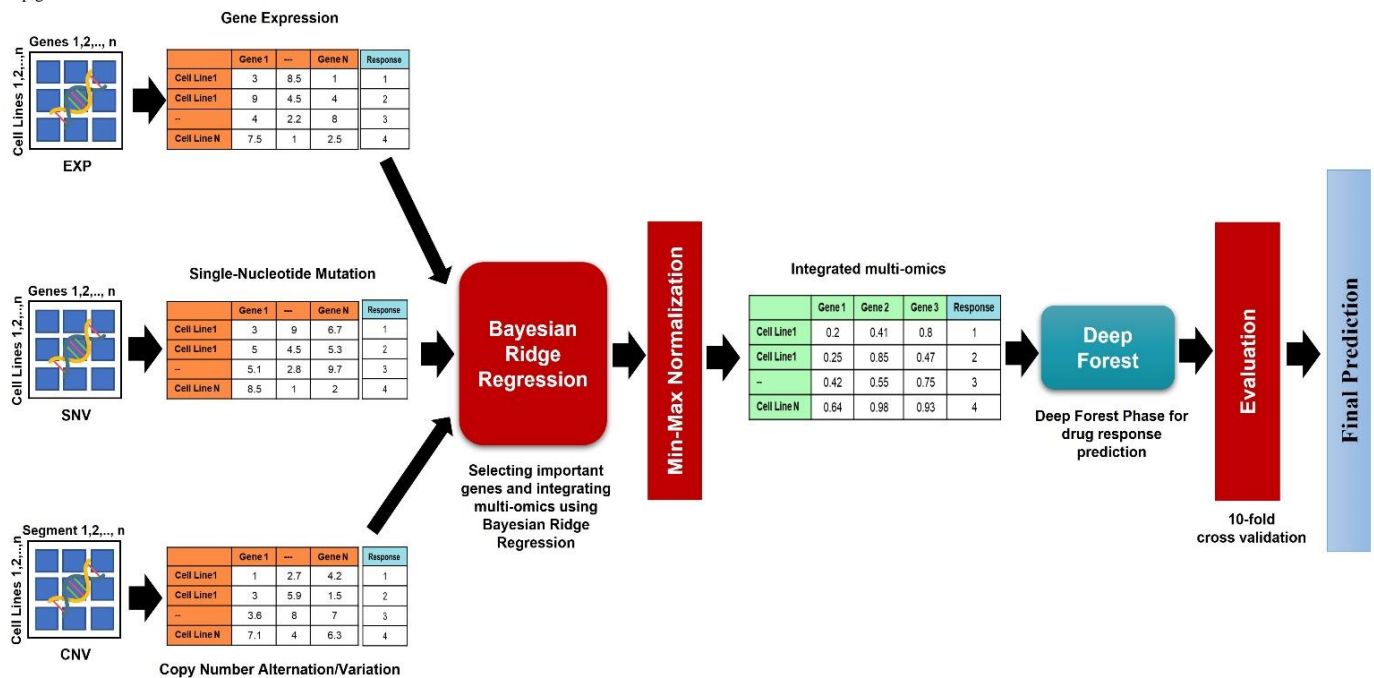


Fig. 1. The framework of BBR-DP to integrate multi-omics data for predicting drug response.

In a similar way, the missing value of IC50 was imputed in the same way as the copy number alteration manner. The

mean value of the nearest cell lines was used to impute the missing value of cell line c .

$$misIC50(c, g) = \sum_{k=1}^K \frac{dis(c, c_k)}{\sum_{k=1}^K dis(c, c_k)} misIC50(c_k, g) \quad (4)$$

K=10 was selected for preparing the CCEL dataset.

The IC50 matrix was converted to a tabular form which had 8712 rows, then all of the drug responses of each cell line were grouped by the mean for each cell line to be considered as the drug response that needed to be predicted in a regression problem. The final total samples were 363 for the IC50 data. Table II shows the total number of samples for the CCEL data.

TABLE II. THE TOTAL NUMBER OF SAMPLES FOR THE CCEL DATA

Type	Raw Data	After Preprocessing
Cell Lines	1061	363
Drugs	24	24
Gene expression	20049 (1061)	19,389 (363)
Single-nucleotide mutation	1667 (1061)	1667 (363)
Copy number alteration	24960 (1061)	24960 (363)

B. Integrating Multi-Omics Bayesian Ridge Regression

Bayesian Ridge Regression (BRR) was used as the feature selection method to reduce dimensionality and integrate multi-omics. This method, which is based on a Bayesian approach, is concerned with selecting subsets of the independent variables in linear regression to predict a response variable. The response variable is first assigned a probability distribution via the specification of a family of prior distributions for the unknown parameters in the regression model. However, because the data influence this family's ultimate choice of the prior distribution, the independent variables are assumed to be distinct observables, and the corresponding regression coefficients are assigned independent prior distributions [41]. BRR fits a model where the weighted sum of the independent variables can predict the response variable. It works by determining a set of coefficients to utilize in the weighted sum to perform a prediction. These coefficients were used as feature importance scores to select the best features of each single omics data.

$$y = \beta_0 + \beta_1 * x_1 + \beta_2 * x_2 + \varepsilon \quad (5)$$

where y is the dependent variable (also known as the response variable) β is the coefficient or model parameter, x is the value of a predictor variable, and there is also an error term describing the effect of variables not included in a model or random sampling noise.

From a Bayesian perspective, probability distributions rather than point estimates are used to build linear regression. The response, y, should be chosen from a probability distribution rather than evaluated as a single number. The goal of Bayesian Linear Regression is to ascertain the posterior distribution for the model parameters rather than to identify the one 'best' value of the model parameters. In addition to the model parameters also coming from a distribution, the response is also generated from a probability distribution. The training inputs and outputs affect the posterior probability of

the model parameters [42], [43]. However, Ridge was embedded with Bayesian regression to reduce the model complexity and multicollinearity by shrinking the coefficients. Most omics data is considered to be small-scale; therefore, Bayesian is suitable for these kinds of cases. It integrates the prior knowledge of the parameter (prior parameter distribution) with the observed data.

The three omics Exp, SNV, and CNV were tested as a single item of data and integrated in different combinations as follows: 1) EXP, 2) SNV, 3) CNV, 4) EXP and SNV, 5) EXP and CNV, 6) SNV and CNV, 7) EXP, SNV, and CNV. In addition, three experiments were implemented to evaluate the proposed solution and to study the multi-omics in various scenarios.

In the first scenario, the Baseline, all features of each single/multi omics were included in the model. It was implemented to test how the three omics affect the drug response without feature selection methods. In the second scenario, BRR was utilized to select the essential features of each single-cell omic - integrating them with the other one. According to the literature review, as a common practice, the mean value of all coefficients was used as a threshold to select features with coefficients higher than or equal to the calculated mean [44]. Also, the coefficients computed by the BRR were used to select important features for each single/multi-omics. In this last scenario, the top 10% of coefficients higher than or equal to the calculated mean were selected as informative features. After implementing various experiments for the different ratios, the ratio of the top 10% was selected, and it was noted that this 10% achieved the best results. This ratio was also used to reduce the computational cost of the model.

C. Drug Response Prediction Using Deep Forest

Deep Forest is a new ensemble Random Forest or decision tree approach that integrates multi-Grained Cascade Forest. This approach utilizes a cascade ensemble to create a deep forest as an alternative to deep learning that supports representation learning in gcForest. When the inputs have a high degree of complexity or dimensionality, multi-grained scanning can boost its representational learning capabilities, possibly helping gcForest to be contextually or structurally knowledgeable [10], [31]. gcForest allows a model complexity to be automatically defined, it performs very well even on small-scale data, and the number of cascade stages may be adjusted adaptively. Additionally, the developers/researchers can tailor their training expenses to their available computing resources. While deep neural networks have many hyper-parameters, gcForest has just a few. Its performance is relatively stable according to the hyper-parameter settings, it can achieve remarkable performance in most scenarios, even across datasets from diverse domains, by utilizing the default option. Through the use of external neural networks, gcForest may be trained and the theoretical analysis made more straightforward. It is noted that ensemble methods or cascade trees are more accessible to analyze than deep learning [10], [45].

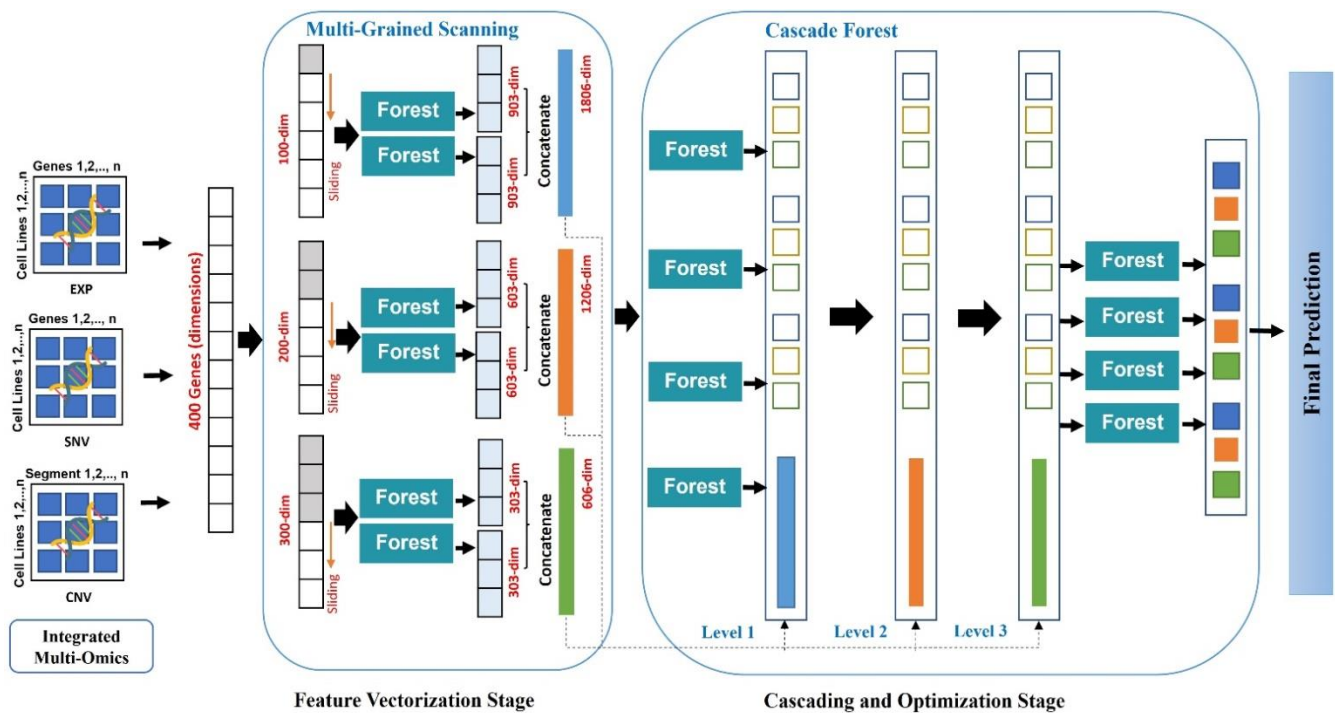


Fig. 2. The flowchart of BBR to integrate multi-omics data.

This phase consists of two stages, shown in Fig. 2: the Feature Vectorization Stage and Cascading and Optimization Stage. Deep Forest relies on multi-grained scanning, which effectively captures the local features. Also, the cascade forests utilize a network structure inspired by a multi-layer artificial neural network for continuously improving results.

1) *Feature vectorization stage*: Multi-grained scanning, motivated by the multi-convolution kernels used in Convolutional Neural Networks (CNNs), can discover and handle feature relationships in the subsequent cascade forests. the sliding window technique utilizes a scanning process to determine the local features and convert the raw data into a chain or set of low-dimensional local feature vectors [9], [31]. These low-dimensional vectors are then used to train a series of forests to get the class distributions for the input vectors.

Therefore, the raw features will be transformed into a high-dimensional feature vector using the multi-grained scanning, in this stage. Multi-Grained Scanning is utilized by sliding the windows to scan the original features and convert them into feature vectors. Suppose there is gene expression data as the sequence data; 400 raw features (dimensions) will be selected. Three sizes of sliding window will be used 100, 200, and 300. After scanning for a window size of 100 features, we will get 301 feature vectors according to this formula (total dimensions N_d - window size w) / the stride of the sliding $s + 1$. The distance the window moves in each step is named the stride. Therefore, $400 - 100 / 1 + 1 = 301$ feature vectors. A window with 100 dimensions will be generated, then 201 feature vectors will be processed for a window size of 200 and 101 feature vectors for a 300- dimensional. The final sample for training will be 903 instances for a window size of 100 features, one random forest, and three classes for

prediction, as an example. If there are two random forests, the total number of samples will be 1806 instances when they are concatenated [31], [46].

2) *Cascading and optimization stage*: Cascade forests employ a network structure similar to a multi-layer artificial neural network, with each layer connected to the layer before it in the network hierarchy. It may be thought of as a collection of randomly generated forests that have been joined together [31]. Several random forests are used to construct each layer, and each decision tree inside a particular forest produces a drug response prediction independent of the others. In the following step, an overall drug response vector for the forest is created by taking the average of the drug responses provided by the decision trees in the forest. In the process of decomposition, the representation vector can be used as an input for the next cascade level in the process of decomposition. Processing is carried out in stages per each layer of the cascade, with each layer sending its results to the next and the processing results being passed on layer by layer until the prediction performance in the next level of the cascade does not increase [10].

D. Evaluation Metrics

The 10-fold cross-validation approach was utilized to evaluate the performance of the proposed solution. The mean of 10 iterations was recorded as the final result. Three evaluation metrics were used in this research, Root Mean Squared Error (RMSE), Pearson Correlation Coefficient (PCC), and the coefficient of determination R-Squared (R^2).

RMSE [25], [26] was utilized to measure the error, which is the difference between the actual drug response values and the predicted values. It is defined as:

$$RMSE = \frac{\sqrt{\sum(y_i - \hat{y}_i)^2}}{N} \quad (6)$$

where y is the real value of drug response, \hat{y}_i is the predicted value of drug response, and N is the sample size.

The PCC [47] value was used to measure the degree of relationship or correlation between the drug response and predictors produced due to the multi-omics integration, defined as:

$$PCC = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2} \sqrt{\sum(y_i - \bar{y})^2}} \quad (7)$$

where x_i is the value of the predictors, y_i is the drug response value, and \bar{x} and \bar{y} indicate the mean of the values.

R^2 [48] was used to measure how much of the variability of drug response can be explained by its relationship to the other predictors which could be formulated as:

$$R^2 = 1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2} \quad (8)$$

where y is the actual value of drug response, and \hat{y}_i is the predicted value of drug response.

E. Comparison Criteria

The proposed Deep Forest was compared to Random Forest (RF) as a traditional machine learning method and CNN as a deep learning method. In addition, RF showed remarkable results according to various studies [19], [21], [49]. Furthermore, these algorithms were selected because CNN and an ensemble RF inspired Deep Forest. Therefore, they were employed to study which algorithm affects the Deep Forest the most.

IV. RESULTS AND DISCUSSION

The performance of the proposed solution was demonstrated using three scenarios: baseline, coefficient higher than or equal to the mean, and the top 10% of coefficients higher than or equal to the mean.

A. Baseline Scenario

In this scenario, all features were included in the model. It was used as a baseline result for measuring the effectiveness of the suggested BRR method. Table III shows the results of the three methods for the baseline.

TABLE III. THE RESULTS OF THE BASELINE SCENARIO FOR THE CCEL DATA

Type	Features	RMSE	R ²	PCC	Time (Sec)
<i>Deep Forest (DF)</i>					
EXP	19389	0.196	0.639	0.8	204.6
SNV	1667	0.238	0.002	0.029	28.1
CNV	24960	0.221	0.161	0.398	242.4
EXP, SNV	21056	0.196	0.624	0.79	138
EXP, CNV	44349	0.198	0.588	0.767	447

SNV, CNV	26627	0.222	0.159	0.396	328.8
EXP, SNV, CNV	46016	0.198	0.587	0.766	550.2
<i>Random Forest (RF)</i>					
EXP	19389	0.184	0.547	0.74	25.6
SNV	1667	0.237	0.016	0.119	0.859
CNV	24960	0.23	0.071	0.261	38.6
EXP, SNV	21056	0.182	0.565	0.752	27.6
EXP, CNV	44349	0.189	0.474	0.688	61.8
SNV, CNV	26627	0.223	0.131	0.357	38
EXP, SNV, CNV	46016	0.187	0.519	0.72	63.6
<i>CNN</i>					
EXP	19389	0.212	0.329	0.572	186
SNV	1667	0.252	0.004	0.047	21.4
CNV	24960	0.243	0.032	0.168	240
EXP, SNV	21056	0.206	0.383	0.618	195
EXP, CNV	44349	0.244	0.297	0.544	426
SNV, CNV	26627	0.237	0.05	0.217	251.4
EXP, SNV, CNV	46016	0.24	0.407	0.637	443.4

In general, DF showed the highest computational cost. Regarding R^2 and PCC, DF achieved the best results, and CNN showed the worst results. RF showed the lowest results from the perspective of RMSE and computational time. When multi-omics were integrated, DF achieved no effect, with EXP having the highest score. RF displayed a 4% improvement ratio when EXP and SNV were integrated. Also, CNN showed a 24% improvement ratio when EXP, SNV, and CNV were integrated.

Fig. 3 to 5 show the differences between the R^2 training and testing results in the Baseline scenario. Those figures measure the differences between prediction results on training data compared to testing data in the term of R^2 . There was overfitting in the three models; this usually happens with small-scale data. The average ratio of overfitting for DF, RF, and CNN was 60%, 62%, and 72%, respectively. In which DF had the smallest differences between training and testing results and CNN showed the highest ratio. This means the models cannot be generalized and needs more data or other techniques to handle overfitting.

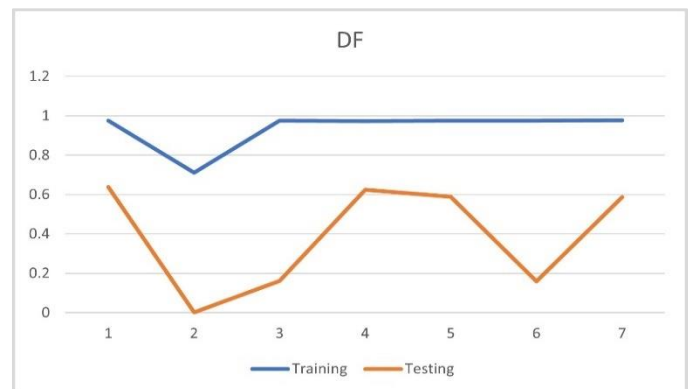


Fig. 3. R² results for the training and testing of the DF in the Baseline scenario.

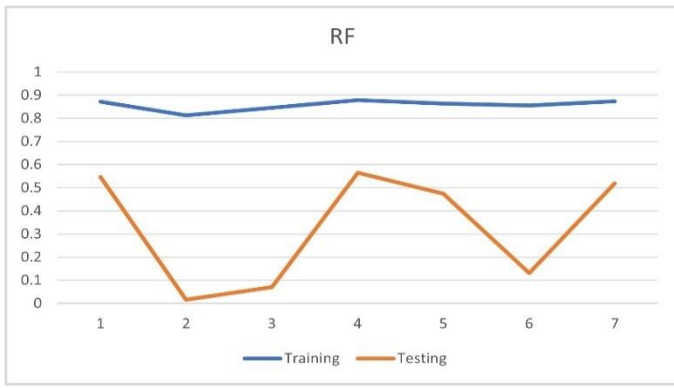


Fig. 4. R² results for the training and testing of the RF in the Baseline scenario.

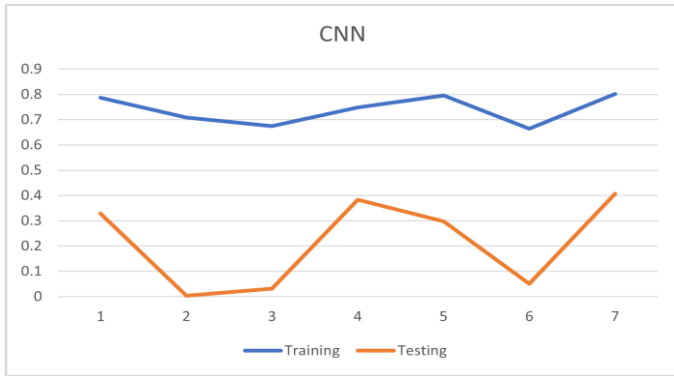


Fig. 5. R² results for the training and testing of the CNN in the Baseline scenario.

B. The Mean of Coefficients as a Threshold

In this scenario, the coefficients of each feature were calculated using BRR. Each feature was considered significant when its coefficient was higher than or equal to the mean of all coefficients. Table IV shows the results of this scenario.

TABLE IV. THE RESULTS OF THE MEAN OF COEFFICIENTS SCENARIO FOR THE CCEL DATA

Type	Features	RMSE	R ²	PCC	Time (Sec)
Deep Forest (DF)					
EXP	10204	0.199	0.594	0.771	89.4
SNV	783	0.241	0.012	-0.097	47.1
CNV	12538	0.226	0.095	0.304	130.8
EXP, SNV	10987	0.197	0.643	0.802	122.4
EXP, CNV	22742	0.201	0.526	0.725	211.2
SNV, CNV	13321	0.226	0.094	0.303	137.4
EXP, SNV, CNV	23525	0.201	0.53	0.728	370.2
Random Forest (RF)					
EXP	10204	0.192	0.479	0.692	13.4
SNV	783	0.258	0.021	-0.14	0.375
CNV	12538	0.234	0.053	0.226	18.4
EXP, SNV	10987	0.196	0.476	0.689	13.5

EXP, CNV	22742	0.2	0.381	0.616	31.9
SNV, CNV	13321	0.233	0.055	0.23	18.5
EXP, SNV, CNV	23525	0.196	0.468	0.683	32.2
CNN					
EXP	10204	0.171	0.664	0.814	85.2
SNV	783	0.234	0.067	0.258	13.5
CNV	12538	0.272	0.007	-0.069	122.4
EXP, SNV	10987	0.166	0.617	0.785	90
EXP, CNV	22742	0.184	0.519	0.72	204.6
SNV, CNV	13321	0.251	0.015	0.114	129.6
EXP, SNV, CNV	23525	0.206	0.595	0.771	208.8

CNN showed the best results in terms of RMSE, R², and PCC; it achieved 0.171, 0.664, and 0.814, respectively. Then DF came second best and finally RF. Both RF and CNN exhibited no effect when multi-omics were integrated because gene expression caused the highest results. DF presented an 8% improvement ratio when EXP and SNV were integrated. Exp played an essential factor in achieving remarkable results, CNV, and SNV.

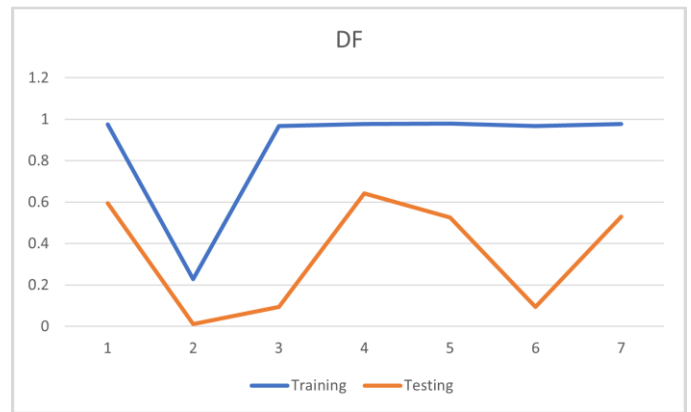


Fig. 6. R² results for the training and testing of the DF in the Mean of Coefficients scenario.

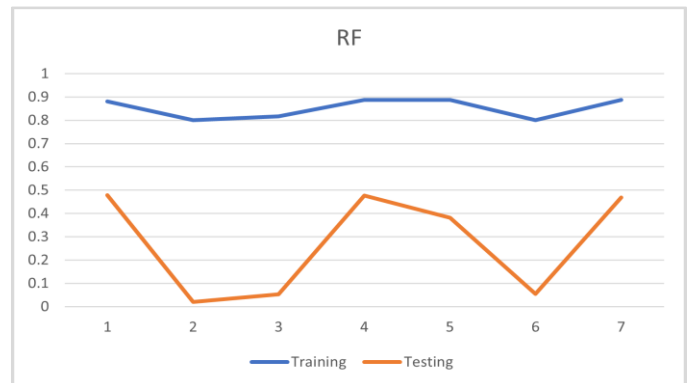


Fig. 7. R² results for the training and testing of the RF in the Mean of Coefficients scenario.

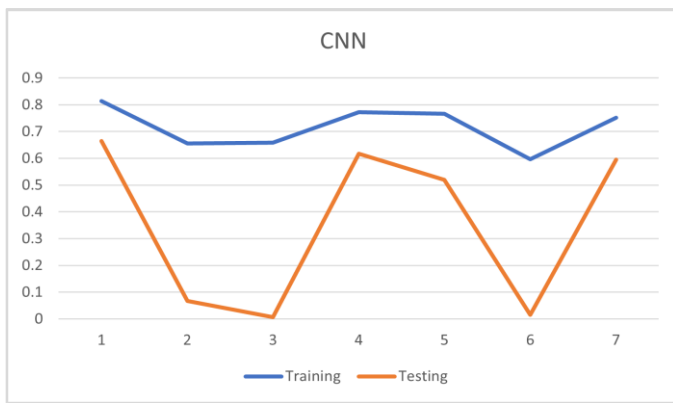


Fig. 8. R² results for the training and testing of the CNN in the Mean of Coefficients scenario.

Fig. 6 to 8 show the differences between training and testing results in The Mean of Coefficients as a Threshold scenario. There is still overfitting even though feature selection, cross-validation, and Dropout were utilized. The average ratio of overfitting for DF, RF, and CNN was 63%, 69%, and 54%, respectively. CNN showed the lowest differences ratio between the R2 training and testing results. CNN overfitting ratio was reduced from 72% to 54% compared to the Baseline scenario. However, RF and DF did not show a positive effect of applying BBR.

C. The Top 10% of Coefficients

In this scenario, the coefficient of each feature was calculated using BRR. Then, the mean of all coefficients was used as a threshold, and the top 10% of features were selected from the features that passed the threshold. Table V shows the results of this scenario.

TABLE V. THE RESULTS OF THE TOP 10% OF COEFFICIENTS SCENARIO FOR THE CCEL DATA

Type	Features	RMSE	R ²	PCC	Time (Sec)
Deep Forest (DF)					
EXP	1020	0.176	0.706	0.84	47.5
SNV	78	0.227	0.087	0.289	23.2
CNV	1253	0.225	0.107	0.322	51.7
EXP, SNV	1098	0.175	0.708	0.842	45.1
EXP, CNV	2273	0.188	0.584	0.764	35
SNV, CNV	1331	0.222	0.127	0.352	66
EXP, SNV, CNV	2351	0.184	0.618	0.786	56
Random Forest (RF)					
EXP	1020	0.192	0.495	0.703	1.48
SNV	78	0.245	0.016	0.116	0.11
CNV	1253	0.234	0.067	0.256	1.88
EXP, SNV	1098	0.19	0.509	0.713	1.53
EXP, CNV	2273	0.193	0.469	0.685	3.01
SNV, CNV	1331	0.235	0.062	0.247	2
EXP, SNV, CNV	2351	0.183	0.583	0.763	3.02

CNN					
EXP	1020	0.171	0.544	0.737	15.5
SNV	78	0.234	0.035	0.182	6.53
CNV	1253	0.229	0.083	0.283	18
EXP, SNV	1098	0.194	0.495	0.703	16.4
EXP, CNV	2273	0.161	0.564	0.751	26.8
SNV, CNV	1331	0.217	0.167	0.407	18.7
EXP, SNV, CNV	2351	0.159	0.585	0.764	27.4

In this scenario, the highest results were noticed when multi-omics were integrated. DF achieved RMSE 0.175, R² 0.708, and PCC 0.842 because of combining EXP and SNV. RF and CNN displayed the best scores when the three omics were integrated. The lowest RMSE -0.159- was achieved by CNN.

Fig. 9 to 11 demonstrate the last scenario: The Top 10% of Coefficients. The average ratio of overfitting for DF, RF, and CNN was 54%, 64%, and 39%, respectively. In this scenario, the overfitting of the DF was reduced from 60% to 54% compared to the baseline and from 72% to 39% for CNN. RF had the highest difference between training and testing for all scenarios. Therefore, this scenario showed the best effect of utilizing BRR in the three models.

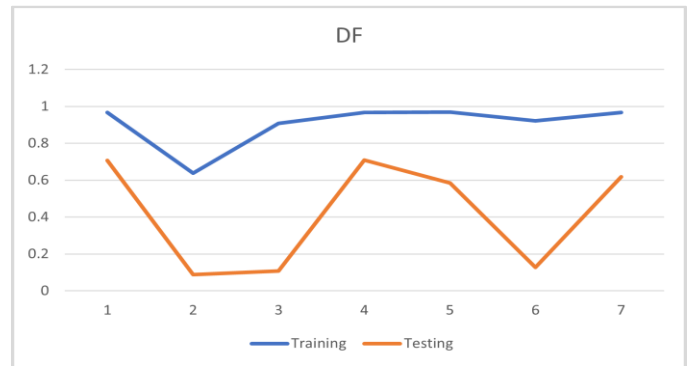


Fig. 9. R² results for the training and testing of the DF in the Top 10% of Coefficients scenario.

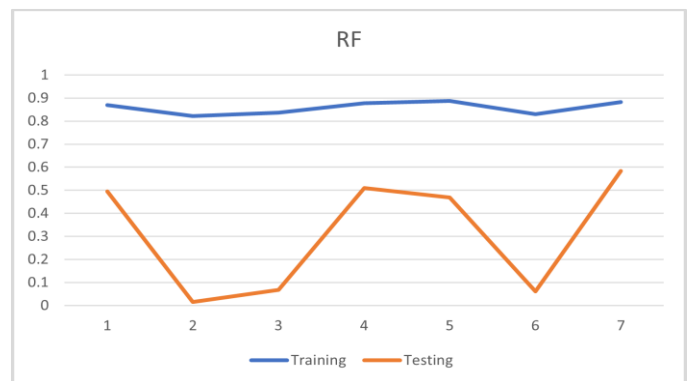


Fig. 10. R² results for the training and testing of the RF in the Top 10% of Coefficients scenario.

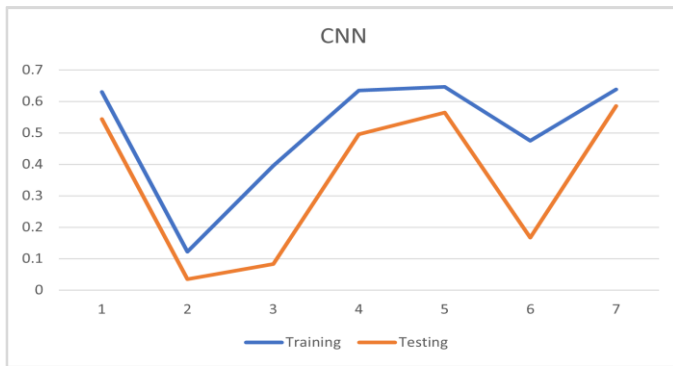


Fig. 11. R^2 results for the training and testing of the CNN in the Top 10% of Coefficients scenario.

D. Summary of the Scenarios and Algorithms

This section presents the comparisons when evaluating which algorithms performed better. The DF, RF, and CNN algorithms were compared in terms of R^2 and RMSE regardless of a specific scenario.

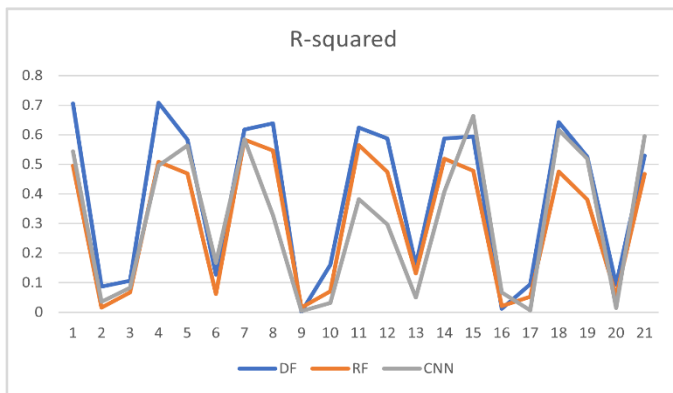


Fig. 12. R^2 results for the DF, RF, and CNN algorithms in all scenarios.

According to Fig. 12, the suggested algorithm Deep Forest (DF) has the best results as it achieved 39% for the average of the R^2 results of all scenarios. Both RF and CNN obtained 31% as the average of R^2 .

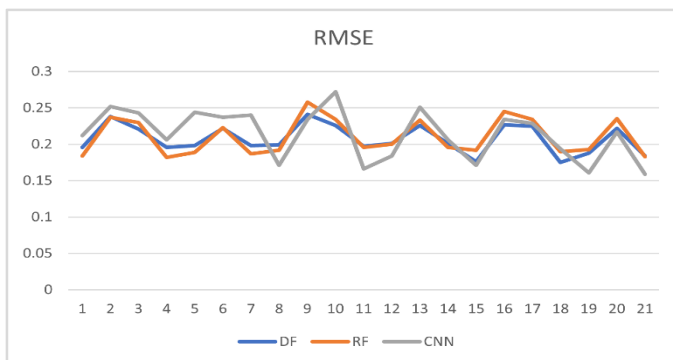


Fig. 13. RMSE results for the DF, RF, and CNN algorithms in all scenarios.

Regarding RMSE, DF obtained the lowest score, as shown in Fig. 13; it was 0.207 which is the average of all scenarios. RF obtained 0.210, and CNN obtained 0.213.

Therefore, the results and performance of the proposed method can be summarized by the following points:

- Bayesian Ridge Regression as a feature selection method for integrating multi-omics showed an 11% improvement ratio in terms of R^2 compared to the Baseline scenario. Also, the complexity time was reduced by 90%.
- The proposed method BRR-DF has the best results in terms of R^2 and RMSE in all three scenarios. The Top 10% scenario exhibited the best performance regardless of the specific algorithm.
- The drug response was mainly explained by the gene expression data more than the copy number and single nucleotide variants.
- Random Forest showed an 18% improvement when the three omics were integrated. Also, it was the fastest algorithm when dealing with these omics data.
- In Deep Forest, integrating gene expression and single nucleotide variant has a better result than integrating all three omics. Both Random Forest and CNN showed better results when all three omics were integrated.

E. Comparison with Related Studies

To evaluate the performance and robustness of the proposed model using the CCLE data, BRR-DF was compared with three state-of-the-art models as follows:

- WGRMF [50]: Weighted Graph Regularized Matrix Factorization is applied for predicting the anti-cancer drug response in cell lines. Their model used the CCLE, which contains 491 cell lines and 23 drugs with 10,870 known responses. WGRMF utilizes gene expression and drug fingerprints as the input for the model.
- DeepDSC [26]: Gene expression is employed to extract the features of cell lines using a stacked deep autoencoder, before the chemical structure is integrated with gene expression to predict the drug response. DeepDSC uses the CCLE, which contains 491 cell lines and 23 drugs with 10,870 known responses.
- SRMF [51]: A Similarity-Regularized Matrix Factorization model combining gene expression with chemical structures for drug response prediction. The CCLE, with 10,870 known responses, contains 491 cell lines and 23 drugs.

Table VI shows a comparison between the proposed method and the three models in the CCLE dataset.

TABLE VI. COMPARISON OF PERFORMANCES WITH OTHER RELATED MODELS

Model	RMSE	PCC	R^2
WGRMF	0.56	0.72	-
DeepDSC	0.23	-	0.78
SRMF	0.57	0.71	-
BBR-DF (Proposed)	0.17	0.84	0.70

The proposed model showed an improvement in terms of achieving the lowest RMSE and highest PCC compared with the other models. R^2 needs to be enhanced, and some of the limitations are discussed in the following section.

F. Effectiveness of Gene Expression in Drug Response

The main challenge in drug development research and clinical trials is the lack of understanding regarding how individuals respond to drugs, which can significantly impact their efficacy and tolerability [52]. The present study aimed to investigate this issue by analyzing gene expression data, copy number alterations (CNA), and single nucleotide variants (SNV) to determine their role in drug response. The results indicated that gene expression data was the most significant factor in describing drug response, as compared to CNA and SNV. To identify the genes that are most important in explaining drug response, the study utilized Bayesian Ridge Regression (BRR) to calculate a coefficient for each gene based on its mRNA expression data. Genes with high coefficients were considered potential candidates for explaining drug response. Table VII presents the top five genes based on their coefficient for 24 drugs, while the complete list of ranked genes for each drug is provided in the Supplementary Materials.

TABLE VII. THE TOP FIVE GENES SELECTED BY THE MODEL FOR 24 DRUGS IN CCLE

Drug	Gene	Drug	Gene
17-AAG	LIN28B	Paclitaxel	ABCB1
	TNFAIP6		UPK1B
	MAGEA4		SLC6A14
	VCAM1		PITX2
	MMP7		PLAC8
AEW541	IFITM2	Panobinostat	CYP1B1
	CD69		CPVL
	CXorf61		TM4SF18
	CLEC2B		VSNL1
	MAGEA11		NMI
AZD0530	MT1E	PD-0325901	DSE
	AC093323.3		COL1A2
	WWC3		MMP1
	CPVL		CXCR7
	SERPINE1		KLHL13
AZD6244	TUBB2B	PD-0332991	SCRN1
	DSE		KLHL13
	ARL4C		AIM2
	CSTA		CSDA
	SRPX2		S100A16
Crizotinib	GSTP1	PHA-665752	CMBL
	CXorf61		FABP4
	TM4SF18		BST2
	TFPI2		CST6
	CR2		LIMCH1

Erlotinib	DKK1	PLX4720	GOLGA8A
	CMBL		TDRD9
	MT1E		MMP1
	GNF		IFITM2
	MUC4		KLHL13
Irinotecan	IFI27	RAF265	CLEC2B
	RBM24		SDC2
	GDF15		ZNF83
	COL11A1		CXCL5
	CA2		PEG10
L-685458	GTSF1	Sorafenib	PRSS21
	CLEC2B		ROBO1
	CSDA		VCAN
	ARHGFE3		ANKRD36BP2
	ABCG1		CYFIP2
lapatinib	MT1E	TAE684	MMP1
	FBP1		HSPA1A
	BST2		RASGRP1
	SPARC		IFI27
	ALKBH3		CHN1
LBW242	AKAP12	TKI258	RGS4
	WASF3		HEY1
	CACHD1		LIN28B
	SLC10A4		SGCE
	EPS8		IGF1R
Nilotinib	DHRS9	Topotecan	MAGEA4
	CPVL		COL11A1
	DDX3Y		NGFRAP1
	PLOD2		CYP24A1
	TFPI2		KLK6
Nutlin-3	BIK	Vandetanib	PODXL
	SAMSN1		CHI3L1
	G0S2		DKK1
	SERPINB1		MT1E
	HLA-DQA1		CRNDE

MT1E (Metallothionein 1E) appears as an important predictor for 4 drugs: AZD0530, Erlotinib, Lapatinib, and Vandetanib. It is a Protein Coding gene. Frontometaphyseal Dysplasia 1 and Bladder Cancer are some of the diseases that are associated with MT1E [53]. In addition, CLEC2B (C-Type Lectin Domain Family 2 Member B) has a high score as an informative gene for 3 drugs: AEW541, L-685458, and RAF265. Several cancers, such as pancreatic adenocarcinoma, melanoma, and clear cell renal cell carcinoma, have been linked to CLEC2B as a marker [54]. However, those genes and their effect on each drug need to be validated in the biological context, which is an essential point in our future work.

V. CONCLUSION

Bayesian Ridge Regression (BRR) was combined with Deep Forest (DF) to enhance drug response prediction by integrating multi-omics data. BRR was used to select informative features for every type based on the coefficient value before integrating it with the other omics. DF works effectively to capture the local features and utilizes a network structure inspired by CNN for continuous improvement. Three scenarios were implemented. In each scenario, three models were utilized to evaluate the proposed model: Deep Forest (proposed), Random Forest, and CNN. BRR-DF displayed an 11% improvement ratio in terms of R^2 compared to the Baseline scenario. Also, the complexity time was reduced by 90%. DF showed the best results in all three scenarios in which it obtained 0.175, 0.842, and 0.708 regarding RMSE, PCC, and R^2 , respectively. The Top 10% scenario exhibited the best performance regardless of the specific algorithm. In DF, integrating gene expression and a single nucleotide variant showed a better result than integrating all three omics. Both Random Forest and CNN exhibited better results when all three omics were integrated. Regarding the multi-omics that were used, the drug response was mainly explained by the gene expression data more than the copy number and single nucleotide variants.

There are some limitations to the proposed solution. Firstly: the experiments showed overfitting even though cross-validation and feature selection were utilized. Techniques such as bootstrapping, ensemble methods, and synthetic oversamples could be investigated. Secondly, we only focused on cell line data. Future work will utilize drug information such as chemical structure and the drug target. Thirdly, selecting the best features was implemented manually, in which the top 10% were chosen. However, an automatic method, such as a voting-based will be studied in future work.

REFERENCES

- [1] Gambardella et al., "Personalized Medicine: Recent Progress in Cancer Therapy," *Cancers (Basel)*, vol. 12, no. 4, p. 1009, Apr. 2020, doi: 10.3390/cancers12041009.
- [2] A. Goodspeed, L. M. Heiser, J. W. Gray, and J. C. Costello, "Tumor-Derived Cell Lines as Molecular Models of Cancer Pharmacogenomics," *Molecular Cancer Research*, vol. 14, no. 1, pp. 3–13, Jan. 2016, doi: 10.1158/1541-7786.MCR-15-0189.
- [3] R. Kurilov, B. Haibe-Kains, and B. Brors, "Assessment of modelling strategies for drug response prediction in cell lines and xenografts," *Sci Rep*, vol. 10, no. 1, p. 2849, Feb. 2020, doi: 10.1038/s41598-020-59656-2.
- [4] E. S. Lander et al., "Initial sequencing and analysis of the human genome," *Nature*, vol. 409, no. 6822, pp. 860–921, Feb. 2001, doi: 10.1038/35057062.
- [5] Z. Cai, R. C. Poulos, J. Liu, and Q. Zhong, "Machine learning for multi-omics data integration in cancer," *iScience*, vol. 25, no. 2, p. 103798, Feb. 2022, doi: 10.1016/j.isci.2022.103798.
- [6] G. Nicora, F. Vitali, A. Dagliati, N. Geifman, and R. Bellazzi, "Integrated Multi-Omics Analyses in Oncology: A Review of Machine Learning Methods and Tools," *Front Oncol*, vol. 10, p. 1030, Jun. 2020, doi: 10.3389/fonc.2020.01030.
- [7] W. Zhong, "Feature selection for cancer classification using microarray gene expression data," 2014. Accessed: May 16, 2023. [Online]. Available: <https://prism.ucalgary.ca/items/0530b8e6-7c69-4a6f-8090-642c9765ef32>.
- [8] M. Walowe Mwadulo, "A Review on Feature Selection Methods For Classification Tasks," *International Journal of Computer Applications Technology and Research*, vol. 5, no. 6, pp. 395–402, Jun. 2016, doi: 10.7753/IJCATR0506.1013.
- [9] G. Hu, H. Li, Y. Xia, and L. Luo, "A deep Boltzmann machine and multi-grained scanning forest ensemble collaborative method and its application to industrial fault diagnosis," *Comput Ind*, vol. 100, pp. 287–296, Sep. 2018, doi: 10.1016/j.compind.2018.04.002.
- [10] Z.-H. Zhou and J. Feng, "Deep forest," *Natl Sci Rev*, vol. 6, no. 1, pp. 74–86, 2019.
- [11] Z.-H. Zhou and J. Feng, "Deep Forest: Towards An Alternative to Deep Neural Networks," in *Proceedings of the Twenty-Sixth International Joint Conference on Artificial Intelligence, California: International Joint Conferences on Artificial Intelligence Organization*, Aug. 2017, pp. 3553–3559. doi: 10.24963/ijcai.2017/497.
- [12] J. Wu, X.-Y. Chen, H. Zhang, L.-D. Xiong, H. Lei, and S.-H. Deng, "Hyperparameter optimization for machine learning models based on Bayesian optimization," *Journal of Electronic Science and Technology*, vol. 17, no. 1, pp. 26–40, 2019, doi: <https://doi.org/10.11989/JEST.1674-862X.80904120>.
- [13] C. Huang, R. Mezencev, J. F. McDonald, and F. Vannberg, "Open source machine-learning algorithms for the prediction of optimal cancer drug therapies," *PLoS One*, vol. 12, no. 10, p. e0186906, Oct. 2017, doi: 10.1371/journal.pone.0186906.
- [14] Q. Liu, Z. Hu, R. Jiang, and M. Zhou, "DeepCDR: a hybrid graph convolutional network for predicting cancer drug response," *Bioinformatics*, vol. 36, no. Supplement_2, pp. i911–i918, Dec. 2020, doi: 10.1093/bioinformatics/btaa822.
- [15] T. Nguyen, G. T. T. Nguyen, T. Nguyen, and D.-H. Le, "Graph Convolutional Networks for Drug Response Prediction," *IEEE/ACM Trans Comput Biol Bioinform*, vol. 19, no. 1, pp. 146–154, Jan. 2022, doi: 10.1109/TCBB.2021.3060430.
- [16] J. C. Costello et al., "A community effort to assess and improve drug sensitivity prediction algorithms," *Nat Biotechnol*, vol. 32, no. 12, pp. 1202–1212, Dec. 2014, doi: 10.1038/nbt.2877.
- [17] M. Gönen and A. A. Margolin, "Drug susceptibility prediction against a panel of drugs using kernelized Bayesian multitask learning," *Bioinformatics*, vol. 30, no. 17, pp. i556–i563, Sep. 2014, doi: 10.1093/bioinformatics/btu464.
- [18] F. Iorio et al., "A Landscape of Pharmacogenomic Interactions in Cancer," *Cell*, vol. 166, no. 3, pp. 740–754, Jul. 2016, doi: 10.1016/j.cell.2016.06.017.
- [19] S. Naulaerts, C. C. Dang, and P. J. Ballester, "Precision and recall oncology: combining multiple gene mutations for improved identification of drug-sensitive tumours," *Oncotarget*, vol. 8, no. 57, pp. 97025–97040, Nov. 2017, doi: 10.18632/oncotarget.20923.
- [20] A. K. Mitra et al., "A gene expression signature distinguishes innate response and resistance to proteasome inhibitors in multiple myeloma," *Blood Cancer J*, vol. 7, no. 6, pp. e581–e581, Jun. 2017, doi: 10.1038/bcj.2017.56.
- [21] X. Xu, H. Gu, Y. Wang, J. Wang, and P. Qin, "Autoencoder Based Feature Selection Method for Classification of Anticancer Drug Response," *Front Genet*, vol. 10, p. 233, Mar. 2019, doi: 10.3389/fgene.2019.00233.
- [22] M. P. Menden et al., "Machine Learning Prediction of Cancer Cell Sensitivity to Drugs Based on Genomic and Chemical Properties," *PLoS One*, vol. 8, no. 4, p. e61318, Apr. 2013, doi: 10.1371/journal.pone.0061318.
- [23] D. Baptista, P. G. Ferreira, and M. Rocha, "Deep learning for drug response prediction in cancer," *Brief Bioinform*, vol. 22, no. 1, pp. 360–379, Jan. 2021, doi: 10.1093/bib/bbz171.
- [24] A. B. Dincer, S. Celik, N. Hiranuma, and S.-I. Lee, "DeepProfile: Deep learning of cancer molecular profiles for precision medicine," *BioRxiv*, p. 278739, 2018, doi: <https://doi.org/10.1101/278739>.
- [25] Y. Chang et al., "Cancer Drug Response Profile scan (CDRscan): A Deep Learning Model That Predicts Drug Effectiveness from Cancer Genomic Signature," *Sci Rep*, vol. 8, no. 1, p. 8857, Jun. 2018, doi: 10.1038/s41598-018-27214-6.
- [26] M. Li et al., "DeepDSC: A Deep Learning Method to Predict Drug Sensitivity of Cancer Cell Lines," *IEEE/ACM Trans Comput Biol*

- Bioinform, vol. 18, no. 2, pp. 575–582, Mar. 2021, doi: 10.1109/TCBB.2019.2919581.
- [27] W. Xu, X. Liu, F. Leng, and W. Li, “Blood-based multi-tissue gene expression inference with Bayesian ridge regression,” *Bioinformatics*, vol. 36, no. 12, pp. 3788–3794, Jun. 2020, doi: 10.1093/bioinformatics/btaa239.
- [28] B. Velten and W. Huber, “Adaptive penalization in high-dimensional regression and classification with external covariates using variational Bayes,” *Biostatistics*, vol. 22, no. 2, pp. 348–364, Apr. 2021, doi: 10.1093/biostatistics/kxz034.
- [29] H. Sharifi-Noghabi, O. Zolotareva, C. C. Collins, and M. Ester, “MOLI: multi-omics late integration with deep neural networks for drug response prediction,” *Bioinformatics*, vol. 35, no. 14, pp. i501–i509, Jul. 2019, doi: 10.1093/bioinformatics/btz318.
- [30] V. Malik, Y. Kalakoti, and D. Sundar, “Deep learning assisted multi-omics integration for survival and drug-response prediction in breast cancer,” *BMC Genomics*, vol. 22, pp. 1–11, 2021.
- [31] Z.-H. Zhou and J. Feng, “Deep forest,” *Natl Sci Rev*, vol. 6, no. 1, pp. 74–86, Jan. 2019, doi: 10.1093/nsr/nwy108.
- [32] R. Su, X. Liu, L. Wei, and Q. Zou, “Deep-Resp-Forest: A deep forest model to predict anti-cancer drug response,” *Methods*, vol. 166, pp. 91–102, Aug. 2019, doi: 10.1016/j.ymeth.2019.02.009.
- [33] R. Hadsell, S. Chopra, and Y. LeCun, “Dimensionality reduction by learning an invariant mapping,” in 2006 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR’06), IEEE, 2006, pp. 1735–1742.
- [34] G. L. Guimaraes, B. Sanchez-Lengeling, C. Outeiral, P. L. C. Farias, and A. Aspuru-Guzik, “Objective-reinforced generative adversarial networks (ORGAN) for sequence generation models,” *arXiv preprint arXiv:1705.10843*, 2017.
- [35] M. Popova, O. Isayev, and A. Tropsha, “Deep reinforcement learning for de novo drug design,” *Sci Adv*, vol. 4, no. 7, p. eaap7885, 2018.
- [36] Y. Chen and L. Zhang, “How much can deep learning improve prediction of the responses to drugs in cancer cell lines?,” *Brief Bioinform*, vol. 23, no. 1, p. bbab378, 2022.
- [37] P. Jia, R. Hu, G. Pei, Y. Dai, Y.-Y. Wang, and Z. Zhao, “Deep generative neural network for accurate drug response imputation,” *Nat Commun*, vol. 12, no. 1, p. 1740, Mar. 2021, doi: 10.1038/s41467-021-21997-5.
- [38] M. Pouryahya et al., “Pan-Cancer Prediction of Cell-Line Drug Sensitivity Using Network-Based Methods,” *Int J Mol Sci*, vol. 23, no. 3, p. 1074, Jan. 2022, doi: 10.3390/ijms23031074.
- [39] H. Wang et al., “GADRP: graph convolutional networks and autoencoders for cancer drug response prediction,” *Brief Bioinform*, vol. 24, no. 1, p. bbac501, Jan. 2023, doi: 10.1093/bib/bbac501.
- [40] J. Barretina et al., “The Cancer Cell Line Encyclopedia enables predictive modelling of anticancer drug sensitivity,” *Nature*, vol. 483, no. 7391, pp. 603–607, Mar. 2012, doi: 10.1038/nature11003.
- [41] T. J. Mitchell and J. J. Beauchamp, “Bayesian Variable Selection in Linear Regression,” *J Am Stat Assoc*, vol. 83, no. 404, pp. 1023–1032, Dec. 1988, doi: 10.1080/01621459.1988.10478694.
- [42] C. M. Bishop and M. E. Tipping, “Bayesian regression and classification,” *Nato Science Series sub Series III Computer And Systems Sciences*, vol. 190, pp. 267–288, 2003.
- [43] J. Q. Shi, R. Murray-Smith, and D. M. Titterton, “Bayesian regression and classification using mixtures of Gaussian processes,” *Int J Adapt Control Signal Process*, vol. 17, no. 2, pp. 149–161, Mar. 2003, doi: 10.1002/acs.744.
- [44] S. Ozdemir and D. Susarla, *Feature Engineering Made Easy: Identify unique features from your dataset in order to build powerful machine learning systems*. Packt Publishing Ltd, 2018.
- [45] Y. Guo, S. Liu, Z. Li, and X. Shang, “BCDForest: a boosting cascade deep forest model towards the classification of cancer subtypes based on gene expression data,” *BMC Bioinformatics*, vol. 19, no. S5, p. 118, Apr. 2018, doi: 10.1186/s12859-018-2095-4.
- [46] C. Xin, X. Shi, D. Wang, C. Yang, Q. Li, and H. Liu, “Multi-grained cascade forest for effluent quality prediction of papermaking wastewater treatment processes,” *Water Science and Technology*, vol. 81, no. 5, pp. 1090–1098, Mar. 2020, doi: 10.2166/wst.2020.206.
- [47] M. Shahzad, M. A. Tahir, M. A. Khan, R. Jiang, and R. A. S. Malick, “EBSRMF: Ensemble based similarity-regularized matrix factorization to predict anticancer drug responses,” *Journal of Intelligent & Fuzzy Systems*, vol. 43, no. 3, pp. 3443–3452, Jul. 2022, doi: 10.3233/JIFS-212867.
- [48] A. Golbraikh and A. Tropsha, “Beware of $q^2!$,” *J Mol Graph Model*, vol. 20, no. 4, pp. 269–276, Jan. 2002, doi: 10.1016/S1093-3263(01)00123-1.
- [49] Y. Fang, P. Xu, J. Yang, and Y. Qin, “A quantile regression forest based method to predict drug response and assess prediction reliability,” *PLoS One*, vol. 13, no. 10, p. e0205155, Oct. 2018, doi: 10.1371/journal.pone.0205155.
- [50] N.-N. Guan, Y. Zhao, C.-C. Wang, J.-Q. Li, X. Chen, and X. Piao, “Anticancer Drug Response Prediction in Cell Lines Using Weighted Graph Regularized Matrix Factorization,” *Mol Ther Nucleic Acids*, vol. 17, pp. 164–174, Sep. 2019, doi: 10.1016/j.omtn.2019.05.017.
- [51] L. Wang, X. Li, L. Zhang, and Q. Gao, “Improved anticancer drug response prediction in cell lines using matrix factorization with similarity regularization,” *BMC Cancer*, vol. 17, no. 1, p. 513, Dec. 2017, doi: 10.1186/s12885-017-3500-5.
- [52] R. Herwig and H. Lehrach, “Expression profiling of drug response - from genes to pathways,” *Dialogues Clin Neurosci*, vol. 8, no. 3, pp. 283–293, Sep. 2006, doi: 10.31887/DCNS.2006.8.3/herwig.
- [53] G. Stelzer et al., “The GeneCards Suite: From Gene Data Mining to Disease Genome Sequence Analyses,” *Curr Protoc Bioinformatics*, vol. 54, no. 1, pp. 1–30, Jun. 2016, doi: 10.1002/cpbi.5.
- [54] X. Li, X. Tao, and X. Ding, “An integrative analysis to reveal that CLEC2B and ferroptosis may bridge the gap between psoriatic arthritis and cancer development,” *Sci Rep*, vol. 12, no. 1, p. 14653, Aug. 2022, doi: 10.1038/s41598-022-19135-2.

Systematic Analysis on the Effectiveness of Covert Channel Data Transmission

Abdulrahman Alhelal, Mohammed Al-Khatib

Computer Science Department, Imam Mohammad Ibn Saud Islamic University, Riyadh, Saudi Arabia

Abstract—A covert channel is a communication channel that allows parties to communicate and transfer data indirectly. Covert channel types are storage, timing, and behavior channels. Covert channels can be used for malicious and benign applications. A covert channel is a mechanism for violating the communication security policy that was not anticipated by the system creator. Recently, covert channels are used to transfer text, video, and audio information between entities. This article, discusses studies related to the development of covert channels as well as the research works that focus on improving the performance/throughput of covert channels. Also, it analyzes the previous studies in terms of publication type, year of publication, article title, article purpose, transferring file format used in covert channel, coding technique, throughput performance, time needed to transfer files, and article limitations.

Keywords—Covert channel; transmission; limitations; file; encoding throughput; performance; time; audio; video; text

I. INTRODUCTION

A covert channel is a mechanism for violating the communication security policy, where it is employed for encoding and decoding [1, 2]. The most important channel types are storage, time, and behavior channels. Storage channels is created using disk, physical memory to be shared between entities during using covert channel. A timing channel is a communication channel that can send/receive data by altering an entity's timing behavior. Covert channel works by altering the behavior of an application. A covert channel is used in data transmission in order to send different types of data between entities. There are several restrictions in the transmission process, such as channel capacity in terms of throughput. This article concentrates on investigating and evaluating the covert channels utilized in data transmission. Then analyze the collected studies about covert channels to identify the mechanisms used to create covert channels. In addition to determine, the throughput needed to transfer files. A comparative survey of related works is done in terms of several dimensions: The technique used to create the channel, the purpose of the channel, data format, coding techniques, throughput performance, time needed to transfer files, and article limitations. The methodology for conducting a comparative analysis about covert channel studies, which concern in data transmission, is shown in Fig. 1.

The rest of the article is structured as follows: Section II provides background and basic knowledge about covert channels, covert channel and scenarios. Section III discusses and analyzes related work about the effectiveness of covert channel data transmission. Section IV discusses the comparative analysis for related works studies and article

recommendations. Section V concludes the article and lists future works.

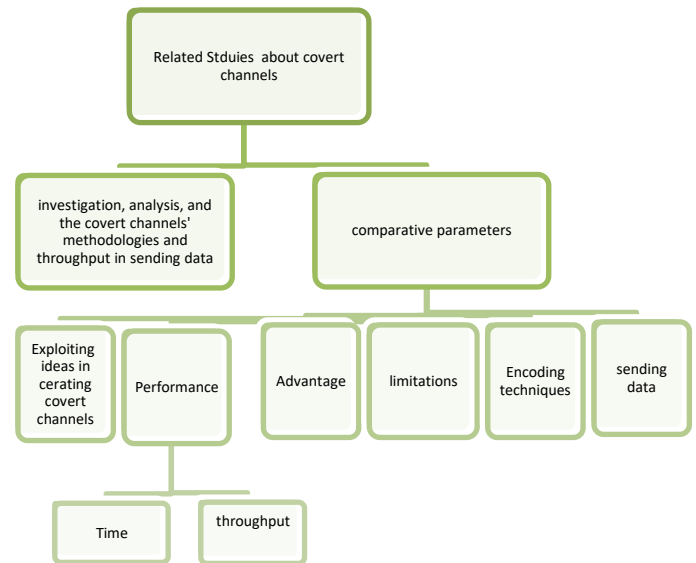


Fig. 1. Comparative survey methodology.

II. BACKGROUND OF COVERT CHANNEL

This section will cover the covert channel, its types, its scenarios, and covert channel applications.

A. Covert Channel

Lampson [3], first one that identifies a covert channel in a single machine computer environment in 1973 in his research titled "A Comment on the Confinement Problem". He describes a covert channel as a channel that is not intended for the transmission of data. Covert channel is a communication channel that allows parties to communicate and transfer data indirectly using per-agreement knowledge. As depicts in Fig. 2, the covert channel model uses to encode and decode the original messages. Covert channel is a mechanism for violating the communication security policy that was not anticipated by the system creator [1, 2, 3].

The sender and receiver (e.g.; Alice and Bob respectively) want to communicate covert message in spite of attacker existence (e.g.; Wendy). A covert channel is a type of secret channel. It sends secret data in an unseen manner by the monitoring system. Covert channel compromises the normal communication connection. Assume that Alice and Bob are connected through networked computers under the supervision of a network administrator.

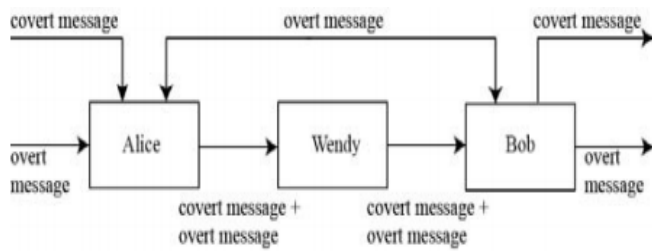


Fig. 2. Covert channel model [2].

As a result, a network covert channel exists when Alice and Bob create a concealed communication channel that is undetectable by the network monitoring system. Alice and Bob must have pre-shared key called pre-agreement knowledge. So the channel is ordinal channel that has covert data from Alice to Bob. Secret data is agreed upon by the entities as pre-agreement knowledge that is used to encode and decode the original messages. For example, if the pre-agreement between client and server is that each word with an even number of letters is read as a 1 and each word with an odd number of letters is read as a 0. For example, if a client sends a message to the server, the "covert channel", the server will interpret it as a "10" [1, 2, 4].

In the communication process, the secure transmission of secret communications relates to two aspects: communication content security and communication connection security. The security of these two features can be improved by using network covert channels [5]. A covert channel can be either a standalone or a networked system. The covert information is exchanged between elements in the stand-alone system. The covert information is sent over the network in a network-based system [6]. Initially, researchers focus on local covert channels, in which two processes with differing levels of security might connect with one another to leak information. Typically, a process with a high security level leaks information to a process with a low security level. With the growth and rapid development of computer networks, the focus has switched to network covert channels, which can embed covert information into network protocols [7].

B. Covert Channel Types

The most important three categories of covert channels are storage covert channels, timing covert channels, and behavior-based covert channels [3, 8, 9, 10]. Fig. 3 shows the main three types of covert channels.

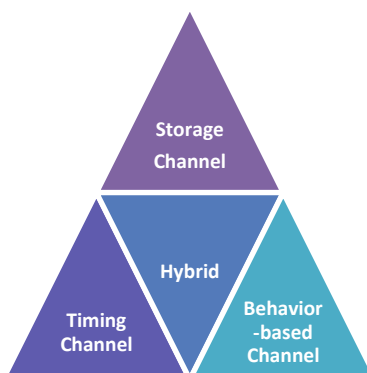


Fig. 3. Types of covert channel.

1) *Storage covert channels*: The sender and receiver create covert channel based on shared storage data agree on shared data. To embed covert data, storage channels primarily modify two characteristics of information.

a) *File names can be utilized* as entity attributes for storage channels. It can be altered by a single process. When any process performs a read operation, a message transfer between the processes occurs. It's also possible to change file attributes, which are properties of a file. Even though requesting a file that does not exist, the file system's feedback status can be used for storage channels [10, 11].

b) *Shared resources*: Storage channels can be made up of disk blocks, physical memory, I/O buffers, allocated I/O devices, and other queues for shared devices like printers and plotters. Storage channels are defined as a system feature that allows one system entity to signal information to another entity by writing to a storage location that is then read by the second entity directly or indirectly. It encrypts data and stores it on a medium that is shared by the endpoints. The shared resource was not made to transport data. A covert channel can be implemented in a networked system by utilizing reserved fields in various packet headers/footers or by hiding data in the payload. Attackers employ storage channels to encrypt information being transferred and then decode it afterwards. Some fields in TCP/IP stacks are left empty or unused. These vacant fields are used by attackers as storage conduits [10, 11].

2) *Timing channel*: A timing channel is a communication channel that can send data to a receiver/decoder by altering an entity's timing behavior. For example, packet delays between packet streams, packet reordering inside packet streams, or encoder resource access time. allows one system entity to communicate with another by manipulating its own use of a system resource in a way that affects the second entity's system response time. It changes the event time so that data can be shared between the endpoints. The main benefit is that the covert channel may be set up without affecting the transmission data stream. To this purpose, timing-based channels can be used with a variety of protocols because they are not affected by the network's packet syntax or semantics.

Attackers employ timing covert channels to modify system resources in order to deliver a message over time. The temporal delay between consecutive packet transfers is known as inter-packet delay. Timing-based covert channels are suitable for designing a complementary nonce synchronization channel that can improve robustness against message loss in existing authentication techniques, according to Vanderhallen et al. [11]. They tested this approach on top of an open-source authenticated CAN communication library, demonstrating that covert timing channels can improve communication robustness in benign situations while without compromising the security guarantees of the underlying authentication primitives when attacked.

3) *Behavior-based covert channels*: Behavior-based covert channels are described as a communication channel in which the sender or receiver's internal states are modulated by

purposefully selecting certain inputs to the systems. It works by altering the behavior of an application on purpose. The endpoints use this change to communicate. Covert channels based on behavior address the application level and are neither synchronized or dependent on a specific network protocol. As a result, they are more difficult to avoid and detect: identifying the message in a covert channel requires complete understanding of the application. Tamer Fatayer et al. [4, 9, 12], proposed behavior based channel through exploiting memory address in Linux operating system, where this channel change the behavior of using system calls and redirect the system call to malicious code implement by attacker to perform specific tasks.

C. Covert Channel Senarios

Zaider et al. [2] mention that that are different applications or usages (legitimate and illegitimate) for cover channel. Many covert channel applications are harmful or undesirable, which poses a severe danger to network security [2, 13, 14, 15, 16]. Malicious covert channel applications compromise network security. The Internet is the ideal high-bandwidth medium for covert communications because of the massive amount of information it contains as well as the enormous variety of data protocols. It is essential to comprehend current covert channel strategies while creating countermeasures. Identification, elimination, and capacity restriction of covert channels must be addressed to protect future computer networks, which is difficult. The current trend of covert channels is used in transforming secret information between entities [4, 9, 12, 17, 18, 19]. The researchers exploit network to transfer secret data (e.g., text, video, web, and audio) between entities. There are various covert channel scenarios:

1) *Storage channel scenarios*: Fatayer [12] developed a covert channel through developing table that is considered as pre-agreement data between entities. The covert channel-using table to transmit secure data that allows two entities to agree on a secret key using encryption to prevent an attacker from getting any information. Qiumin Xu et al. [20] a Trojan application can cause resource contention by altering the contents of a cache set to encode '1' and leaving the resource idle to encode '0'. On the other hand, the Spy application visits the cache and measures its access time in order to decode the transferred bit. Similarly, a Trojan application can cause contention by consuming a lot of execution units, warp schedulers, and instruction fetch units to encode '1' and then leaving those resources idle to encode '0,' which the spy can decode.

2) *Timing channel scenario*: Timing channels seek for TCP segments, which provide a finer range of information encoding options. For instance, steganography methods may take use of ACK/SYN sequences [21]. Information-containing segment patterns and artificial reordering. Following the same patterns as legal traffic and are immune to regularity testing. Active timing channels, on the other hand, create traffic and may easily maintain the form of the distribution, making them less susceptible to shape detection tests. However, they are

unable to maintain pattern recurrence and are easily detected using a regularity test.

3) *Behavior-based scenario*: Fatayer et al. [9] exploit buffer overflow vulnerability in C language on the Linux operating system to develop a covert channel. They exploit stack-overflow attacks vulnerability and address space layout randomization on Linux to transmit different file formats between entities. On entity tries to guess the randomization value that cause buffer overflow in Linux memory, while the other entity monitoring the count the guessing numbers till the success guess.

III. LITERATURE REVIEW ANALYSIS

This article will discuss studies that target covert channels utilized in data transmission between entities in this section. After that, we will analyze those studies to investigate the shortcomings and limitations of cover channel throughput during sending data by addressing these restrictions and limitations.

A. Covert Channels in Data Transmission

Channel in a wireless communication system with adaptive rate: They were able to effectively demonstrate a covert channel with a throughput of more than 150 Mbps that reliably delivered the hidden payload while minimizing the mistakes seen in the underlying communications system. Although the focus of this study was on IEEE 802.11ad, additional adaptive rate communication protocols should be able to benefit from using modulation and coding schemes selection to increase covert channel capacity. The selection of a cover object is limited to objects that can tolerate a certain amount of distortion (e.g., Audio and video), which is a significant flaw in this method. They don't used text or executable files. To minimize distortion on the underlying communications channel without compromising the covert channel's throughput, a modified embedding mechanism was developed.

Wendzel et al. [22] introduce a full survey covert channel that used to hide information inside network protocol. They investigated and analyzed around 109 techniques targeting covert channels that hide communication protocol. They classified a covert channel according to special pattern. They classify the covert channel according to eleven patterns which are Size Modulation, sequence of header/PDU elements to encode hidden information, add redundancy, PDU corruption/Loss pattern, random value pattern, value modulation pattern, reserved/unused pattern (a reserved or unused header/PDU element was used by the covert channel to encode data), inter-arrival time pattern, data rate of a traffic, PDU order patter, and retransmission pattern as depicts in Fig. 4.

In this survey we concerned with data rate of a traffic pattern, which allows covert channel sender alters the data rate of a traffic flow to the covert channel receiver. Using exception handling, we will construct a covert channel that we will utilize to deliver files to the server. Additionally, we employed a pattern called program flow pattern, which modifies program execution and transmits covert data to the receiver.

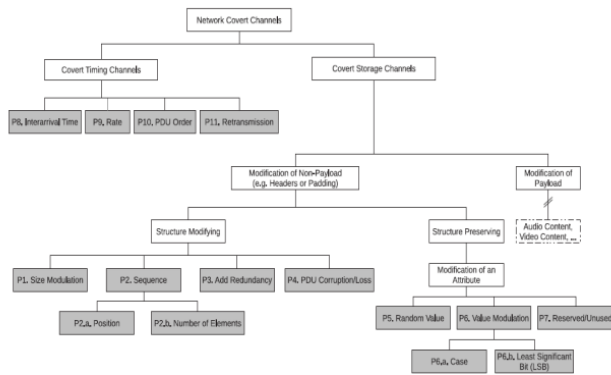


Fig. 4. Classification pattern of covert channel [22].

Zander et al. [22] presented a survey of developing network covert channels. The terms, adversary scenario, covert channel techniques, and countermeasures are all covered in this survey. Covert channels are used in sending information through network protocols. The survey showed the covert channel may use unused header bits, header extensions, padding, the IP Identifier and Fragment Offset, the TCP Initial Sequence Number (ISN), checksum fields, the time to live (TTL) field, the modulation of address fields and packet lengths, the modulation of timestamp fields, packet rate and timing, message sequence timing, packet loss and packet sorting, frame collisions, and ad hoc routing protocols. Also, they mention the counter measures techniques that used to detect and prevent covert channel. The following countermeasures are used such as:

- 1) Eliminate the channel including host security, Network security, traffic normalization.
- 2) Limit the bandwidth of the channel.

They introduced [22] an explanation of covert channel capacity, the amount of information that can be encoded in a resource's size (storage channels) or the speed at which it can be modulated (timing channels) can be used to estimate the covert channel capacity. Estimating the capacity in terms of bits per packet or bits per message sequence is simple for some channels. The amount of overt communication between covert sender and receiver or the amount of acceptable overt traffic accessible in the network determines capacity in bits per second. Therefore, it must modify the mechanisms for generating and producing covert channels in order to boost their capacity.

Schmidbauer et al. [18] present two covert channels that exploit nonce-based network authentication. First covert channel exploit key-based authentication and the second covert channel exploit hash-based authentication. These channels are used for sending encrypted information between parties. They investigated and exploited the challenge-response authentication with a nonce for transfer secret information. They evaluated their covert channel in terms of throughput rate. They increased the performance of the throughput by applying Compression and codebook techniques. They measure the throughput through number of attempt to achieve challenge-response authentication mechanism. Fig. 5 shows that using a compressed JS-Hex file requires 500 attempts to

communicate 4 bytes over Hash-based covert channel, whereas using an uncompressed JS-Hex file requires 3000 attempts.

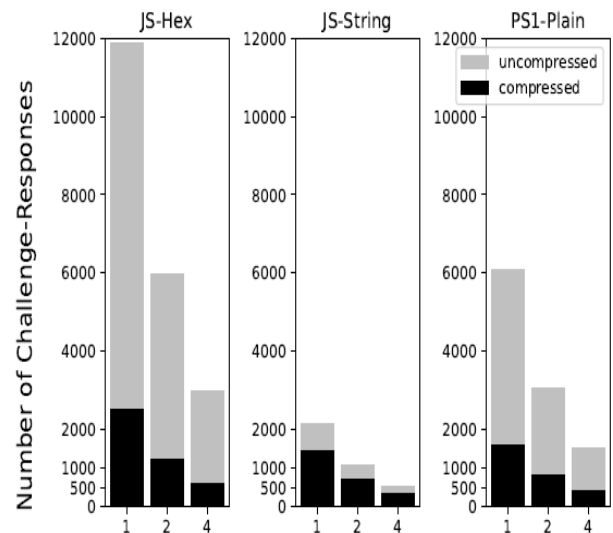


Fig. 5. Throughput hash-based covert channel [18].

Fatayer [12] developed a storage covert channel through developing a storage memory to be a pre-agreement data store between entities. Data structures are utilized to establish the covert channel, which will be used to transfer secure data between entities. This covert channel enabled parties to agree on a secret key. This mechanism is flexible in generating key with different size. On the other hand, it cost more traffic overheads and time consuming.

Fatayer et al. [9] exploit stack-overflow attacks and address space layout randomization on Linux to transmit different file formats. The sender tries to guess the delta_mmap memory (length 16 bit). One entity wants to send Files indirectly to other entity through a server. They are located in the same machine. Client tries to guess the random memory offset of standard C-library (delta_mmap) of the vulnerable server, and Bob tracks Alice's guessing attempts by monitoring the server process. Information to be sent is encoded in the number of failed guesses before success. They transmitted text and audio files between entities. They achieve best throughput performance using hexadecimal coding as depicts in Table I.

TABLE I. COVERT CHANNEL PERFORMANCE DURING TRANSFERRING AUDIO FILES [9]

Audio file size	Optimization time	Without optimization
2.3 KB	.76 minute	1.01 minute
1.2 MB	91.9 minute	234 minute

They suggested researchers to use encoding techniques to enhance the throughput performance. Additionally, they will look into methods for boosting channel throughput by determining the ideal block size, ideal number of tables, and ideal region number encoding—possibly utilizing Huffman-code. This article contribution is stemmed from this point. This article will develop covert channel to send file with different format with coding mechanism such as Byte, Hexadecimal, Huffman, and base64 coding.

Elsadig et al. [17], introduce a full comprehensive survey about the usage of covert channels and their types. They mention several benign usages of the covert channel, where the author considers it a new direction in security. Previous works focus on developing covert channels that depend on a new idea and the advantages and disadvantages of existing covert channels. These researches mention that there is limitation in throughput performance. Few research works investigated the use of covert channels to send files with different formats. Moreover, the performance of such covert channels has not been adequately explored. Previous researches did not investigate the use of encoding algorithms to improve the throughput performance of covert channels as well.

Jens et al. [19] exploit VoIP communications as a technique to increase privacy in sending files. They suggested hiding traffic within VoIP conversations to prevent disclosure from blocking the ongoing exchange of information. They use the voice activity detection features which found in client interfaces to create phony quiet packets that may be utilized as a carrier for transferring secret data. Results show that the suggested method may be effective for enforcing privacy in practical use scenarios, particularly for file transfers. They leveraged VoIP traffic by developing a virtual network interface for tunneling protocols of the TCP/IP suite.

Privacy Enhancing Technology Voice Activity Detection (PETVAD) is slower than a direct access because HTTP is influenced by the TCP's subpar performance when there are significant delays. Part of results in [19] as depicted in Table II, which indicates that to send 1 MB webpage it cost 283 (KB/s) as throughput and 3.61 second in the existence of 100ms delays [19]. Throughput is measure through constructing local area and wide area network configurations. They used three webpages to be sent through the covert channel. Each page has 1, 10, and 100 inline objects, each of which is 1MB, 100 KB, and 10 KB in size.

Cumulative Distribution Functions (CDFs) that describe the probability distribution of random variables of transfer over times. As it is visible, the larger the size of the website, the higher the variations experienced by the users when retrieving a page as shown in Fig. 6. The low bandwidth may cause interactive services (like web surfing) to lag too much, hence some sort of optimization or content scaling may be advised in these situations.

TABLE II. TIME AND THROUGHPUT FOR DIRECT AND PETVAD COVERT CHANNELS [19]

web pages size	Time (second)	Rate (KB/s)	Techniques	Delay
1* 1MB	3.61	283	Direct	100 ms
10* 100K	4.98	205		
100 * 10 K	21.65	47		
1* 1MB	422.21	2.43	PETVAD	
10* 100K	442.53	2.31		
100 * 10 K	660.53	1.55		

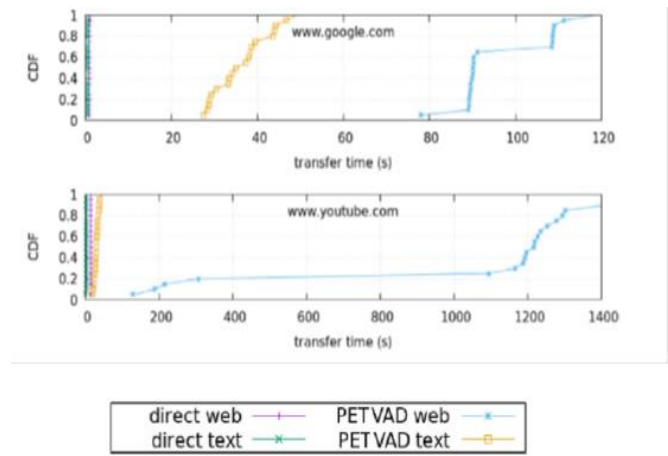


Fig. 6. Using a VIOP covert channel to transfer web sites [19].

B. Analysis Summary

The covert channels utilized for data transfer between entities are the topic of this article. There are several methods for creating covert channels, each of which can be used to encode and decode information. There are several types of information that are sent through channels, such as text files, audio, video, and web pages. We analyze and evaluate the performance of the covert channel in terms of throughput. The term "throughput" in this article means the number of transmitted bits per second. We observed from related works that the covert channel has low throughput. The authors use several mechanisms to enhance the performance, such as using encoding techniques.

IV. DISCUSSION ANALYSIS AND RECOMMENDATION

A. Systemic Review Discussion

This article discusses and analyzes studies related to the development of covert channels as well as the research works that focus on improving the performance/throughput of covert channels. This article analyzes the previous studies in terms of publication type, year of publication, article title, article purpose, transferring file format used in covert channel, coding technique, throughput performance, time needed to transfer files, and article limitations. Then compare conventional and modern mechanisms for creating covert channels. Table III, shows that covert channel is used for transferring files between entities. There are several mechanisms for creating covert channels. Current trends for creating covert channel through exploiting: Networks protocol (e.g., TCP), System interfaces, and Programming language.

Table III, examines previous studies to investigate covert channel capacity, throughput, and data transfer time; a comparative survey of related work in terms of exploiting ideas to create covert channels, channel type (e.g., storage channel), creation purpose (malicious and benign), data transmission type (e.g., audio and video), measurement performance, optimization techniques, advantages, and drawbacks where it's clear that the covert channel can be used to send different type of data such as audio, video, webpages, and text. The covert channel must be supported with coding techniques to increase the channel throughput. The covert channel must authenticate

parties before using it to send data. Furthermore, one of the primary goals of the covert channel is to improve throughput performance.

TABLE III. COVERT CHANNELS OF PREVIOUS STUDIES

Terms	Collected research
Exploiting idea	Ideas of collected article [4, 18, 19, 22, 23, 24] exploits networks protocol (e.g., TCP), system interfaces
Channel Type	Storage channel, timing channel, program flow
Purposed	Most of article s target is attack purposes. Some of them used to send secret data.
File Type	Text file, webpages and voice [19],
Measurement performance	Articles measure throughput and time of sending files performance.
Coding Optimization	Hex-coding [12], compression and code book technique [18], without coding [19].
Advantage	Every article is consideration as a new idea for a covert channel. These article s serve as warnings about the threats against network and software.
Drawbacks	The throughput performance is still low and needed to be improved.

Evaluating and analyzing the previous related works is depicted in Table IV in terms of publication type (conference or journal), publication year, article title, main idea of generating a covert channel, type of data transmission, coding techniques used in generating data, throughput performance in sending data, time performance in sending data, and article covert channel limitations.

TABLE IV. (A). THE MAIN COMPARISON POINTS FOR PROPOSED COVERT CHANNEL AND PREVIOUS COLLECTED ARTICLES

article reference	Publication type/year	Article Name	Main idea	Data transfer type
[18]	Conference/ 2022	"Challenging channels: Encrypted covert channels within challenge-response authentication.	They investigated and exploited the challenge-response authentication with a nonce for transfer secret information	They mention JS hexadecimal, JS-string, JS-plain, And ASCII alphabet
[4, 9, 12]	Conference/ 2011	OverCovert: Using Stack Overflow Software Vulnerability to Create a Covert Channel	Exploiting stack memory to hacks Linux memory functions to create covert channel.	Text and audio file

[19]	Journal/ 2020	VoIP network covert channels to enhance privacy and information Sharing	Develop covert channel depends on using the voice activity detection features which found in client interfaces to create phony quiet packets that may be utilized as a carrier for transferring secret data	Web pages as Google YouTube
proposed	2022	Exploiting a program execution for developing a high throughput covert channel.	exploit program execution	Text, audio, video,

TABLE V. (B). THE MAIN COMPARISON POINTS FOR OUR PROPOSED COVERT CHANNEL AND PREVIOUS COLLECTED ARTICLES

article reference	Coding	Throughput Concept	Time	Limitation
[18]	compression and codebook techniques	Number of attempts Needs to achieve challenge-response authentication	Not computed	countermeasures that allow the limitation of bandwidth, for example the utilization of appropriate RSA keys, and the elimination of the CC through the deployment of application-level firewalls
[4, 9, 12]	Used just hexadecimal coding	Number of bit sending during time	Time for agreement time and time for sending different files	Throughput is still low and authors just used hexadecimal . They presumptively believe that a server program is monitored by a local program that resides on the server's computer. They presume that the server cooperate with two parties.
[19]	There no special coding it just using two networks	Number of object(KB) in web pages transmitted per second	Computed	content-rich web browsing may require further optimizations, such as operating in a text-only fashion

B. Recommendation

Through related works analysis and developing covert channel, the following recommendations are

1) To develop covert channel countermeasure, we must understand covert channel mechanisms in terms of identification, elimination, and the capacities.

2) Applications and scenarios for covert channels in computer networks are varied.

3) Increased channel capacity can be achieved by changing the processes used to create and develop covert channels.

4) Both beneficial and harmful purposes are carried out through the covert channel.

5) The researchers concentrate on the fact that the channel capacity has a gap, which has to be filled by future researchers.

6) Using coding techniques maybe increase the throughput of channel in sending data.

7) Sending information through covert channel need security issues (e.g., entities authentication) beside sending data covertly.

V. CONCLUSION

Covert channel has several types: storage, timing, and behavior channels. Covert channel has several applications including data transmission. In this article, we focused on investigating and assessing the covert channels that used in data transfer. We collected earlier studies to identify methods for creating covert channels and how they measured the throughput at which data was delivered between organizations. We do a comparative survey of related work in terms of exploiting ideas to create covert channels, channel type (e.g., storage channel), creation purpose (malicious and benign), data transmission type (e.g., audio and video), measurement performance, optimization techniques, advantages, and drawbacks. We determine recommendations based on conducted survey, including: Applications and scenarios of covert channels in computer networks are varied. Increased channel capacity can be achieved by changing the technique that used to create and develop covert channel. In covert channel, coding techniques increase throughput of channel in sending information through covert channel need security issues (e.g., entities authentication) besides sending data covertly. The covert channel must be supported with coding techniques to increase the channel throughput. The covert channel must authenticate parties before using it to send data. Furthermore, one of the primary goals of the covert channel is to improve throughput performance.

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REFERENCES

- [1] Elsadig, M. A., & Fadlalla, Y. A. (2018). Packet length covert channels crashed. *J Comput Sci Comput Math*, 8(4), 55-62.
- [2] Zander, S., Armitage, G., & Branch, P. (2007). A survey of covert channels and countermeasures in computer network protocols. *IEEE Communications Surveys & Tutorials*, 9(3), 44-57.
- [3] Lampson, B. W. (1973). A note on the confinement problem. *Communications of the ACM*, 16(10), 613-615.
- [4] Xing, J., Kang, Q., & Chen, A. (2020, January). Netwarden: Mitigating network covert channels while preserving performance. In *USENIX Security*.
- [5] Tian, J., Xiong, G., Li, Z., & Gou, G. (2020). A survey of key technologies for constructing network covert channel. *Security and Communication Networks*, 2020, 1-20.
- [6] Dakhane, D. M., & Deshmukh, P. R. (2015, January). Active warden for TCP sequence number base covert channel. In *2015 International Conference on Pervasive Computing (ICPC)* (pp. 1-5). IEEE.
- [7] Wendzel, S., Zander, S., Fechner, B., & Herdin, C. (2015). Pattern-based survey and categorization of network covert channel techniques. *ACM Computing Surveys (CSUR)*, 47(3), 1-26.
- [8] Alcaraz, C., Bernieri, G., Pascucci, F., Lopez, J., & Setola, R. (2019). Covert channels-based stealth attacks in industry 4.0. *IEEE Systems Journal*, 13(4), 3980-3988.
- [9] Fatayer, T. S., Khattab, S., & Omara, F. A. (2011, February). OverCovert: Using stack-overflow software vulnerability to create a covert channel. In *2011 4th IFIP International Conference on New Technologies, Mobility and Security* (pp. 1-5). IEEE.
- [10] Gasser, Morrie. *Building a secure computer system*. New York: Van Nostrand Reinhold Company, 1988.
- [11] Vanderhallen, S., Van Bulck, J., Piessens, F., & Mühlberg, J. T. (2021). Robust authentication for automotive control networks through covert channels. *Computer Networks*, 193, 108079.
- [12] Fatayer, T. S. (2020). *Secure Communication Using Cryptography and Covert Channel*. In *Computer and Network Security*. IntechOpen.
- [13] Giffin, J., Greenstadt, R., Litwack, P., & Tibbetts, R. (2003). Covert messaging through TCP timestamps. In *Privacy Enhancing Technologies: Second International Workshop, PET 2002 San Francisco, CA, USA, April 14-15, 2002 Revised Article s 2* (pp. 194-208). Springer Berlin Heidelberg.
- [14] Dong, P., Qian, H., Lu, Z., & Lan, S. (2012). A Network Covert Channel Based on Packet Classification. *Int. J. Netw. Secur.*, 14(2), 109-116.
- [15] Yuan, B., & Lutz, P. (2005). A covert channel in packet switching data networks.
- [16] Akhtari, S., Moghim, N., & Mahdavi, M. (2020). Middleman covert channel establishment based on MORE routing protocol using network coding in ad hoc networks. *International Journal of Communication Systems*, 33(7), e4320.
- [17] Elsadig, M. A., & Fadlalla, Y. A. (2016). Survey on covert storage channel in computer network protocols: detection and mitigation techniques. *International Journal of Advances in Computer Networks and Its Security*, 6(3), 11-17.
- [18] Schmidbauer, T., Keller, J., & Wendzel, S. (2022, August). Challenging channels: Encrypted covert channels within challenge-response authentication. In *Proceedings of the 17th International Conference on Availability, Reliability and Security* (pp. 1-10).
- [19] Saenger, J., Mazurczyk, W., Keller, J., & Caviglione, L. (2020). VoIP network covert channels to enhance privacy and information sharing. *Future Generation Computer Systems*, 111, 96-106.
- [20] Xu, Q., Naghibijouybari, H., Wang, S., Abu-Ghazaleh, N., & Annavaram, M. (2019, June). Gpuguard: Mitigating contention based side and covert channel attacks on gpus. In *Proceedings of the ACM International Conference on Supercomputing* (pp. 497-509).
- [21] Nowakowski, P., Zórawski, P., Cabaj, K., & Mazurczyk, W. (2020, August). Network covert channels detection using data mining and

- hierarchical organisation of frequent sets: an initial study. In *Proceedings of the 15th International Conference on Availability, Reliability and Security* (pp. 1-10).
- [22] Zander, S., Armitage, G., & Branch, P. (2007). A survey of covert channels and countermeasures in computer network protocols. *IEEE Communications Surveys & Tutorials*, 9(3), 44-57.
- [23] Cabuk, S., Brodley, C. E., & Shields, C. (2004, October). IP covert timing channels: design and detection. In *Proceedings of the 11th ACM conference on Computer and communications security* (pp. 178-187).
- [24] Berk, V., Giani, A., & Cybenko, G. (2005). Detection of covert channel encoding in network packet delays.

Towards Analysis of Biblical Entities and Names using Deep Learning

Mikolaj Martinjak^{1*}, Davor Lauc², Ines Skelac³

Faculty of Philosophy and Religious Studies, University of Zagreb, Zagreb, Croatia^{1,3}
Faculty of Humanities and Social Sciences, University of Zagreb, Croatia²

Abstract—Scholars from various fields have studied the translations of the Bible in different languages to understand the changes that have occurred over time. Taking into account recent advances in deep learning, there is an opportunity to improve the understanding of these texts and conduct analyses that were previously unattainable. This study used deep learning techniques of NLP to analyze the distribution and appearance of names in the Polish, Croatian, and English translations of the Gospel of Mark. Within the scope of social network analysis (SNA), various centrality metrics were used to determine the importance of different entities (names) within the gospel. Degree Centrality, Closeness Centrality, and Betweenness Centrality were leveraged, given their capacity to provide unique insights into the network structure. The findings of this study demonstrate that deep learning could help uncover interesting connections between individuals who may have initially been considered less important. It also highlighted the critical role of onomastic sciences and the philosophy of language in analyzing the richness and importance of human and other proper names in biblical texts. Further research should be conducted to produce more relevant language resources, improve parallel multilingual corpora and annotated data sets for the major languages of the Bible, and develop an accurate end-to-end deep neural model that facilitates joint entity recognition and resolution.

Keywords—Bible; deep learning; gospel of mark; natural language processing; social network analysis

I. INTRODUCTION

The Bible is a significant religious text that has been translated into many languages and is one of the world's most widely studied ancient texts. However, the translations of the Bible exhibit substantial variation across the languages into which they have been translated, and these translations have undergone numerous revisions over the years. As a result, studying the translations of the Bible in different languages and understanding the changes that have taken place over time are essential for scholars in several fields, including theology, linguistics, religious studies, and history.

With recent advances in deep learning, there is an opportunity to improve understanding of these texts and conduct previously impossible analyses. Deep learning techniques are still not commonly used in this field of research, but they can help scholars analyze and interpret biblical text by enabling them to process large amounts of data and identify connections and information that cannot be identified using traditional methods. In this context, one application of deep learning is the use of natural language

processing (NLP) to analyze the language used in the text. Natural language processing can be used to identify patterns in the use of words and phrases, as well as in the syntax and grammar of the text.

Recent research has explored the use of SNA to study language and culture. Social network analysis is a useful tool for identifying patterns in large data sets, and has been applied to various domains, including linguistics, anthropology, and sociology. It is also a useful technique that can be used to uncover patterns and relationships between Bible translations by analyzing the frequency of words and phrases in different translations.

In this case study, the use of deep learning techniques is explored to analyze the distribution and appearance of names in the Polish, Croatian, and English translations of the Bible. For this research, data from the 100-language parallel corpora created by Christos Christodouloupoulos and Mark Steedman are used [1]. When multiple versions of the Bible were available, the creators of the corpora preferred to use the oldest translation available. For example, the King James Version was used for the English language.

Furthermore, this analysis uses the methodology of distant reading [2]. It aims to analyze large collections of texts using computational tools and techniques, as this allows for the generalization and identification of patterns that would otherwise be impossible to detect. The present case study uses SNA techniques to investigate the relationships and interactions within a network of entities in the selected book of the Bible. When SNA techniques are applied to large data sets of translations, insights can be gained into the relationships between translations and the religious and linguistic factors that influence the translation process.

This study aims to strengthen the robustness of biblical text analysis across multiple languages; therefore, it should be viewed as a first step or pilot research. As a starting point, the Gospel of Mark is chosen. The Gospel of Mark's Footprint will be expanded to other languages and subsequently to the entire New Testament and later to the entire Bible. The goal is to enhance understanding of the distribution of names in the biblical text and provide a framework for analyzing other interdisciplinary aspects, including theological, linguistic, and philosophical ones. Finally, during this analysis, different philosophical questions about the status of the names appeared and have been discussed using a framework from the analytical philosophical tradition.

In this paper, after the review of existing research and available language resources, the methods and results of entity recognition and resolution in a selected Gospel will be presented. Finally, the obtained results and the possibilities of future research will be discussed.

II. LITERATURE OVERVIEW

A. *About the Gospel of Mark*

The Gospel of Mark was written in the first century for a general audience of Christians, although scholars debate the exact audience and purpose of the gospel [3]. It is the shortest of the four canonical gospels and is believed to have been written between AD 65 and 70. Hence, it is one of the earliest written accounts of Jesus Christ's life and teachings.

In the Gospel of Mark, Jesus is presented as the Son of God and the long-awaited Messiah (Christ) of Jewish prophecy. Throughout the gospel, Jesus performs miracles and teaches with authority, attracting crowds of followers while challenging the religious and political authorities of his time. This gospel emphasizes Jesus' role as a suffering servant who will be rejected, betrayed, and crucified but will also rise from the dead and bring salvation to humanity. Specifically, Mark portrays Jesus as a human being with a divine mission who is uniquely qualified to fulfill the promises and prophecies of the Hebrew Bible. Jesus' identity is gradually revealed throughout the gospel as he heals the sick, forgives sins, calms storms, feeds the multitudes, and confronts demons. At Jesus' baptism, a voice from heaven proclaims, "...Thou art my beloved Son, in whom I am well pleased." (Mk 1:11) [4], confirming the divine identity of Jesus. Despite Jesus' powerful teachings and miraculous deeds, many people rejected him, including the religious leaders of his day, who saw him as a threat to their authority. This leads to Jesus' arrest, trial, and crucifixion, but also sets the stage for his ultimate triumph over death and evil powers.

The Gospel of Mark contains a distinctive theology that emphasizes certain key themes and ideas. There are a few theological themes found in this Gospel. For this research, the most prominent theme is the Messianic Secret. The Gospel of Mark portrays Jesus as the Messiah, while emphasizing that his identity is often hidden or a secret. This is because Jesus repeatedly commands those he has healed or exorcised to tell no one about what he has done, and he often speaks in parables that are difficult for his disciples and others to understand.

The reference for all names mentioned in the text is not obvious from the text. Sometimes it relates to our knowledge of the Bible, especially other synoptic gospels [5]. The Gospel of Mark gives us names such as Jesus, Simon, John, James, etc. However, who was James? It should be concluded that from the text itself. Another challenge is that there is more than one James, and, in some cases, it is not so evident to which person the text refers. The same thing happened with the name John, where it can distinguish at least John the Baptist and John the Apostle, and with the other names as well. The solution for distinguishing is mentioned in the Results and Discussion section.

B. *The Analysis of NLP Resources for Bible Studies*

There are various applications of NLP resources for Bible studies thus far. Natural language processing tools can be used to analyze the language and style of the Bible, which can provide insights into the authorship and composition of different biblical texts. However, using NLP tools for biblical studies has several challenges and limitations. For example, the complexity and diversity of biblical texts makes it difficult to create NLP resources that can capture all the nuances and subtleties of the language. In addition, the cultural and historical contexts in which the Bible was written can be difficult to capture using NLP tools alone and may require additional theological expertise. Therefore, NLP tools should be used in conjunction with other methods and expertise, not in place of close reading and interpretation of texts.

Büchler and Mellerin [6] discuss the use of NLP resources for Bible studies. This article provides an overview of several NLP tools and resources designed specifically for analyzing biblical texts, such as morphological analyzers, part-of-speech taggers, syntactic parsers, and named entity recognition systems. These tools enable scholars to identify patterns of language use, track the evolution of specific words and phrases, and uncover hidden connections between different parts of the Bible. The authors also discuss the potential benefits of using NLP tools for biblical studies. For example, they propose that NLP can help scholars identify allusions and quotations from other texts in the Bible, which can shed light on the cultural and historical contexts in which the Bible was written.

Another topic that can be investigated using NLP is authorship attribution. According to [7], attribution of authorship involves analyzing various linguistic features of a text to determine the probability that a given author wrote the text. The authors discuss challenges that arise when applying authorship attribution to the Bible, such as the use of pseudonyms and the difficulty of obtaining enough training data for accurate analysis and provide examples of how authorship attribution has been used to analyze different parts of the Bible, such as the Psalms and the Pauline epistles. Despite these challenges, authorship attribution can provide valuable insights into authorship and the historical context of biblical texts. Thus, by identifying the authors of different parts of the Bible, scholars and researchers could gain a deeper understanding of the historical and cultural contexts in which these texts were written.

In addition, several studies have been conducted to compare Bible translations in different languages. Using SNA techniques, a study examined the frequency of words in the English and German translations of the Bible. The study found that some words were used more frequently in one translation than in the other, which could be attributed to differences in language structure, culture, and translation choices [8]. By comparing translations in different languages, scholars can better understand the choices made by translators and the cultural and linguistic factors that influence those choices.

As stated previously, NLP tools are used for various analyses of the biblical text; however, none of the existing studies conducted a comparative analysis of personal names in

different languages. This analysis can have several outcomes: 1) It can show linguistic (phonetic) differences between Bible translation and different languages, allowing for a language distance analysis; 2) It can provide a parallel philosophical and theological perspective to the name analysis; 3) It can use SNA to show differences in social connections between different translations of the Bible, which can help in determining some ambiguous places in understanding personal relations in the Bible.

III. METHODS

A. Distant Learning Method of Literary Analysis

In recent years, distant reading, a literary analysis method that involves analyzing large bodies of texts using computational techniques, has been applied to biblical studies. This method has been used to identify patterns and trends in the use of language and themes across multiple biblical texts, shedding new light on the historical and cultural contexts in which these texts were written. One of the key aspects of distant reading is the use of quantitative methods to measure and compare literary phenomena. Moretti [2] suggests that we should examine the “big picture” of literary history by analyzing large data sets and mapping out the evolution of genres, themes, and styles over time. A general goal of distant reading is to uncover broad patterns and trends in literature that can reveal new insights and understandings about literary history, genres, and themes [9].

In doing so, patterns that may not be visible at the level of individual texts or authors can be identified. Another important aspect of distant reading is the use of computational tools to process and analyze textual data. Moretti argues that we should go beyond traditional methods of literary analysis, such as close reading and interpretation, and embrace the potential of digital technologies to handle large amounts of data [2]. By using tools such as text mining, topic modeling, and network analysis, hidden patterns and connections in the literature that would otherwise be impossible to discern can be uncovered.

However, distant reading also faces several challenges and limitations. One of the main criticisms of distant reading is that it prioritizes quantitative analysis over qualitative interpretation and reduces literary texts to mere data points. Despite this limitation in this study, the results obtained using this methodology are always discussed and verified using traditional theological and linguistic methodologies.

B. Construction of the Entity Graph

The entity graph is built in two phases. In the first phase, named entities are recognized and classified using the ByT5 neural model [10] fine-tuned in the relevant parts of the multilingual named entity recognition (NER) data set. The results were manually evaluated and corrected, and the data set will be used to fine-tune the NER model in the future. The second phase was manual disambiguation and classification of the recognized named entities. The graph (social network) was constructed based on counts of co-occurrence of the entities of type person in the verses.

C. Social Network Analysis Metrics

Within SNA, various centrality metrics are used to determine the importance of network entities. In this research, degree centrality, closeness centrality, and betweenness centrality were used, each providing unique insights into the structure of the network.

Degree Centrality is a simple metric that counts the number of direct connections (edges) an entity has with other entities in the graph. Higher-degree centrality values indicate a higher number of connections. This metric can be used to identify nodes that are well connected and potentially influential within the network. Closeness centrality measures how close a node is to all other nodes in the network. It is calculated by taking the inverse of the sum of the shortest path distances between a node and all other nodes in the network. A higher closeness centrality value indicates that an entity is more central and can reach other nodes in the graph more quickly. Betweenness centrality, a related metric, measures the extent to which an entity acts as a bridge to other entities. It indicates how often a node lies on the shortest path between pairs of other nodes [11].

IV. RESULTS

An entity graph (a social network) created by the described method reveals interesting insights into relationships among people mentioned in the gospel. The selected centrality measures – degree centrality (D), closeness centrality (C), and betweenness centrality (B) – for the English, Croatian, and Polish languages are presented in Table I.

The difference between languages and the apparent difference in numbers on individuals and their relationship or closeness demonstrated in Table I is in significant part due to the use of pronouns. Each language will use a different number of pronouns, corresponding to the development and flow of the language. SNA metrics show that Jesus is a central figure, but also give some surprising results, such as that Mary Magdalene is closer in a relationship and connections than Mary, mother of Jesus. Yet, it is also due to how the gospel was written.

Differences and similarities between centrality measures are easier to interpret when visualized using a spring graph layout, as shown in Fig. 1, Fig. 2, and Fig. 3.

The graphs in the three languages show that Jesus is a central figure of the gospel. Obviously, many connections led to Jesus, especially those closest to him – for example, John the Baptist, Simon Peter, John and James Zebedee, and others. When the names of Timaeus and Bartimaeus are looked at, it is noticed that they are closer to Jesus in the Croatian language than in others. In that sense, they are not directly connected to Jesus in English or Polish but are in the Croatian version of the graph. The main reason for this occurrence is that Jesus was specifically mentioned by name in the Croatian version of the text. Another intriguing part of the graph is the name of Simon, who is in the text distinguished as a Cyrenian and his two sons, who have no connection to Jesus in the graph. However, according to knowledge of other gospels and reading of the Gospel of Mark, it is known that Simon was the one who assisted Jesus in carrying his cross. Mary Magdalene,

Mary the mother of James and Joses, and Salome all experienced similar events. There are no direct connections to Jesus in the graphs, even though it is known from other resources and standard interpretations of the Bible that there is a connection. Aside from the obvious connections, it was interesting to see the link between Jesus, Barabbas, Pilate, and Joseph of Arimathea, who are all directly connected to Jesus. Note that Joseph is only identified by his first name in the Croatian and Polish versions of the graph.

In the King James version of the English translation, which is used in this analysis, the name James Zebedee is used, while in the Croatian and Polish translations, the name is Jakob or Jakov. In graphs, it is evident that the same person is in question, since there is a connection between him, his brother John, and his father (signed just as Zebedee). For some other figures, a 'new' or a bit untraditional method was used. For the research, the surnames that are not present in the gospel were added to distinguish similar names that refer to different people.

TABLE I. SELECTED SNA METRICS (D – DEGREE, C – CLOSENESS, B - BETWEENNESS) ORDERED BY THE BETWEENNESS CENTRALITY IN THE ENGLISH TRANSLATION

	ENTITY	ENGLISH			CROATIAN			POLISH		
		D	C	B	D	C	B	D	C	B
0	Jesus Christ	0.29	0.38	0.3	0.43	0.46	0.25	0.28	0.33	0.15
1	Andrew - brother of Peter	0.32	0.34	0.24	0.09	0.22	0	0.08	0.17	0
2	John the Baptist	0.15	0.28	0.12	0.14	0.31	0.09	0.14	0.24	0.07
3	Simon Peter	0.18	0.38	0.11	0.17	0.31	0.02	0.17	0.24	0.01
4	Mary Magdalene	0.09	0.27	0.08	0.09	0.27	0	0.08	0.22	0.05
5	James Zebedee	0.15	0.37	0.07	0.14	0.3	0.02	0.14	0.24	0.02
6	John Zebedee	0.15	0.37	0.07	0.14	0.3	0.02	0.14	0.24	0.02
7	Elias	0.12	0.32	0.02	0.11	0.31	0.01	0.11	0.24	0.01
8	Zebedee	0.06	0.25	0	0.06	0.2	0	0.06	0.16	0
9	Alphaeus	0.24	0.26	0	0	0	0	0	0	0
10	Bartholomew	0.24	0.26	0	0.17	0.17	0	0.22	0.22	0
11	James Alphaeus	0.24	0.26	0	0.17	0.17	0	0.22	0.22	0
12	Matthew	0.24	0.26	0	0.17	0.17	0	0.22	0.22	0
13	Philip	0.24	0.26	0	0.17	0.17	0	0.22	0.22	0
14	Simon the Canaanite	0.24	0.26	0	0.17	0.17	0	0.22	0.22	0
15	Thaddaeus	0.24	0.26	0	0.17	0.17	0	0.22	0.22	0
16	Thomas	0.24	0.26	0	0	0	0	0.22	0.22	0
17	Joses Nazarean	0.09	0.09	0	0.11	0.11	0	0.11	0.11	0
18	Juda Nazarean	0.09	0.09	0	0.11	0.11	0	0.11	0.11	0
19	Mary mother of Jesus	0.09	0.09	0	0.11	0.11	0	0.11	0.11	0
20	Simon Nazarean	0.09	0.09	0	0.11	0.11	0	0.11	0.11	0
21	Herod the King	0.09	0.21	0	0.09	0.21	0	0.08	0.17	0
22	Herodias	0.09	0.21	0	0.09	0.21	0	0.08	0.17	0
23	Philip, brother of Herod	0.09	0.21	0	0.09	0.21	0	0.08	0.17	0
24	Moses	0.09	0.3	0	0.09	0.28	0	0.08	0.22	0
25	Bartimaeus	0.03	0.03	0	0.06	0.27	0	0.03	0.03	0
26	Timaus	0.03	0.03	0	0.06	0.27	0	0.03	0.03	0
27	Pontius Pilate	0.09	0.26	0	0.09	0.27	0	0.08	0.21	0
28	Barabbas	0.06	0.26	0	0.06	0.27	0	0.06	0.21	0
29	Alexander of Simon C.	0.06	0.06	0	0.06	0.06	0	0.06	0.06	0
30	Rufus of Simon C.	0.06	0.06	0	0.06	0.06	0	0.06	0.06	0
31	Simon Cyrenian	0.06	0.06	0	0.06	0.06	0	0.06	0.06	0
32	Mary, mother of James and Joses	0.06	0.2	0	0.09	0.27	0	0.06	0.16	0
33	Salome	0.06	0.2	0	0.09	0.27	0	0.06	0.16	0
34	Joseph of Arimathea	0.06	0.26	0	0.06	0.27	0	0.06	0.21	0
35	David the King	0	0	0	0.03	0.26	0	0	0	0
36	Andrew	0	0	0	0.17	0.17	0	0.22	0.22	0
37	James Nazarean	0	0	0	0.11	0.11	0	0.11	0.11	0

It is common for biblical names to be translated differently in different languages, depending on the linguistic and cultural traditions of each language. James has become a common English name and is often used to refer to the biblical figure. Many English-speaking readers may not recognize that the name Jacob refers to the same person. However, some English translations use the name Jacob instead of James, particularly in recent translations that seek to be more faithful to the original Hebrew and Greek texts.

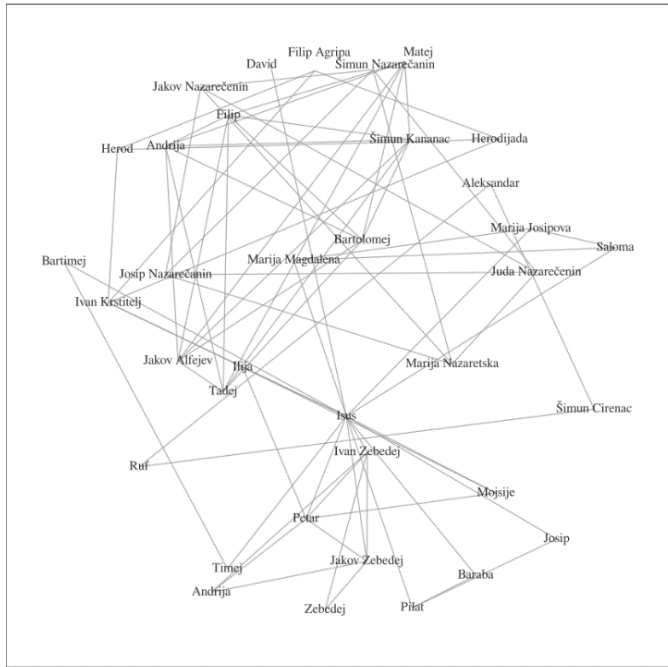


Fig. 1. Entity graph for English language.

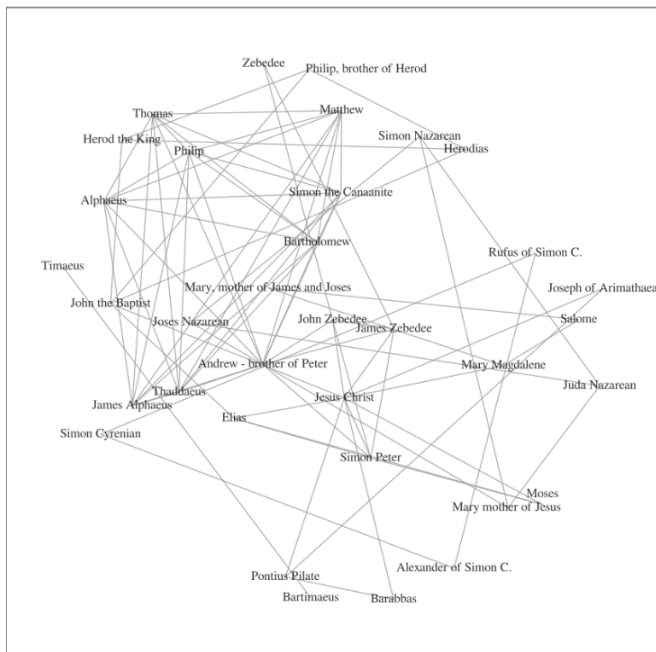


Fig. 2. Entity graph for Croatian language.

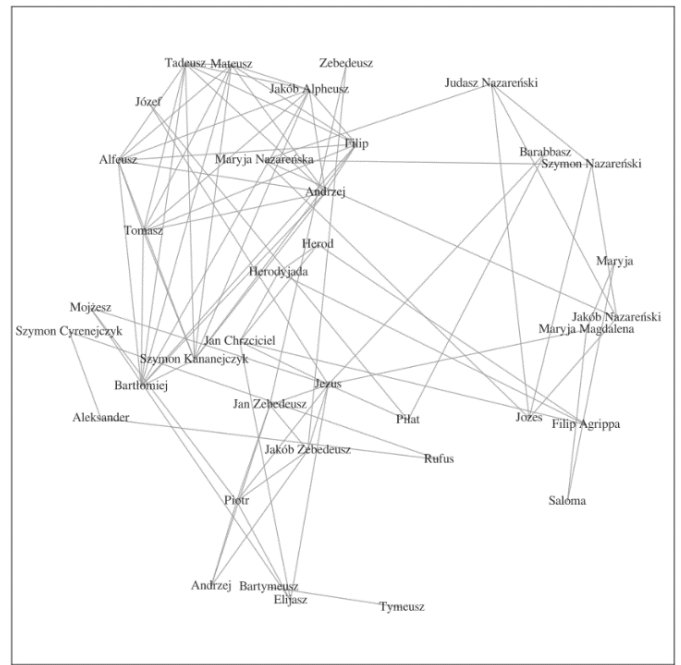


Fig. 3. Entity graph for Polish language.

V. DISCUSSION

A. Theological Perspective

During the manual evaluation and correction process, the greatest diversity came from the differences in the languages and the use of names in specific languages. Some Bible translations do not follow the phonetic development of an original name but instead use more common names that evolved over time and even morphed into different names. However, some names needed to be differentiated even more in the text itself. The first task was to distinguish between the names of places, towns, regions, and individuals. It was also necessary to differentiate between functions such as Caesar, Pharisee, etc., and individuals since the program recognized them as specific names of people rather than functions. In that sense, a boat (pol. *łódź*) was recognized as a proper name in the Polish version of the text, probably because there is a town with the same name in Poland.

Furthermore, the main challenge in identifying individuals in the Gospel is that the text provides only a first name, occasionally giving a last name or what we would call, in today's terms, a last name [12]. In biblical terms, they almost always represent a connection with a particular person in parent-child relationships. The name Bartimaeus, the son of Timaeus, is the most notable and precise connection between father and son (Mk 10:46-52) [4]. It is a Greek name that means "son of Timaeus." "There are no similar connections in other places of the gospel. Instead, one can see "son of Alphaeus," "son of Zebedee," or even "Son of David," which is sometimes applied to "Jesus". The problem emerged because those connections are not evident in the text unless manually marked. As a result, last names were required to make clearer distinctions. Moreover, the apostles James and John were given the surname Zebedee, but that did not resolve the issue, especially since there were other people named

James. One is known as “James Alphaeus” and is sometimes referred to as “the lesser”. Additionally, he is supposed to be Levi’s (Mathew) brother. The information on Levi as Mathew is reconstructed from other synoptic gospels and textual connections that are not obvious from a single reading of the story.

There is also a problem with the name Simon, which is given to Peter as he becomes a disciple, but it is also the same name of individuals who are difficult to distinguish. In some ways, one is unsure if those are two different people or if they are referred to differently, as in the case of Levi.

In our analysis of the text, it was important to differentiate Christ as a name from Christ as a reference to Jesus, as Ehrman concludes [13]. In other words, a problem emerged during the name analysis because it was necessary to distinguish between Christ as a name and Christ as a function. That is, in terms of theology, Ehrman’s work made sense to this. The concept of the Messianic secret in the Gospel of Mark has important implications for understanding the relationship between Jesus and his disciples, the apostles.

B. Philosophical Perspective

Except for the beginning of the Gospel of Mark, where the syntagm ‘Jesus Christ’ is used, it cannot be sure if Christ refers to Jesus in other places. However, it is clear in some places that it does not or can be questioned. This is a challenge for linguistic analysis because the question is: when Christ refers to Jesus, is it only when there is a syntagm Jesus Christ, and is it possible that Christ does not refer to any specific person in some places?

The famous location is (Mk 8: 29), where Jesus asks his disciples: “...But whom say ye that I am? And Peter answered and saith unto him, Thou art the Christ.” [4] As a result, the syntagm Jesus Christ is not the only place where Christ refers to Jesus.

For linguistic analysis, “Christ” can be interpreted as a function in Frege’s terms [14], with Jesus serving as the object that fulfills the function of being “Christ.” In the case of “Christ” in the Gospel of Mark, one could interpret it as a function that assigns the value of being the Messiah, the Savior, or some other similar role to a particular object. Depending on the context, the object that fulfills this function could be Jesus or another individual. However, the function would remain the same regardless of the specific object that performed it.

If Jesus is the only object that fulfills this function, then the function would have a unique value, and any use of the term “Christ” would necessarily refer to Jesus. However, Frege’s theory of functions allows for the possibility of multiple values that fulfil a function. The specific number and nature of these values would be determined by the context and interpretation of the term “Christ.”

If one wants to limit “being a Christ” to one person, then it is better to understand “Christ” as a name and not a function. According to Kripke [15], names are rigid designators; therefore, the meaning of a name is fixed and independent of any specific description or property of the individual. With

this definition, it can be said that Christ, as a rigid designator, has the same fixed meaning as the name Jesus when it is known that these two names refer to the same person (compare [16, 17]). This meaning, or the object of reference, could be Jesus or another figure, such as the Messiah or the Savior. Still, the name “Christ” would always refer to the same individual, regardless of the specific properties or descriptions used to describe them. Kripke’s theory also allows the possibility of reference failure, in which a name does not refer to any individual in the world. This could happen if the name is used in a context where no individual matches the description associated with it (for example, before Jesus was born) or if it is unknown that Christ has the same reference as Jesus. In the case of “Christ” in the Gospel of Mark, it is also possible that the name Christ does not refer to any specific individual in some contexts, either because it is used in a general sense or because there is ambiguity or uncertainty about its referent.

Therefore, “being a Christ” can be understood as a function in Frege’s terms. Kripke’s theory of reference provides a more useful framework for understanding how names refer to individuals in the world when this individual is unknown or uncertain.

VI. CONCLUSION

From a theological perspective, this study demonstrates that in some cases it is difficult to distinguish an individual from the mission or even from another individual. Almost everyone in the world knows who Jesus is and perhaps who Peter or Judas is. Still, this research showed that some interesting connections between individuals who seemed less important could be discovered through deep learning. Even with this small extract of the text and only a few languages, it will become even more prominent on a larger scale.

Given the importance and influence of Bible, the relative scarcity of available language resources is surprising. Therefore, our future research will initially focus on creating more relevant resources, starting with improving parallel multilingual corpora and annotated data sets for all the major languages of the Bible. These resources are necessary to train more accurate multilingual language models for named entity recognition and entity resolution. Based on these data sets, the intention is to develop an accurate end-to-end deep neural model for joint entity recognition and resolution, which would facilitate numerous other research projects in digital humanities, theology, and related fields.

Another unexpected early finding was that the newer NER models performed worse than older models on biblical texts, contrary to the standard benchmarks, which should be thoroughly researched and explained.

Further research using other metrics and techniques from SNA in studying the interaction of entities in the Bible and validating those findings against traditional research should yield interesting results.

Finally, given the richness and importance of human and other proper names in biblical texts, several interesting studies in onomastic sciences and sociolinguistics could be conducted, ranging from analyses of the similarity and differences of

biblical names across different languages to the creation of alternative similarity matrices among languages.

REFERENCES

- [1] C. Christodouloupoulos and M. Steedman, "A massively parallel corpus: the Bible in 100 languages," *Language Resources and Evaluation*, Language Resources and Evaluation, 2015.
- [2] F. Moretti, *Distant reading*, Verso Books, 2013.
- [3] L. W. Hurtado, *The Earliest Christian Artifacts: Manuscripts and Christian Origins*, Wm. B. Eerdmans Publishing Co., 2008.
- [4] *The Holy Bible: King James Version*, Dallas, TX: Brown Books Publishing, 2004.
- [5] J. Rubalcaba, *Who's Who in the Bible: Everyone You Need to Know from the Old and New Testaments*, National Geographic, 2018.
- [6] M. Büchler and L. Mellerin, "JDMDH Special Issue on Computer-Aided Processing of Intertextuality in Ancient Languages," *Journal of Data Mining and Digital Humanities*, 2017, pp. 1-10.
- [7] D. E. Mills, *Authorship attribution applied to the Bible*, Texas Tech University, 2003.
- [8] I. Goodfellow, Y. Bengio and A. Courville, *Deep learning*, MIT press, 2016.
- [9] L. M. E. Goodlad, "A Study in Distant Reading: Genre and the Longue Durée in the Age of AI," *Modern Language Quarterly*, vol. 81, no. 4, 2020, pp. 491-525.
- [10] L. Xue, A. Barua, N. Constant, R. Al-Rfou, S. Narang, M. Kale, A. Robert and C. Raffel, "Byt5: Towards a token-free future with pre-trained byte-to-byte models," *Transactions of the Association for Computational Linguistics*, vol. 10, 2022, pp. 291-306.
- [11] S. P. Borgatti and D. J. Brass, *Social Networks at Work*, Routledge, 2019.
- [12] D. Hey, *The Oxford Guide to Family History*, Oxford University Press, 2002.
- [13] B. D. Ehrman, *The Orthodox Corruption of Scripture: The Effect of Early Christological Controversies on the Text of the New Testament*. Updated and with a new afterword ed., Oxford University Press, 2011.
- [14] G. Frege, "Function and Concept," in *Translations from the philosophical writings of Gottlob Frege*, Basil Blackwell, 1960, pp. 21-35.
- [15] S. Kripke, *Naming and Necessity*, Harvard University Press, 2001.
- [16] J.T. Turner. Hylemorphism, rigid designators, and the disembodied 'Jesus': a call for clarification. *Religious Studies*, vol. 57, no. 2, 2021. pp. 193-208.
- [17] W. Wood. *Analytic theology and the academic study of religion*. Oxford University Press, USA. 2021.

Deadline-aware Task Scheduling for Cloud Computing using Firefly Optimization Algorithm

BAI Ya-meng*, WANG Yang, WU Shen-shen

School of Information Engineering, Jiaozuo University, Jiaozuo 412000, China

Abstract—Task scheduling poses a major challenge for cloud computing environments. Task scheduling ensures cost-effective task execution and improved resource utilization. It is classified as a NP-hard problem due to its nondeterministic polynomial time nature. This characteristic motivates researchers to employ meta-heuristic algorithms. The number of cloud users and computing capabilities is leading to increased concerns about energy consumption in cloud data centers. In order to leverage cloud resources in the most energy-efficient manner while delivering real-time services to users, a viable cloud task scheduling solution is necessary. This study proposes a new deadline-aware task scheduling algorithm for cloud environments based on the Firefly Optimization Algorithm (FOA). The suggested scheduling algorithm achieves a higher level of efficiency in multiple parameters, including execution time, waiting time, resource utilization, the percentage of missed tasks, power consumption, and makespan. According to simulation results, the proposed algorithm is more effective and superior to the CSO algorithm under HP2CN and NASA workload archives.

Keywords—Cloud computing; energy efficiency; task scheduling; firefly algorithm

I. INTRODUCTION

In recent years, wireless and emerging technologies have undergone significant progress, particularly the Internet of Things (IoT) [1, 2], artificial intelligence [3], machine learning [4-6], smart grids [7], Blockchain [8], 5G connectivity [9], and cloud computing [10], resulting in a number of positive effects on society. Cloud computing offers convenient, flexible, and ubiquitous access to a set of configurable computing resources, such as servers, storage, applications, and services, which are delivered via the web and released instantly [11, 12]. It allows users to access computer resources without having to manage them actively [13]. In this regard, three types of services can be provided by a cloud: infrastructure, software, and platform [14]. The first service is infrastructure as a service (IaaS), which offers storage and computational resources [15]. In the second service, users can access the software remotely without installing it locally, which is called software as a service (SaaS) [16, 17]. The third service is the platform as a service (PaaS), which provides a platform on which clients can build applications [18]. Virtual Machines (VMs) are provided by cloud providers as computing resources. To improve the efficiency of cloud computing, optimal task scheduling is critical when numerous users demand services from the cloud [19].

To achieve the desired quality of service (QoS), efficient task scheduling allocates resources optimally across the desired tasks in a timely manner. Optimizing a given objective involves building a schedule of tasks to be allocated to VMs with consideration of some constraints [20]. Each cloud infrastructure relies on a task scheduling algorithm as a key component. The performance metrics used in scheduling procedures involve computation-based indicators, including response time, energy consumption, and makespan, and network-based indicators, including round trips, communication cost, and traffic volume [21]. There are three types of optimal task scheduling approaches in cloud computing: heuristic, meta-heuristic, and hybrid. Heuristic task scheduling algorithms offer ease of scheduling and deliver the best possible solution, but they do not guarantee optimal outcomes. A meta-heuristic approach can find optimal solutions to task scheduling problems in a polynomial amount of time. The hybrid task scheduling algorithm combines both the heuristic and meta-heuristic approaches [22, 23].

Although there are promising approaches to efficient task scheduling in the cloud, the problem of task scheduling remains NP-complete [24, 25]. This paper proposes and uses the Firefly Optimization Algorithm (FOA) in order to schedule a bag of tasks in a cloud environment, avoiding network communication and data transfer costs. In the experimental setup, the proposed algorithm is compared to the Highest Response Ratio Next (HRRN), Shortest Process Next (SPN), First Come First Served (FCFS), and PSO algorithms. The proposed method was tested using various distributions to gain insight into its performance trend. By optimizing both the time overhead and the energy consumption of the mobile device, the QoS for mobile users is enhanced by maximizing the overall system benefits. The main contributions of this paper are as follows:

- Defining the task scheduling problem and formulating mathematical models and the objective functions used to optimize the allocation of tasks to virtual machines.
- Analyzing the performance of the proposed algorithm in terms of execution time, makespan, and energy consumption.
- Verifying the experimental results by comparing them to CSO, FCFS, and PSO findings.

The remainder of the paper follows in the following order. A discussion of recent cloud task scheduling methods is presented in Section II. Section III describes and models the problem of task scheduling in a cloud computing environment, followed by an explanation of the proposed algorithm. Section IV discusses the simulation results. The paper concludes with Section V.

II. RELATED WORK

Yu and Su [26] proposed a system called Three Queues (TQ) that uses dynamic priorities and three queues in order to cope with the increasing heterogeneity of cloud computing clusters. Based on the priority of tasks, the algorithm places tasks in a waiting queue and then categorizes them based on the input amount, output amount, number of current tasks running on a node, completion time, and disk I/O rate of the Map phase. Hardware utilization is improved by placing jobs in corresponding queues. It has been demonstrated that this algorithm improves task scheduling performance in the presence of both CPU-intensive and I/O-intensive tasks and shortens task execution times. The genetic algorithm proposed by Sun, et al. [27] uses phagocytosis as a crossover operation, generates a sub-chromosomal individual by phagocytosing two mother chromosomes, produces a random third individual, and determines a new individual resulting from phagocytosis based on the load-balancing standard deviation and fitness factor, which results in a high percentage of high-quality individuals. An evolutionary genetic algorithm for multiple populations is then used that creates initial subpopulations using the Min-Min algorithm, and these subpopulations are evolved using an improved genetic algorithm. According to simulations, the proposed algorithm schedules cloud tasks efficiently.

Al-Maytami, et al. [28] developed a new scheduling algorithm using Directed Acyclic Graphs (DAG) and Prediction of Tasks Computation Time (PTCT). Furthermore, by reducing the Expected Time to Compute (ETC) matrix using Principle Components Analysis (PCA), the proposed algorithm significantly improves makespan and minimizes complexity and computation. According to simulation results, the algorithm outperforms other algorithms for heterogeneous systems regarding schedule length rate, response time, and efficiency. Prasanna Kumar and Kousalya [29] used the Crow Search Algorithm (CSA) to schedule cloud tasks. The CSA draws inspiration from the food-collecting behavior of crows. The crow keeps on searching for a better food source than its current food source as it keeps watching its mates. This paper uses the CSA to find suitable VMs and minimize the makespan. CloudSim is used to measure CSA's performance over ACO algorithms. Simulation results indicate that the CSA algorithm is superior to the ACO algorithms.

Panda and Jana [16] developed an energy-efficient task scheduling algorithm (ETSA) to resolve task scheduling problems. The algorithm considers and normalizes both the completion time and the total resource utilization of a task. ETSA was evaluated for its ability to measure energy efficiency and makespan in heterogeneous environments. ETSA was tested in a wide variety of heterogeneous environments, and the test results showed that it was able to achieve better energy efficiency and makespan than existing

algorithms. The algorithm also accounts for both completion time and resource utilization, which gives it an advantage over other scheduling algorithms. Na, et al. [30] propose a Squid operator and Nonlinear Inertia Weight PSO (SNW-PSO) algorithm to better meet the users' QoS requirements in cloud computing. Execution cost and execution time are optimized by the algorithm. As part of its optimization process, nonlinear inertia weights are introduced to prevent the algorithm from jumping from its local optimum. Furthermore, the squid operator allows for greater particle diversity and faster convergence to optimal positions within particle swarms. This algorithm compensates for the weaknesses of the traditional PSO algorithm, namely its ease of over-convergence and tendency towards the local optimum. The SNW-PSO algorithm converges more quickly than an LDIC-PSO algorithm and reduces both task completion time and cost when compared to a PSO algorithm with linearly decreasing inertia weight.

III. PROPOSED METHOD

In cloud computing, different quality of service parameters is optimized by scheduling tasks. The task scheduling problem entails allocating several tasks appropriate to a certain number of VMs. This section proposes an evolutionary task scheduling approach using FOA. Environmental dynamics, deadlines, and declining the entire task are the basis of the proposed method. The task scheduling problem is modeled based on the following assumptions:

- The VMs are heterogeneous in terms of processing power and power consumption;
- There is no migration of tasks between VMs;
- All submitted tasks are independent.

A. FOA Formulation for Task Scheduling Issue

The firefly algorithm is a novel technique based on fireflies' social behaviors in nature. They flash short lights rhythmically. Each one's flashing pattern is unique and different from the rest. They utilize the lights for the mate-attracting process and attract prey. Furthermore, these lights can function as a protective mechanism in favor of fireflies. The rhythmic light, flashing rate, and time interval between flashing signals cause the two sexes to get attracted to each other. Each parcel is a firefly which is updated according to a firefly's awareness of its neighbors in the multidimensional search space through attracting dynamically. The parameters of FOA are described in the following.

- Light intensity factor (I): In the firefly algorithm, the light intensity factor is defined by Eq. 1. In this equation, I_0 denotes the initial light, r is the distance between two fireflies, and I is the received light intensity.

$$I = \frac{I_0}{r^2} \quad (1)$$

- Attractiveness: The amount of a firefly's attractiveness corresponds to the light intensity that neighboring firefly witnesses and is defined by Eq. 2 and Eq. 3. The parameter β is used for measuring the attractiveness (attraction) between two fireflies.

$$\beta = \beta_0 \times e^{-\gamma r} \quad (2)$$

$$\beta = \frac{\beta_0}{1 + \gamma r^2} \quad (3)$$

- The distance between fireflies: Euclidean distance determines the distance between two fireflies, calculated as follows.

$$r_{ij} = \|x_i - x_j\| = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (4)$$

- Luciferin release: Like other algorithms, the firefly algorithm starts with a randomly selected population. Therefore, the optimization begins randomly with a population of n fireflies in the search space. According to Eq. 5, the algorithm first updates the luciferin share of every firefly and then updates their position in every repetition.

$$l_j(t + 1) = (1 - \rho)l_j(t) + \gamma j_j(t + 1) \quad (5)$$

In each repetition, the luciferin amount for every firefly is determined according to the fitness of its position. It means, based on the amount of fitness, some luciferin is added to the previously available amount for every repetition. In the above equation, $j_j(t + 1)$ represents the fitness function (the fitness of the position) of the i -th firefly in t repetition of the algorithm, γ is the luciferin rise constant, and $(1 - \rho)l_j(t)$ is the amount of luciferin decrease.

- The probability of firefly selection: for every firefly i , the probability of turning toward the brighter neighbor j is expressed as follows. In Eq. 6, t denotes the time measure, $d_{i,j}(t)$ is the distance between two fireflies, $r_d^i(t)$ is the decision-making (intuitive) radius of a firefly, and $N(t)$ is the ensemble of neighboring fireflies of the firefly i at time t .

$$P_{ij}(t) = \frac{l_j(t) - l_i(t)}{\sum_{k \in N(t)} l_k(t) - l_i(t)} \quad j \in N(t), N(t) = \{j: d_{i,j}(t) < r_d^i(t), l_i(t) < l_j(t)\} \quad (6)$$

- Updating the firefly position (a novel solution): The time-district moving of a firefly could be presented as follows:

$$x_i(t + 1) = x_i(t) + s \left(\frac{x_j(t) - x_i(t)}{\|x_j(t) - x_i(t)\|} \right) \quad (7)$$

In the above equation, $x_i(t)$ refers to the m -dimension vector of the firefly i at time t , and s stands for the number of moving steps.

B. Task Scheduling Algorithm based on Discrete FOA

The original purpose of the firefly algorithm was to solve continuous optimization problems, so it may not be effectively employed for discrete optimization problems. Therefore, in this paper, the Smallest Position Value (SPV) rule proposed by Bean [31] is implemented for the discrete firefly algorithm. The implementation is as follows:

1) *Solution representation:* The search space has n dimensions corresponding to the tasks' number; thus, every dimension represents one task. The vector $x_i^t = (x_{i1}^t, x_{i2}^t, \dots, x_{in}^t)$ denotes the fireflies' positions in the search space. The SPV rule assigns tasks based on their positions. Fig. 1 illustrates an acyclic graph structure relevant to this research, consisting of six tasks. Table I presents the scheduling solutions. As dimension 4 in Table I has the smallest position value, it is the first task to be assigned, and dimension three is the second task, and so on. Initial population: Discrete firefly algorithms generate the initial population using a uniform distribution, similar to most meta-heuristic algorithms that generate the initial population randomly. The position values are also generated randomly by applying uniform random numbers to intervals of $[0, 1]$.

2) *Solutions update:* Every firefly is evaluated using this permutation to determine its fitness function value. Every firefly's fitness function value is influenced by light intensity. Dim fireflies are attracted to bright ones. The firefly's attractiveness is determined by Eq. 2 and Eq. 3. The distance between two fireflies is measured by Eq. 4, and tasks are assigned using the SPV rule. Every firefly's attractiveness is calculated and then based on this value, its movement is determined by Eq. 7. The mentioned steps are repeated until the completion term is met when all the fireflies are attracted. To calculate the number of missed tasks, the beginning time and deadline of tasks are taken into account. In task scheduling, the main goal is to minimize the total execution time and the number of missed tasks. Eq. 8 calculates the fitness value of the proposed method for reducing total task execution time and the number of missed tasks. The input parameters are also normalized using Eq. 9.

$$\text{Fitness} = w_1 \times \text{Makespan} + w_2 \times \text{Missed Task} \quad w_1 + w_2 = 1 \quad (8)$$

$$\text{Normalized}(m) = (m - M_{\min}) / (M_{\max} - M_{\min}) \quad (9)$$

Eq. 9 normalizes the parameter m between the largest and smallest values. Both cases were used in simulations to obtain the total execution time and the number of missed tasks. As shown in Eq. 10, the proposed method uses the tasks' completion times to determine the tasks' total execution times.

$$\text{Makespan} = \min(C_{\max}^{\{j_0\}}), \text{ where } C_{\max} > C_t, t = 1, 2, 3, \dots, n \quad (10)$$

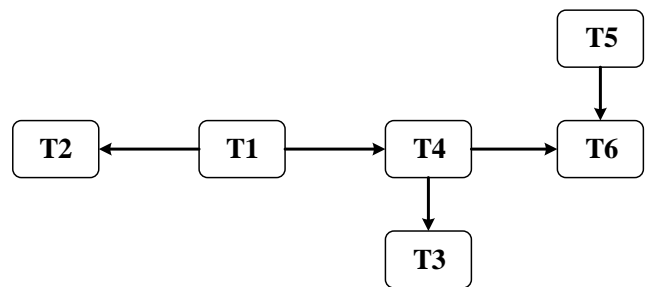


Fig. 1. DAG graph for six tasks.

TABLE I. THE SOLUTION EXAMPLE FOR SIX TASKS

	1	2	3	4	5	6
x_{ik}^t	0.3	0.4	0.092	0.035	0.59	0.61
Tasks	T3	T4	T2	T1	T5	T6

In the equation, t denotes a task, cmax is the maximum time required to complete it, and ct is the completion time of the task t.

C. Solving an Example

In this subsection, the proposed method procedure is illustrated using an example of 6 VMs and 30 tasks whose durations are 100 and 200, and their deadlines are determined according to Table II. The completion time is 1.53 seconds, and the number of missed tasks' is 1. It should be noted that the initial attraction intensity for every firefly is randomly determined based on the Gaussian distribution and initial position of fireflies. Every firefly is assessed to calculate the fitness function value. The fitness function value for every firefly is associated with light intensity. Dim fireflies are

attracted to bright ones. The firefly's attractiveness is determined by Eq. 3, and the distance between two fireflies is measured by Eq. 4. Tasks are assigned using the SPV law. Every firefly's attractiveness is calculated, and then based on this value, its movement is determined by Eq. 7. The mentioned steps are repeated until the completion term is met when all the fireflies are attracted. The proposed method's way of assigning and scheduling tasks is presented in Fig. 2.

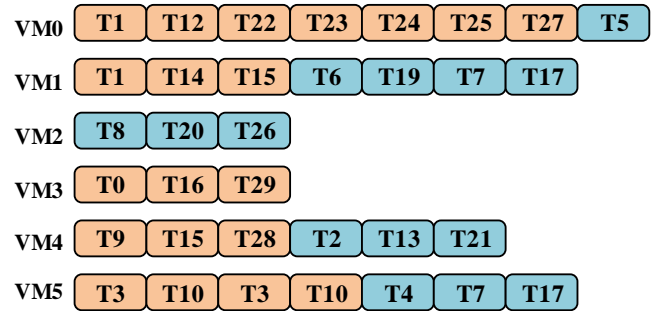


Fig. 2. Gantt chart for 30 tasks and six VMs.

TABLE II. DETAILS OF 30 TASKS

#Task	Arrival Time	service time	Deadline	Dependency	#Task	Arrival Time	service time	Deadline	Dependency	#Task	Arrival Time	service time	Deadline	Dependency
1	14	4	8	-	11	15	9	18	5,3	21	17	9	18	8
2	15	2	4	-	12	9	9	18	10	22	11	6	12	21
3	19	5	10	1	13	3	7	14	-	23	20	6	12	19,29
4	14	8	16	1	14	4	3	6	11	24	6	6	12	16,19,27
5	9	9	18	-	15	5	5	10	16	25	11	4	8	16
6	9	2	4	2	16	7	4	8	15,2	26	10	7	14	23
7	6	1	2	5	17	8	3	6	15,11	27	9	9	18	17
8	18	8	16	-	18	2	1	2	-	28	18	4	8	16
9	20	3	6	1,7	19	13	7	14	8,9,13	29	4	1	2	-
10	2	5	10	2,5,7	20	5	8	16	5	30	13	4	8	31

IV. EXPERIMENTAL RESULTS

Cloudsim is used to implement the proposed algorithm for task scheduling. The proposed method was simulated and compared to the available algorithms using the data in Table II [32]. In the proposed method, the entrance times of all tasks are equal, but the serving times, deadlines, and the tasks' interdependencies are considered according to Table II. For example, task 9 requires three units of time to get served, and its deadline to complete execution is 6. Also, tasks 1 and 7 should be completed prior to task 9. Table III presents the tasks' characteristics, Table IV contains the features of VMs, Table V outlines the features of data centers, and Table VI shows the parameters of the firefly algorithm.

A. First Experiment: Evaluation of the Proposed Method Compared to [32]

The experiment simulates eight cloud resources and creates and executes thirty tasks, as shown in Table II. The tasks are

designed to emulate real-world workloads and evaluate the performance of cloud resources. The experiment results are then used to analyze the performance of various cloud resource configurations. In order to examine the efficiency of the proposed algorithm, we compared it with HRRN, SPN, FCFS, and PSO algorithms. Fig. 3 to 6 illustrate that our method outperforms others in terms of overall execution time, average service time + waiting time, percentage of missed tasks, and resource utilization. The results show that our proposed algorithm can effectively optimize resource utilization and reduce the overall execution time of the cloud system. This is beneficial for cloud computing users, as it can reduce their costs and improve their performance. Furthermore, our proposed algorithm also provides more efficient scheduling and task assignment, resulting in better task scheduling, faster task completion, and higher resource utilization. This improved performance leads to better user experience and satisfaction.

TABLE III. TASKS' CHARACTERISTICS

Parameters	Values
Task length	1 – 100
Input size	300
Output size	300
Number of processors	1

TABLE IV. FEATURES OF VMS

Parameters	Values
MIPS	80-500-750-100
Number of processors	1
RAM	128
Bandwidth	2500

TABLE V. DATA CENTERS' FEATURE

Parameters	Values
Speed	500000
Physical machine capacity	10000
Storage capacity	1000000
MIPS Bandwidth	100000

TABLE VI. FIREFLY ALGORITHM PARAMETERS

Parameters	Values
β	Min: 0, Max: 1, Mean: 0.5
γ	Min: 0.5, Max: 1, Mean: 0.75
A	Min: 0, Max: 1, Mean: 0.5

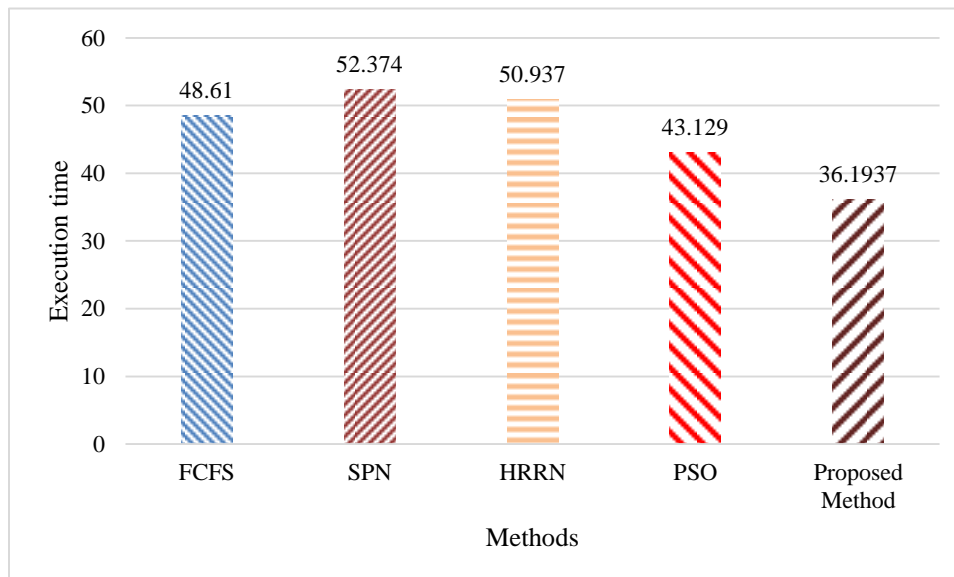


Fig. 3. Execution time comparison.

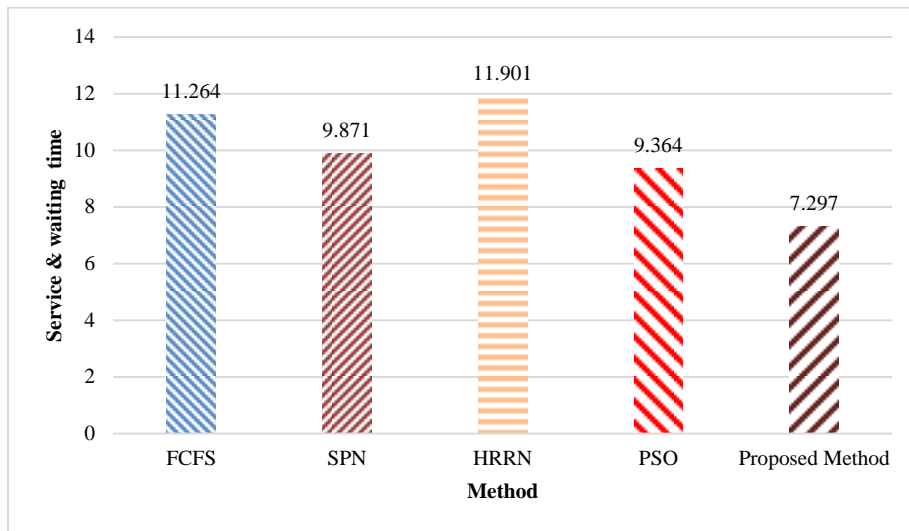


Fig. 4. Service and waiting time comparison.

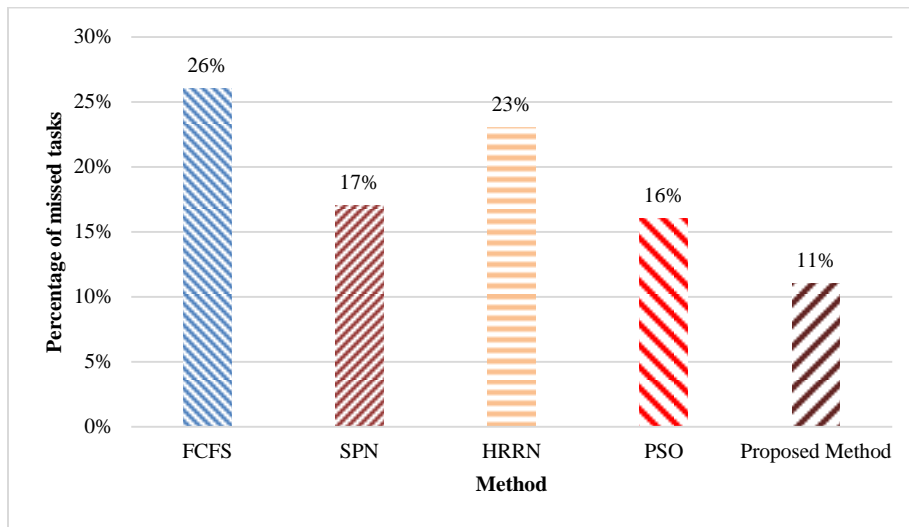


Fig. 5. Number of missed tasks comparison.

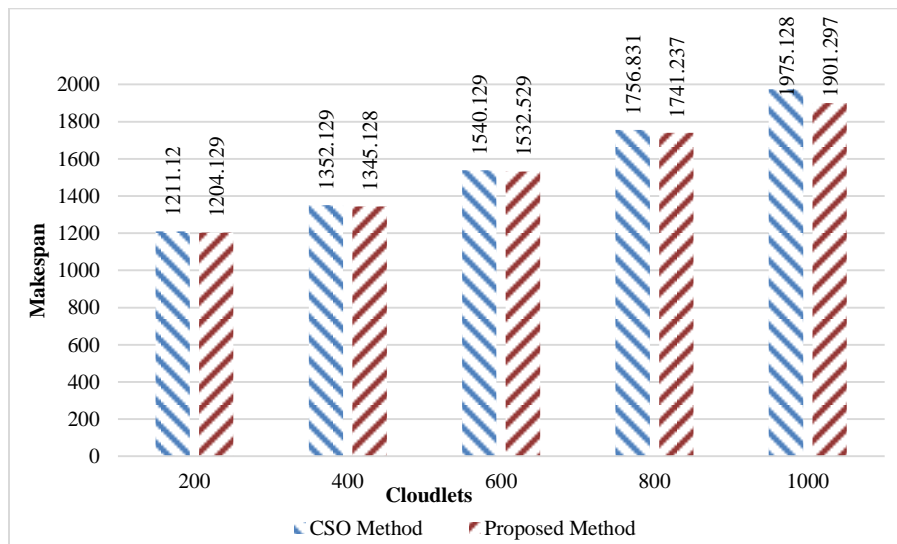


Fig. 6. Makespan comparison based on HP2CN workload.

B. First Experiment: Evaluation of the Proposed Method Compared to [33]

This experiment compares the proposed method with the method presented in [33] regarding makespan and power consumption. HPC2N and NASA workloads were evaluated using 500 physical machines, 200 virtual machines, and 100 to 1000 tasks. As shown in Fig. 6 to 9, our method provides better performance. The proposed scheduler outperforms the existing CSO algorithm by approximately 10% in terms of makespan under HPC2N workloads. When compared to the CSO algorithm, our algorithm improved the makespan by 8% under NASA workloads. Energy consumption is an important

parameter that impacts both the cloud provider and the cloud user. In the cloud computing paradigm, the goal is to minimize energy consumption by which cloud providers can effectively run tasks on virtual resources in the cloud by consuming a minimal amount of energy. The cloud user is also benefited from the availability of resources at a lower cost since resources are readily available. HPC2N and NASA workload archives were used to evaluate energy consumption. We compared our algorithm with the CSO algorithm under HPC2N workloads, and the results indicated a significant reduction in energy consumption, up to 10%. Compared to the CSO algorithm, our algorithm consumes up to 12% less energy under NASA workload archives.

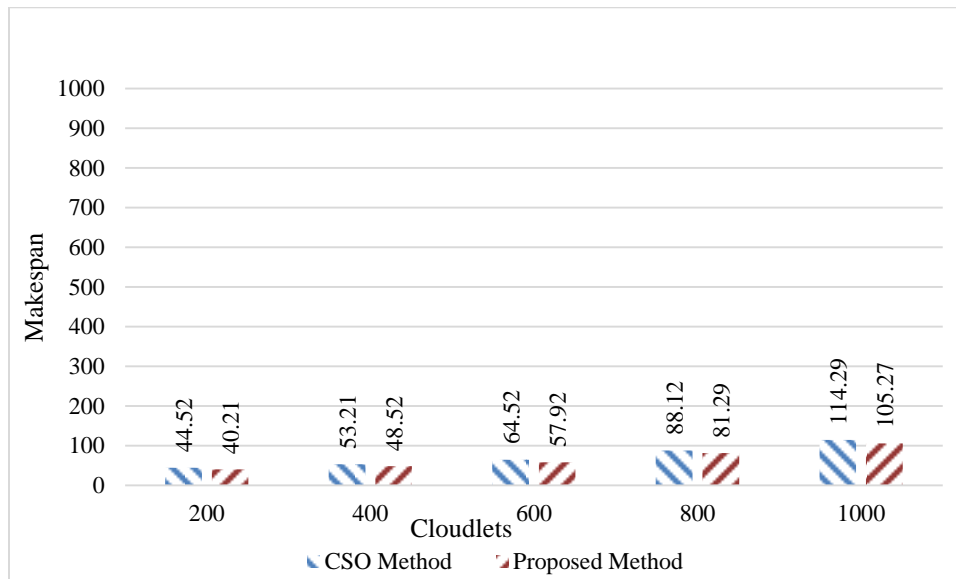


Fig. 7. Makespan comparison based on NASA workload.

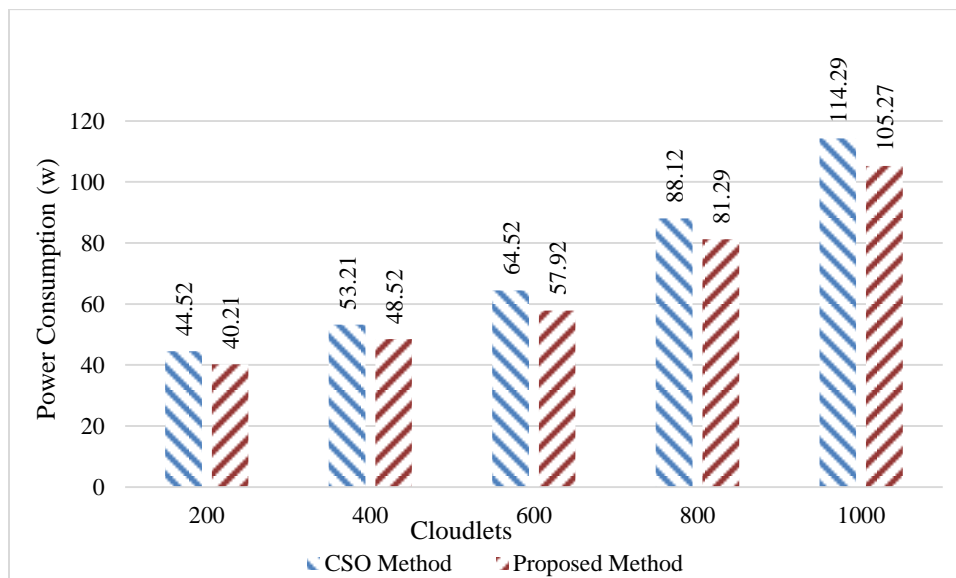


Fig. 8. Power consumption comparison based on HP2CN workload.

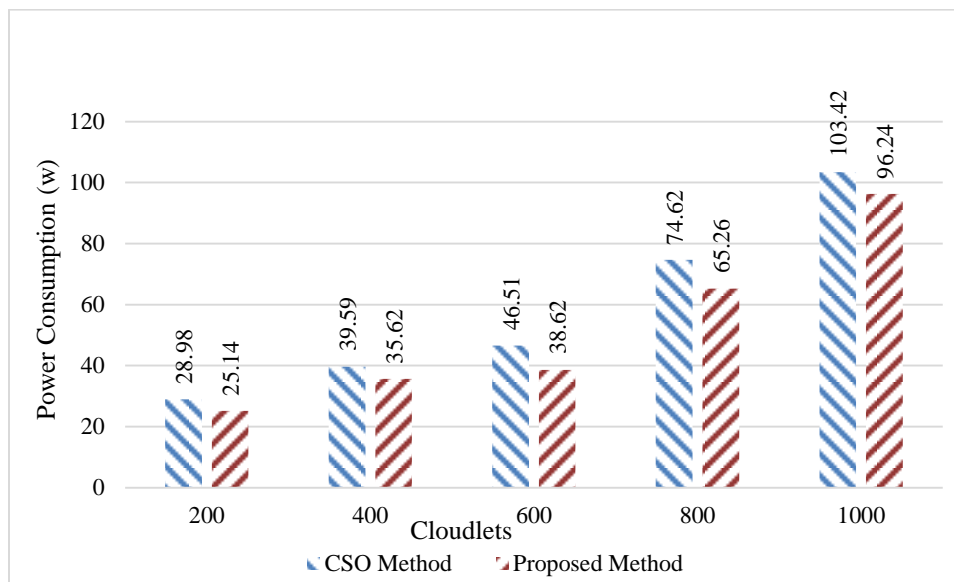


Fig. 9. Power consumption comparison based on NASA workload.

V. CONCLUSION

Cloud computing allows users to access shared computing resources. Requests and demands are the basis of cloud computing, where users request resources from service providers and access them. Due to the dynamic nature of cloud environments and user requests changing over time, we need a scheduling method that can handle more tasks in less time. This paper proposed a new deadline-aware task-scheduling technique based on the firefly optimization algorithm. The experiments were conducted on different workloads. The experimental results proved that the proposed algorithm performed better than previous works concerning waiting time, execution time, missed tasks percentage, and resource utilization. Future work may examine the use of different heuristics to determine optimal initial conditions for FOA or other meta-heuristic algorithms. Our future plans include further exploring the time and space complexity of the proposed algorithm, examining the effective combination of artificial intelligence technology and task scheduling algorithm, and analyzing the energy consumption optimization of green cloud computing data centers.

REFERENCES

- [1] A. Mehbodniya, J. L. Webber, R. Neware, F. Arslan, R. V. Pamba, and M. Shabaz, "Modified Lamport Merkle Digital Signature blockchain framework for authentication of internet of things healthcare data," *Expert Systems*, vol. 39, no. 10, p. e12978, 2022.
- [2] F. Kamalov, B. Pourghbleh, M. Gheisari, Y. Liu, and S. Moussa, "Internet of Medical Things Privacy and Security: Challenges, Solutions, and Future Trends from a New Perspective," *Sustainability*, vol. 15, no. 4, p. 3317, 2023.
- [3] S. P. Rajput et al., "Using machine learning architecture to optimize and model the treatment process for saline water level analysis," *Journal of Water Reuse and Desalination*, 2022.
- [4] J. Akhavan, J. Lyu, and S. Manoochehri, "A deep learning solution for real-time quality assessment and control in additive manufacturing using point cloud data," *Journal of Intelligent Manufacturing*, pp. 1-18, 2023.
- [5] R. N. Jacob, "Non-performing Asset Analysis Using Machine Learning," in *ICT Systems and Sustainability: Proceedings of ICT4SD 2020*, Volume 1, 2021: Springer, pp. 11-18.
- [6] C. Han and X. Fu, "Challenge and Opportunity: Deep Learning-Based Stock Price Prediction by Using Bi-Directional LSTM Model," *Frontiers in Business, Economics and Management*, vol. 8, no. 2, pp. 51-54, 2023.
- [7] S. H. Haghshenas, M. A. Hasnat, and M. Naeni, "A Temporal Graph Neural Network for Cyber Attack Detection and Localization in Smart Grids," *arXiv preprint arXiv:2212.03390*, 2022.
- [8] S. Meisami, M. Beheshti-Atashgah, and M. R. Aref, "Using Blockchain to Achieve Decentralized Privacy In IoT Healthcare," *arXiv preprint arXiv:2109.14812*, 2021.
- [9] S. Vairachilai, A. Bostani, A. Mehbodniya, J. L. Webber, O. Hemakesavulu, and P. Vijayakumar, "Body Sensor 5 G Networks Utilising Deep Learning Architectures for Emotion Detection Based On EEG Signal Processing," *Optik*, p. 170469, 2022.
- [10] B. Pourghbleh, A. A. Anvigh, A. R. Ramtin, and B. Mohammadi, "The importance of nature-inspired meta-heuristic algorithms for solving virtual machine consolidation problem in cloud environments," *Cluster Computing*, pp. 1-24, 2021.
- [11] M. Mohseni, F. Amirghafouri, and B. Pourghbleh, "CEDAR: A cluster-based energy-aware data aggregation routing protocol in the internet of things using capuchin search algorithm and fuzzy logic," *Peer-to-Peer Networking and Applications*, pp. 1-21, 2022.
- [12] F. Nzanywayingoma and Y. Yang, "Efficient resource management techniques in cloud computing environment: a review and discussion," *International Journal of Computers and Applications*, vol. 41, no. 3, pp. 165-182, 2019.
- [13] V. Hayyolalam, B. Pourghbleh, M. R. Chehrehzad, and A. A. Pourhaji Kazem, "Single-objective service composition methods in cloud manufacturing systems: Recent techniques, classification, and future trends," *Concurrency and Computation: Practice and Experience*, vol. 34, no. 5, p. e6698, 2022.
- [14] P. Loubière and L. Tomassetti, "Towards cloud computing," *TORUS 1-Toward an Open Resource Using Services: Cloud Computing for Environmental Data*, pp. 179-189, 2020.
- [15] D. Gabi, A. S. Ismail, A. Zainal, Z. Zakaria, A. Abraham, and N. M. Dankolo, "Cloud customers service selection scheme based on improved conventional cat swarm optimization," *Neural Computing and Applications*, pp. 1-22, 2020.
- [16] S. K. Panda and P. K. Jana, "An energy-efficient task scheduling algorithm for heterogeneous cloud computing systems," *Cluster Computing*, vol. 22, no. 2, pp. 509-527, 2019.
- [17] V. Kunwar, N. Agarwal, A. Rana, and J. Pandey, "Load balancing in cloud—A systematic review," *Big Data Analytics*, pp. 583-593, 2018.
- [18] Y. Wang, J. Wen, Q. Wu, L. Guo, and B. Tao, "A dynamic cloud service selection model based on trust and SLA in cloud computing,"

- International Journal of Grid and Utility Computing, vol. 10, no. 4, pp. 334-343, 2019.
- [19] P. Kumar and A. Verma, "Scheduling using improved genetic algorithm in cloud computing for independent tasks," in Proceedings of the international conference on advances in computing, communications and informatics, 2012, pp. 137-142.
- [20] I. Attiya, M. Abd Elaziz, L. Abualigah, T. N. Nguyen, and A. A. Abd El-Latif, "An improved hybrid swarm intelligence for scheduling iot application tasks in the cloud," *IEEE Transactions on Industrial Informatics*, 2022.
- [21] H. Yan, X. Zhu, H. Chen, H. Guo, W. Zhou, and W. Bao, "DEFT: Dynamic fault-tolerant elastic scheduling for tasks with uncertain runtime in cloud," *Information Sciences*, vol. 477, pp. 30-46, 2019.
- [22] A. Amini Motlagh, A. Movaghar, and A. M. Rahmani, "Task scheduling mechanisms in cloud computing: A systematic review," *International Journal of Communication Systems*, vol. 33, no. 6, p. e4302, 2020.
- [23] M. Soualhia, F. Khomh, and S. Tahar, "Task scheduling in big data platforms: a systematic literature review," *Journal of Systems and Software*, vol. 134, pp. 170-189, 2017.
- [24] M. R. Alizadeh, V. Khajehvand, A. M. Rahmani, and E. Akbari, "Task scheduling approaches in fog computing: A systematic review," *International Journal of Communication Systems*, vol. 33, no. 16, p. e4583, 2020.
- [25] A. Keivani, F. Ghayoor, and J.-R. Tapamo, "A review of recent methods of task scheduling in cloud computing," in 2018 19th IEEE Mediterranean Electrotechnical Conference (MELECON), 2018: IEEE, pp. 104-109.
- [26] Y. Yu and Y. Su, "Cloud task scheduling algorithm based on three queues and dynamic priority," in 2019 IEEE International Conference on Power, Intelligent Computing and Systems (ICPICS), 2019: IEEE, pp. 278-282.
- [27] Y. Sun, J. Li, X. Fu, H. Wang, and H. Li, "Application research based on improved genetic algorithm in cloud task scheduling," *Journal of Intelligent & Fuzzy Systems*, vol. 38, no. 1, pp. 239-246, 2020.
- [28] B. A. Al-Maytami, P. Fan, A. Hussain, T. Baker, and P. Liatsis, "A task scheduling algorithm with improved makespan based on prediction of tasks computation time algorithm for cloud computing," *IEEE Access*, vol. 7, pp. 160916-160926, 2019.
- [29] K. Prasanna Kumar and K. Kousalya, "Amelioration of task scheduling in cloud computing using crow search algorithm," *Neural Computing and Applications*, vol. 32, no. 10, pp. 5901-5907, 2020.
- [30] L. Na, L. Fei, and D. W. Chao, "Cloud Task Scheduling Algorithm Based on Squid Operator and Nonlinear Inertia Weight," in 2019 IEEE Symposium Series on Computational Intelligence (SSCI), 2019: IEEE, pp. 3104-3109.
- [31] J. C. Bean, "Genetic algorithms and random keys for sequencing and optimization," *ORSA journal on computing*, vol. 6, no. 2, pp. 154-160, 1994.
- [32] F. S. Milani and A. H. Navin, "Multi-objective task scheduling in the cloud computing based on the patrice swarm optimization," *Int J Inf Technol Comput Sci*, vol. 7, no. 5, pp. 61-66, 2015.
- [33] S. Mangalampalli, S. K. Swain, and V. K. Mangalampalli, "Multi Objective Task Scheduling in Cloud Computing Using Cat Swarm Optimization Algorithm," *Arabian Journal for Science and Engineering*, vol. 47, no. 2, pp. 1821-1830, 2022.

A Method for Network Intrusion Detection Based on GAN-CNN-BiLSTM

Shuangyuan Li¹, Qichang Li², Mengfan Li³

Information Construction Office, Jilin Institute of Chemical Technology, Jilin, China¹
School of Information and Control Engineering, Jilin Institute of Chemical Technology, Jilin, China^{2,3}

Abstract—As network attacks are more and more frequent and network security is more and more serious, it is important to detect network intrusion accurately and efficiently. With the continuous development of deep learning, a lot of research achievements are applied to intrusion detection. Deep learning is more accurate than machine learning, but in the face of a large amount of data learning, the performance will be degraded due to data imbalance. In view of the serious imbalance of network traffic data sets at present, this paper proposes to process data expansion with GAN to solve data imbalance and detect network intrusion in combination with CNN and BiLSTM. In order to verify the efficiency of the model, the CIC-IDS 2017 data set is used for evaluation, and the model is compared with machine learning methods such as Random Forest and Decision Tree. The experiment shows that the performance of this model is significantly improved over other traditional models, and the GAN-CNN-BiLSTM model can improve the efficiency of intrusion detection, and its overall accuracy is improved compared with SVM, DBN, CNN, BiLSTM and other models.

Keywords—Intrusion detection; GAN; CNN; BiLSTM

I. INTRODUCTION

Technology is developing very fast these days, and the internet has become an indispensable tool in our daily lives. It brings great convenience to all walks of life. However, in today's network environment, a variety of new means of attacking the network continue to emerge, with increasingly larger impact scales and higher attack frequencies. As a result, network security has become a growing concern. The task of network intrusion detection is to find suspicious attacks and take appropriate protective measures to re-duce the possibility of subsequent attacks and minimize corresponding economic losses. Therefore, research on Intrusion Detection (ID) has become a major research direction in the field of network security [1-2].

The intrusion detection system is one of the most promising methods for quickly identifying and dealing with network intrusions. It can identify whether the system is being attacked or has been attacked, and can take preventive measures against possible network attacks. An intrusion detection system can detect and analyze network activities on a computer, thereby protecting sensitive information, preventing unauthorized user access, system misoperation, and malicious intrusion. However, in the current network traffic, the volume of normal data flow is much larger than that of abnormal data flow. This results in a serious imbalance in the proportion of data occupied by normal flow and abnormal flow, which

significantly reduces the learning performance and accuracy of the classifier.

Intrusion detection technology has developed rapidly over the years and has become a crucial aspect of network security. The main focus of intrusion detection is to detect any suspicious activity that may lead to network breaches and take appropriate measures to prevent them. There are two primary methods of intrusion detection - signature-based and anomaly-based. Signature-based intrusion detection is a rule-based method that compares incoming network traffic with a pre-defined set of signatures or patterns. While this method is highly accurate, it cannot detect new or unknown attacks and requires frequent updates of the signature database to maintain effectiveness [3]. On the other hand, anomaly-based intrusion detection works by identifying abnormal patterns in network traffic that deviate significantly from the expected behavior of the network. This method is useful for detecting unknown attacks that do not match any known signature, but it can also produce false positives by flagging normal behavior as suspicious. Anomaly-based intrusion detection can be achieved through various techniques such as machine learning, data mining, data statistics, and deep learning.

Machine learning algorithms can learn from labeled data sets and identify the patterns that distinguish normal and malicious traffic. Data mining techniques can be used to extract useful knowledge from large-scale network data sets and identify abnormal behaviors. Data statistics can help identify unusual changes in the network, while deep learning algorithms can analyze large amounts of data and identify complex patterns and correlations that are difficult to detect through other methods.

In conclusion, intrusion detection is critical for ensuring network security, and the choice of intrusion detection method depends on the specific needs of the network and the level of threat faced. Both signature-based and anomaly-based intrusion detection methods have their advantages and limitations, and the optimal approach often involves combining multiple techniques to achieve the best results.

At present, machine learning has been widely used in intrusion detection, but machine learning is mostly shallow learning, focusing on feature engineering and selection, and the accuracy will be degraded when dealing with a large volume of real network traffic data. Deep learning can deal with a large volume of data, and thus it is more accurate and effective in intrusion detection. Convolutional Neural Networks (CNN) and Bidirectional Long Short-Term Memory (BiLSTM) can

automatically learn feature representations from input data, while Random Forest, Decision Tree, and SVM require manual feature design or rely on feature engineering. This gives CNN and BiLSTM an advantage in handling complex data such as images, speech, and text. BiLSTM is specifically designed for handling sequential data and can capture long-term dependencies within sequences. In contrast, methods like Random Forest, Decision Tree, and SVM are not well-suited for modeling sequential data. CNN and BiLSTM have the property of parameter sharing and weight sharing, making the training of the models more efficient and allowing them to handle problems with a large number of parameters. On the other hand, Random Forest and Decision Tree require more parameters and computational resources. The generator in Generative Adversarial Networks (GANs) utilizes a CNN architecture, which exhibits excellent generation capabilities and can generate realistic synthetic data. CNN and BiLSTM can efficiently process large-scale data through mini-batch training, especially when accelerated by GPUs. In comparison, Random Forest and Decision Tree may face limitations in memory and computational resources when dealing with large-scale data. However, due to the imbalance of the data sets, the performance will be significantly degraded as the volume of abnormal data is much smaller than the volume of normal data. Therefore, this paper proposes to solve data imbalance via GAN, which has been widely and effectively used in speech and image fields. In this paper, GAN is used to create virtual data similar to the minority class for resampling to improve the efficiency and accuracy of intrusion detection. Moreover, it is found that the effect of using multi-model mixture is better than that of using single model. Therefore, this paper adopts the method of combining CNN and BiLSTM to conduct experiments. The main contributions of this paper are summarized as follows:

1) Proposed to use of GAN pairs to solve the problem of data imbalance, and add an attention mechanism to solve the problem of inaccurate model results caused by unreasonable convolution kernel settings.

2) Propose the design and implementation of an intrusion detection model based on CNN-BiLSTM, and combine CNN with BiLSTM to build the intrusion detection classification model. In addition, add a self-attention mechanism to BiLSTM to make the model more effective and more accurate.

3) Study the performance and effect of the data set in machine learning such as Naive Bayes, Random Forest and Decision Tree, and compare with the model in this paper. The experimental result shows that the performance of GAN-CNN-BiLSTM is higher than the traditional classification model, so the performance of the model proposed in this paper is higher than other traditional models, which can improve the efficiency of intrusion detection and the overall accuracy.

Starting from the data, this paper first uses GAN to balance the data, which lays a good foundation for the subsequent training of the classification model, improving the accuracy of intrusion detection. Then, it obtains the final model through continuous improvement. Moreover, the CIC-IDS-2017 data set is used for experimental verification, and compared with CNN, BiLSTM, SVM and other models. The experimental

result shows that the detection model proposed in this paper has a better effect and higher accuracy.

The proposed model in this paper can provide network security protection for the following:

1) Protection of critical infrastructure: It can be applied to critical infrastructure such as power grids, water supply systems, transportation systems, etc. It helps detect and prevent potential network attacks, hacker intrusions, and data breaches, ensuring the security and reliable operation of this infrastructure.

2) Security for companies and organizations: It can protect the network and information security of companies, organizations, and institutions. It helps identify malware, phishing attacks, data theft, and other security threats, providing real-time threat intelligence and defense measures.

3) Government agencies and military applications: It holds significant importance in government agencies and military sectors. It can be applied to network security and intelligence analysis, aiding in the discovery and prevention of cyber espionage, malicious attacks, and information warfare.

4) Security in the financial industry: It can be used in the financial industry to safeguard the network security of banks, payment systems, and financial institutions. It detects and prevents network fraud, credit card fraud, hacker attacks, and other financial crimes.

In Section II, a review of prior research and methods related to network intrusion detection is provided. Traditional intrusion detection techniques, as well as machine learning and deep learning-based approaches, are introduced, and their advantages and disadvantages are discussed. In Section III, the architecture and working principles of the proposed GAN-CNN-BiLSTM model are presented. The functionality and interactions of each component are explained, highlighting the model's strengths and innovations. Section IV describes the experimental setup designed and executed in this study, showcasing the experimental results and performance evaluation. A comparison is conducted between the proposed model and other methods, analyzing the reliability and effectiveness of the results. Finally, the main findings and contributions of the paper are summarized in Section V, and prospects for further research are outlined.

II. RELATED WORK

A. Related Study on Intrusion Detection Models

Intrusion detection generally consists of two steps: preprocessing and classification. Preprocessing technology, also known as feature selection technology, is a key technology in the process of intrusion detection. It can reduce the size of the original data, improve the training efficiency of the model and the accuracy of the classifier. According to whether feature selection is independent of classifier, feature selection methods can be divided into two categories: filtering and packaging. Filtering method is independent of classifier, and it carries out feature selection according to the statistical characteristics of original data. In traditional intrusion detection system, the original data needs to be sent to a classifier after preprocessing.

Because of the progress of artificial intelligence (AI) technology in intrusion detection system (IDS), detection methods based on AI, such as Decision Tree[4], Support Vector Machine (SVM)[5], CNN[6-8], Long Short-Term Memory (LSTM)[9-11] and Recurrent Neural Network (RNN)[12-13], are widely and effectively used in intrusion detection systems. Vinayakumar R et al. proposed an intrusion detection method in combination with CNN and LSTM, and the experimental result show that it performs better in all indicators than only using CNN or CNN-RNN [14]. Tetsushi Ohki, et al. proposed a dimensionality reduction technique in combination with information gain and principal component analysis (PCA), using support vector and other means to detect intrusions, and the experimental result shows that the mixed dimensionality reduction method is better than the single dimensionality reduction method[15]. Liu Yuefeng et al. proposed an intrusion detection method based on multi-scale CNN, which uses convolution kernel of different scales to extract the optimal features of data. This method not only converges quickly, but also improves detection accuracy [16]. Lirim Ashiku et al. used the DNN network for intrusion detection training, which is optimized on the basis of CNN and deepens the network structure to improve the detection accuracy [17]. Yin C L et al. proposed the use of RNN to build an IDS detection model for identification in consideration of the time series relationship for feature extraction, but for high-dimensional features, RNN is significantly incapable of feature extraction, resulting in poor model performance [18].

The research shows that these deep learning-based intrusion detection systems perform better when dealing with big data, but there are still some problems:

1) *Outdated data set*: Most of the previous intrusion detection research is based on KDD-CUP99 or NPL-KDD data set, which has a history of more than 20 years, and cannot reflect the current network situation well.

2) *The data samples are unbalanced*: Classification research usually pays more attention to improving the overall evaluation indicators of the model, such as accuracy, precision, etc., and ignores the classification of minority samples. But in the real network environment, these minority attacks will produce more damage and impact than the majority attacks. However, the current researches based on KDD-CUP99 and other datasets usually directly use the official training and testing samples, and few research works deal with the problem of data imbalance under the intrusion detection problem and the related solutions.

3) *Feature learning is not comprehensive most of the previous studies are based on a single neural network*: CNN can learn the spatial features in the data and extract the local features accurately, but it cannot learn the temporal features. RNN can extract temporal features in data and analyze long-term dependencies of information, but it cannot effectively extract spatial features. In addition, RNN can only learn the temporal characteristics of the data in a single direction, and does not fully consider the joint influence of the information before and after the traffic data on the current state.

Intrusion detection is being extensively studied because it is an important security guarantee not only for the traditional Internet, but also for the Internet of Things and other networks. However, most of the previous studies used traditional machine learning or simple deep learning, and the data sets used, such as KDD-CUP99 and NSL-KDD, are too old to reflect the current network traffic well, and it is difficult for traditional machine learning algorithms to deal with a large volume of data, therefore, this paper uses the large data set CIC-IDS 2017 containing the latest attacks to solve the problems in current research by a multiway method.

B. Related Study on Data Imbalance

Data imbalance means there are large quantitative gaps among different data categories. Deep learning algorithms can get the best result when there are similar quantities among categories, so data imbalance is one of the factors degrading the deep learning performance.

In order to solve the problem of imbalanced data, one idea is to start from the algorithm level, according to the defects of the algorithm in solving the imbalanced problem, combined with the characteristics of imbalanced data, the algorithm is improved to improve the ability of the algorithm to deal with imbalanced classification problems. The other is to start from the data level. Existing studies solve the problem of data imbalance mainly through random undersampling, random oversampling and SMOTE. Random oversampling will expand the data scale and prolong the training time, which is easy to fall into overfitting; random undersampling will blindly delete some data, influencing the classification accuracy; the samples generated by SMOTE have no diversity [19].

To improve the model performance by sampling and optimizing the data, Yan B, et al. used SMOTE technology to sample the NSL-KDD data sets, and compared the performance of the newly sampled data with some algorithms such as RF, SVM and Backpropagation Neural Network (BPNN) [20]. Min E X, et al. built a new network architecture on GAN to generate data against data imbalance [21]. However, it has been proven that GAN training may lead to gradient vanishing, making the generator output invalid and making the result poor.

Therefore, this paper proposes a method to solve the problem of data imbalance and generate higher-quality data sets via Generative Adversarial Networks (GAN), GAN is a new generative model, which learns the probability distribution of the target data sample to generate forged samples that are greatly similar to the target data sample. It is a new generative model that directly compares the distribution of forged samples and target samples for training and generation, and continuously generates forged samples that are as close as possible to the real sample by means of confrontation. It improves the generation quality of forged samples and effectively solves the problem of overfitting caused by the lack of training samples in the generation process of traditional generative models. Therefore, GAN has been applied to the generation of data in many fields and achieved good results, but it has not been applied to the imbalance problem of network intrusion detection data. Then, a classification model is built in combination with CNN and BiLSTM, and balanced

data sets are used for training to obtain a model which is more stable in training and gives better results.

III. INTRUSION DETECTION MODEL BASED ON GAN-CNN-BILSTM

Fig. 1 shows the structure of the GAN-CNN-BiLSTM model, as there is only a little abnormal data in intrusion detection, data distribution of the data sets used for intrusion detection is unbalanced. Thus this paper generates and expands the minor training samples with GAN to reduce the impact of imbalanced training samples on the detection accuracy. After the data set is balanced using GAN, the generated minor samples and the original data set are combined into a new data set with balanced sample distribution, and then the data set is normalized and other preprocessed. Finally, the data set is used to train the CNN-BiLSTM model and obtain the classified detection results.

A. Data Set Balance

Generative Adversarial Networks (GAN), a new regression generation model proposed by Goodfellow, et al in 2014, consists of Discriminative Network (D) and Generative Network (G), which are rivals, as Generative Network creates a new data instance while Discriminative Network evaluates the data authenticity, both try to outperform each other and thus gradually improve in this process [22]. GAN learns the probability distribution of the target data samples to generate fake samples highly similar to the target data samples, it is a generative model as it directly compares the distribution of the fake samples and the target samples to train and generate new ones, and fake samples which are as close as possible to real

samples are continuously generated by confronting, improving the generation quality of fake samples and solving the problem of overfitting caused by insufficient training samples in traditional generative models. Its structure is a two-person zero-sum game, where one's gain is the other's loss.

If the convolution kernel setting of GAN is too small, the dependency in the data will not be obvious, while if the convolution kernel setting is too large, the computational efficiency will be degraded. Therefore, this paper intends to introduce an attention mechanism, which sets different weights for different parts of these vectors according to their importance, so as to sort the importance of information and quickly extract the key feature information. It not only saves model computation and storage but also enables the model to judge more accurately.

Fig. 2 shows the structure diagram of a GAN model with added attention mechanism. Real data is the real data of the data set, and generated data is the data generated by G. Random noise can make the network random and generate distribution, so that it can be sampled. In the training process of GAN, G and D are continuously optimized and enhanced, as G is to make D unable to distinguish while D is to enhance its ability to judge the authenticity of the data through continuous improvement, and the principle can be expressed as formula (1):

$$\min_G \max_D V(D, G) = E_{x \sim P_{data}(x)} [\ln D(x)] + E_{z \sim P_z(z)} [\ln (1 - D(G(z)))] \quad (1)$$

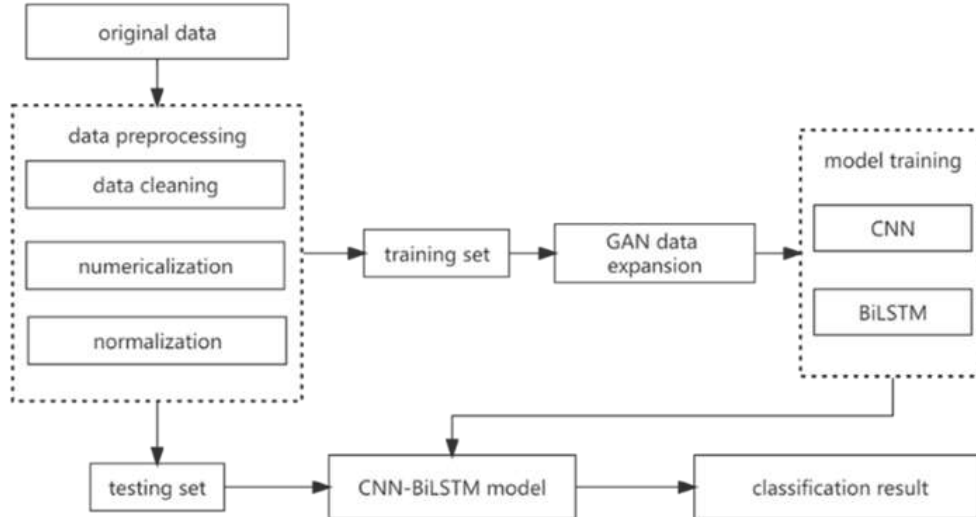


Fig. 1. Flow Chart of intrusion detection model based on GAN-CNN-BiLSTM.

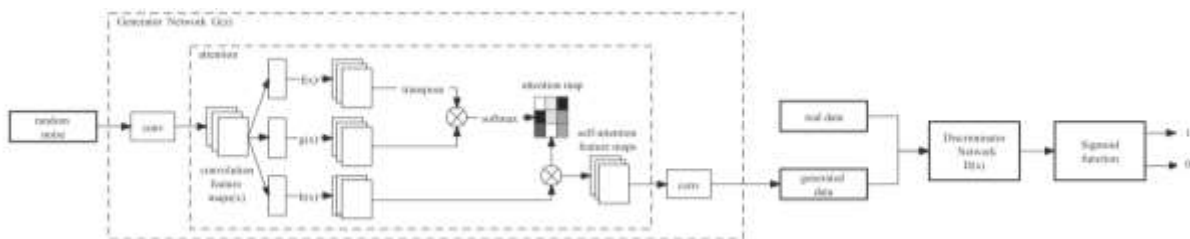


Fig. 2. Structure diagram of a GAN model with added attention mechanism.

In the formula, $V(D, G)$ is the objective function, P_{data} is the real sample distribution, P_z is the generated sample distribution, $D(x)$ is the probability of x being the real sample, and $G(z)$ is the sample generated by model G based on the input z .

After the convolution processing in the attention mechanism module of the model, the resulting convolution feature vector X serves as input. The processing shown in formulas (2) to (4) is then applied to obtain $f(x)$, $g(x)$, and $h(x)$ with different output channel sizes, where W_f , W_g , and W represent weight matrices trained through different methods. Next, $f(x)$ is transposed and multiplied by $g(x)$ using formula (5). Finally, an attention map is obtained after Softmax processing.

$$f(x) = W_f x \quad (2)$$

$$g(x) = W_g x \quad (3)$$

$$h(x) = W x \quad (4)$$

$$s_{ij} = f(x_i)^T g(x_j) \quad (5)$$

Next, $h(x)$ is used to perform pixel-by-pixel multiplication with the obtained attention map, resulting in the feature map of adaptive attention. Eq. (6) is used to compute the attention weights, where $\beta_{j,i}$ represents the degree of influence of the model on the i th position when synthesizing the J TH region. Then, Eq. (7) is used to obtain the attention feature map. Finally, the feature map with attention mechanism is combined with the feature vector X using formula (8) to obtain the feature map with attention mechanism.

$$\beta_{j,i} = \frac{\exp(s_{ij})}{\sum_{i=1}^N \exp(s_{ij})} \quad (6)$$

$$o_j = \sum_{i=1}^N \beta_{j,i} h(x_i) \quad (7)$$

$$y_i = \gamma o_j + x_j \quad (8)$$

The main process of GAN model training is shown in Algorithm 1.

Algorithm 1: GAN model training algorithm

Input: normal traffic T_{normal} , attack traffic T_{attack} , noise N

Output: GAN model, trained generator G and discriminator D

Initial generator G , Discriminator D , Deep Intrusion Detection System CNN-BiLSTM

for $i = 0, 1, 2$, do

 for G-steps do

 attention model generate attention weights.

G generates the malicious traffic examples based on T_{attack}

 Update the parameters of G

 end for

 for D-steps do

D classifies the training set including T_{normal} and $G(T_{attack}, N)$

D classifies the training set, getting predicted labels

 Update the parameters of D

 end for

end for

B. CNN-BiLSTM Model

Convolutional Neural Networks (CNN), belong to a multi-layer supervised learning neural network, consists of the input layer, the convolutional layer, the pooling layer, the fully connected layer and the output layer. A CNN model can be composed of multiple convolutional layers, pooling layers and fully connected layers, and the convolutional layer and the pooling layer generally appear alternately. The pooling layer is usually followed by the fully connected layer and the output layer is usually followed by the fully connected layer, or the classification layer in other words. Classification is realized by logistic regression, Softmax regression or even a SVM, and the features extracted by the CNN, which is the result of the classification, are classified and output by the output layer. The loss function takes the gradient descent to reversely regulate the weight parameters in the neural network layer by layer at minimum, and improves the accuracy of the network through continuous training. CNN can extract and classify features in the meantime, so that feature classification can effectively use feature extraction; weight sharing can effectively reduce the training parameters, making the neural network structure simpler and more adaptable, and Fig. 3 shows its structure.

For Bidirectional Long Short-Term Memory (BiLSTM), the Long Short-Term Memory (LSTM) is a variant of traditional RNN, but the structure of LSTM, which is more complex, can be divided into four parts for interpretation: forget gate, input gate, cell state and output gate. Compared with the classical RNN, the gate structure of LSTM can effectively capture the semantic correlation between long sequences and alleviate gradient disappearance or explosion. BiLSTM is composed of forward LSTM and backward LSTM, which enhances the LSTM and improves the performance of the model. It trains two LSTMs on the input data, the first LSTM is on the original data and the other is on the reversed data so that more features are added to the network, the result is obtained faster, and the defect of gradient vanishing is eliminated. Fig. 4 shows the structure of BiLSTM.

BiLSTM needs to calculate the output according to the time sequence, if the distance between the interdependent features is too far, it will take several time steps to accumulate information and connect the two, and with the increase of the distance, the possibility of capturing effective information will gradually decrease. However, the self-attention mechanism will connect any two words directly through a calculation result, which shortens the distance between long-distance dependent features and is conducive to the effective use of these features. Therefore, this paper adds a self-attention mechanism to BiLSTM to improve the efficiency of the model.

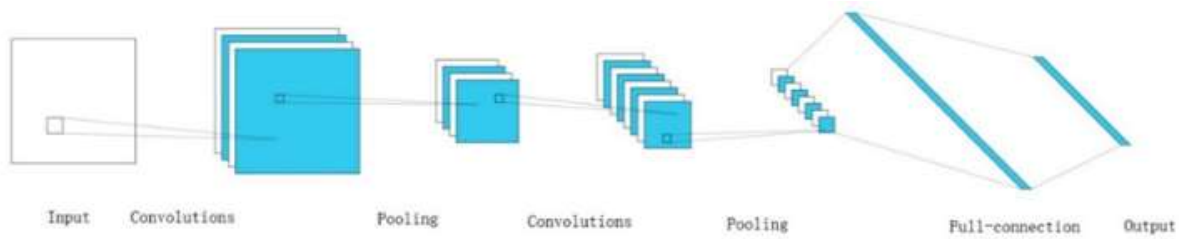


Fig. 3. Model of CNN.

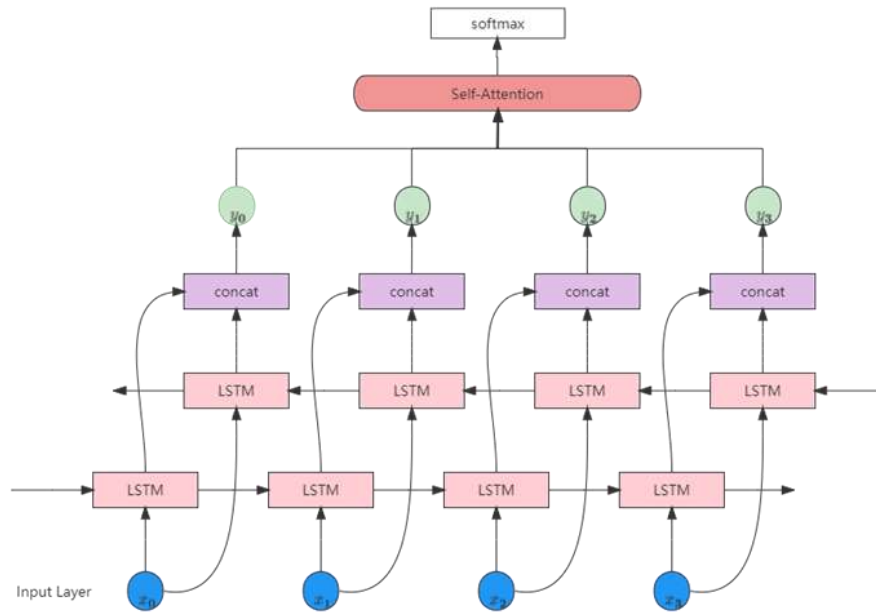


Fig. 4. Model of BiLSTM.

IV. EXPERIMENT AND RESULT ANALYSIS

A. Experimental Environment

In order to verify the intrusion detection model in this paper and build a simulation experiment environment, the Pytorch 10.2 deep learning framework is used to build the model in Pycharm, and data are processed by Python 3.6; the operating system is 64-bit Windows 10, the CPU is Intel core i5-7300HQ 2.50 GHz, and the memory is 16 GB DDR.

B. Data Set

The data set used in this paper is CIC-IDS-2017, which contains normal data similar to real data and the latest attacking data. The information of this data set, which contains a large number of network intrusion traffic data, can better reflect the current network environment, and the training set and test set are adjusted to improve the test result in the complex network environment at present, 80% was randomly selected as the training set and 20% as the test set. This data set contains benign and recent common attacks, similar to real-world data (PCAPs). It also includes the result of network traffic analysis by CICFlowMeter, using tagged flows based on timestamp, source and destination IP, source and destination port, protocol and attacks (CSV file), and a data set containing 15 class labels (1 normal label + 14 attack labels). Table I lists the volumes of various attack data:

TABLE I. CIC-IDS-2017 DATASET

Attack Type	Number of Instances
BENIGN	2359087
FTP-Patator	7938
SSH-Patator	5897
DDos	41835
Dos Hulk	231072
Dos GoldenEye	10293
Dos slowloris	5796
Dos Slowhttptest	5499
WebAttack-Brute Force	1507
Web Attack-XSS	652
WebAttack-SQL Injection	21
Bot	1966
Infiltration	36
PortScan	158930
Heartbleed	11

C. Data Preprocessing

1) *Data cleaning*: The missing values in this dataset all appear under the Flow Bytes/s feature. When dealing with the problem of missing data, methods such as deletion, completion and imputation are usually used. Since the dataset is very large and the missing ratio is small, this paper uses the tuple deletion method to delete the data rows with missing values. Infinite values exist under the features Flow Bytes/s and Flow Pkts/s. During data processing, the infinity value cannot be calculated properly. The infinite values of this data set basically appear in normal traffic and have no effect on classification. Therefore, the information lines containing infinite values are directly deleted. Duplicate data is hardly helpful to the training of intrusion detection system, therefore, only the first occurrence of data is kept and the duplicate data is removed. When the data set is recorded, the table header information is mistakenly written into the data multiple times, and it is directly deleted here to ensure that the data is comprehensive, clean, and error-free.

2) *Numericalization of character-type features*: Convert character attributes in the data set to binary features. This is a crucial step in many machine learning tasks as most algorithms cannot work directly with non-numeric data. In the context of intrusion detection, many datasets contain character-based features such as protocol types, service types, or flag values. These features are often categorical in nature, meaning that they take on a limited number of distinct values. To turn these categorical features into numerical ones, one common technique is to use binary encoding. By converting categorical features into binary features, we can ensure that all features in the dataset are numerical, which is necessary for most machine learning algorithms. This process also helps to reduce the impact of bias on the algorithm's results and increase the accuracy of the model. Overall, numericalization of character-type features is an important step in preprocessing data for intrusion detection and other machine learning tasks. It helps to ensure that the data is ready for use with a variety of algorithms and can improve the performance of the model.

3) *Normalization processing*: Normalization is an essential preprocessing step in machine learning, which involves scaling the features of a dataset to a standardized range. This is necessary because different features often have different scales or units, which can lead to biased predictions or overemphasis on certain features. In intrusion detection, normalization is particularly important due to the diverse nature of network traffic data. The min-max normalization method is a popular technique for scaling data to a standardized range. It involves scaling the values of each feature to a range of [-1, 1], based on the minimum and maximum values of that feature in the dataset. This normalization method preserves the relative distances between values within a feature and ensures that all features have equal influence on the learning process. The advantage of the min-max normalization method is that it is simple and easy to implement, and it maintains the original information and structure of the data. It also helps to prevent

the model from being overly influenced by outliers or extreme values. The min-max formula is shown in Eq. (2), where max represents the maximum value of each feature, and min represents the minimum value.

$$y_i = \frac{x_i - \text{Min}}{\text{Max} - \text{Min}} \quad (9)$$

D. Parameter Setting

In the model of this paper, the parameters of GAN were set as batch-size 50, epoch 500 and learning rate 0.001, the Relu function is selected as the activation function and the Adam optimizer is used for the model. The convolution layer and pooling layer of CNN have two layers respectively. The initial parameters of CNN include convolution kernel size set to 3, activation function set to the Relu function, pooling layer size set to 2 and fully connected layer size set to 16, and a Dropout layer is added to avoid overfitting. In the BiLSTM network of this paper, the output size is set to 10, the features extracted by CNN and BiLSTM are fused in parallel, the fused features are added into the self-attention layer, and different weights are assigned to different features.

E. Measurement Indicators

In this paper, Accuracy, Precision, Recall and F-score are mainly used to evaluate the models.

Accuracy: It represents the proportion of samples that are correctly predicted by the model, providing an overall measure of classification or prediction accuracy.

Precision and Recall: Precision and recall are commonly used in binary or multi-class classification problems. Precision measures the proportion of true positive predictions among all samples predicted as positive, while recall measures the proportion of true positive samples correctly identified by the model.

F1 Score: The F1 score is a metric that combines precision and recall, calculated as the harmonic mean of precision and recall. It provides a balanced measure of model performance, giving equal weight to precision and recall. It is particularly useful for imbalanced datasets and classification tasks.

So as to evaluate the detection performance of different models, as below:

$$\text{Accuracy} = \frac{TP+TN}{TP+TN+FP+FN} \quad (10)$$

$$\text{Precision} = \frac{TP}{TP+FP} \quad (11)$$

$$\text{Recall} = \frac{TP}{FN+TP} \quad (12)$$

$$F - \text{score} = \frac{2TP}{2TP+FP+FN} \quad (13)$$

Where, TP is the quantity of correct traffic, TN is the quantity of normal traffic in correct judgment, FP is the quantity of normal traffic in incorrect judgment, and FN is the quantity of incorrect traffic in incorrect judgment.

F. Results

In order to analyze the influence of the expanded data set on the detection accuracy, GAN is used to expand the minor

classes in the training set in different percentages: 0%, 40%, 80% and 120%, and the results are shown in Table II, indicating that the accuracy rate is the highest when the expansion percentage is 80%, so the expansion percentage in this experiment is 80%.

In order to illustrate the effects of the models proposed in this paper, CIC-IDS-2017 data sets were selected for experiments, and CNN, RNN, BiLSTM and CNN-BiLSTM were used for comparative experiment. Common intrusion detection algorithms such as SVM, NBM, Decision Tree and Random Forest are applied to the data set in this experiment for comparison. The results are shown in Table III and Fig. 5 shows the accuracy of the deep learning algorithm

TABLE II. THE ACCURACY OF DIFFERENT EXPANSION RATIO

data expansion ratio	Web Attack-XSS (ACC)	Web Attack-SQL Injection (ACC)	Infiltration (ACC)	Heartbleed (ACC)	Total (ACC)
0%	62.08	63.57	60.26	58.49	92.15
40%	65.27	67.08	64.92	63.64	95.03
80%	67.25	68.74	66.21	68.49	96.53
120%	65.83	67.72	65.35	65.83	95.76

TABLE III. MODEL COMPARISON

Model	Evaluation Index (%)			
	Accuracy	Precision	Recall	F-score
CNN	93.74	92.52	93.47	92.45
RNN	83.65	81.73	82.77	82.76
SVM	61.37	61.21	60.75	61.46
NBM	79.85	83.36	78.52	77.94
Decision Tree	84.63	85.27	84.32	84.49
Random Forest	86.26	87.48	87.27	87.64
BiLSTM	93.06	91.75	92.52	93.26
CNN-BiLSTM	94.51	93.37	92.78	94.21
GAN-CNN-BiLSTM	96.32	96.55	95.38	96.04

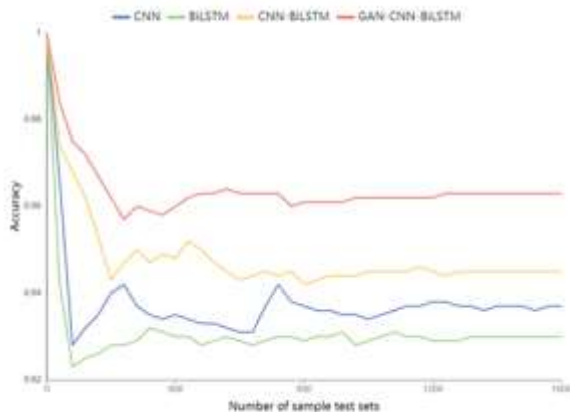


Fig. 5. Algorithm accuracy comparison.

The study compared the performance of the proposed GAN-based data expansion method with several common models such as CNN, BiLSTM, SVM, NBM, and Random Forest. The results indicated that the accuracy of the GAN-based model was significantly higher than that of CNN and BiLSTM by 2.58% and 3.26%, respectively. The accuracy of the GAN-based model was also 1.81% higher than that of CNN-BiLSTM. Additionally, the performance of some classic models such as SVM and NBM were not satisfactory, whereas the Random Forest model performed better than these models.

However, the GAN-based model outperformed all these models in terms of accuracy. The proposed model based on CNN-BiLSTM and GAN was able to solve the problem of imbalanced dataset and achieved an accuracy improvement of 10.06%. This improvement proved the effectiveness and innovation of the proposed model. Therefore, it can be concluded that the GAN-based data expansion method is a promising approach for improving the performance of intrusion detection systems. It is expected to have significant implications for the development of future intrusion detection techniques.

V. CONCLUSION

This paper proposes a novel model called GAN-CNN-BiLSTM, which aims to enhance the performance of intrusion detection. The main challenge in intrusion detection is the class imbalance problem, where the normal class dominates the data set, while the abnormal class is relatively small. To address this issue, GAN is introduced to expand the size of the abnormal class, CNN-BiLSTM is adopted for feature extraction and classification, and the CIC-IDS 2017 data set is utilized for evaluation. The proposed model is compared with other traditional models, and the experimental results demonstrate that GAN can effectively eliminate the class imbalance problem, and the CNN-BiLSTM model outperforms other models in terms of accuracy.

Although the proposed model uses a widely adopted data set, it has not been tested in a real network environment. Collecting large-scale, high-quality data and annotating it in real-world environments is a challenging task. Data privacy and security are crucial. Transferring models from the lab to real environments requires considering adaptability and generalization. Real-world data has greater variations and noise, requiring the model to maintain good performance. To overcome these challenges, reasonable data collection and processing methods are needed, ensuring dataset diversity and representativeness. Data privacy and security measures must be in place to protect the data. Model optimization is necessary, including fine-tuning, regularization, and parameter adjustment in real environments, to improve generalization. Future research will focus on exploring and improving the model by utilizing larger and more diverse data sets, and optimizing the intrusion detection model. This will enable the model to be tested in a real network environment, and validate its performance for real-world applications of network intrusion detection. The GAN-CNN-BiLSTM model's enhancements in intrusion detection bolster the identification and defense against network attacks. Its impact includes improved network security for critical infrastructure,

companies, and government institutions, minimizing risks and losses from threats. The study showcases the efficacy of multimodal data processing and deep learning in intrusion detection, providing valuable insights for future research. The integrated model's design and optimization offer new directions for further advancements in intrusion detection.

REFERENCES

- [1] Zhang Hao, Zhang Xiaoyu, Zhang Zhenyou, Li Wei. A review of Intrusion detection models based on Deep Learning [J]. Computer Engineering and Applications, 2022, 58(06):17-28. doi: 10.3778/j.issn.1002-8331.2107-0084.
- [2] K. Zheng, Z. Cai, X. Zhang, Z. Wang, and B. Yang, "Algorithms to speedup pattern matching for network intrusion detection systems," Comput. Commun., vol. 62, pp. 47-58, May 2015. doi: 10.1016/j.comcom.2015.02.004.
- [3] NIKOLOVA E., JECHEVA V. Some similarity coefficients and application of data mining techniques to the anomaly-based IDS [J]. Telecommunication Systems, 2012, 50(2):127-135. doi: 10.1007/s11235-010-9390-3.
- [4] Jing X . Innovative Two-Stage Fuzzy Classification for Unknown Intrusion Detection. 2016. doi: 10.25148/etd.FIDC000288.
- [5] Ahmim A, Maglaras L, Ferrag M A, et al. A Novel Hierarchical Intrusion Detection System Based on Decision Tree and Rules-Based Models [C]// 1st International Workshop on Security and Reliability of IoT Systems - SecRIot 2019. doi: 10.1109/dcoss.2019.00059.
- [6] Vinayakumar R, Soman K P, Poornachandran P . Applying convolutional neural network for network intrusion detection [C]// 2017 International Conference on Advances in Computing, Communications, and Informatics (ICACCI). 2017. doi: 10.1109/icacci.2017.8126009.
- [7] Y. Xiao, C. Xing, T. Zhang, and Z. Zhao, "An Intrusion Detection Model Based on Feature Reduction and Convolutional Neural Networks," in IEEE Access, vol. 7, pp. 42210-42219, 2019. doi: 10.1109/access.2019.2904620.
- [8] Naseer S, Saleem Y . Enhanced Network Intrusion Detection using Deep Convolutional Neural Networks [J]. KSII Transactions on Internet and Information Systems, 2018, 12(10):5159-5178. doi: 10.3837/tiis.2018.10.028.
- [9] Wang Zhu, ZHAO Jianxin, ZHANG Hongying, LI Yajun, Leng Dan. Intrusion Detection Algorithm based on Hybrid Model of VDCNN and LSTM [J]. Fire Control & Command Control, 2022, 47(02):170-175. doi: 10.3778/j.issn.1002-8331.2107-0084.
- [10] Imrana Y, Xiang Y, Ali L, et al. A bidirectional LSTM deep learning approach for intrusion detection [J]. Expert Systems with Applications, 2021, 185(8):115524. doi: 10.1016/j.eswa.2021.115524.
- [11] Poornachandran P , Vinayakumar R , Soman K P . A Comparative Analysis of Deep Learning Approaches for Network Intrusion Detection Systems (N-IDSs): Deep Learning for N-IDSs [J]. International journal of digital crime and forensics, 2019, 11(3):65-89. doi: 10.4018/ijdcf.2019070104.
- [12] Yan B, Han G . LA-GRU: Building Combined Intrusion Detection Model Based on Imbalanced Learning and Gated Recurrent Unit Neural Network [J]. Security and Communication Networks, 2018, 2018:1-13. doi: 10.1155/2018/6026878.
- [13] Chaibi N, Atmani B, Mokaddem M . Deep Learning Approaches to Intrusion Detection: A new Performance of ANN and RNN on NSL-KDD [C]// ISPR '20: The international conference on Intelligent systems and Pattern recognition. 2020. doi: 10.1145/3432867.3432889.
- [14] Vinayakumar R, Soman K P, Poornachandran P . Applying convolutional neural network for network intrusion detection [C]// 2017 International Conference on Advances in Computing, Communications and Informatics (ICACCI). 2017. doi: 10.1109/icacci.2017.8126009.
- [15] T. Ohki, V. Gupta and M. Nishigaki, "Efficient Spoofing Attack Detection against Unknown Sample using End-to-End Anomaly Detection," 2019 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA ASC), 2019. doi: 10.1109/apsipaasc47483.2019.9023183.
- [16] Liu Yuefeng, Wang Cheng, Zhang Yabin, Yuan Jianghao. Multi-scale convolution CNN model for Network Intrusion Detection [J]. Computer Engineering and Applications, 2019, 55(03). doi: 10.3778/j.issn.1002-8331.1712-0021.
- [17] Ashiku L, Dagli C . Network Intrusion Detection System using Deep Learning [J]. Procedia Computer Science, 2021, 185(1):239-247. doi: 10.1016/j.procs.2021.05.025.
- [18] Yin C L, Zhu Y F, Fei J L, et al. A Deep Learning Approach for Intrusion Detection Using Recurrent Neural Networks [J]. IEEE Access, 2017, PP(99):1-1. doi: 10.1109/access.2017.2762418.
- [19] Soltanzadeh P, Hashemzadeh M. RCSMOTE: Range-Controlled synthetic minority over-sampling technique for handling the class imbalance problem [J]. Information Sciences, 2021, 542: 92-111. doi: 10.1016/j.ins.2020.07.014.
- [20] Yan B H, Han G D, MD Sun, et al. A novel region adaptive SMOTE algorithm for intrusion detection on imbalanced problem [C]// 2017 3rd IEEE International Conference on Computer and Communications (ICCC). IEEE, 2017. doi: 10.1109/compcomm.2017.8322749.
- [21] Min E, Long J, Qiang L, et al. TR-IDS: Anomaly-Based Intrusion Detection through Text-Convolutional Neural Network and Random Forest [J]. Security & Communication Networks, 2018, 2018:1-9. doi: 10.1155/2018/4943509.
- [22] Lee J H, Park K H . GAN-based imbalanced data intrusion detection system [J]. Personal and Ubiquitous Computing, 2019(9). doi: 10.1007/s00779-019-01332-y.

A Consumer Product of Wi-Fi Tracker System using RSSI-based Distance for Indoor Crowd Monitoring

Syifaul Fuada¹, Trio Adiono², Prasetyo³, Harthian Widhanto⁴, Shorful Islam⁵, Tri Chandra Pamungkas⁶

Program Studi Sistem Telekomunikasi, Universitas Pendidikan Indonesia, Bandung, Indonesia¹

Faculty of ITEE-Centre for Wireless Communications (CWC), University of Oulu, Oulu, Finland¹

School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Bandung, Indonesia²

School of Electrical Engineering, Korea Advanced Institute of Science and Technology, Daejeon, South Korea³

Stream Intelligence Ltd., London, United Kingdom^{4,5,6}

Abstract—This study aims to design and develop Wi-Fi tracker system that utilizes RSSI-based distance parameters for crowd-monitoring applications in indoor settings. The system consists of three main components, namely 1) an embedded node that runs on Raspberry-pi Zero W, 2) a real-time localization algorithm, and 3) a server system with an online dashboard. The embedded node scans and collects relevant information from Wi-Fi-connected smartphones, such as MAC data, RSSI, timestamps, etc. These data are then transmitted to the server system, where the localization algorithm passively determines the location of devices as long as Wi-Fi is enabled. The mentioned devices are smartphones, tablets, laptops, while the algorithm used is a Non-Linear System with Lavenberg–Marquart and Unscented Kalman Filter (UKF). The server and online dashboard (web-based application) have three functions, including displaying and recording device localization results, setting parameters, and visualizing analyzed data. The node hardware was designed for minimum size and portability, resulting in a consumer electronics product outlook. The system demonstration in this study was conducted to validate its functionality and performance.

Keywords—Wi-Fi tracker system; RSSI-based distance; crowd monitoring; Unscented Kalman Filter; indoor

I. INTRODUCTION

Wi-Fi tracking technology enables the detection of Wi-Fi signals emitted by individuals or objects, allowing for tracking their locations. This technology finds applications in indoor environments such as laboratories and nursing homes, where it can be beneficial for monitoring the health of the residents. [1]. Two primary types of Wi-Fi tracking system exist, including active and passive. Active tracking relies on individuals carrying a dedicated tracking device at all times, which can be inconvenient due to the constant need for device presence [1]. In contrast, passive Wi-Fi tracking does not require individuals to carry a tracking device but can only track the behavior of detected objects within the operational area [2].

Wi-Fi tracker system has garnered significant attention and found extensive applications in many cases. It has been employed for diverse purposes, including monitoring bus passenger volume, public transit ridership, human movement analytics, tourism mobility, tracking pets or wildlife, analyzing visitor behavior, tracking indoor pedestrian

movement, capturing shopper activities, detecting client positions, monitoring patients, and tracking attendance of officers, students, and teachers. [3]–[14]. System has also been successfully applied in various settings, such as museums, buildings, malls, campuses, schools, offices, airport areas, bus stations, theaters, etc. Wi-Fi tracking technology allows for the detection and tracking of smartphone locations using Wi-Fi probes [9], [15], [16]. This capability enables the analysis of device distributions, particularly in outdoor and indoor areas, providing insights into crowd levels and density [13], [17], including crowdedness levels [4].

The design and development of Wi-Fi tracking system involved conducting intensive preliminary study, which focused on studying the behavior of smartphones during connection. The evaluation was also carried out to determine the suitability of RSSI method for the tracking system [18]. The conducted experiments showed that system could collect important information such as RSSI (Wi-Fi signal strength) and MAC address of the smartphone. These two data are the required information that needs to be processed further. When Wi-Fi is enabled on a smartphone, it broadcasts packet request data containing the protocol, channel, and MAC address through Wi-Fi signal [18]. The initial step in implementing Wi-Fi tracking system using RSSI method involved sniffing these data packets and measuring the corresponding RSSI level at each node [19].

The use of RSSI method in Wi-Fi tracker system necessitates consideration of several factors. Firstly, RSSI value can exhibit instability [16]. Secondly, the interval time for broadcasting packet request data is variable and dependent on the state of the smartphones [20]. Thirdly, each smartphone emits a distinct initial power level [19]. Therefore, to address these challenges, a localization algorithm was developed to determine the location of the smartphone based on information gathered from all nodes. Study was conducted on digital filter design to enhance detection accuracy [21], [22]. Two candidate algorithms, namely the Intersection density algorithm and the Non-linear Least Square (NLS) algorithm, were evaluated in terms of their performance. The NLS algorithm was selected as the localization algorithm considering the issue of unstable RSSI values [22]. Unscented Kalman filter (UKF) algorithm was employed to reduce the noise value as well as enhance the detection accuracy. This

algorithm reduces noise and contributes to a more stable RSSI value, improving prediction accuracy [21], [23].

The ongoing study aims to develop Wi-Fi tracking system for indoor crowd-monitoring applications. This system enables the estimation and determination of the number of people in a room. It also acts as portable sensor because the nodes receive RSSI and capture Wi-Fi power emitted by Wi-Fi devices. The captured data is then transmitted using the Message Queue Telemetry Transport (MQTT) protocol and processed on the server. During the capturing process, the nodes collect data for duration of 5 seconds and store it locally in a circular file with up to five files stored in the active directory. The processor reads the third file in the active directory, parses and encapsulates the data in JSON format, and sends it to an available server.

According to the findings in study [18], when smartphones activate their Wi-Fi function and connect to an available Wi-Fi hotspot, they transmit a unique wireless signature known as MAC address. Additionally, the timestamp and RSSI values of smartphones vary depending on their types, models, and vendors. These data can be utilized as valuable references for constructing Wi-Fi tracking system. Fig. 1 shows the proposed architecture of Wi-Fi tracker system, comprising two main subsystems, including the node and server subsystem. The node subsystem is responsible for sniffing smartphone data transmitted at specific locations. Installing more than three nodes within the target area is advisable to ensure comprehensive coverage. The collected data from the nodes is then sent to the server for further processing. The server subsystem performs data computation using suitable algorithms and conducts analysis. The resulting data are summarized and presented on an online dashboard for visualization purposes.

Several steps need to be followed to operate system. Firstly, nodes are placed at desired locations within the target

area. Subsequently, when smartphones in proximity have their Wi-Fi switched to on/active, they will broadcast packet request data to the surrounding environment. Alternatively, smartphones can connect to nearby Access Points (AP), and system remains active as long as broadcast packet request data is continuously processed. Each node within the location then captures and sniffs smartphone packet data. To perform this function, the nodes must be configured in monitoring mode, and once captured, the nodes transmit the data to the server. However, before sending the data, it is encrypted using Transport Layer Security/Secure Sockets Layer (TLS/SSL) with 1024-RSA encryption to ensure compliance with data security requirements. This step is crucial as the data transmitted during communication are susceptible to vulnerabilities [[24], [25]]. Subsequently, the nodes establish a connection with Wi-Fi tracker AP and the collected data is finally transmitted to the server using MQTT protocol.

The server plays a crucial role in system by collecting data from all nodes. It achieves this by subscribing to MQTT broker based on the designed topic. Upon receiving the data, the server decrypts the packet data and organizes it based on MAC address information. This process results in a set of MAC address data along with their corresponding RSSI values from each node. By utilizing this data set, the server proceeds to compute the location of each device using two algorithms, including UKF and the NLS algorithm. The raw data, as well as the processed data containing the smartphones and their respective locations, are stored in the database. MongoDB was selected as the database system for Wi-Fi tracking system, while an online dashboard was developed to provide a user-friendly interface for accessing and visualizing the data. This dashboard is a web application running on the server, which also serves as a platform for basic system configuration and presents the results of the analyzed data.

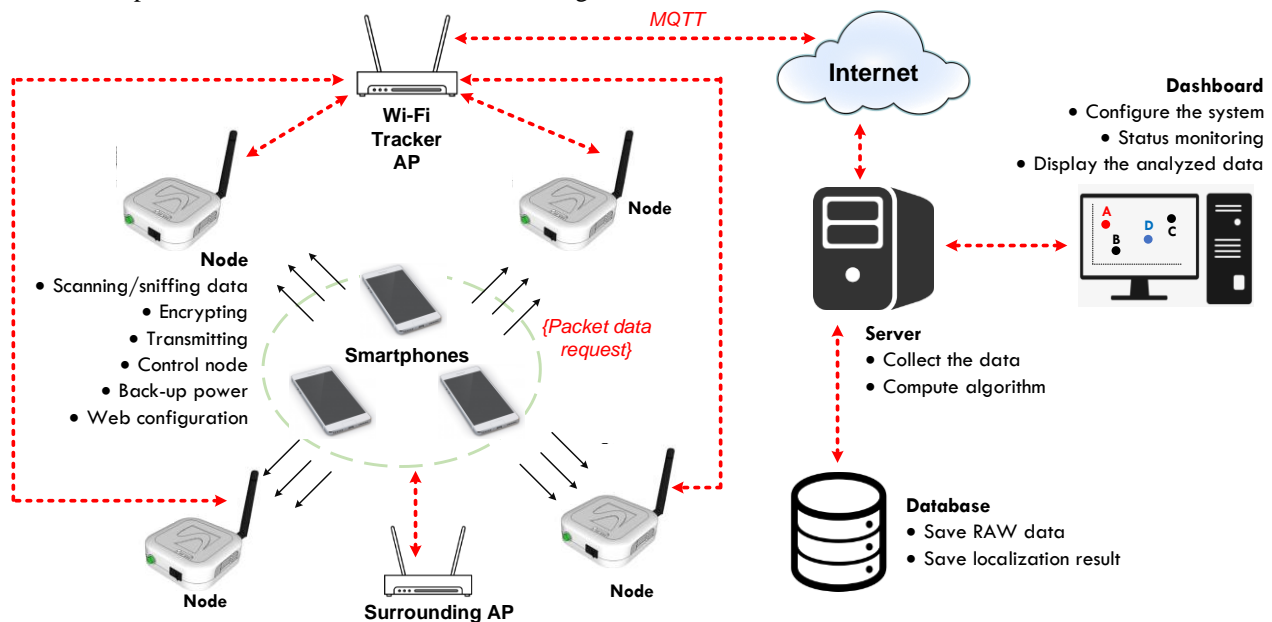


Fig. 1. The architecture of the proposed Wi-Fi tracker system.

This study consists of six sections, namely introduction, system overview, embedded node (hardware and software), localization algorithm, server system, and online dashboard. The final section encompasses a functional test conducted through system demonstration. As the focus of this study is primarily on describing the structure of system, the proposed results are limited to system demo. Wi-Fi tracker system presented is a result of extensive study in the field of Wi-Fi tracking, and it has been successfully implemented on real hardware. The viability of the proposed concept has been carefully validated. Therefore, future study efforts should aim to evaluate the proposed system comprehensively. This evaluation should include assessing accuracy in relation to the number of smartphone entities, power consumption analysis, measuring actual access time with varying user numbers, testing against multiple attack scenarios to assess vulnerability, and conducting other relevant analyses.

II. RELATED WORKS

Wi-Fi Tracker system typically comprises two primary components, including the node and the server system. The node system acts as a sensor that scans smartphone information. The scan results obtained from the node system are then transmitted to the server for further processing using various algorithms. The server system performs computations using the collected data from multiple nodes to predict the location of the smartphones. Additionally, a dashboard, which can be a web-based or smartphone-based application, may be incorporated into system to configure the algorithms and display the results.

Numerous frameworks have been introduced to facilitate the prototyping of Wi-Fi tracker system. These include CrowdProbe [26], mD-Track [27], Widar [28], IndoTrack [29], Beanstalk [30], SenseFlow [31], ARIEL [32], Probr [33], MOBYWIT [34], etc. However, many of these studies lack comprehensive discussions on all aspects of Wi-Fi tracking system, including the hardware, software, algorithms, server system, web-based application, and system demonstration. To address this gap, the focus of this study is to provide a comprehensive design of Wi-Fi tracking system that offers a clearer understanding. The study aims to delve into the different components of system in greater detail compared to previous studies [[18-26]. It is expected to make it easier for readers to understand the whole system.

In comparison to previous studies [3]–[14], [26]–[33], this Wi-Fi tracking system offers additional components such as a server system and a user-friendly web-based application.

These additions enable real-time monitoring of passive smartphone positions based on RSSI values. The online dashboard included in system provides various features, including a heat map, time reports, and user identification based on MAC data. The server system plays a critical role in gathering all the scanned information from the nodes. It performs the localization algorithm and employs UKF for computation. The collected raw data, as well as the computation results, are stored in the database. Additionally, the database is used for a Graphical User Interface (GUI) to configure system, display the results, and present the analyzed data. Wi-Fi tracking system has been designed and packaged as a consumer electronics product. This aspect has a positive implication, as it ensures that system is well-suited for market deployment in the future [35].

III. METHODS

A. Embedded Node

The node system of Wi-Fi tracking system is developed on the Linux platform. Specifically, the current version of the node system is designed to run on Raspberry Pi Zero W, with Raspbian (Debian 9) as its operating system. A web application is created using the NodeJS framework to simplify system configuration process. The services of the node system are managed using pm2, allowing users to configure system via a local IP browser (<http://10.42.0.1>). Additionally, the node system can be controlled through a dashboard deployed on the server. Users can use the dashboard reboot button to reboot a specific node. The communication between the dashboard and the node system is facilitated through MQTT protocol. The node subscribes to the command topic while the dashboard publishes commands to the same topic. This enables seamless command exchange between the dashboard and the node system. The node system can be further divided into two main components, namely hardware, and software, which will be explained in detail as follows:

1) *Hardware part (Raspberry Pi)*: This embedded node hardware is designed to carry out the following tasks with optimal functionality: a) perform the main function, which is scanning, encrypting, storing, and sending the data, b) auto-connect to the network, c) provide node configuration system, d) supply backup power system, and e) be controlled remotely by the user. After the requirement has been defined carefully, tracker node hardware specification is decided, as shown in Table I.

TABLE I. HARDWARE SPECIFICATIONS

No.	Specification	Description
1	Power Input	Main DC 9V 1.5 A Back-up power: LI-ION bat 3.8V/ 4500mAh
2	Operating Temperature	Normal operation: -10°C ~ +60°C Storage operation: -20°C ~ +70°C
3	Feature	Remotely controlled (By internet and GSM module), it has a configuration system interface (web apps), Power back-up (up to 8 hours), LED indicator
4	Dimension	10 10 × 5 cm
5	Portability & Lightweight	11 Yes

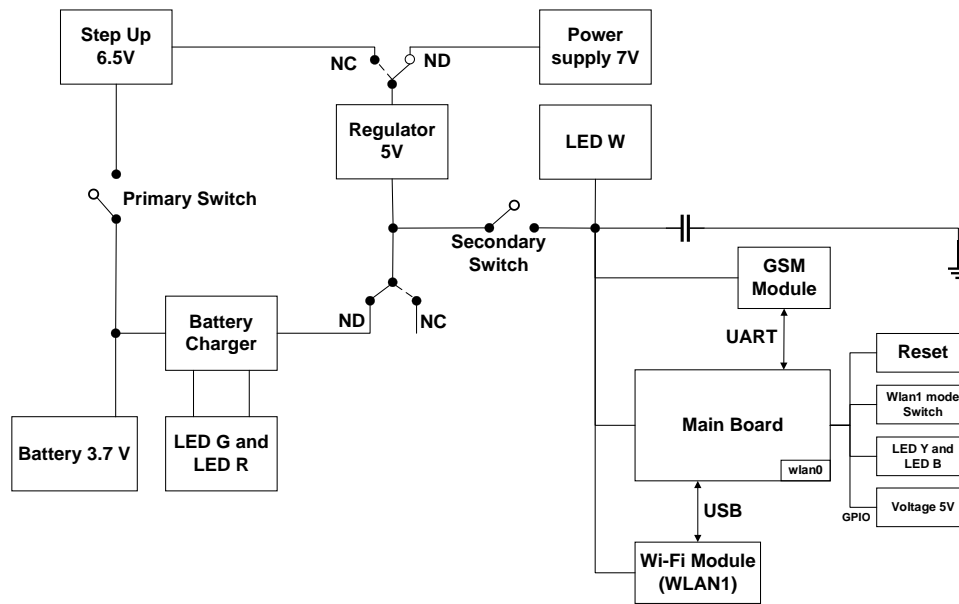


Fig. 2. Block diagram of node hardware.

The node system utilizes the Raspberry Pi Zero W, known as the mainboard, a compact and powerful development board running on the Linux platform. This mainboard provides excellent processing capability despite its small size. The functionality of the node is enhanced by connecting it to a complement board that integrates various components. These components include power management circuits, LED indicators, physics controls, GSM modules, and external antenna connectors. GSM module communicates with the mainboard using the UART Serial protocol, allowing efficient data transfer and communication. An external antenna is utilized, connected via a USB type B connector, and configured as wlan1 while the wlan0 is embedded in the mainboard.

Fig. 2 shows the structure of the node hardware, which is designed based on the requirements and functionality of the node. The main board is responsible for scanning/sniffing the packet request data through wlan1 and transmitting the data to the server through wlan0. The node hardware consists of two main power sources, including the main supply adaptor with a voltage of 7V and a backup supply in the form of a 3.7V battery. By default, when the main supply is available, the module draws power from it while the battery charge module charges the battery. Two LED indicators are provided, namely LED R and LED G indicating that the battery is charging and fully charged, respectively. When the main power is off, the relay switches from normally closed (NC) to normally open (NO), allowing the power supply to be sourced from the backup battery. The 5V regulator is necessary to ensure that the mainboard operates at its designated operating point. Additionally, a step-up module is used to ensure that the 3.7V battery voltage is appropriately boosted to drive the 5V regulator.

A capacitor bank is added to ensure a stable power supply during the switching process of the relay. It provides temporary power when the relay changes its state, and the main power becomes temporarily unavailable. Additionally, a

switch is incorporated to allow the user to manually turn on and off the node, serving as both a primary and secondary switch. GSM module is responsible for receiving Short Message Service (SMS) commands from the user. The data is sent to the mainboard for processing when an SMS is received. The mainboard verifies the validity of the command, and when it is valid, the node will be restarted. There are two options for GSM module, including SIM800L version 1 and SIM800L version 2. SIM800L version 1 operates at an operating point between 3.4V and 4.4V, while SIM800L version 2 operates at 5V. When SIM800L version 1 is chosen, an additional regulator is required to provide the correct voltage. However, since the hardware only provides a 5V power line, SIM800L version 2 can be used without needing an additional regulator to supply 4V. This means that SIM800L version 2 is selected for this system configuration.

Two LED indicators (LED B and LED Y) are connected to GPIO pins on the mainboard to provide visual indicators. These LEDs can be programmed to function according to specific requirements, such as light up when the node sniffs or sends packets. A reset button is also included to allow for external hard resetting of the mainboard. System also features a wlan1 mode switch, which allows for changing the mode of wlan1 between AP mode and monitoring mode. AP mode is used when the user wants to access and configure system node through web browsing. On the other hand, monitoring mode is utilized when the node is actively sniffing packet data.

The PCBs are designed with a focus on minimalism, ensuring that the electronic components can be integrated efficiently without adding unnecessary bulk to the case of the node. This design approach aligns with market demands for electronic devices that are lightweight, portable, modern, elegant, and simple. The hardware implementation of tracker node, based on the design shown in Fig. 2, is illustrated in Fig. 3. The casing of the node is made from Polylactic Acid (PLA), the same material used in other consumer-based product developed by Pusat Mikroelektronika ITB. Examples include

IR-based remote controllers [36], humidity and temperature sensor nodes [37], electronic transaction devices [38], and generic power sockets [39]. This material is suitable for a proper case because it is light, low-cost, solid, and resistant to dust particles & water.



Fig. 3. Photographs of trackernode hardware.

2) *Software part (Program node)*: Five programs running in the node include a) Main program (i.e., Sniffing, Encrypting, and Sending data), b) Sending node status, c) GSM module, d) Web control, and e) Web configuration. The description of each program is explained as follows:

a) *Sniff the packet data*: Fig. 4 illustrates the workflow of the program used to control Wi-Fi tracker and gather the required packet request data. It is crucial to consider the frequency at which devices broadcast packet request data as it directly impacts the accuracy and reliability of system. The more frequently devices send probe requests, the better the results can be achieved. During observations, several factors were identified that influence the frequency of packet requests, including the type of smartphones and the individual states. Different smartphone models may have varying time intervals for sending out packet requests, hence, to capture and analyze Wi-Fi data, Tshark, a packet sniffing tool, is utilized. The question of how Tshark analyzed the data was demonstrated in [18].

Smartphones with different chipsets and wireless adapters exhibit variations in their scanning behavior, which can be observed through the differences in scanning results. Several smartphones have a feature that enables power-saving mode, leading to slower probe request broadcasts than smartphones without this feature. Based on preliminary observations of various smartphone types, probe requests are sent at different intervals. The fastest observed interval between probe requests is approximately 3 seconds, while the slowest interval is around 60 seconds. The frequency of probe requests is higher in active scanning mode and lower during other smartphone activities such as web browsing, files downloading, or sleep mode.

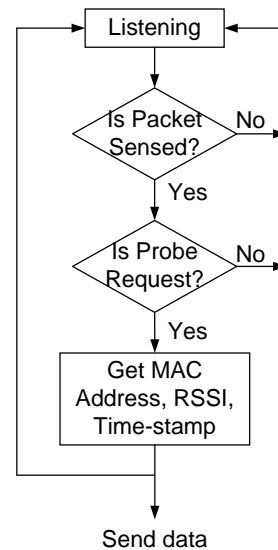


Fig. 4. Flowchart of scanning data for smartphone connected to Wi-Fi.

When considering smartphones, two scanning methods are used for active Wi-Fi AP as defined by [13], namely active and passive scanning. In passive scanning, the smartphone receiver is turned on to listen to each channel for the beacon. This scan is completely passive, and nothing is transmitted from the smartphone. While for active scanning, the smartphone will broadcast the packet on each channel. Probe requests are sent on the currently tuned channel to discover existing AP. The main focus of this system design is tracking the location of smartphones rather than AP. By setting the node to monitoring mode, no packet data is sent, thereby requiring smartphones to be in active scanning mode.

b) *Encryption*: As discussed in the previous chapter, security, and privacy issues are important concerns in the application due to the utilization of user information. MAC address emitted by smartphones has a considerably unique nature, allowing potential tracking of user whereabouts [11]. For example, unauthorized individuals can steal information stored in MAC address and use it to identify peoples' location and duration of stay in a building [24]. This raises significant safety and privacy concerns [25]. In this study, TLS/SSL is employed for MQTT communication to ensure secure transmission due to its ability to provide a secure communication channel between the client and server. TLS operates at the transport layer, enabling encryption without the need for application-layer encryption implementation. TLS/SSL consists of two main components, including securing the connection between the client and server using Certificate-Based Key Exchange and securing the sent messages using RSA encryption. The workflow of TLS/SSL in this system is shown in Fig. 5.

A certificate-based key exchange mechanism is employed to ensure a secure connection. The authorized user provides a certificate to both the server and node, which establish a connection assuming they possess the same certificate. The server generates private and public keys for encryption and decryption of information. The public key is then shared with the node using the certificate. The node, having the matching

certificate, can access and utilize the public key. The information is encrypted using the public key, employing the RSA method with a 1024-bit key in this study. All scanned data in the node, including the node status, will be encrypted. Similarly, the server, possessing the private key, is used to decrypt the encrypted information.

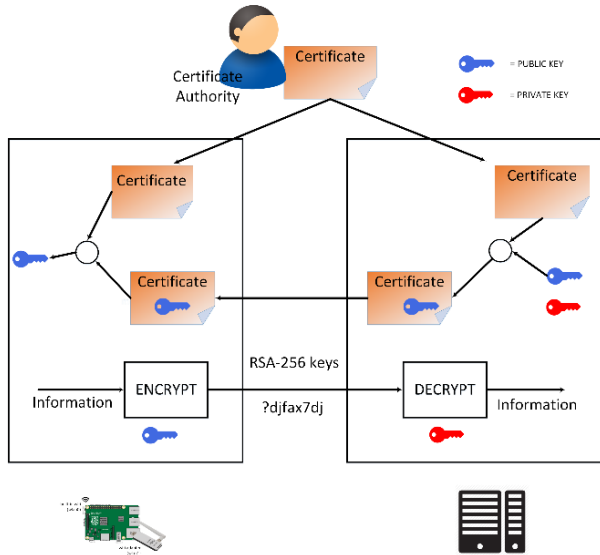


Fig. 5. TLS/SSL block diagram.

c) *Sending node status:* As described earlier, tracker node sends the captured data to the server using MQTT protocol, a client-server publish/subscribe messaging transport protocol. MQTT is widely known for its lightweight and efficient nature in terms of bandwidth usage. It is a popular choice for IoT platforms due to its low-power consumption and ease of implementation [40]. In system, small amounts of data are transmitted at frequent intervals, as opposed to sending large chunks of data less frequently [41]. MQTT protocol, with its support for the publish/subscribe scheme, was chosen for this purpose. Fig. 6 shows the data transmission process from the node to the server, utilizing the built-in Wi-Fi interface (wlan0) to connect to AP.

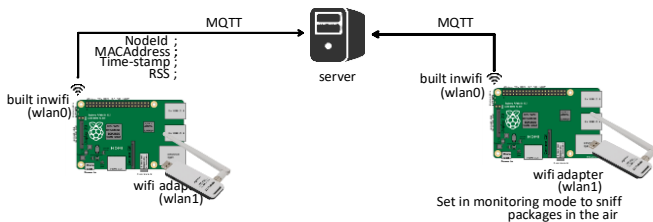


Fig. 6. Sending data from node.

MQTT protocol is utilized to send data in the form of a JSON object. The publisher (node) establishes two distinct topics, namely the main and the status topics. The main topic is responsible for transmitting the primary data whenever the device is scanned, while the status handles the status information of the node, which is sent every 10 seconds. The node status indicates the connectivity status with the server. An example of the main information JSON object, which has a data size of approximately 107 bytes, is provided below.

```
{
  "device_addr": "AA:BB:CC:DD:FF:GG,"
  "rssi_dbm": "-23",
  "time_epoch": "1493901414.065620"
}
```

An example of the node status JSON object, which has a data size of approximately 57 bytes, is provided below:

```
{
  "MAC_addr_node": "B8:27:EB:EB:D8:42"
}
```

d) *GSM module operation:* GSM/SMS service enables remote node control through GSM frequency by sending a message to a specific node phone number. The available remote-control actions include allowing the configuration to state/AP and rebooting the node. The commands can be found in a default configuration with only numbers listed under authorized phone numbers capable of controlling the node. GSM module receives an SMS representing the command to restart the node. First, the command is sent to the mainboard using a serial connection. Then the mainboard processes the node and executes the command (reset the board). This functionality proves useful when a specific program, such as the scanning mode, stops working and there is no internet connection available. Table II provides a list of some AT commands, while the port for GSM module is depicted in Fig. 7. The SIM800L module is a widely used GSM/GPRS module for serial communication. It is commonly employed in remote control projects, allowing smartphones with a Microsim-type SIM card to send messages for control purposes. This module utilizes the TTL serial port and features an LED indicator. The LED blinks slowly when the module is connected to a GSM network and blinks rapidly when there is no signal. Although the module provides 13 ports, only a few of them are utilized in this study. GSM hardware is initially connected to the Raspberry Pi for development purposes, as shown in Fig. 8. The experiment involved several components, including the Raspberry Pi, a computer running Python, the SIM800 module, and various jumpers. The connection was carefully made, considering the functions of each port (especially RX, TX, GND, and VCC) to ensure the program was successfully downloaded.

The flowchart shown in Fig. 9 illustrates the control process of GSM module using the mainboard (Raspberry Pi). The main board is responsible for four tasks, including setting up GSM module to SMS mode, extracting commands, making the decision to require a restart, and executing the reboot script. On the other hand, GSM module has four tasks, including listening to incoming SMS, deciding on incoming SMS, reading the SMS, and sending messages to the mainboard. UART communication is used between the two components. In the initial step, GSM module is set up in SMS mode by sending a sequence of AT commands from the mainboard to the module. When there are no errors, GSM module enters SMS mode and listens for incoming messages. When an SMS is received, GSM module will transmit it to the mainboard via UART. The mainboard will then verify the message and extract the content to determine whether it is a restart command to execute a reboot script to restart the node.

TABLE II. COMMANDS OF THE AT

Command	Description
AT+CMGF=1	Set module to operate at SMS/Text mode
AT+CMEE=1	Check whether SMS mode is supported or not
AT+CNMI	New SMS indication
AT+CMGR	Read an SMS

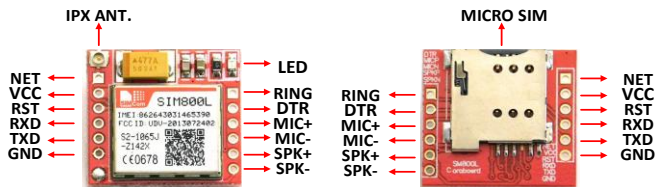


Fig. 7. GSM module SM800L port (top and bottom views).



Fig. 8. GSM hardware setup for development purposes.

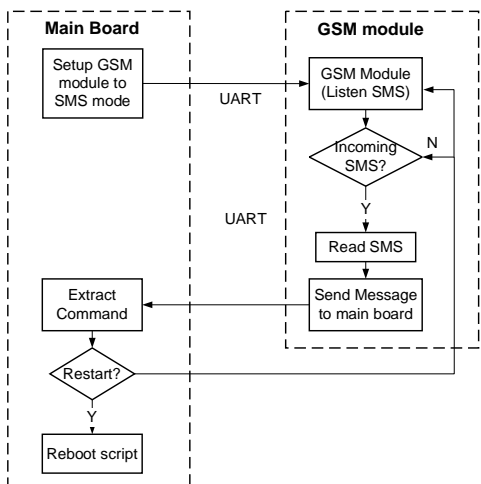


Fig. 9. Flowchart of GSM controller.

During the development process, a problem arose where the flowchart did not work correctly. The possible issue is related to the signal antenna GSM, serial communication (UART), or an incorrect AT command sequence. To resolve this problem, the code and commands were modified using the Python library. Eventually, the node was successfully tested and demonstrated the ability to receive commands from SMS and execute them.

e) *Web control system:* A GUI is provided in the dashboard, which includes a function to monitor the status of the nodes, whether they are sending data or not. The dashboard offers real-time data presentation with the following features: i) Basic map cartesian and dynamic configuration, the basic map will display the tracked device

location in cartesian mode, ii) The trajectory of the smartphone graph, iii) Node status monitoring and iv) Calibration page. The layout can be configured from the map setting container on the right side of the map, as shown in Fig. 10. The devices map menu is used to display the algorithm result in a real-time. The map setting is used to set into desired area/location because there is also a form of MAC address filter to display only specific MAC addresses. It is useful for testing the accuracy of the algorithm purpose.

Furthermore, additional features in the dashboard were implemented, as shown in Fig. 11. These include the node name, node status, and a reset command. The reset command menu is used to reset a specific node. The node name corresponds to MAC address of Wi-Fi module connected to Wi-Fi tracker AP. Each node name is published to a different topic, and the node subscribes to the topic based on its Wi-Fi MAC address (wlan0 interface). This allows the status of each node to be displayed in the dashboard.

In system specification, the remote-control functionality of the node was defined, but the web server lacks knowledge of the address, preventing direct command transmission. MQTT protocol was employed to address this, followed by a publish and subscribe scheme. Instead of directly sending commands to the node, they are published to MQTT broker using a known address. The node then subscribes to the relevant topics to receive and execute the commands, allowing it to restart the board. The illustration of the scheme is presented in Fig. 12. An online dashboard is developed using Node.js, a popular full-stack JavaScript web application framework, to enhance the user experience. The integration with Mongo and front-end development with Angular are also implemented.

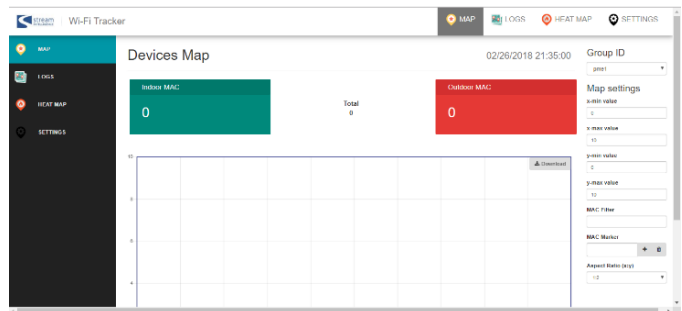


Fig. 10. Basic cartesian map, all detected devices/smartphones after the computation process is displayed in this map. Using MAC address, RSSI, and time stamp data, the location of devices can also be determined.

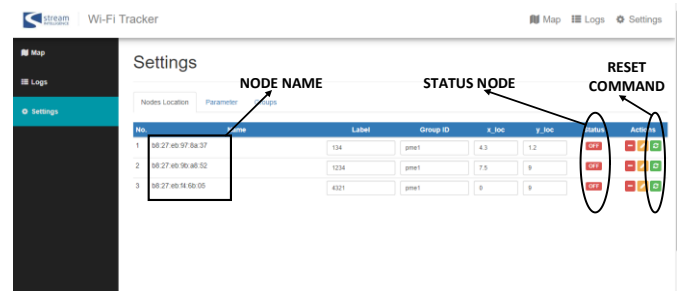


Fig. 11. Appearance of the dashboard for node status and controller.

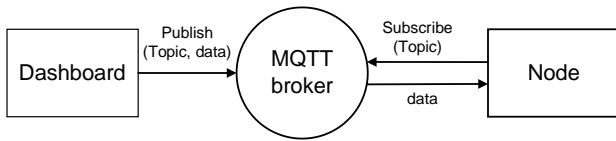


Fig. 12. MQTT broker scheme.

B. Localization Algorithm

This section describes the localization algorithm applied in system. The algorithm predicts the location of devices based on previously obtained information. For this purpose, distance-based method is implemented, which is an RSSI-based localization algorithm. Based on the set of RSSI measurement results, the location of devices is predicted using the estimated distance between tracker nodes and smartphones. In addition, UKF is used to enhance system performance, consisting of three steps, namely modeling, predicting, and correcting, as summarized in Table III. The detailed derivation and simulation under MATLAB are explained in [21], [22]. The calculations are performed in the Apache Storm-based server, and the algorithms are written in Python script. The *NumPy* library is used to perform matrix computation in Python. The code includes a function to initialize the Kalman model used in this work. The prediction and correction steps of UKF are implemented to predict the next state value from the current state and store it in memory.

C. Server System Dashboard

1) *Brief description of system structure:* The server is deployed on the Debian 9.1 Linux platform and has two main functions, including collecting data from all nodes and estimating the location of detected devices. The data transport from nodes to the server is facilitated through three mechanisms, namely MQTT protocol, a message broker server for MQTT, and Apache Storm. Apache Storm enables distributed real-time computation with the NoSQL platform MongoDB used to store the data. The users can set the configuration and real-time localization from web apps deployed under the Nodejs platform.

The main processor of the server utilizes Apache Storm 1.1.0, which is built on the Java platform and enables distributed computation. Apache Storm is supervised and monitored by the Supervisor and ZooKeeper components. It follows a spout-bolt architecture, where the input data is received by the spout and processed by separate bolts. Python programming language (version 2.7) was chosen for the algorithm implementation due to its extensive library support, facilitating faster development. Apache Storm is implemented using the Streamparse framework, as shown in Fig. 13. This framework allows real-time visualization on the Map dashboard, although global grouping is not currently implemented in the framework.

Serializer Spout is the data flow gate subscribing to certain topics where nodes publish. In this Spout, serializer (message parsing) is conducted from JSON format to a tuple of the device address, timestamp, node ID, and RSSI. Finally, all parsed data are sent to InsertDeviceBolt to be stored in MongoDB as devices collection and BufferMsgBolt.

TABLE III. UKF ALGORITHM FOR THE PROPOSED SYSTEM

Model
$RSSI(t+1) = RSSI(t) - 10\alpha * v(t) * 10^{\frac{(Pinit(t)-RSSI(t))}{10\alpha}} * \Delta t$ $v(t+1) = v(t)$ $Pinit(t+1) = Pinit(t)$ $Z = [RSSI]$ $R = \left[\left(\frac{3.0 * RSSI + 340}{70} \right)^2 \right]$ $Q = \sigma^2 \begin{bmatrix} \Delta t^3/3 & \Delta t^2/2 & 0 \\ \Delta t^2/2 & \Delta t & 0 \\ 0 & 0 & 1 \end{bmatrix}$
Prediction Step
<ul style="list-style-type: none"> Calculate weight, sigma-point: $W_0^m = \frac{\lambda}{n + \lambda}$ $W_0^c = \frac{\lambda}{n + \lambda} + 1 - \alpha^2 + \beta$ $W_i^m, W_i^c = \frac{1}{2(n + \lambda)}, i = 1, 2, \dots, 2n$ $\lambda = \alpha^2 (n + k) - n$ $\chi_0 = \mu$ $\chi_i = \begin{cases} \mu + [\sqrt{(n + \lambda)\Sigma}]_i, & \text{for } i = 1, 2, \dots, n \\ \mu - [\sqrt{(n + \lambda)\Sigma}]_{i-n}, & \text{for } i = n + 1, \dots, 2n \end{cases}$ Unscented transform $\psi_i = f(\chi_i), z_i = h(\chi_i)$ Transition state: $\bar{y} = \sum_{i=0}^{2n} W_i^m \psi_i$ $P_{yy} = \sum_{i=0}^{2n} W_i^c (\bar{y} - \psi_i) (\bar{y} - \psi_i)^T + Q$
Correction Step
<ul style="list-style-type: none"> Kalman Gain: $\bar{z} = \sum_{i=0}^{2n} W_i^m z_i$ $P_{zz} = \sum_{i=0}^{2n} W_i^c (\bar{z} - z_i) (\bar{z} - z_i)^T + R$ $P_{yz} = \sum_{i=0}^{2n} W_i^c (\bar{y} - \psi_i) (\bar{z} - z_i)^T$ $K = P_{yz} * P_{zz}^{-1}$ Correct the prediction: $X_{k+1} = \bar{y} + K * (Z_k - \bar{z})$ $P_{k+1} = P_{yy} - K * P_{yz} * K^{-1}$

BufferMsgBolt receives the data from Serializer Spout and temporarily stores it until enough data from at least three nodes with the same device address are collected. In this stage, the data is filtered using UKF and stored as the maximum RSSI value. Afterward, the NLS algorithm is applied to compute the location of the device, and the result is sent to InsertDeviceLocBolt to be stored in the locations of MongoDB collection. System called heartbeat is implemented to maintain a constant stream of data in Storm, which keeps

system alive by checking the incoming stream data within a timeout range. Since the server has only one deployment, the service needs to run for a long time, which is served by a component called heartbeat_keeper.

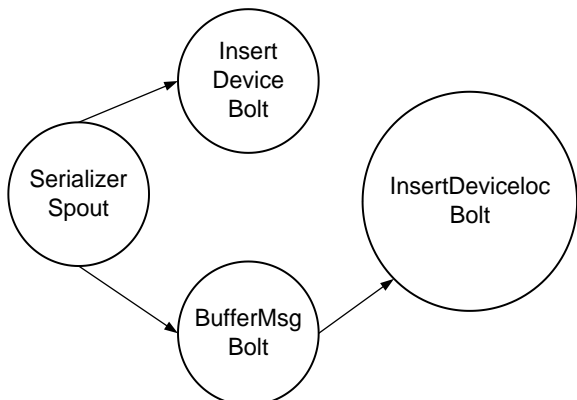


Fig. 13. Storm implementation.

2) *Server system:* The server system performs data calculations using Apache Storm, a parallel streaming processor. Large companies widely use Apache Storm for processing big data in near-real time. It is an open-source distributed computation system that is free to use, simple, and compatible with various programming languages. In this implementation, Python was chosen as the programming language. The server system architecture is shown in Fig. 14, with a message broker employed to receive data from the nodes. Mosquito, a lightweight and straightforward MQTT broker framework in Python, is used for this purpose.

During the first phase of server system development, Cassandra was chosen as the database solution before MongoDB usage. Cassandra is renowned for its clustered architecture and high availability. However, later in the development process, the decision was made to switch to MongoDB for storing the computation results. MongoDB was preferred due to its document-based database flexibility and ease of querying and inserting data. It is important to note that for optimal performance in a clustered environment, the tables must be structured maturely and well-designed. As a proposed solution, a scenario can be devised where, once all executions and developments are stabilized, a migration back to Cassandra can be considered for further enhancements and improvements in the server system.

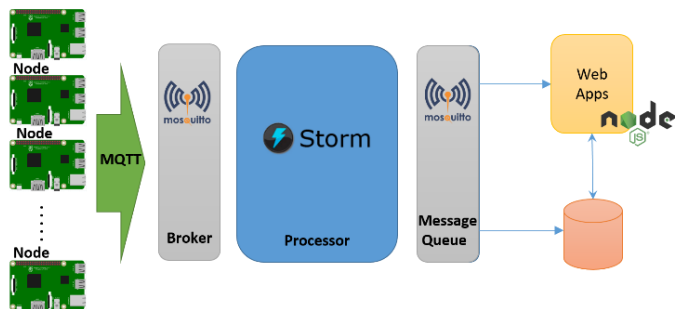


Fig. 14. Server system architecture.

3) *MQTT broker:* A broker is a message pool that manages where the message is delivered. When a broker receives a message on a particular topic, it broadcasts them to every subscriber who subscribes to the same topic. The broker concept for the proposed system is shown in Fig. 15. It illustrates that node 5 published a “Hi!” message in topic /hello/world/, and MQTT broker will broadcast to wherever node is subscribing to the same topic /hello/world/. Therefore, nodes 3 and 1 receive the message because they subscribe to the/hello/* topic. Meanwhile, node 4 will not receive the message due to different topics and node 2. This is because node 2 and 4 serves as a publisher. MQTT security is implemented by exchanging data in an SSL tunnel connection. The client, who acts as publisher or subscriber, needs to have certificates with username and password inputted before sending the message. In the server as a subscribe, the node sends data to the broker (publish mode) in a specific topic. Therefore, to receive data from nodes, the subscriber needs to subscribe to the same topic. For example, the server as a subscriber receives data in a topic: com. stream/track/Wi-Fi/device. The payload of this message is presented in the program as follows:

```

{
  "device_addr": "AA:BB:CC:DD:FF:GG", // uniqueID of device
  "rssi_dbm": "-23", // signal strength which read by Node
  "time_epoch": "1493901414.065620", // epoch time of data being sent
  "nodeID": "11:22:33:44:55:66" // uniqueID of the node which sends the data
}
  
```

In the server as a publisher, the result of computation needs to be pushed immediately to web apps to gain real-time experience. This feature is served by implementing a publisher which broadcasts the process to every web app. An example is in the program below, where the device is unique of the device, x_loc and y_loc denote the x and y positions of the device.

```

{
  "dev_in": 3, // amount of devices in the room
  "dev_out": 10, // amount of devices out of the room
  "devices": [ // list of devices
    { "device": "B3:B9", "x_loc": -0.19, "y_loc": -5.77 },
    { "device": "FD:78", "x_loc": 12.17, "y_loc": 14.51 }
  ]
}
  
```

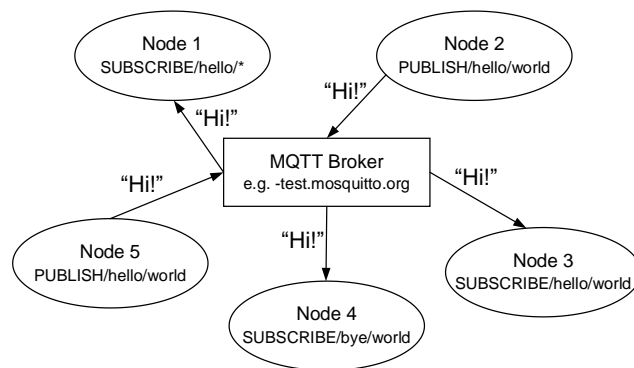


Fig. 15. MQTT broker concept.

4) *Processor description in detail:* As discussed earlier, Apache Storm is utilized as a processor in the server. The Storm topology consists of Spouts, which receive the data, and Bolts, as micro-computations or processes. The Storm computation is based on micro-computation, so every computation needs to be distributed in Bolts. Every incoming message from *the broker* is serialized in *SerializerSpout* and turned into a tuple. These tuples are then forwarded to the *BufferMsgBolt*, where they are merged with messages from other nodes, which is processed by the algorithm. The computed result is stored in a database through the *RecordStreamBolt* and sent to the dashboard using the *ResultPubBolt*. The workflow of the processor is illustrated in Fig. 16. Meanwhile, in Fig. 17, the flowchart depicting the implementation of UKF algorithm is shown. Firstly, the algorithm parameters are initialized, such as the path-loss exponent, node location, room location, and other relevant parameters. The user configures these parameter values through the web interface, and the database stores these configured values. Finally, when the algorithm is executed, it retrieves the configured values from the database for processing.

The Table State and Table Device serve as temporary memory to store the previous state of UKF and the previous set of smartphone data, respectively. The Table State keeps track of the previous RSSI values and covariance matrix for all existing nodes and smartphones. On the other hand, the Table Device stores the previous information of the devices detected. The long Table State and Table Device were used to determine the time to live (TTL). The program regularly checks the tables and deletes any values that have expired. This approach addresses the issue that the node may not always be able to scan RSSI values from devices, allowing us to utilize the previous values. The TTL helps determine the validity duration for using the stored data.

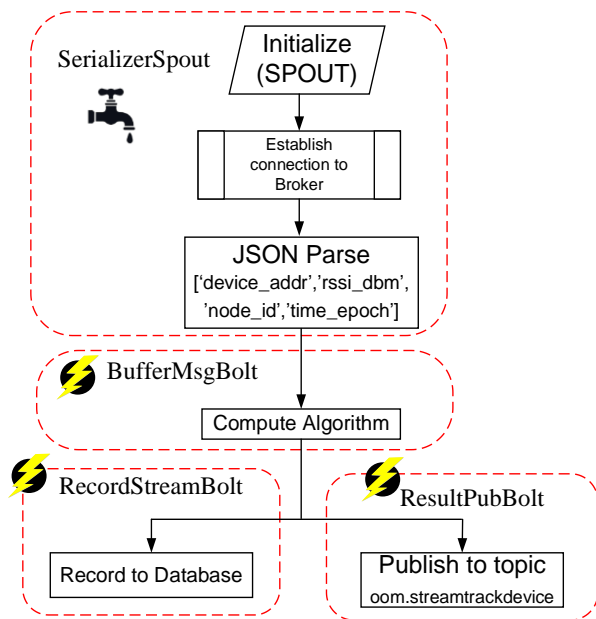


Fig. 16. Storm flowchart.

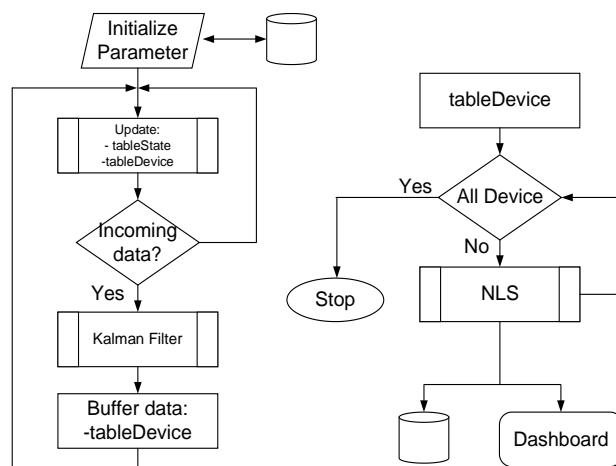


Fig. 17. Workflow of algorithm in general.

The program continuously checks the Table Device and performs the localization algorithm computation for all the available data stored. The resulting localization information is then saved in a database and sent to the dashboard for visualization. The data was modified for the algorithm by employing the NLS with initial power (NLS1). First, it will be used to decide whether the device is inside or not, followed by refining the detection using the NLS with power difference (NLS2). Fig. 18 is the flowchart of the NLS implementation.

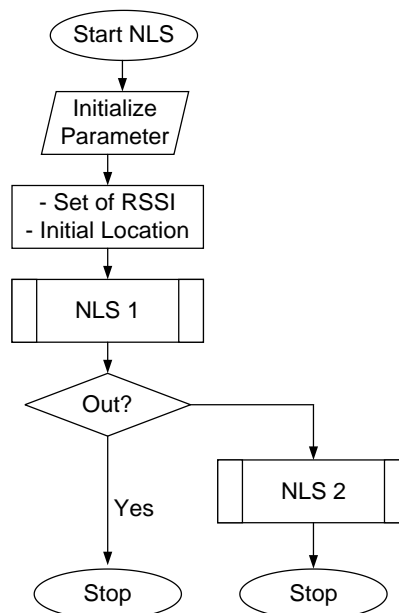


Fig. 18. The NLS algorithm flowchart.

5) *Database:* Data is stored in various collections with their respective data structures, which are shown in Table IV. Config collection contains display configurations and some parameters used in the algorithm. The Devices collection stores all raw data captured by the nodes. The Collections collection includes all the computation results (documents) of the devices, including their location and status. Finally, the Nodes collection contains information about all registered nodes. Database Structure.

TABLE IV. THE DATABASE STRUCTURE

Structure	Description
Configs	{ "_id" : ObjectId("5979a1c2e70bc538eba1b612"), "groupId" : "pme1", "_v" : 0, "mapConfig" : { "xmin" : 0, "xmax" : 10, "ymin" : 0, "ymax" : 10 }, "roomSize" : { "xmin" : 0, "xmax" : 10, "ymin" : 0, "ymax" : 10 }, "pathloss" : 23 }
Devices	{ "_id" : ObjectId("5976c272e28b3501e5bdef2c"), "timestamp" : "", "rssi_dbm" : 0, "node_id" : "", "device_id" : "SA:SD" }
Locations	{ "_id" : ObjectId("5979f740e28b350ff263b31a"), "status" : 0, "modified" : ISODate("2017-07-27T21:22:56.598Z"), "loc_z" : null, "loc_x" : -1.8633060346972499, "loc_y" : 2.9159220745415255, "device_id" : "DA:A1:19:99:84:A4" }
Nodes	{ "_id" : ObjectId("59788125287c9919e0295b0b"), "nodeId" : "C", "groupId" : "pme1", "locX" : 12, "locY" : 12, "_v" : 0, "modified" : ISODate("2017-07-26T03:37:29.433Z") }

Config fields:

- `_id`: id of document.
- `GroupId`: Id of a group of configurations. This will be used to group of nodes.
- `mapConfig`: configuration for display in cartesian
 - `xmin` : x min value of map
 - `xmax` : x max value of map
 - `ymin` : y min value of map
 - `ymax`: y max value of map.
- `roomSize`: the size of the room
 - `Pathloss`: Pathloss value of room of observation. This is used for calibration.
 - `xmin`: x min value of room
 - `xmax`: x max value of room
 - `ymin`: y min value of room
 - `ymax`: y max value of room

Devices fields:

- `_id`: id of document.
- `timestamp`: timestamp
- `rssi_dbm`: received signal strength in dbm
- `node_id`: uniqueID of the node where message comes from

Location fields:

- `_id`: id of document.
- `status`: define where the devices regarding room size config. 1 inside, 0 outside.
- `modified`: last updated record. Format: 2017-07-27T21:22:56.598Z
- `loc_z`: z location in cartesian. For current development, always null.
- `loc_x`: x location in cartesian
- `loc_y`: y location in cartesian.
- `device_id`: id of device

Nodes fields:

- `_id`: id of document.
- `nodeId`: uniqueID of node
- `groupId`: group Id of node
- `loc_z`: z location in cartesian. For current development, always null.
- `loc_x`: x location in cartesian
- `loc_y`: y location in cartesian.
- `Modified`: last updated record with the format as follows: 2017-07-27T21:22:56.598Z

6) *Data exchange*: This subsection provides a more detailed analysis of the data exchange mechanism in the server system. As previously stated, data are exchanged via MQTT protocol from the node to the server, where nodes publish the message to the topic (then denoted as "A"). The *SerializerSpout* subscribes to this topic, allowing it to receive messages from any nodes that send data to topic A. The received data is then processed and inserted into a database using Pymongo. The insertion is carried out by the *InsertDeviceBolt* and *InsertDeviceLocBolt*, which store the computation results in the locations and devices collections.

IV. RESULTS AND ANALYSIS

A. Setting at a Glance of System

This subsection provides a comprehensive explanation of how to utilize system. The process will be described step-by-step, starting from the initial hardware node setup and leading up to displaying the scanning results on an online dashboard. In order to implement system in the field, different user access levels were defined. System consists of two types of users, namely, admin and dashboard users. Admin users are Wi-Fi tracker developers responsible for setting up and configuring the node and server system, while dashboard users can adjust algorithm parameters and view the results. For indoor localizer environment (Wireless Sensor Network), a minimum of three nodes is required, although using at least four nodes is recommended for more accurate data collection. Distance between nodes should not exceed 20 meters. Positioning the nodes at elevated points, away from obstructions, and ensuring they are connected to Wi-Fi router is advisable. The chosen location used for the live demonstration of system follows the spot-point used in [18]. A glass wall surrounds the room and has a dimension of 30m x 10m, with two static obstacles (concrete pillars) located in the middle. Four tracker nodes are used for this test, with each node placed in a corner, as illustrated in Fig. 19.

Each tracker node is powered by an Adaptor 9V 2A, which serves as the main power and is backed up with a battery of 3.7V 4500mAh, switched with a physical switch relay. The node is configured by enabling AP mode, which is done by pressing the green button for approximately 5 seconds. Subsequently, the node enters AP mode when the configuration indicator turns on (blue light) and the active

indicator turns off (orange light). The configuration process can be carried out by connecting to the default SSID and password and accessing the specific local IP of the node through a web browser. The values that can be configured include the node connection, credentials account (e.g., secret-id, secret-key, and target host), phone number, and authorized phone numbers. While in the configuration state, the node does not capture data. Once the configuration is complete, the submit button should be clicked to apply the new settings, automatically rebooting the node. Finally, the node collects data and sends it to the server.

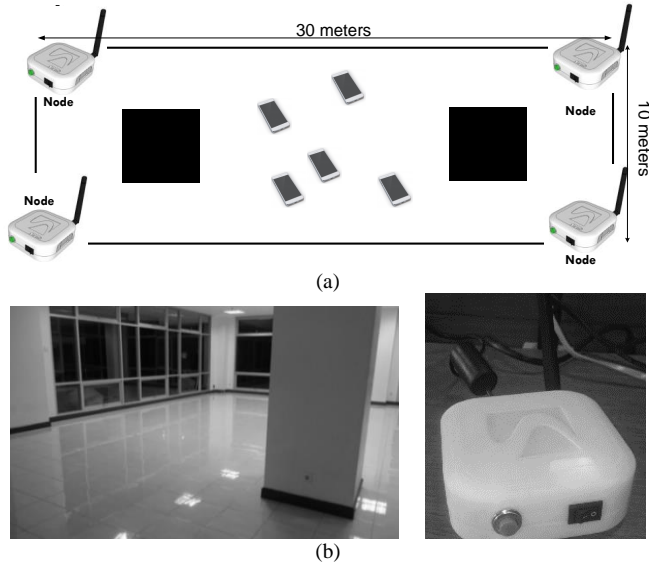


Fig. 19. Demonstration setup: (a) Map of the room for system demonstration; (b) Photographs of the room situation and placed tracknode.

In order to transmit data to the server, the node requires an internet connection. A web client interface has been created based on the NodeJs framework, operating on a node, and this interface supports real-time visualization. Messages are sent from the server (Apache storm - *Buffermsgbolt*) to the NodeJs using MQTT, with the NodeJs acting as a subscriber. A sockets connection is implemented in NodeJs to enable updates whenever new messages arrive. The UI for the angular server and communication with the REST API is implemented using the express framework. To access the website, users need to follow these steps: i) Activate the configuration mode of the node. ii) Open a web browser and navigate to <http://10.42.0.1>. iii) Enter the required credentials and configurations. iv) Fill out the available forms and initiate a reboot. Detailed instructions for these steps are provided in the subsequent section.

B. Detail Setting

The first step involves setting Wi-Fi interface into AP mode by activating a provided button. Instead, the wlan1 interface was utilized, and specifically designated for sniffing packet data, as previously explained. Once wlan1 is in AP mode, other computers or laptops can connect to the established AP. Users can then open a browser and enter the address 192.168.0.1 to access the configuration web interface. The node was restarted after making the necessary changes. The online dashboard will display a setting summary of the node, as shown in Fig. 20(a). Users can click the edit configuration button to view the surrounding APs detected by the node. To send data to the server, the wlan0 interface of the node will establish a connection with one of the detected APs, as illustrated in Fig. 20(b).

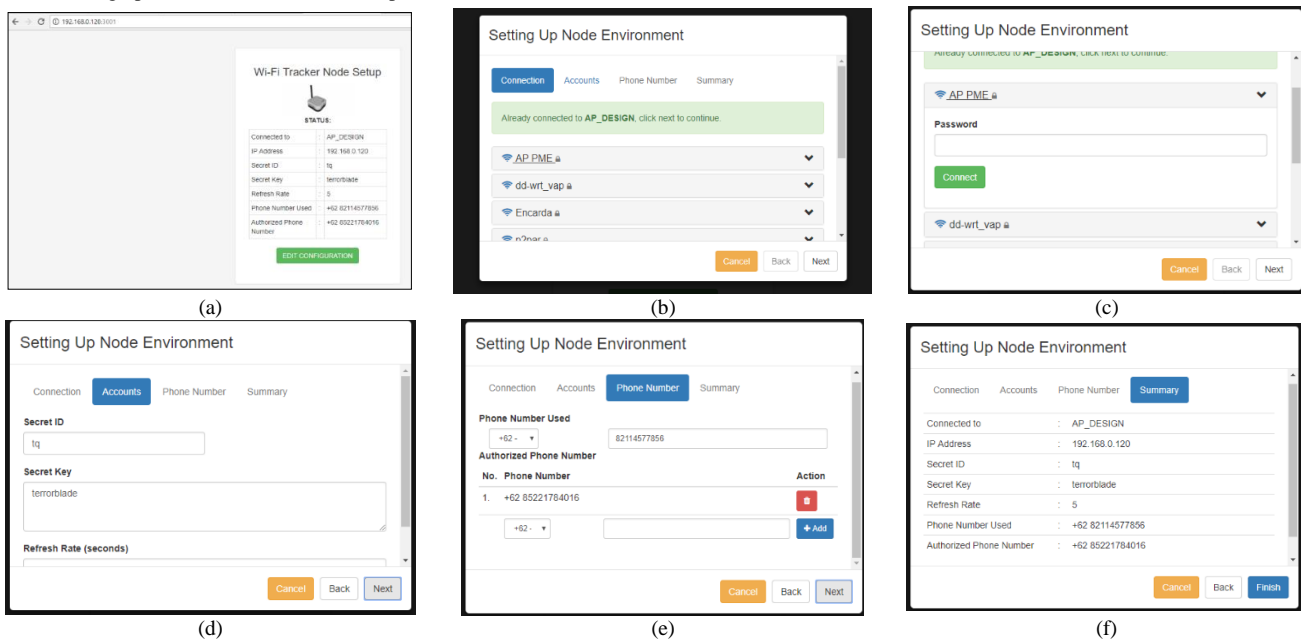


Fig. 20. Demonstration setting flow: (a) Summary of Wi-Fi tracker node setup, Informing the node status, Wi-Fi tracker AP, IP address, Secret ID, Secret key, Refresh rate, Phone number used, and Authorized phone number; (b) Setting up node environment in step I; (c) Select AP and insert password; (d) Setting up node environment in step II: user name and password setting for MQTT; (e) Setting up node environment in step III: GSM number setting used in node and list of authorized number; (f) Summary of the setting.

In the following steps, the user selects the name (SSID) of Wi-Fi network from the available connections list and clicks the connect button, as shown in Fig. 20 (c). Once the device is connected, the user proceeds by selecting the next button and enters the secret ID, secret key, and host obtained from the service provider. It is essential to keep this information private and not share it with others. Clicking the test button prompts a success message when the entered account details are correct. When the user encounters a failed message (Fig. 20d), they are encouraged to contact the provider for assistance. Upon completing a step, they can continue with the optional case by clicking the next button to activate the SMS Service. Next, the user is advised to input their phone number and authorized phone numbers. Finally, the submit button is selected, as shown in Fig. 20(e), to initiate a reboot of tracker node. The setting summary of the node is then displayed (Fig 20f). After clicking the finish button, the online dashboard is presented (Fig. 21). MAC field can be used to filter the displayed devices and leaving it empty will show all detected devices. Devices of interest can be marked in red using MAC marker. The aspect ratio setting determines the ratio of the x-axes and y-axes.

The configuration of each node location is performed in the menu section for node location settings, and all nodes have been placed in specific locations. This setting indicates the location of the node to the algorithm using the x_loc and y_loc coordinates. The menu also displays the status of the node, indicating whether it is available or not, in the status column. Additionally, any unregistered nodes are shown, allowing for the addition of their locations and saving them to the database. The nodes are monitored by being set in the settings menu (Fig. 22), and their status is updated every 1 minute. For system calibration, there is a parameter tab available in the settings. This tab allows for the adjustment of room size, map values, and path-loss of components (Fig. 23). The settings for room size and path-loss exponent can be found under the setting menu within the parameter tab. Path loss calibration is used to represent the surrounding conditions or barriers within the room for the algorithm. The room size parameter determines the observation space and helps consider whether the device is inside or outside the room.



Fig. 21. Node location setup.

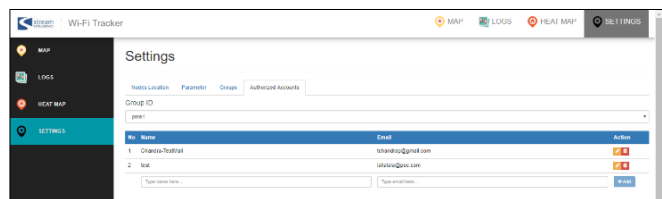


Fig. 22. Node status and setup dashboard.



Fig. 23. Calibration and room setting dashboard.

C. Displaying other Data Analysis

The dashboard includes a real-time device monitoring feature on the map, as well as the percentage of people inside versus outside the observed room to enhance analysis. A marker has been added, which turns red when devices are outside and green when inside. Fig. 24 provides an example of data analysis during the field test, showing the number of smartphones inside the room (green), outside the room (red), and in a specific location (orange) for a day.

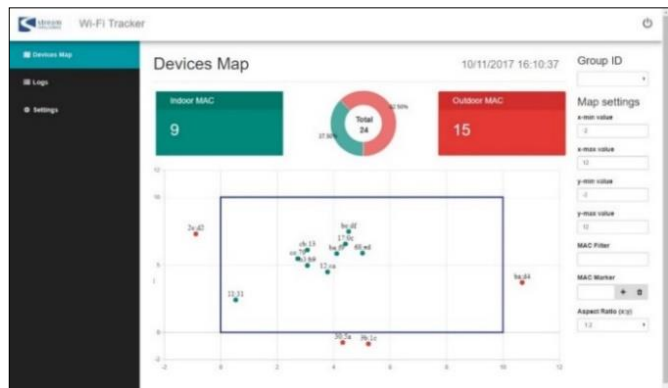


Fig. 24. Devices map on the online dashboard, red represents external devices by time, cyan represents inside, and yellow amount of device in a certain place.

The report can be accessed by daily inquiries on two pages, namely, Logs [34] and Heatmap [33]. The Logs page displays a report based on the access time parameter, while the Heatmap page displays a report based on the parameter of locations. Furthermore, the Logs page allows users to view crowd density in a room over time, with the option to select a specific date for more detailed information. The three categories in this menu are outside, inside, and certain places, with the need to define the latter before accessing system as shown in Fig. 25; it illustrates the volume of people in the test room over time, with data sampled every five seconds. The administrator can download the chart image of Logs (time reports) by clicking the calendar icon and submit button. On the other hand, CSV file containing the raw data of this day can also be downloaded smoothly by clicking CSV icon. The administrator can hide the need data to be analyzed by choosing menu as follows: outside, inside, and ranged devices. The Heatmap feature visually represents the activity density in the observed room throughout the day. By setting the desired date and submitting it, users can obtain the Heatmap, which is centered on the origin point of the room ($x = 0, y = 0$). Red indicates high activity, while grey represents low activity,

similar to a graph (Fig. 26). The Heatmap can be accessed daily by clicking the Heatmap page, automatically displaying the report of the day. A black square represents the room, and users can adjust the X and Y values to navigate the map. The maximum heat value can also be adjusted to define the intensity of activity. In conclusion, the dashboard enables crowd detection through the visualization of Heatmap data.

Wi-Fi tracking system should offer three important parameters, namely, device classification, user localization, and user profiling [35]. The proposed system is currently capable of defining only the location of the user. In future updates, additional services will be added to gain more benefits, such as user profiling and device classification based on RSSI signal emitted by the smartphones of users. Furthermore, system provides trajectories of devices, which can be accessed through the Logs bar. This feature displays the number of devices (smartphones) present inside or outside the room at specific times. It also allows monitoring of specific places, regardless of whether they are inside or outside the room. The Log bar is utilized to display the data analysis, allowing the user to observe the number of devices inside or outside the room at a particular time.

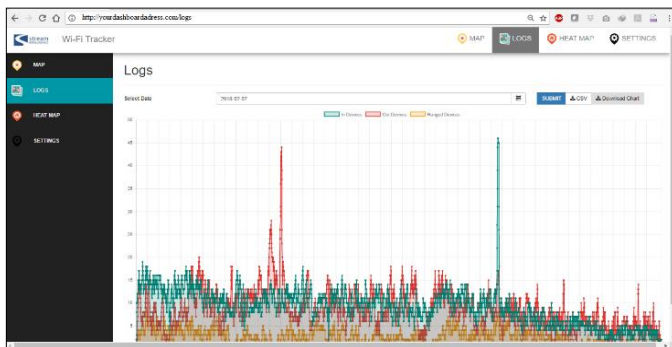


Fig. 25. Time reports.

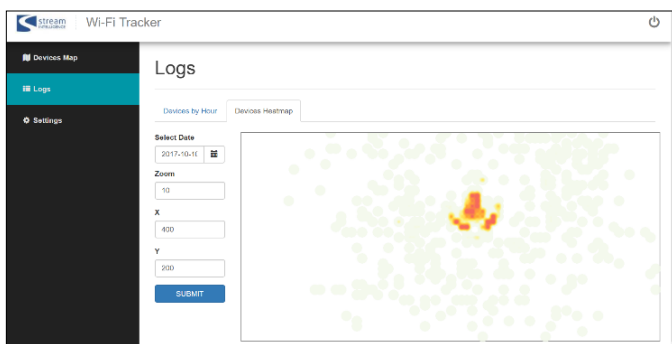


Fig. 26. Heatmap reports.

D. Discussion

The popularity of smartphones as study objects in the computing field is increasing with Wi-Fi tracker system [31]. This is because wireless human sensing system can be carried out accurately and with far coverage. Smartphones can periodically send Wi-Fi request packets which tracker can detect by capturing the passive signal information of the smartphone, including MAC address and RSSI [4], [42]. In comparison to other technologies for human sensing, such as

infrared or video thermal cameras, which are less accurate in identifying indoor crowd density, Wi-Fi tracker offers greater accuracy and coverage. These alternative technologies have limitations in terms of a fixed location, angle, and limited range for detecting human presence in various indoor areas. Given the widespread use of smartphones with Wi-Fi connectivity, Wi-Fi tracker system attempts to extract information about human density in a room through smartphones. By utilizing RSSI parameter, system can determine the position of smartphones and their users in a specific area. While the current Wi-Fi tracker system is relatively simple and based on limited-scale trials, it can serve as a solution for monitoring crowd density, which is crucial in social activities. The applications of this system are diverse, such as tracking the number of daily visitors to a shopping center and identifying the most frequently visited stores. Conversely, it can also provide insights into the number of people present and working in a building. This human sensing information helps service providers understand patterns in public spaces within indoor areas. System can be implemented on campuses for various applications, including tracking occupancy in academic spaces such as offices, libraries, laboratories, lecture halls, meeting rooms, faculty rooms, and seminar auditoriums.

The proposed system has the potential to be implemented as a position-tracking and indoor crowd-monitoring solution, which is widely used in modern cell phones. This tracking methodology can be applied to monitor individuals in various indoor locations such as logistics warehouses, hospitals, or airports. Unlike GPS, which has limited accuracy, system utilizing RSSI level from Wi-Fi routers can provide higher accuracy. Wi-Fi routers are already installed in many places, resulting in a lower initial cost during system development by leveraging existing Wi-Fi infrastructure. Therefore, they offer an advantage over GPS. Wi-Fi tracking system, based on RSSI-based distance, can be implemented in indoor applications, such as campus areas, as demonstrated in this paper (i.e., ITB area). It is recommended to conduct further studies to assess the performance of system in real-world settings, as all the demonstrations were conducted in a controlled environment. The accuracy of system in tracking various elements in the real world also needs to be examined.

The demonstration results show the successful monitoring of crowdedness using the online dashboard. System effectively captures the volume of smartphones connected to Wi-Fi, as anticipated, and crowdedness data is displayed at five-second intervals. Furthermore, the online dashboard provides the ability to specify the location of smartphones, such as inside devices, outside devices, and within a specific range. This study does not include statistical analysis as it solely reports on system architecture and system demo. A previous study presented a similar framework, but it was specifically dedicated to outdoor applications in wide areas, particularly for smart city scenarios [34]. In contrast, this proposed system is intended for indoor areas. The scientific advancement highlighted by this system is the visualization purpose of the dashboard.

Future study will encompass the evaluation of other performance metrics and practical performance measurements,

as identified by Xia et al. These metrics include accuracy, precision, complexity, robustness, scalability, and costs [43]. Several existing RSSI-based localization methods can be incorporated to enhance the proposed system and achieve an optimal balance. These methods include fingerprinting, distance-based approaches, statistical techniques, machine learning, deep learning, etc. Exploring these algorithms will allow for the identification of the most suitable approach within system.

V. CONCLUSION AND FUTURE WORKS

A significant area of study in recent years has been the development of Wi-Fi tracking system driven by the increasing number of smartphone users. People tend to be constantly connected to the internet through various sources, including free Wi-Fi spots. Therefore, there is a growing interest in tracking individuals using the signals emitted by their smartphones. This study focuses on designing, implementing, and demonstrating Wi-Fi Tracker system specifically for indoor crowd monitoring. System comprises two main subsystems, namely, tracker node and the server. To utilize system, users must place a minimum of three tracker nodes in a specific location to establish wireless networks. These tracker nodes serve as wireless sensors that scan smartphone packet request data. Simultaneously, the server and an online dashboard must be prepared to display real-time data. System captures three crucial pieces of information, namely, Received Signal Strength Indicator (RSSI), Media Access Control (MAC) address, and timestamp of the smartphones. These data are then transmitted from tracker node to the server. Once received, the server performs computations on the data, including processing MAC address, timestamp, and RSSI. By implementing a localization algorithm configured through the web-based dashboard, system can predict the location of smartphones and analyze their distribution. The dashboard is accessible through a specific PC using a unique web address.

The primary significance of the described system lies in its ability to capture and analyze MAC addresses and RSSI instances. However, the challenge posed by MAC randomization is an important consideration for future work. Nowadays, most smartphones employ MAC randomization techniques to prevent Wi-Fi tracking. This behavior involves broadcasting a randomized MAC address instead of the actual one, making it challenging to track and identify devices accurately. In practice, this could result in an influx of fake users generated by the same smartphone, particularly in scenarios where two users are close. Addressing this issue and developing strategies to differentiate between genuine and fake users in real-world situations is essential.

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REFERENCES

- [1] L.-P. Tian, L.-Q. Chen, Z.-M. Xu, and Z. (David) Chen, "Wits: An Efficient Wi-Fi Based Indoor Positioning and Tracking System," *Remote Sensing*, vol. 14, no. 1, p. 19, Jan. 2022, doi: 10.3390/rs14010019.
- [2] M. Ribeiro, D. Teixeira, P. Barbosa, and N. J. Nunes, "Using passive Wi-Fi for community crowd sensing during the COVID-19 pandemic," *Journal of Big Data*, vol. 10, no. 1, p. 7, Jan. 2023, doi: 10.1186/s40537-022-00675-3.
- [3] N. Jarvis, J. Hata, N. Wayne, V. Raychoudhury, and M. O. Gani, "MiamiMapper: Crowd Analysis using Active and Passive Indoor Localization through Wi-Fi Probe Monitoring," in *Proceedings of the 15th ACM International Symposium on QoS and Security for Wireless and Mobile Networks*, in Q2SWinet'19. New York, NY, USA: Association for Computing Machinery, Nov. 2019, pp. 1–10. doi: 10.1145/3345837.3355959.
- [4] X. Tang, B. Xiao, and K. Li, "Indoor Crowd Density Estimation Through Mobile Smartphone Wi-Fi Probes," *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, vol. 50, no. 7, pp. 2638–2649, Jul. 2020, doi: 10.1109/TSMC.2018.2824903.
- [5] T. D. Vy, T. L. N. Nguyen, and Y. Shin, "Pedestrian Indoor Localization and Tracking Using Hybrid Wi-Fi/PDR for iPhones," in *2021 IEEE 93rd Vehicular Technology Conference (VTC2021-Spring)*, Helsinki, Finland: IEEE, Apr. 2021, pp. 1–7. doi: 10.1109/VTC2021-Spring51267.2021.9448859.
- [6] A. Hidayat, S. Terabe, and H. Yaginuma, "Bus Passenger Volume and Origin-Destination Based on Field Surveys Using a Wi-Fi Scanner," *Transportation Research Procedia*, vol. 48, pp. 1376–1389, Jan. 2020, doi: 10.1016/j.trpro.2020.08.169.
- [7] A. Hidayat, S. Terabe, and H. Yaginuma, "Estimating bus passenger volume based on a Wi-Fi scanner survey," *Transportation Research Interdisciplinary Perspectives*, vol. 6, p. 100142, Jul. 2020, doi: 10.1016/j.trip.2020.100142.
- [8] D. B. Paradedá, W. K. Junior, and R. C. Carlson, "Bus passenger counts using Wi-Fi signals: some cautionary findings," *TRANSPORTES*, vol. 27, no. 3, pp. 115–130, Nov. 2019, doi: 10.14295/transportes.v27i3.2039.
- [9] S. Ryu, B. B. Park, and S. El-Tawab, "Wi-Fi Sensing System for Monitoring Public Transportation Ridership: A Case Study," *KSCE J Civ Eng*, vol. 24, no. 10, pp. 3092–3104, Oct. 2020, doi: 10.1007/s12205-020-0316-7.
- [10] G. Pipelidis, N. Tsiamitros, M. Kessner, and C. Prehofer, "HuMAN: Human Movement Analytics via Wi-Fi Probes," in *2019 IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops)*, Kyoto, Japan: IEEE, Mar. 2019, pp. 370–372. doi: 10.1109/PERCOMW.2019.8730703.
- [11] D. N. Fernández, "Implementation of a WiFi-based indoor location system on a mobile device for a university area," in *2019 IEEE XXVI International Conference on Electronics, Electrical Engineering and Computing (INTERCON)*, Lima, Peru, Aug. 2019, pp. 1–4. doi: 10.1109/INTERCON.2019.8853556.
- [12] K. S. Chaitra and P. Parimala, "Client Position Detection using Wi-Fi Technology," in *2020 Second International Conference on Inventive Research in Computing Applications (ICIRCA)*, Coimbatore, India: IEEE, Jul. 2020, pp. 620–624. doi: 10.1109/ICIRCA48905.2020.9182890.
- [13] J. Andi3n, J. M. Navarro, G. L3pez, M. 3lvarez-Campana, and J. C. Due3as, "Smart Behavioral Analytics over a Low-Cost IoT Wi-Fi Tracking Real Deployment," *Wireless Communications and Mobile Computing*, vol. 2018, p. e3136471, Dec. 2018, doi: 10.1155/2018/3136471.
- [14] Y. Zeng, P. H. Pathak, and P. Mohapatra, "Analyzing Shopper's Behavior through Wi-Fi Signals," in *Proceedings of the 2nd Workshop on Workshop on Physical Analytics, in WPA '15*. New York, NY, USA: Association for Computing Machinery, May 2015, pp. 13–18. doi: 10.1145/2753497.2753508.

- [15] A. Hidayat, S. Terabe, and H. Yaginuma, "Mapping of MAC Address with Moving Wi-Fi Scanner," *International Journal of Artificial Intelligence Research*, vol. 1, no. 2, pp. 34–40, Oct. 2017, doi: 10.29099/ijair.v1i2.27.
- [16] Y. Wang, B. Zhao, and Z. Jiang, "RSSI-Based Smooth Localization for Indoor Environment," *The Scientific World Journal*, vol. 2014, p. e639142, Jun. 2014, doi: 10.1155/2014/639142.
- [17] F. Potorti, A. Crivello, M. Girolami, P. Barsocchi, and E. Traficante, "Localising crowds through Wi-Fi probes," *Ad Hoc Networks*, vol. 75–76, pp. 87–97, Jun. 2018, doi: 10.1016/j.adhoc.2018.03.011.
- [18] S. Fuada et al., "Your MAC Address Can be Detected Easily When Your Smartphone Connected to the Wi-Fi," *International Journal of Interactive Mobile Technologies (IJIM)*, vol. 15, no. 07, pp. 176–184, Apr. 2021.
- [19] Y. Li, J. Barthelemy, S. Sun, P. Perez, and B. Moran, "A Case Study of Wi-Fi Sniffing Performance Evaluation," *IEEE Access*, vol. 8, pp. 129224–129235, 2020, doi: 10.1109/ACCESS.2020.3008533.
- [20] M. Cunche, "I know your MAC address: targeted tracking of individual using Wi-Fi," *J Comput Virol Hack Tech*, vol. 10, no. 4, pp. 219–227, Nov. 2014, doi: 10.1007/s11416-013-0196-1.
- [21] S. Fuada, T. Adiono, and P. Prasetyo, "Accuracy Improvement of RSSI-based Distance Localization using Unscented Kalman Filter (UKF) Algorithm for Wi-Fi Tracking Application," *International Journal of Interactive Mobile Technologies (IJIM)*, vol. 14, no. 16, pp. 225–233, Sep. 2020.
- [22] S. Fuada, T. Adiono, P. -, and H. Widhanto, "Modelling an Indoor Crowd Monitoring System based on RSSI-based Distance," *IJACSA*, vol. 11, no. 1, 2020, doi: 10.14569/IJACSA.2020.0110181.
- [23] Y. Sung, "RSSI-Based Distance Estimation Framework Using a Kalman Filter for Sustainable Indoor Computing Environments," *Sustainability*, vol. 8, no. 11, p. 1136, Nov. 2016, doi: 10.3390/su8111136.
- [24] C. Matte and M. Cunche, "DEMO: Panoptiphone: How Unique is Your Wi-Fi Device?," in *Proceedings of the 9th ACM Conference on Security & Privacy in Wireless and Mobile Networks*, in *WiSec '16*. New York, NY, USA: Association for Computing Machinery, Jul. 2016, pp. 209–211. doi: 10.1145/2939918.2942417.
- [25] S. Jain, E. Bensaïd, and Y.-A. de Montjoye, "UNVEIL: Capture and Visualise Wi-Fi Data Leakages," in *The World Wide Web Conference*, in *WWW '19*. New York, NY, USA: Association for Computing Machinery, May 2019, pp. 3550–3554. doi: 10.1145/3308558.3314143.
- [26] H. Hong, G. D. De Silva, and M. C. Chan, "CrowdProbe: Non-invasive Crowd Monitoring with Wi-Fi Probe," *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.*, vol. 2, no. 3, p. 115:1–115:23, Sep. 2018, doi: 10.1145/3264925.
- [27] Y. Xie, J. Xiong, M. Li, and K. Jamieson, "mD-Track: Leveraging Multi-Dimensionality for Passive Indoor Wi-Fi Tracking," in *The 25th Annual International Conference on Mobile Computing and Networking*, in *MobiCom '19*. New York, NY, USA: Association for Computing Machinery, Aug. 2019, pp. 1–16. doi: 10.1145/3300061.3300133.
- [28] K. Qian, C. Wu, Y. Zhang, G. Zhang, Z. Yang, and Y. Liu, "Widar2.0: Passive Human Tracking with a Single Wi-Fi Link," in *Proceedings of the 16th Annual International Conference on Mobile Systems, Applications, and Services*, in *MobiSys '18*. New York, NY, USA: Association for Computing Machinery, Jun. 2018, pp. 350–361. doi: 10.1145/3210240.3210314.
- [29] X. Li et al., "IndoTrack: Device-Free Indoor Human Tracking with Commodity Wi-Fi," *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.*, vol. 1, no. 3, p. 72:1–72:22, Sep. 2017, doi: 10.1145/3130940.
- [30] N. Nunes, M. Ribeiro, C. Prandi, and V. Nisi, "Beanstalk: a community based passive Wi-Fi tracking system for analysing tourism dynamics," in *Proceedings of the ACM SIGCHI Symposium on Engineering Interactive Computing Systems*, in *EICS '17*. New York, NY, USA: Association for Computing Machinery, Jun. 2017, pp. 93–98. doi: 10.1145/3102113.3102142.
- [31] K. Li, C. Yuen, and S. Kanhere, "SenseFlow: An Experimental Study of People Tracking," in *Proceedings of the 6th ACM Workshop on Real World Wireless Sensor Networks*, in *RealWSN '15*. New York, NY, USA: Association for Computing Machinery, Nov. 2015, pp. 31–34. doi: 10.1145/2820990.2820994.
- [32] Y. Jiang et al., "ARIEL: automatic Wi-Fi based room fingerprinting for indoor localization," in *Proceedings of the 2012 ACM Conference on Ubiquitous Computing*, in *UbiComp '12*. New York, NY, USA: Association for Computing Machinery, Sep. 2012, pp. 441–450. doi: 10.1145/2370216.2370282.
- [33] J. Scheuner et al., "Probr - A Generic and Passive Wi-Fi Tracking System," in *2016 IEEE 41st Conference on Local Computer Networks (LCN)*, Dubai, United Arab Emirates, Nov. 2016, pp. 495–502. doi: 10.1109/LCN.2016.30.
- [34] A. Fernández-Ares et al., "Studying real traffic and mobility scenarios for a Smart City using a new monitoring and tracking system," *Future Generation Computer Systems*, vol. 76, pp. 163–179, Nov. 2017, doi: 10.1016/j.future.2016.11.021.
- [35] A. E. C. Redondi and M. Cesana, "Building up knowledge through passive Wi-Fi probes," *Computer Communications*, vol. 117, pp. 1–12, Feb. 2018, doi: 10.1016/j.comcom.2017.12.012.
- [36] T. Adiono et al., "Prototyping design of IR remote controller for smart home applications," in *TENCON 2017 - 2017 IEEE Region 10 Conference*, Penang, Malaysia: IEEE, Nov. 2017, pp. 1304–1308. doi: 10.1109/TENCON.2017.8228059.
- [37] T. Adiono, M. Y. Fathany, S. Fuada, I. G. Purwanda, and S. F. Anindya, "A portable node of humidity and temperature sensor for indoor environment monitoring," in *2018 3rd International Conference on Intelligent Green Building and Smart Grid (IGBSG)*, Yi-Lan: IEEE, Apr. 2018, pp. 1–5. doi: 10.1109/IGBSG.2018.8393575.
- [38] S. Fuada, A. Alfaruq, and T. Adiono, "A Portable Electronic Transaction Device Based on Dual Interface Smart Card," *International Journal of Online and Biomedical Engineering (iJOE)*, vol. 16, no. 03, pp. 27–45, Mar. 2020.
- [39] T. Adiono, M. Y. Fathany, S. Feranti Anindya, S. Fuada, and I. G. Purwanda, "Using A Smart Plug based on Consumer Electronics to Support Low Power Smart Home," in *2019 4th International Conference on Intelligent Green Building and Smart Grid (IGBSG)*, Hubei, Yichang, China: IEEE, Sep. 2019, pp. 376–379. doi: 10.1109/IGBSG.2019.8886272.
- [40] M. B. Yassein, M. Q. Shatnawi, S. Aljwarneh, and R. Al-Hatmi, "Internet of Things: Survey and open issues of MQTT protocol," in *2017 International Conference on Engineering MIS (ICEMIS)*, Monastir, Tunisia: IEEE, May 2017, pp. 1–6. doi: 10.1109/ICEMIS.2017.8273112.
- [41] S. Krajjak and P. Tuwanut, "A survey on internet of things architecture, protocols, possible applications, security, privacy, real-world implementation and future trends," in *2015 IEEE 16th International Conference on Communication Technology (ICCT)*, Hangzhou, China: IEEE, Oct. 2015, pp. 26–31. doi: 10.1109/ICCT.2015.7399787.
- [42] R. S. Campos, L. Lovisolo, and M. L. R. de Campos, "Wi-Fi multi-floor indoor positioning considering architectural aspects and controlled computational complexity," *Expert Systems with Applications*, vol. 41, no. 14, pp. 6211–6223, Oct. 2014, doi: 10.1016/j.eswa.2014.04.011.
- [43] S. Xia, Y. Liu, G. Yuan, M. Zhu, and Z. Wang, "Indoor Fingerprint Positioning Based on Wi-Fi: An Overview," *ISPRS International Journal of Geo-Information*, vol. 6, no. 5, p. 135, May 2017, doi: 10.3390/ijgi6050135.

A Knowledge Based Framework for Cardiovascular Disease Prediction

Abha Marathe, Dr. Virendra Shete, Dr. Dhananjay Upasani

Department of Electronics and Telecommunication Engineering, MIT School of Engineering and Sciences, Pune, India

Abstract—Cardiovascular disease has become more concern in the hectic and stressful life of modern era. Machine learning techniques are becoming reliable in medical treatment to help the doctors. But the ML algorithms are sensitive to data sets. Hence a Smart Robust Predictive System is almost essential which can work efficiently on all data sets. The study proposes ensemble classifier validating its performance on five different data sets- Cleveland, Hungarian, Long Beach, Statlog and Combined datasets. The developed model deals with missing values and outliers. Synthetic Minority Oversampling Technique (SMOTE) was used to resolve the class imbalance issue. In this study, performance of five individual classifiers – Support Vector Machine Radial (SVM-R), Logistic Regression (LR), Naïve Bayes (NB), Random Forest (RF) and XGBoost, was compared with five ensemble classifiers on five different data sets. On each data set the top three performers were identified and were combined to give ensemble classifiers. Thus, in all total 25 experimentation were done. The results have shown that out of all classifiers implemented, the proposed system outperforms on all the data sets. The performance was validated by 10-fold cross validation. The proposed system gives the highest accuracy and sensitivity of 87% and 86% respectively.

Keywords—Machine learning; ensemble classifier; cardiovascular disease; performance metrics; classifier techniques

I. INTRODUCTION

The urbanization of the population in the world resulted in the increase in the urban population from 37% in 1970 to the projected 61% in 2025[1]. One of the major impacts of such lifestyle is cardiovascular disease-CVD. According to WHO [2] 17.9 million people died in 2019 because of CVD which is nearly 32% of world-wide deaths. For predicting the CVD risk, different traditional risk calculators are used. They assign certain weights to the risk factors and calculate the risk scores. But these calculators have limitation that they are population specific as certain population was considered in the respective cohort study. Also, the risk factors considered are different for different calculators. The decisions given by these calculators differ on the same population [3], hence they are not consistent as well. Therefore, designing a robust system which is applicable for all type of population is the need of the hour. This can be done with the help of ever evolving and reliable sophisticated machine learning and deep learning approaches. Because of manual constraints, many modern age researchers moved towards these approaches. These algorithms are sensitive to data sets. The literature surveyed has revealed that for all different dataset different machine learning techniques were found to be different. The objective of the study is to propose a novel robust algorithm which works on diverse

dataset efficiently. This proposed algorithm is a uniquely developed ensemble classifier of three individual classifiers Random Forest, Support Vector Machine Radial and XGBoost. The performance was validated on five different datasets to prove its consistency.

The paper is divided into six sections. Besides Introduction, Section II discusses about the work done till date, Section III focuses on the proposed system, Section IV contains different evaluation parameters used for classifier performance, Section V reveals the results and their discussions and the last Section VI is the conclusion and future scope of the study.

II. RELATED WORK

In past few decades many Machine learning techniques have been used for prediction of heart disease. Many studies involved the comparison of traditional CVD risk calculators with different Machine learning algorithms. Many studies of heart disease prediction used cohort data set. The comparison of traditional CVD risk calculator models with different machine learning models[4] used nearly 30000 subjects from eastern China who were having high risk of CVD for 3-year risk assessment. Random forest was found to be the best with AUC of 0.787. Similarly, in the other study from Korea 4699 subjects were extracted from Korean National Health Insurance Service Health Screening Database. Out of all the 10 ML algorithms applied, XGBoost, Gradient Boost (GB) and RF with AUC nearly 0.81 performed even better than the existing risk models- Framingham and ACC/AHA American College of Cardiology /American Heart Association risk model [5]. Another cohort study based on same population compared the Pooled cohort equations, Framingham risk model and QRISK3 model with different machine learning algorithms. Neural network was found to have highest C-statistics of 0.751[6]. Another study from Athens, Greece which used 10 years of follow up compared the machine learning techniques with statistical approach of Hellenic Score. The Random Forest algorithm gave the best results [7]. One more study where electronically recorded data by UK National Health Service (NHS) was used. The performance was validated by Harrell's c-statistic. The traditional ACC/AHA model was compared with different ML algorithms like Random Forest, Logistic Regression, Gradient Boosting and Neural Networks. AUC-c statistics was found to be best for Neural network with 0.764 value.[8]. Another cohort study from UK compared the Framingham model, Cox proportional Hazard model and ML algorithms like SVM, RF, NN, AdaBoost, Gradient boosting and Auto prognosis-advanced Bayesian optimization technique to predict the

CVD. The missing values were addressed by Miss Forest algorithm. Auto prognosis performed best out of all the techniques compared [9]. Cohort study for CVD prediction was carried out in Northern California with 32192 patients. Atherosclerotic CVD i.e. ACVD patients were also included in the study. The machine learning algorithms like RF, GBM, XGBoost and logistic regression were compared. XGBoost demonstrated highest AUC 0.70 (95% CI 0.68 to 0.71) in the full CVD cohort and AUC 0.71 (95% CI 0.69 to 0.73) in patients with ASCVD, with comparable performance by GBM, RF and Regression [10]. Apart from cohort studies many researchers used the data sets which are directly provided by the data providers like Cleveland, Hungarian, long Beach, Switzerland, Statlog etc. These data sets are available on UC Irvine Machine learning Repository. There are 76 attributes out of which most relevant 14 attributes are provided by the data providers. Machine learning algorithms are very much sensitive to data sets. To get high efficiency and reliability the data sets need to be properly formed. Before implementing any algorithm, data preprocessing is a must. Data Preprocessing includes steps of data cleaning like addressing the missing values, identifying the outliers, checking for duplicate records etc. In many real-life problems data imbalance is a major challenge in front of the researchers. Specifically, for a medical study like disease detection the data points with one class i.e., normal, and healthy person is more as compared to the patient suffering from a particular disease. This results in class imbalance. Hence before application of any algorithm balancing the data by addressing this data skew becomes a need. Such data preprocessing seen in different studies often leads in better results. In [11] Cleveland data set which is most widely used data set was used for prediction of heart disease. The authors generated artificial records in 5%, 10%, 20% and 50%. They proposed a data duplicate finder algorithm which removes the duplicates in the record. The decision tree C5.0 was used as a classifier which gives the better results for the data set without duplicates as compared to with duplicates. Like the duplicate records, the missing values and outliers are very crucial to handle. These missing values can be either removed with no information loss or can be imputed. In [12], the missing values were imputed by Mean whereas the outliers were identified by Boxplot and were removed. The class imbalance problem was solved by SMOTE technique. Such imbalance in the data set of Framingham data set was balanced by Random Oversampling examples in [13]. The AUC was used as a performance metrics. It reported the maximum achieved AUC by SVM of 0.75. Like the imbalance data set where the number of instances is required to be balanced, the number and the relevance of the attributes is also very important in any predictive system. Addition of irrelevant features in the dataset may misguide the model, hence identification of important attributes and their inclusion in the model is very important. Ample studies are done where different techniques of feature selections and their role in improving the performance of the model are discussed. In [14] different classifiers like Linear Discriminant Analysis-LDA, Decision tree (DT), SVM, GB and RF were used. For feature selection sequential feature selection (SFS) was used. Use of SFS reduces the number of features and hence optimizes

computation time. It was found that for Hungary, Switzerland & Long Beach V and Heart Statlog Cleveland Hungary Datasets, Random Forest Classifier SFS and Decision Tree Classifier SFS achieved the highest accuracy ratings of 100%, 99.40% and 100%, 99.76% respectively. There are other feature selection methods like Fast Correlation-Based Filter Solution (FCBF), minimal redundancy maximal relevance (mRMR), Least Absolute Shrinkage and Selection operator (LASSO), and Relief which were used in [15]. It has used 10 ML algorithms and indicated the best algorithm for feature selection method. Extra tree (ET) classifier was found to be superior amongst all. Accuracy of top performer ET and GB found to be 92.09% and 91.34% when all attributes were considered. With relief feature selection algorithm, the accuracy of ET increased from 92.09% to 94.41% whereas for GB the increase was from 91.34% to 93.36% when FCBF feature selection was applied. Another study used the feature selection methods like Relief Feature selection technique and least absolute shrinkage and selection operator algorithm (LASSO) [16]. The data set contained 13 attributes out of which Random Forest bagging method (RFBM) identified most relevant 10 features and accuracy achieved with this was 99.05%. Addition to these traditional feature selection methods, [17] proposed fast conditional mutual information (FCMIM) technique which is based on selection of features on the basis of features mutual information. The combination of SVM-FCMIM gave the highest accuracy of 92.37%. In [18] the heart disease prediction was carried out by dimension reduction method. PCA and Chi-square analysis with Random Forest shown the best performer with 98.7% accuracy. When weak performers are combined, a strong predictive system can be generated. These are called as Ensembled classifiers. Researchers have experimented with different ensemble classifiers and comparison made with individual classifiers. Studies like [19] weighted majority voting ensemble was used. The weights assigned to the individual classifiers' votes were decided as per their AUC values. The results observed were that this ensembled classifier performed best with AUC value of 83.9 for with laboratory parameters and 83.1 without laboratory parameters. There are three different types of ensemble techniques, Bagging, Boosting and Stacking. In [20] all these techniques along with majority voting were used. With bagging technique, the accuracy improved by 6.92%, with boosting this improvement was found to be by 5.94%, with stacking it improved by 6.93% whereas the highest improvement was observed by majority voting which was 7.26%.

III. PROPOSED SYSTEM

This study proposes five different ensembled classifiers- E₁, E₂, E₃, E₄ and E₅. The composition of these ensembled classifiers is detailed later. The entire work done was divided into four main phases:

- Phase 1: Five different individual classifiers were trained, tested and validated by five different data sets.
- Phase 2: These classifiers were used to construct the five proposed ensemble classifiers.

- Phase 3: These ensembled classifiers were trained, tested and validated by all data sets.
- Phase 4: The individual and the ensembles were compared with different performance metrics and conclusions were drawn.

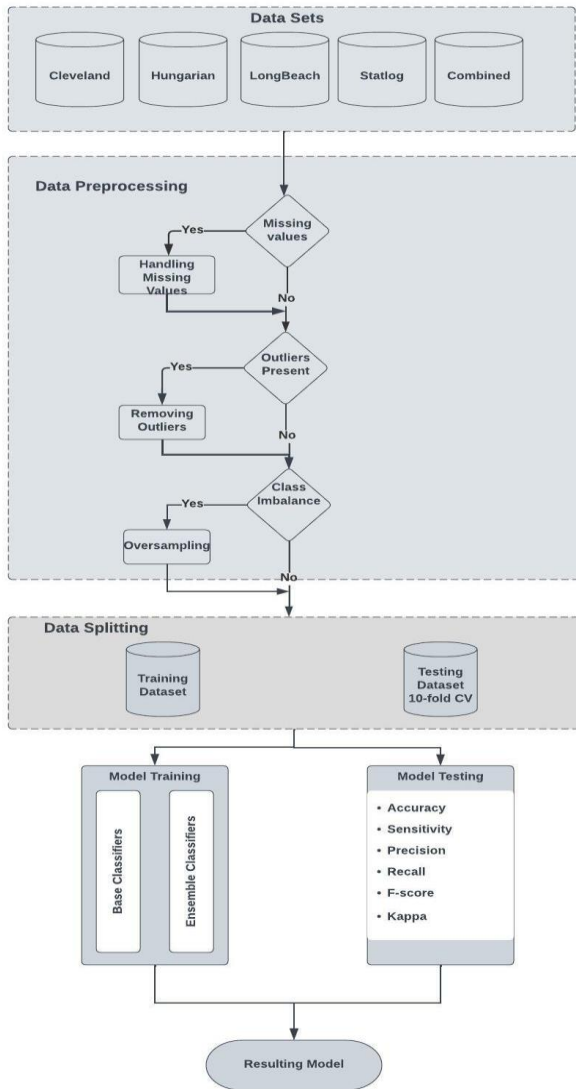


Fig. 1. Proposed system.

The entire system is depicted in Fig. 1. R programming language with R-studio as its IDE is used for this study.

A. Data Set Description

Five different datasets were used for this study-Cleveland, Hungarian, Long Beach, Statlog and Combined datasets taken from UCI Machine Learning repository [21,22]. The Cleveland data set is most used data set by all researchers working on heart diseases. In actual it consists of total 76 attributes, but out of them only 14 are more accurate and are widely used and given by data set provider. The number of instances is 303 with 13 predictors and one response variable. Here the target variable is represented as “num”, where 1

stand for presence of heart disease whereas 0 represents absence of heart disease. Similarly, the other data sets are Hungarian dataset with 294 instances, Long Beach Dataset with 200 instances, Statlog Data set contains 270 instances with same attributes and combination of all datasets with 797 instances.

B. Data Preprocessing

Data cleaning is an important task in any machine learning problem. The quality of data becomes more crucial in medicine area [23]. Data cleaning in this study was done by finding missing values, finding outliers and checking and class imbalance problem. The missing values were removed without loss of information. In second step the outliers were checked and were removed from the data set. Third step was for checking the class imbalance in data set. It happens if there are a greater number of samples belonging to one class as compared to other class which may result into biased classifier. Many methods are presented by different researchers to tackle this problem [24]. In this paper, this issue was addressed by Synthetic Minority Oversampling Technique, i.e., SMOTE.

C. Synthetic Minority Oversampling Technique-SMOTE.

In this method minority class is oversampled by creating Synthetic examples unlike oversampling which generates the duplicate data points [25]. It uses the KNN algorithm to generate these synthetic points. A random sample from minority class is selected. Then one sample from K neighbor is selected and the distance vector between this selected point and current data point is calculated and further multiplied by any random number between 0 to 1. This is then added to current point and synthetic data point is created. Class imbalance was found in Hungarian and Long Beach Data sets. SMOTE technique was used to solve this issue in these two data sets.

D. Proposed Ensemble Classifiers

The study proposes five different ensembled classifiers as discussed below:

E₁: It was designed by combining all the base classifiers. Majority voting scheme was used for the prediction. All the five classifiers were considered for voting with same importance. The class label w was predicted by the decision given by each classifier C_i for every feature vector x as given in (1). Mode indicates majority as per usual statistical meaning.

$$w = \text{mode}\{\text{decisions}(C_1(x), C_2(x), \dots, C_m(x))\} \quad (1)$$

E₂: This ensemble classifier was based on the baseline accuracy of individual classifier. The classifier with highest accuracy was assigned with more weight. This assigned value of weight was then used as a multiplier for the prediction probability of the respective classifier. For a given feature vector x , depending on the probability of the label class the final decision was taken. The weight of the individual classifier was calculated as given in (2).

$$W_i = \frac{A_i}{\sum_i^m A} \quad (2)$$

TABLE I. TOP THREE PERFORMERS

Data Sets	Classifiers				
	RF	NB	SVM-R	LR	XgBoost
Cleveland	✓		✓		✓
Hungarian	✓	✓			✓
Long Beach	✓		✓		✓
Statlog		✓	✓		✓
Combined	✓		✓		✓

Where

A_i : Accuracy of individual Classifier

m : Number of classifiers used

W_i : Weight of individual Classifier

The final prediction probability for each class label is calculated as in (3).

$$p = \sum_i^m (W_i * A_i) \quad (3)$$

The class label having highest probability for a given feature vector was assigned to that vector. All the classifiers are considered in this voting scheme.

Total datasets considered for this study are five. All five individual classifiers were applied to all five datasets. Thus total 25 individual experimentations were done. Then for each data set top three performing classifiers based on their accuracies were identified. The top three classifiers for individual datasets are given in Table I.

Thus, three following different unique combinations of classifiers emerge which were considered for further experimentation.

E_3 : It was the first combination RF+SVM-R+XgBoost. These three classifiers were used for majority voting. Label class w was assigned for a given feature vector given in (4).

$$w = mode\{Decisions(RF, SVM - R, XgBoost)\} \quad (4)$$

e.g., let for any feature vector x , the decisions are as- RF: Class 0, SVM-R: Class 0, XgBoost: Class1. Then the final decision was taken as in (5).

$$w = mode\{0,0,1\} \Rightarrow w = 0: Class 0 \quad (5)$$

E_4 : This was the second unique combination of RF+NB+XgBoost. These three classifiers were used for majority voting. Label class w was assigned for a given feature vector as shown in (6).

$$w = mode\{Decisions(RF, NB, XgBoost)\} \quad (6)$$

E_5 : This was the third unique combination of RF+SVM+XgBoost. These three classifiers were used for majority voting. Label class w was assigned for a given feature vector as in (7).

$$w = mode\{Decisions(NB, SVM, XgBoost)\} \quad (7)$$

The different ensembles are depicted in Fig. 2.

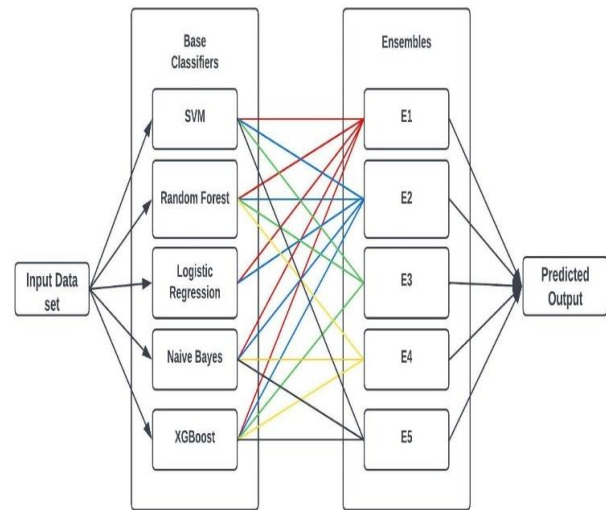


Fig. 2. Construction of ensemble classifier.

IV. EVALUATION PARAMETERS

The evaluation of performance of all the classifiers i.e., individual and ensemble were done by creating an error matrix or Confusion matrix specified in Table II. It shows four different notations True Positive TP these are the patients who are suffering from CVD and the algorithm also predicts the same. The number FN is False negative which shows that these many patients are suffering from disease but they are predicted as they are not suffering. This number needs to be less and costs more in medical studies. False positive FP indicates the number of patients not suffering from disease but identified as they are suffering. True negative refers to the true classification of normal patients. The performance of any classifier is characterized by values of FP and FN. These metrics are discussed below:

TABLE II. CONFUSION MATRIX

		Predicted	
		Positive	Negative
Actual	Positive	TP	FN
	Negative	FP	TN

Accuracy: It is the ratio of total true predictions to total number. It is given by (8)

$$Accuracy = \frac{(TP+TN)}{(TP+FP+FN+TN)} \quad (8)$$

Sensitivity: It is also called as true positive rate. It is the ratio of positive number classified correctly to the total positive instances. It is given by (9).

$$Sensitivity = \frac{(TP)}{(TP+FN)} \quad (9)$$

Specificity: It is defined as true negative rate. It is the ratio of measures of negative number classified correctly to the total negative instances. It is given by (10).

$$Specificity = \frac{(TN)}{(TN+FP)} \quad (10)$$

Precision: It is also known as positive predictive value. It is the ration of proportion of positive number classified correctly to total predicted positive. It is given by (11).

$$Precision = \frac{(TP)}{(TP+FP)} \quad (11)$$

F-measure: It is a measure of model performance that combines precision and recall into single number. It is given by (12).

$$Fmeasure = \frac{(2*Precision*Recall)}{(Recall+Precision)} \quad (12)$$

Kappa: It is the measure which accounts for correct classification due to chance

If $K > 0$: Classification is better than chance classification.

$K < 0$: Classification is not better than chance Classification.

$K = 1$: Perfect Classification.

$K = 0$: Pure chance classification.

V. RESULTS AND DISCUSSIONS

An elaborated discussion of the different results obtained for individual and ensemble classifiers is given below. The various performance metrics are compared and conclusions are drawn. The performance validation of all the models was done by 10-fold cross validation.

A. With Individual Models

The five different individual classifiers- RF, SVM, NB, LR and XGBoost were first applied on all the five data sets. For each data set the top performers based on different performance parameters were identified. On Cleveland data set, XGBoost was observed to be the best performer in terms of accuracy with 87.78% value, followed by RF and SVM-R with 84.44% and 83% of accuracy. Same is true for other performance metric like Specificity and Precision. Though the sensitivity of LR is highest amongst all, but it lags in the other parameters. Hence for Cleveland data set, the top three performers are considered as XGBoost, RF and SVM-R. The performance is given in Table III. For Hungarian data set, XGBoost, RF and NB comes out to be the top 3 performers with 91.26%, 90.29% and 86.41% of accuracy. These models also head in the important parameter i.e., Sensitivity with values 94.5%, 89.47% and 90.20%, Table IV shows the comparison. For the third data set which is Long Beach dataset, SVM Radial performs best with accuracy 88.64%. It also leads in the other parameters like Sensitivity, Specificity and Precision as well. The second topper is XGBoost and RF. Therefore, the top three identified classifiers for Long Beach Data Set are XGBoost, RF and SVM-RBF, shown in Table V. The next data set was Statlog data set. The findings depict that, XGBoost, SVM-R, NB and are top three classifiers. Their accuracy values are 86.42%, 86.42% and 85.19% respectively. The parameters are compared in Table VI.

The last data set considered was Combined data set. It was found that RF performed best from all models with highest accuracy of 89.06%. The next followers were observed as XGBoost and SVM-R. These three classifiers were toppers in the performance parameters like Sensitivity, Specificity and Precision as well apart from accuracy. This is shown in Table VII. Thus, for Cleveland, Hungarian and Statlog dataset it is XGBoost which is best performer in terms of accuracy whereas for Long Beach it is SVM-R and for Combined data set it is Random Forest. The performance parameters averaged on all dataset for all individual classifier is shown in Table VIII.

TABLE III. PERFORMANCE COMPARISON ON CLEVELAND DATA SET

Techniques	Accuracy	Sensitivity	Specificity	Precision	F Measure	Kappa
RF	84.44	82.05	86.27	82.05	82.05	0.68
NB	82.22	79.49	84.31	79.49	79.49	0.64
SVM-RBF	83.33	80.0	86.0	82.05	81.01	0.66
LR	82.22	84.85	80.70	71.79	77.78	0.63
Xgboost	87.78	82.05	92.16	88.89	85.33	0.75

TABLE IV. PERFORMANCE COMPARISON ON HUNGARIAN DATA SET

Techniques	Accuracy	Sensitivity	Specificity	Precision	F Measure	Kappa
RF	90.29	89.47	91.3	92.73	91.07	0.81
NB	86.41	90.20	82.69	83.64	86.80	0.73
SVM-RBF	79.61	79.31	80.0	83.64	81.42	0.59
LR	81.55	80.0	83.72	87.27	83.48	0.63
Xgboost	91.26	94.5	87.5	89.66	92.02	0.82

TABLE V. PERFORMANCE COMPARISON ON LONG BEACH DATA SET

Techniques	Accuracy	Sensitivity	Specificity	Precision	F Measure	Kappa
RF	81.82	85.0	79.17	77.27	80.95	0.64
NB	79.55	84.21	76.0	72.73	78.05	0.59
SVM-RBF	88.64	90.48	86.96	86.36	88.37	0.77
LR	79.55	88.24	74.07	68.18	76.92	0.59
Xgboost	84.09	81.82	86.36	85.71	83.72	0.68

TABLE VI. PERFORMANCE COMPARISON ON STATLOG DATA SET

Techniques	Accuracy	Sensitivity	Specificity	Precision	F Measure	Kappa
RF	83.95	81.08	86.36	83.33	82.19	0.67
NB	85.19	78.57	92.31	91.67	84.62	0.70
SVM-RBF	86.42	82.05	90.48	88.89	85.33	0.72
LR	82.72	78.95	86.05	83.33	81.08	0.65
Xgboost	86.42	86.11	86.67	83.78	84.93	0.73

TABLE VII. PERFORMANCE COMPARISON ON COMBINED DATA SET

Techniques	Accuracy	Sensitivity	Specificity	Precision	F Measure	Kappa
RF	89.06	85.81	92.12	91.10	88.38	0.78
NB	82.19	81.12	83.05	79.45	80.28	0.64
SVM-RBF	85.31	83.67	86.71	84.25	83.96	0.70
LR	81.25	80.28	82.02	78.08	79.16	0.62
Xgboost	84.06	82.19	85.63	82.76	82.47	0.68

TABLE VIII. AVERAGE PERFORMANCE COMPARISON ON ALL DATA SETS OF INDIVIDUALS

Techniques	Accuracy	Sensitivity	Specificity	Precision	F Measure	Kappa
RF	85.91	84.68	87.04	85.29	84.92	0.72
NB	83.11	82.71	83.67	81.39	81.84	0.66
SVM-RBF	84.66	83.10	86.03	85.03	84.01	0.69
LR	81.45	82.46	81.31	77.73	79.68	0.62
Xgboost	86.72	85.33	87.66	86.16	85.69	0.73

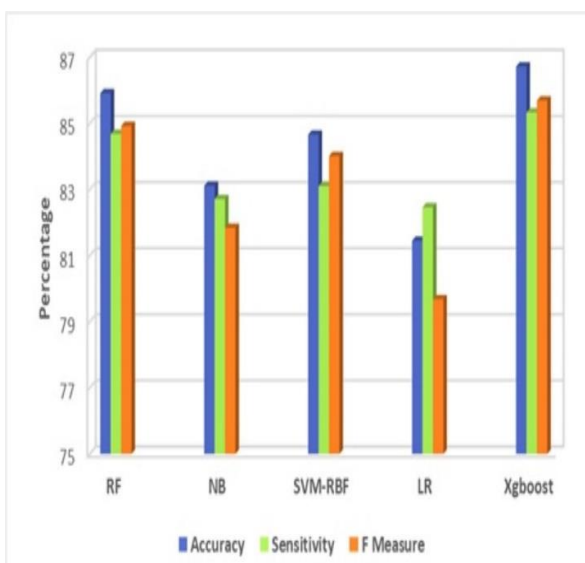


Fig. 3. Performance comparison of individual classifier.

Fig. 3 shows the performance of individual classifiers. The parameters taken for graphical representations are Accuracy, Sensitivity and F measure.

B. With Ensemble Classifiers

After applying individual models for all data sets, ensemble classifiers were designed based on Majority Voting and Weighted Voting. Firstly, all individual classifiers were considered for voting with same importance which forms Ensemble E1. Then the weighted voting was considered with all models with assigned weight as per the accuracy. This gave second ensemble E2. The next three ensemble were E3, E4 and E5, emerged as the top three performers for all five data sets. It was observed that out of all ensembles, E3 performs best with highest accuracy of 88.89% accuracy and 87.18% sensitivity on Cleveland data set and with 90.29% Accuracy and 89.47% Sensitivity for Hungarian Data set, refer Table IX and Table X respectively. Similarly, for Statlog data set as well, E3 is best performer with Accuracy 86.42% and Sensitivity 83.78%, as given in Table XI.

For Long Beach data set, E5 leads with 88.64% accuracy and sensitivity 90.48%. shown in Table XII. For Combined data set it is E4 which has highest accuracy of 86.88% and sensitivity of 85.62% amongst all ensembles shown in Table XIII. The values of different performance parameters of all ensembles averaged on all data sets are shown in Table XIV. Out of all ensembled classifier, the proposed ensemble classifier i.e., E3 is observed to have highest accuracy, sensitivity, F measure and Kappa values the best ensemble classifier. The graphical information in Fig 4, shows that E3 has highest Accuracy, Sensitivity and F-measure amongst all Ensembles. When all individual and all ensemble classifiers were compared on their average values of all data sets, proposed ensemble E3 was found to be the best amongst all with highest accuracy, sensitivity, F- measure, and high Kappa values as given in Fig 5.

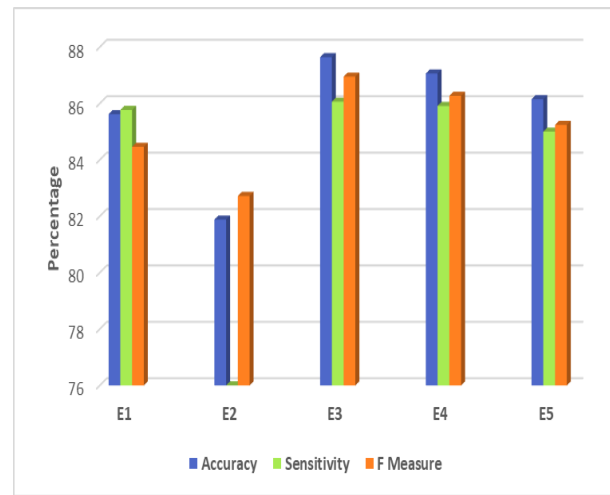


Fig. 4. Performance comparison of ensembles.

TABLE IX. PERFORMANCE COMPARISON OF ENSEMBLES ON CLEVELAND DATA SET

Techniques	Accuracy	Sensitivity	Specificity	Precision	F Measure	Kappa
E1	85.56	84.21	86.54	82.05	83.12	0.71
E2	81.11	72.92	90.48	89.74	80.46	0.63
E3	88.89	87.18	90.20	87.18	87.18	0.77
E4	88.89	87.18	90.20	87.18	87.18	0.77
E5	83.33	80.0	86.0	82.05	81.01	0.66

TABLE X. PERFORMANCE COMPARISON OF ENSEMBLES ON HUNGARIAN DATASET

Techniques	Accuracy	Sensitivity	Specificity	Precision	F Measure	Kappa
E1	87.38	87.50	87.23	89.09	88.29	0.76
E2	82.52	76.81	94.12	96.36	85.48	0.64
E3	90.29	89.47	91.30	92.73	91.07	0.80
E4	90.29	89.47	91.30	92.73	91.07	0.80
E5	87.38	88.89	85.71	87.27	88.07	0.78

TABLE XI. PERFORMANCE COMPARISON OF ENSEMBLES ON STATLOG DATASET

Techniques	Accuracy	Sensitivity	Specificity	Precision	F Measure	Kappa
E1	86.42	83.78	88.64	86.11	84.93	0.73
E2	81.48	71.43	96.88	97.22	82.35	0.64
E3	86.42	83.78	88.64	86.11	84.93	0.73
E4	85.19	81.58	88.37	86.11	83.78	0.70
E5	86.42	82.05	90.48	88.89	85.33	0.73

TABLE XII. PERFORMANCE COMPARISON OF ENSEMBLES ON LONG BEACH DATASET

Techniques	Accuracy	Sensitivity	Specificity	Precision	F Measure	Kappa
E1	84.09	89.47	80.0	77.27	82.92	0.68
E2	81.82	79.17	85.0	86.36	82.61	0.64
E3	86.36	86.36	86.36	86.36	86.36	0.73
E4	84.09	85.71	82.61	81.82	83.72	0.68
E5	88.64	90.48	86.96	86.36	88.37	0.77

TABLE XIII. PERFORMANCE COMPARISON OF ENSEMBLES ON COMBINED DATASET

Techniques	Accuracy	Sensitivity	Specificity	Precision	F Measure	Kappa
E1	84.69	83.92	85.31	82.19	83.05	0.69
E2	82.5	75.28	91.55	91.78	82.72	0.65
E3	86.25	83.55	88.69	86.99	85.24	0.72
E4	86.88	85.62	87.93	85.62	85.62	0.74
E5	85.0	84.03	85.80	82.88	83.45	0.69

TABLE XIV. AVERAGE PERFORMANCE COMPARISON ON ALL DATA SETS OF ENSEMBLES

Techniques	Accuracy	Sensitivity	Specificity	Precision	F Measure	Kappa
E1	85.62	85.77	85.54	83.34	84.46	0.71
E2	81.88	75.12	91.60	92.29	82.72	0.64
E3	87.64	86.06	89.03	87.87	86.95	0.75
E4	87.06	85.91	88.08	86.69	86.27	0.74
E5	86.15	85.0	86.99	85.49	85.24	0.57

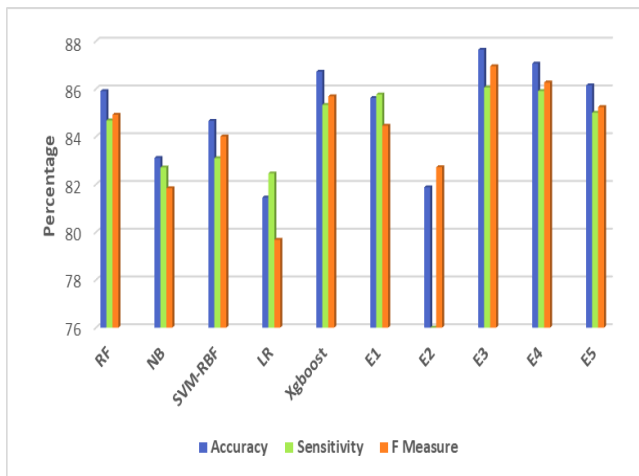


Fig. 5. Performance comparison of all individual and all ensembles.

VI. CONCLUSION AND FUTURE SCOPE

This article presents a reliable framework which can be used for predicting the cardiovascular disease. It deals with data cleaning by removing the noise from the data like outliers and missing values. For the Hungarian and Long Beach data to overcome the class imbalance, Synthetic Minority Oversampling Technique-SMOTE was used. Support Vector Machine Radial (SVM-R), Logistic Regression (LR), Naïve Bayes (NB), Random Forest (RF) and XGBoost were first implemented on all five data sets. Then five different ensembled classifiers were constructed. First ensemble classifier E₁ is designed considering all individual classifiers. Based on majority voting the final decision was taken for prediction. For second ensembled classifier E₂, all independent classifiers were considered but the prediction was done based on weighted majority voting. The weights to the classifiers were assigned depending on the accuracy of the classifier. For third, fourth and fifth ensembles, top three performers were identified on all five data sets. Out of these five different combinations of top performers, three unique combinations were selected. Hence, the third classifier E₃

consists of RF, SVM-R and XGBoost. The fourth ensembled E₄ is made up of RF, NB and XGBoost. The fifth one E₅ is constructed with NB, SVM-R and XGBoost. An exhaustive comparison of all individual classifier along with all ensembled classifiers was done. For any machine learning technique, the true classification rate is very important. Hence accuracy was given first importance. But at the same time for any medical study, the False Negative number is crucial. This number should be as less as possible. Therefore, sensitivity parameter is also focused. 10-fold cross validation was performed for validation. The results have shown that the amongst individual classifier XGBoost has performed the best on all data sets with average 86.7% accuracy, 85.3% sensitivity, 87.6% specificity, 86.1% Precision, 85.6% F-measure and 0.73 as Kappa value. The parameters were found to be improved with E₃ ensembled classifier as 87.6% accuracy, 86.0% Sensitivity, 89.0% Specificity, 87.8% Precision, 86.9% F-measure and 0.75 as Kappa value. Thus, SRPS proves out to be most reliable for CVD prediction amongst all discussed. The future endeavor of the study could be the use of subset of the data set in terms of the attributes. In this study, all features were used for diagnosis. The further improvement can be made by using different feature selection methods like Wrapper method, Correlation based feature selection method, etc. Also, Principal Component Analysis can be used to reduce the dimension. Further, this proposed ensembled classifier can be used for other disease prediction as well.

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REFERENCES

- [1] I. Mohan, R. Gupta, A. Misra, K. Sharma, A. Agrawal, N. Vikram, et al. "Disparities in Prevalence of Cardio metabolic Risk Factors in Rural, Urban-Poor, and Urban-Middle Class Women in India", Available: <https://pubmed.ncbi.nlm.nih.gov/26881429/>, 2016.

- [2] World Health Organization, "Cardiovascular Disease", who.int, https://www.who.int/health-topics/cardiovascular-diseases#tab=tab_1, accessed on 8 January 2022.
- [3] G. Allan, F. Nouri, C. Korownyk, M. Kolber, B. Vandermeer, J. McCormack. "Agreement among cardiovascular disease risk calculators." *Circulation*. 127(19):1948-56. doi: 10.1161/CIRCULATIONAHA.112.000412. Epub 2013 Apr 10. PMID: 23575355, 2013.
- [4] L. Yang, H. Wu, X. Jin, P. Zheng, S. Hu, W. Yu, et al. "Study of cardiovascular disease prediction model based on random forest in eastern China." *Sci Rep* 10, 5245. doi.org/10.1038/s41598-020-62133-5, 2020.
- [5] J. Kim, Y. Jeong, J. Kim, J. Lee, D. Park, H. Kim, "Machine Learning-Based Cardiovascular Disease Prediction Model: A Cohort Study on the Korean National Health Insurance Service Health Screening Database". *Diagnostics*, 11, 943. doi.org/10.3390/diagnostics11060943, 2021.
- [6] S. Cho, S. Kim, S. Kang, K. Lee, D. Choi, S. Kang, et al. "Pre-existing and machine learning-based models for cardiovascular risk prediction." *Sci Rep* 11, 88862021. doi.org/10.1038/s41598-021-88257, 2021.
- [7] A. Dimopoulos, M. Nikolaidou, M. Caballero, W. Engchua, A. Niubo, H. Arndt, et al. Machine learning methodologies versus cardiovascular risk scores, in predicting disease risk. *BMC Med Res Methodology*, 18, 179, 2018.
- [8] S. Weng, J. Reys, J. Kai, J. Garibaldi, N. Qureshi, et al, "Can machine-learning improve cardiovascular risk prediction using routine clinical data?" *PLoS ONE* 12(4): e0174944. doi.org/10.1371/journal.pone.0174944, 2017.
- [9] A. Alaa, T. Bolton, E. Angelantonio, J. Rudd, M. Schaar, et al, "cardiovascular disease risk prediction using automated machine learning: A prospective study of 423,604 UK Biobank participants." *PLoS ONE* 14(5): e0213653. <https://doi.org/10.1371/journal.pone.0213653>, 2021.
- [10] A. Sarraju, A. Ward, S. Chung, J. Li, D. Scheinker, F. Rodríguez et al. "Machine learning approaches improve risk stratification for secondary cardiovascular disease prevention in multi-ethnic patients." *Open Heart*; 8: e001802. doi:10.1136/openhrt-2021-001802, 2021.
- [11] L. Hafsa, A. Salem, H. Henda, H. Ghezala, et al, "Does data cleaning improve heart disease prediction?" *Procedia Computer Science*, Volume 176, Pages 1131-1140, ISSN 1877-0509, doi.org/10.1016/j.procs.2020.09.109, 2020.
- [12] A. Rahim, Y. Rasheed, F. Azam, M. Anwar, M. Rahim, A. Muzaffar, "An Integrated Machine Learning Framework for Effective Prediction of Cardiovascular Diseases", *IEEE Access*, vol. 9, pp.106575-106588, doi: 10.1109/ACCESS.2021.3098688, 2021.
- [13] J. Beunza, E. Puertas, E. Ovejero, G. Villalba, E. Condes, G. Koleva, et al, "Comparison of machine learning algorithms for clinical event prediction (risk of coronary heart disease)", *Journal of Biomedical Informatics*, Volume 97, 103257, ISSN 1532-0464, doi.org/10.1016/j.jbi.2019.103257, 2019.
- [14] G. N. Ahmad, S. Ullah, A. Algethami, H. Fatima, S. Akhter, "Comparative Study of Optimum Medical Diagnosis of Human Heart Disease Using Machine Learning Technique with and Without Sequential Feature Selection", in *IEEE Access*, vol. 10, pp.2380823828, doi:10.1109/ACCESS.2022.3153047, 2022.
- [15] Y. Muhammad, M. Tahir, M. Hayat, K. Chong, "Early and accurate detection and diagnosis of heart disease using intelligent computational model". *Sci Rep* 10, 19747. doi.org/10.1038/s41598-020-76635-9, 2020.
- [16] P. Ghosh, S. Azam, M. Jonkman, A. Karim, F. Shamrat, E. Ignatious, et al., "Efficient Prediction of Cardiovascular Disease Using Machine Learning Algorithms with Relief and LASSO Feature Selection Techniques," in *IEEE Access* vol. 9, pp.19304-19326, doi:10.1109/ACCESS.2021.3053759, 2021.
- [17] J. P. Li, A. U. Haq, S. U. Din, "Heart Disease Identification Method Using Machine Learning Classification in E-Healthcare", in *IEEE Access*, vol. 8, pp. 107562-107582, doi:10.1109/ACCESS.2020.3001149, 2020.
- [18] A. Escamilla, A. Hassani, E. Andrés, "Classification models for heart disease prediction using feature selection and PCA," *Informatics in Medicine Unlocked*, Volume 19, 100330, ISSN 23529148, doi.org/10.1016/j.imu.2020.100330, 2020.
- [19] A. Dinh, S. Miertschin, A. Young, S. Mohanty, "A data-driven approach to predicting diabetes and cardiovascular disease with machine learning". *BMC Med Inform Decision Making*, 211. doi.org/10.1186/s12911-019-0918-5, 2019.
- [20] C. Latha, S. Jeeva, "Improving the accuracy of prediction of heart disease risk based on ensemble classification techniques", *Informatics in Medicine Unlocked*, Volume 16, 100203, ISSN 2352-9148, doi.org/10.1016/j.imu.2019.100203, 2019.
- [21] Heart Disease Data: UCI Machine Learning Repository Center for Machine Learning and Intelligent Systems [online] Available: <https://archive.ics.uci.edu/ml/datasets/heart+disease>, accessed on 8 January 2022.
- [22] Statlog(Heart) Data Set : UCI Machine Learning Repository Center for Machine Learning and Intelligent Systems [online] Available: [https://archive.ics.uci.edu/ml/datasets/statlog+\(heart\)](https://archive.ics.uci.edu/ml/datasets/statlog+(heart)), accessed on 8 January 2022.
- [23] A. AbuHalimeh, "Improving Data Quality in Clinical Research Informatics Tools". *Front. Big Data*, 5:871897. doi: 10.3389/fdata.2022.871897, 2022.
- [24] G. Rekha, A. Tyagi, N. Sreenath, S. Mishra, "Class Imbalanced Data", *Open Issues and Future Research Directions, 2021 International Conference on Computer Communication and Informatics (ICCCI)*, pp. 1-6, doi: 10.1109/ICCCI50826.2021.9402272, 2021.
- [25] N. Chawla, K. Bowyer, L. Hall, W. Kegelmeyer, "SMOTE: Synthetic Minority Over-sampling Technique", *Journal of Artificial Intelligence Research*, Volume 16, pages 321-357, doi.org/10.1613/jair.95, 2002.

Unsupervised Bearing Fault Diagnosis via a Multi-Layer Subdomain Adaptation Network

Nguyen Duc Thuan, Nguyen Thi Hue, Hoang Si Hong*

School of Electrical and Electronic Engineering, Hanoi University of Science and Technology, Hanoi, Vietnam

Abstract—Bearings play a crucial role in the functioning of rotating machinery, making it essential to monitor their condition for maintaining system stability and dependability. In recent years, intelligent diagnostic techniques for bearing issues have made significant progress due to advancements in artificial intelligence. These methods rely heavily on data, requiring data collection and labeling to develop the learning model, which is often highly challenging and nearly infeasible in industrial settings. As a result, a domain adaptation-based transfer learning approach has been suggested. This approach aims to minimize the difference between the distribution of accessible data and the unlabeled real-world data, enabling the model trained on public data to function effectively with actual data. In this paper, we introduce a sophisticated subdomain adaptation technique for cross-machine bearing fault diagnosis using vibration, termed multi-layer subdomain adaptation. Verification experiments were conducted, and the findings indicate that the proposed approach offers relatively high accuracy up to 97.47% and excellent transferability. Comparative experiments revealed that the proposed method is a superior technique for bearing fault diagnosis and slightly outperforms other methods (3-5%) in both predictive and noise-ignore capabilities. Comprehensive validation experiments were conducted using the HUST dataset.

Keywords—Bearing fault; fault diagnosis; domain adaptation; transfer learning

I. INTRODUCTION

Bearings are an essential component in rotating machinery. Bearing-related failures account for up to 50% of total machine failures [1]. Precise detection of rolling element bearing faults is crucial for ensuring the reliable operation of rotating machinery. This is because any failure in the bearing could directly impact the functioning of the entire machine. Luckily, modern machine learning techniques have helped make significant progress in data-driven approaches to bearing fault diagnosis [1]. As a result, traditional methods that rely heavily on expert knowledge are no longer required. This has attracted considerable attention and is an area of extensive research [2].

The traditional data-driven approaches for fault diagnosis have been successful in achieving accurate results. However, this is only possible when sufficiently labeled samples or data are available (vibration, acoustic emission, current, etc.). To guarantee high accuracy in fault diagnosis, the testing data must match or is similar in probability distribution to the dataset used for training [3]. This is important because the fault diagnosis models need to be carefully trained and may be difficult to apply directly to different machines or operating conditions.

Transfer learning is a promising tool to overcome the limitations of traditional data-driven approaches for fault diagnosis. It involves transferring knowledge from one task to another, and one commonly utilized technique is domain adaptation [3]. To extract good feature representation across domains, various methods have been proposed, such as the deep adaptive network (DAN) introduced by Long et al. [4] and the hybrid distance-guided adversarial network (HDAN) proposed by Han et al. [5]. However, current domain adaptation methods are limited to diagnosing faults within the same equipment under varying conditions, making it difficult to obtain specific data to train the expected fault diagnosis model. Therefore, transfer fault diagnosis across different machines has become increasingly important. Song et al. [6] introduced a retraining strategy-based domain adaptation network, while Guo et al. [7] utilized a one-dimensional generation adversarial network (MLI-D-GAN) to jointly train generated and real damage data, enabling sufficient labeled data to overcome the limitation of existing models. Recently, Feng et al. [8] presented a domain adversarial similarity-based meta-learning network (DASMN) and Li et al. [9] developed an optimal ensemble deep transfer network (OEDTN) that utilized maximum mean discrepancy (MMD) with different kernels to construct multiple diverse DTNs.

Although transfer fault diagnosis across machines has been achieved with existing methods, there are still weaknesses in terms of fault diagnosis accuracy. The reason is that most of the mentioned methods are based on reducing the discrepancy in feature distribution. They may only adjust the overall distribution since the criteria function only accounts for the statistical parameters of the entire domain and not for each individual class/subdomain. Thus, to overcome this limitation and enhance the transfer fault diagnosis performance across different machines, we introduce a novel multi-layer adaptation network based on LMMD [10] criteria over layers in this article. The methodology is in Section II and experiments are in Section III. The main contributions of this paper are:

- We propose a novel multi-layer subdomain adaptation method that adjusts the domain distribution in each layer of the shared feature extraction module.
- We evaluate the performance of the proposed method on HUST bearing dataset and do comparative experiments to verify its ability to improve fault diagnosis accuracy across different bearings/machines.

*Corresponding Author.

II. METHODOLOGY

A. Problem Description

In this section, we start by discussing the issue of bearing fault diagnosis across machines. We begin by assuming that there is a rolling bearing monitoring dataset labeled from one (source) machine $D_s = \{(x_i^s, y_i^s)\}_{i=1}^{N_s}$, which we call the source domain data. The dataset contains N_s samples with labels y_i^s which belong to the labeled space Y_s . The samples x_i^s belong to the sample space X^s and are governed by the marginal probability distribution $P_s(X^s)$. We also have another rolling bearing monitoring dataset without labels from another (target) machine, called the target domain data $D_t = \{(x_i^t)\}_{i=1}^{N_t}$, which contains N_t samples and all samples are governed by the marginal probability distribution $P_t(X^t)$. Since the two datasets come from different machines, their marginal probability distributions are different, and we have $P_s \neq P_t$.

The main focus of this paper is on the transfer fault diagnosis of rolling bearings across different machines i.e., from the source to the target domain. Traditional data-driven methods rely solely on the source domain data with labels to train a classification neural network, which is a nonlinear mapping between the sample space X^s and the labeled space Y^s [11]. However, directly using the established nonlinear mapping/network to recognize the health status of unlabeled samples from the target domain will yield low fault diagnosis accuracy, as the two domains have different data distributions [12]. Thus, to improve the fault diagnosis accuracy, it is crucial to train the fault diagnosis model using not just labeled data from the source domain but also unlabeled data from the target domain. This presents the challenge of learning domain-invariant features by minimizing the data distribution discrepancy between the source and target domain data. As a

result, knowledge obtained from one machine can be used for fault diagnosis in another machine.

B. Proposed Method

In this study, a multi-layer subdomain adaptation model is developed to transfer fault diagnosis between different bearings. As shown in Fig. 1, our goal is to train a feature extractor that can accurately diagnose bearing faults for data in the target domain. The training process involves iteratively calculating the objective functions and updating the model parameters using the backpropagation algorithm. Afterwards, we obtain a trained model that can predict the label of new data in the target domain.

The training process is described as follows: the training data consists of labeled source data (x^s, y^s) and unlabeled target data (x^t) . Different domains use the same feature extractor, consisting of three one-dimensional convolutional layers and two fully connected layers (see Table I). The output of the feature extractor is the predicted label for the input data, used to calculate the objective functions based on the training objective. The training objective is to classify faults and minimize the distance of probability distribution between the outputs of different domains. Therefore, there are two objective functions: the objective function for classification (L_{cls}) and the objective function for adaptation (L_{ada}). The classification objective function is calculated based on the true label and predicted one of the data in the source domain. The adaptation objective function is calculated by sum of the distribution discrepancies (LMMD) between hidden features from different domains. This is a new and important aspect of this method, instead of relying solely on the distribution distance of features in the last layer. The important concept of computing the distribution discrepancy will be clarified in Section II C.

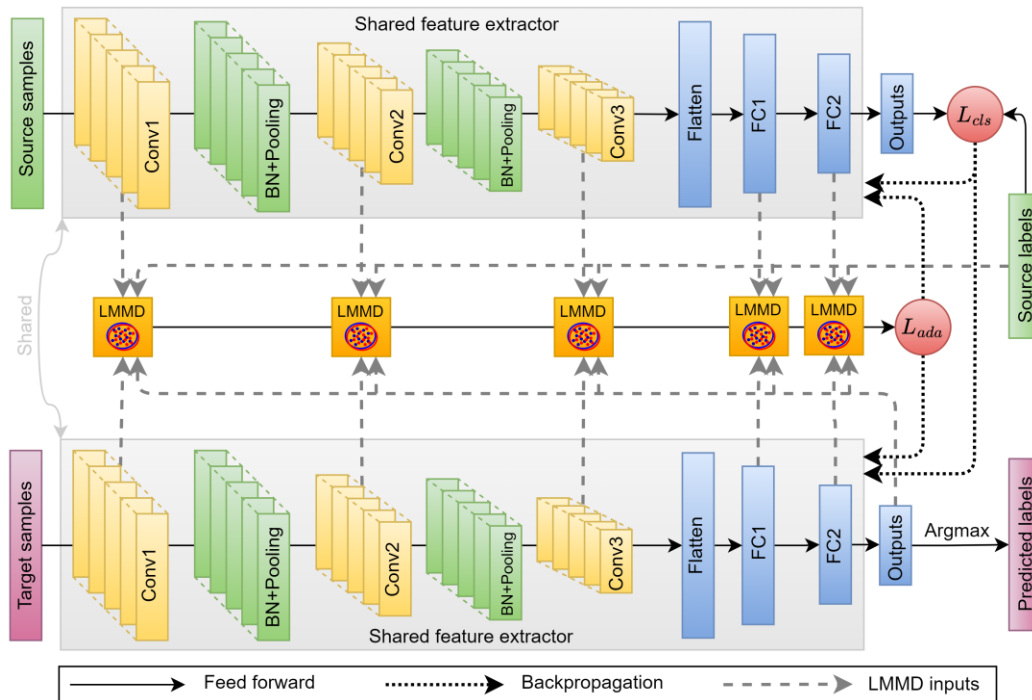


Fig. 1. Overview of the proposed method.

TABLE I. SPECIFICATION OF THE FEATURE EXTRACTOR

No.	Layer	Filter size	Output size	Activation function	BN/Pooling
0	Input	-	(4096, 1)	-	-
1	Conv1	(15, 1, 16)	(4096, 4)	ReLU	BN+Pooling
2	Conv2	(5, 16, 16)	(1024, 8)	ReLU	BN+Pooling
3	Conv3	(3, 32, 16)	(256, 16)	ReLU	-
-	Flatten	-	(4096, 1)	-	-
4	FC1	(4096, 512)	(512, 1)	ReLU	-
5	FC2	(512, 64)	(64, 1)	ReLU	-
6	Output	(64, 4)	(4, 1)	Softmax	-

BN: Batch Normalization

C. Loss Function

The objective of the model is fault classification and domain adaptation based on minimizing the distribution distance. For the classification objective function, it relies on the well-known cross-entropy function:

$$L_{cls} = - \sum_{i=1}^n y_i \log(\hat{y}_i) \quad (1)$$

where n is the number of classes, y_i is the ground-truth label, and \hat{y}_i is the softmax probability for the i -th class. As for the adaptation objective function, LMMD is an MMD-based criterion for measuring distribution discrepancy [10]. The MMD formula for calculating the distribution distance is described as follows:

$$MMD(P_s, P_t) \triangleq \|\mathbf{E}_{P_s}[\Phi(x^s)] - \mathbf{E}_{P_t}[\Phi(x^t)]\|_H^2 \quad (2)$$

where P_s, P_t denote the distribution of source and target domain; \mathbf{E} denotes the expectation; H denotes the reproducing kernel Hilbert space; $\Phi: X^{s,l}, X^{t,l} \rightarrow H$. In practice, an estimate of the MMD compares the square distance between the empirical kernel mean embeddings as:

$$MMD(P_s, P_t) \approx \frac{1}{N_s^2} \sum_{i=1}^{N_s} \sum_{j=1}^{N_s} k(x_i^s, x_j^s) + \frac{1}{N_t^2} \sum_{i=1}^{N_t} \sum_{j=1}^{N_t} k(x_i^t, x_j^t) \quad (3)$$

where N_s, N_t stand for the number of samples in source and target domain; the kernel k means $k(x_i, x_j) = \langle \Phi(x_i), \Phi(x_j) \rangle$. The MMD-based techniques primarily emphasized the alignment of overall distributions while disregarding the connections between subdomains within the same category. It is crucial to consider the relationships between these relevant subdomains and align their distributions between the source and target domains. To achieve this, we considered the Local Maximum Mean Discrepancy (LMMD) method in (4). In (4), the letter c denotes the class label. Eq. (4) is then estimated as (5). In (5), $\omega_i^{sc}, \omega_j^{tc}$ stand for the weight of x_i^s, x_j^t belonging to class c , are computed as (6). In (6), y_{ic} is the c -th entry of the output vector y_i with input x_i .

$$LMMD(P_s, P_t) \triangleq \mathbf{E}_c \|\mathbf{E}_{P_s^c}[\Phi(x^s)] - \mathbf{E}_{P_t^c}[\Phi(x^t)]\|_H^2 \quad (4)$$

$$LMMD \approx \frac{1}{C} \sum_{c=1}^C \left\| \sum_{i=1}^{N_s} \omega_i^{sc} \Phi(x_i^s) - \sum_{j=1}^t \omega_j^{tc} \Phi(x_j^t) \right\|_H^2 \quad (5)$$

$$\omega_i^c = \frac{y_{ic}}{\sum_{j=1}^N y_{jc}} \quad (6)$$

Afterward, the adaptation loss L_{ada} is computed as (7). It must be noted that for the convolution layer, the feature maps are flatted before calculating the LMMD. It means that layer number 3 and the next flatten layer utilize the same LMMD.

$$L_{ada} = \sum_{i=1}^5 LMMD \text{ at layer } i \quad (7)$$

Finally, the overall objective function in (8) is the sum of the two aforementioned objective functions. With this, the model can maintain its classification ability while also adjusting the embedding features to a common distribution.

$$L = L_{cls} + L_{ada} \quad (8)$$

III. EXPERIMENTS

A. HUST bearing Dataset

The verification experiments were conducted exclusively on the HUST bearing dataset as in our previous work [1]. What makes this dataset especially advantageous is that it contains fault signals from five bearings across different types of defects and working conditions. The data acquisition system is shown in Fig. 2. The data acquisition system includes a 1-HP induction motor, an accelerometer of PCB352C33 and a measurement module with torque and velocity sensors.

Because of this, we can assess the performance of our proposed method for various domain adaptation tasks across different bearings or machines. For the purpose of test analysis, we selected bearings of types 6205, 6206, and 6207 with a no-load shaft speed. Each type of bearing includes four health conditions: normal (N), inner race fault (I), outer race fault (O), and ball fault (B). The faults were generated using the wire-cutting method, which creates cracks with a size of 0.2 mm. The accelerometer captured the vibration signals at a sampling rate of 51,200 samples per second for 10 seconds. To augment training/test data, the raw vibration signal was truncated into segments with a length of 4096 with 75% overlap. Then we obtain 496 segments/class/bearing with each segment as an input of the model.

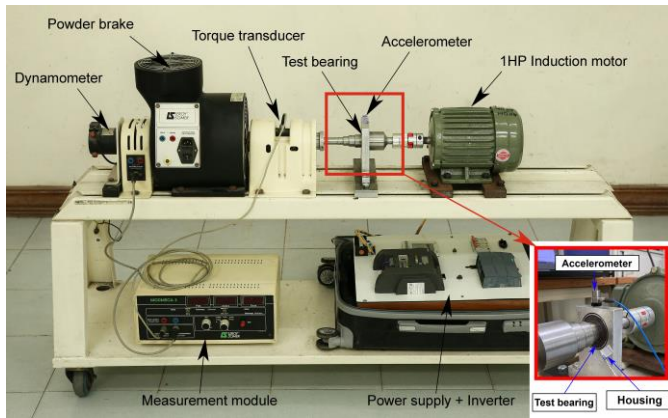


Fig. 2. HUST bearing data acquisition system [1].

The adaptation tasks are defined as S5-6, S5-7, S6-5, S6-7, S7-5, S7-6, M5, M6, and M7. Each task name includes 2 parts: the prefix (S: single-source | M: multiple-source), and the suffix to supplement information for the prefix (5: 6205 | 6: 6206 | 7: 6207). In detail, for single-source tasks, the suffix denotes the source bearing and the target one e.g., 5-6 means that the source bearing is 6205 and the target one is 6206. As for multiple-source tasks, the suffix number denotes the target bearing, while the source is the remaining two bearings. For each task, 80% source data and 80% target data are used to train the network, while the remaining 20% source data is used to validate and 20% target data is used to test/evaluate.

B. Experiments Setup

In this section, we describe the experimental setup. The first experiment is to evaluate the effectiveness of the proposed method in transferring knowledge to adaptive tasks defined in Section III A. The second experiment is an extension of the first experiment with added multi-level noise components in the training/testing data. The purpose of the second experiment is to assess the proposed method's performance in the presence of noise, which is common in real-world scenarios. Finally, the third experiment aims to compare the proposed method's performance with other methods to demonstrate its superiority in adaptability. All models were trained/evaluated on the same HUST bearing dataset to ensure fairness in comparison. The metrics for model evaluation are (overall) accuracy (9), precision (1), sensitivity (11), F1-score (12), confusion matrix, and t-SNE visualization to observe the feature distribution of source and target domains [13].

$$Accuracy = \frac{No. of correct predictions}{No. of all samples} \quad (9)$$

$$Precision = \frac{No. of true positive predictions}{No. of all positive predictions} \quad (10)$$

$$Sensitivity = \frac{No. of true positive predictions}{No. of all positive samples} \quad (11)$$

$$F1 - score = 2 \times \frac{Precision \times Sensitivity}{Precision + Sensitivity} \quad (12)$$

The verification experiments were conducted on a computer with the following specifications: an Intel i7 12700F CPU, 16 GB of RAM, and a 24GB Nvidia GeForce GTX 3090 GPU. These experiments were implemented utilizing the PyTorch framework from the source <https://github.com/ZhaoZhibin/UDTL> [14]. For the training process, the hyperparameters were configured as follows: the number of epochs was set to 100, the batch size at 64, the learning rate to 0.001, the momentum at 0.9, the optimizer was Adam, and the weight decay was 0.00001. To provide a reliable measure of accuracy, each model was re-trained 10 times, and the results were reported as mean and standard deviation values.

IV. RESULTS AND DISCUSSIONS

In the first experiment, we evaluated the performance of the proposed method across all tasks. Table II shows the overall accuracy, precision, sensitivity, and F1-score of the model with the test data in the target domain. It can be seen that the overall accuracy of the single-source tasks is quite good, ranging from 86% to 96%. Specifically, task S6-5 had the lowest accuracy of 86.62%, while task S6-7 had the highest accuracy of 96.46%. Furthermore, the inversely related tasks (e.g. S5-6 and S6-5) had similar accuracy. This reveals that the result of transfer learning depends on the relationship between domains and not on which domain is the source and which is the target.

Regarding other metrics for single-source tasks, we can see that precision, sensitivity, and F1-score are relatively consistent for each task. The magnitude of these metrics varies by no more than 1%. This is achieved by the class balance in the test data set.

TABLE II. TRANSFER FAULT DIAGNOSIS RESULTS WITH THE PROPOSED METHOD

Task	Overall accuracy (%)	Precision (%)	Sensitivity (%)	F1-score (%)
S5-6	88.38	89.43	88.38	88.90
S5-7	92.93	93.78	92.93	93.35
S6-5	86.62	87.91	86.62	87.26
S6-7	96.46	96.60	96.46	96.53
S7-5	89.14	90.27	89.14	89.70
S7-6	94.44	94.64	94.44	94.54
M5	92.42	92.75	92.42	92.59
M6	95.71	95.87	95.71	95.79
M7	97.47	97.54	97.47	97.51

In Table II, for multi-source tasks, it is easy to see that their performance is significantly improved compared to the single-source tasks. Task M5 achieved 92.42% accuracy, higher than Sx-5 tasks due to more contribution from the source domain. Tasks M6 and M7 both scored above 95% on all criteria. This superiority is achieved through an increase in source data, which can compensate for each other's deficiencies to help the model learn more effectively. From this, we can conclude that enhancing the source domain data will improve the model's diagnostic capabilities. Additionally, we can observe a trend where the accuracy of multi-source tasks depends on the shared target domain of the single-source tasks. This means that the Mx predictive ability will be a function of the Ma-x abilities.

Fig. 3 illustrates the confusion matrices corresponding to the considered tasks. Unlike overall accuracy, the confusion matrix provides a clearer explanation of the accuracy for each class, with the value in each cell being the number of instances. At a glance, we can see that the highest accuracy is concentrated on classes I and O in all tasks. We believe this is due to the clear defect patterns in these two classes, making

them easier to identify for the model. In the dataset, defects related to class B are difficult to predict accurately and are often confused with faults in class I. This phenomenon is seen from 6205-related tasks i.e., the fault characteristic of class I and B of bearing 6205 may be hard to distinguish (e.g., the fault frequency). For the case of the healthy bearing, tasks M6 and M7 achieve almost perfect accuracy, while tasks M5, S6-5, S7-5, S5-6, and S5-7 show worse accuracy. It can be speculated that there are issues with the N data for bearing 6205 (e.g., a small crack may exist). However, this is not as serious as misclassifying failures as non-failures.

Fig. 4 visualizes the distribution of features in the final layer of the neural network in the Descartes coordinate system using a visualization method called t-distributed stochastic neighbor embedding (t-SNE), which is a dimensionality reduction algorithm. We observe that the mispredictions in the classes occur due to the mismatch between the source and target class distributions of the data. To address this issue, some studies have proposed labeling some of the training data in the target domain, which can be further explored in [15].

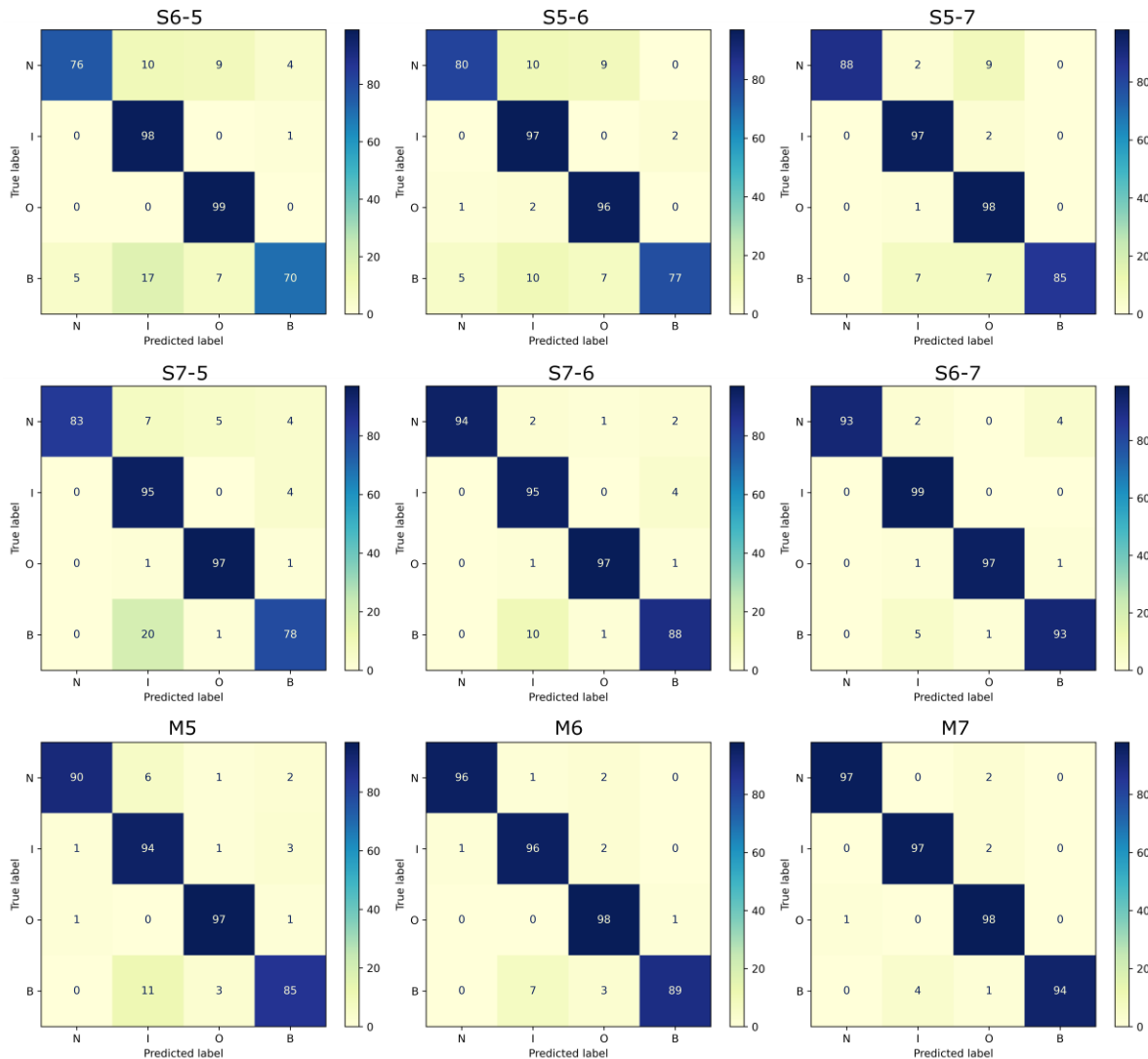


Fig. 3. Confusion matrices for all tasks.

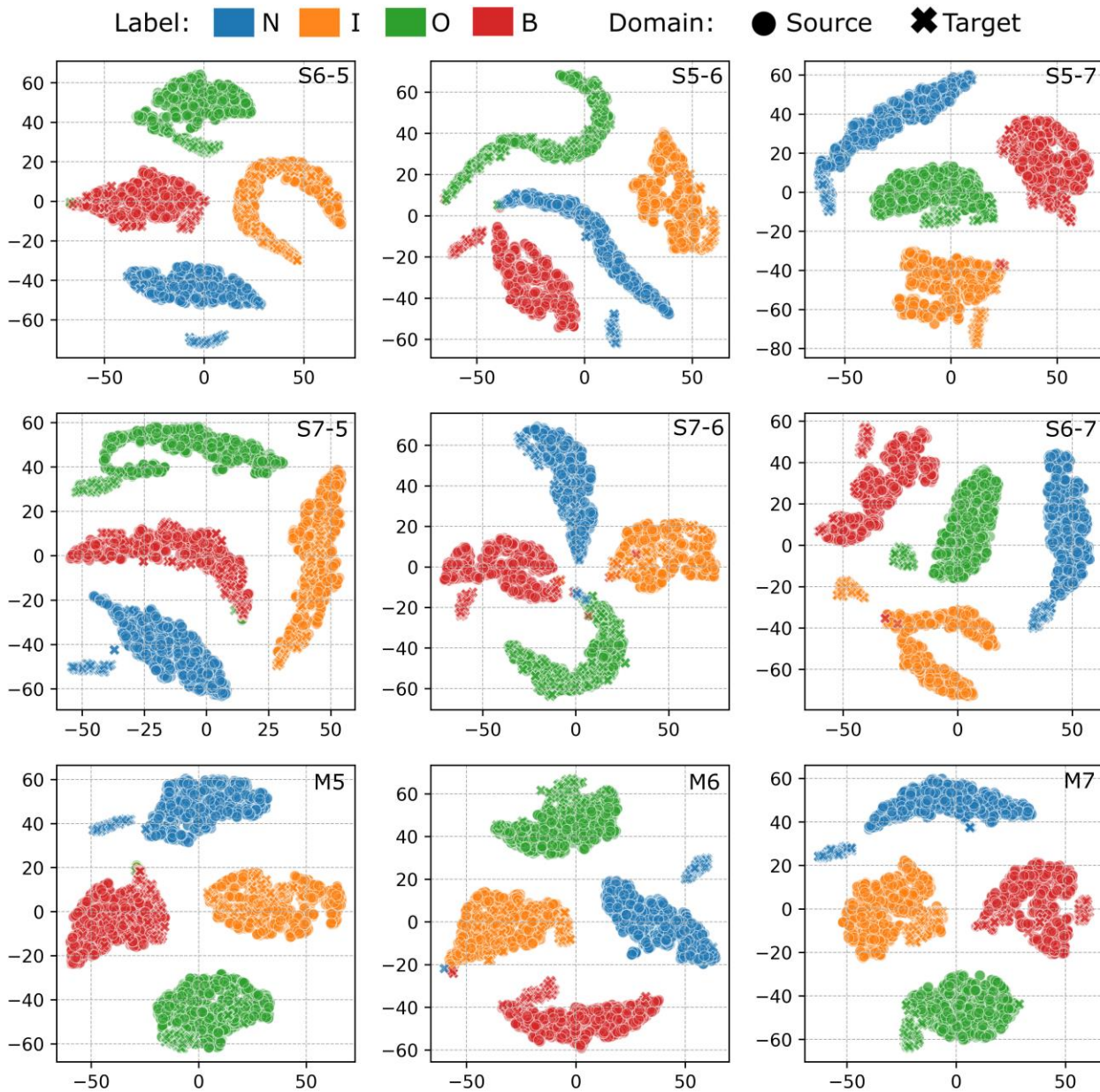


Fig. 4. t-SNE visualization of the last features in all tasks.

In the second experiment, we examined the performance of our proposed method in the presence of noise in the data. We added Gaussian white noise with a mean of 0 and a standard deviation of 1 to the training and test data. To vary the intensity of the noise, we scaled the amplitude by different coefficients ranging from 0 to 0.9 with a step of 0.3. In the third experiment, we compared our proposed method with other popular domain adaptation methods, including JMMD [16], MKMMD [17], CORAL [18], DANN [19], and CDAN [20], in the presence of noise. The effect of noise was also included to provide a comprehensive comparison. The results of the experiments demonstrated the effectiveness of our proposed method in the presence of noise. Our method outperformed the other popular domain adaptation methods, particularly as the

intensity of the noise increased. The results are presented in Fig. 5.

In Fig. 5, as the level of noise increases, all examined methods experience a decrease in performance. Multi-source tasks show a decrease from 92-97% to 89-93%, while single-source tasks experience a decrease from 86-96% to 81-92%. Notably, while the other methods experience a significant accuracy drop of up to 10%, our proposed method only experiences a slight decrease of around 5% for all tasks. This indicates that our method is less affected by noise, promising stability and high reliability. Regarding the correlation between the methods, it is truly difficult to distinguish because they differ slightly in their predictive capabilities.

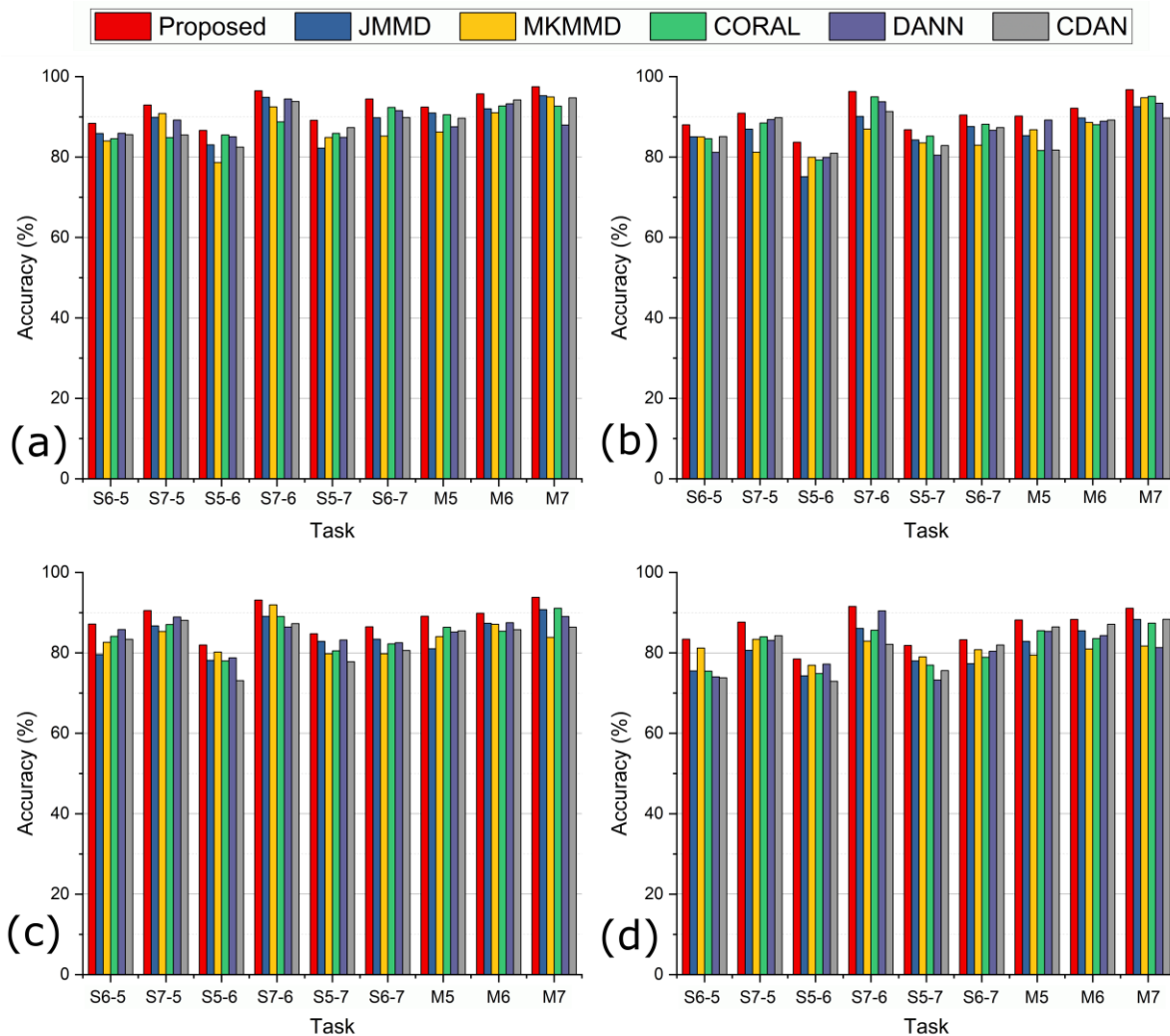


Fig. 5. The performance of different methods under different levels of noise. Noise levels are: (a) 0; (b) 0.3; (c) 0.6; (d) 0.9.

Nonetheless, we still recognize the effectiveness of our proposed method because, in all cases, it slightly outperforms the other methods. Our success can be attributed to taking into account the varying distributions between classes (subdomains), which sets us apart from other approaches. Furthermore, our approach is reinforced by a thorough examination of all hidden layers, an aspect that has been overlooked by many previous studies. Going forward, we aim to explore algorithms that improve adaptability in scenarios where distributions cannot be homogenized.

V. CONCLUSION

This study introduces a new method based on transfer for fault diagnosis in bearings across various machines, named weighted multi-layer subdomain adaptation. Due to the weakness of traditional metrics as MMD for feature alignment between different domains, we inspired by LMMD to develop a new model architecture for the task of domain adaptation. This method is validated using HUST bearing dataset for nine transfer fault diagnosis tasks where labeling of target domain data is not required. Verification experiments were conducted, and the findings indicate that the proposed approach offers

relatively high accuracy up to 97.47% and excellent transferability. Comparative experiments revealed that the proposed method is a superior technique for bearing fault diagnosis and slightly outperforms other methods (3-5%) in both predictive and noise-ignore capabilities.

ACKNOWLEDGMENT

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REFERENCES

- [1] N. D. Thuan and H. S. Hong, "HUST bearing: a practical dataset for ball bearing fault diagnosis," Feb. 2023, doi: 10.48550/arXiv.2302.12533.
- [2] N. Duc Thuan, N. Thi Hue, P. Quang Vuong, and H. Si Hong, "Intelligent Bearing Fault Diagnosis With a Lightweight Neural Network," in 2022 11th International Conference on Control, Automation and Information Sciences (ICCAIS), Nov. 2022, pp. 261–266. doi: 10.1109/ICCAIS56082.2022.9990211.
- [3] B. Yang, Y. Lei, F. Jia, and S. Xing, "An intelligent fault diagnosis approach based on transfer learning from laboratory bearings to locomotive bearings," *Mech. Syst. Signal Process.*, vol. 122, pp. 692–706, May 2019, doi: 10.1016/j.ymssp.2018.12.051.

- [4] M. Long, Y. Cao, J. Wang, and M. I. Jordan, "Learning Transferable Features with Deep Adaptation Networks," Feb. 2015, doi: doi.org/10.5555/3045118.3045130.
- [5] B. Han, X. Zhang, J. Wang, Z. An, S. Jia, and G. Zhang, "Hybrid distance-guided adversarial network for intelligent fault diagnosis under different working conditions," *Measurement*, vol. 176, p. 109197, May 2021, doi: 10.1016/j.measurement.2021.109197.
- [6] Y. Song, Y. Li, L. Jia, and M. Qiu, "Retraining Strategy-Based Domain Adaption Network for Intelligent Fault Diagnosis," *IEEE Trans. Ind. Informatics*, vol. 16, no. 9, pp. 6163–6171, Sep. 2020, doi: 10.1109/TII.2019.2950667.
- [7] Q. Guo, Y. Li, Y. Song, D. Wang, and W. Chen, "Intelligent Fault Diagnosis Method Based on Full 1-D Convolutional Generative Adversarial Network," *IEEE Trans. Ind. Informatics*, vol. 16, no. 3, pp. 2044–2053, Mar. 2020, doi: 10.1109/TII.2019.2934901.
- [8] Y. Feng et al., "Similarity-based meta-learning network with adversarial domain adaptation for cross-domain fault identification," *Knowledge-Based Syst.*, vol. 217, p. 106829, Apr. 2021, doi: 10.1016/J.KNOSYS.2021.106829.
- [9] X. Li, S. Huo, and B. Xi, "Updating the resolution for 16S rRNA OTUs clustering reveals the cryptic cyanobacterial genus and species," *Ecol. Indic.*, vol. 117, p. 106695, Oct. 2020, doi: 10.1016/J.ECOLIND.2020.106695.
- [10] Y. Zhu et al., "Deep Subdomain Adaptation Network for Image Classification," *IEEE Trans. Neural Networks Learn. Syst.*, vol. 32, no. 4, pp. 1713–1722, Apr. 2021, doi: 10.1109/TNNLS.2020.2988928.
- [11] Y. Lei, B. Yang, X. Jiang, F. Jia, N. Li, and A. K. Nandi, "Applications of machine learning to machine fault diagnosis: A review and roadmap," *Mech. Syst. Signal Process.*, vol. 138, p. 106587, Apr. 2020, doi: 10.1016/j.ymssp.2019.106587.
- [12] K. Saito, K. Watanabe, Y. Ushiku, and T. Harada, "Maximum Classifier Discrepancy for Unsupervised Domain Adaptation," Dec. 2017, doi: arXiv:1712.02560.
- [13] H. M and S. M.N, "A Review on Evaluation Metrics for Data Classification Evaluations," *Int. J. Data Min. Knowl. Manag. Process*, vol. 5, no. 2, pp. 01–11, Mar. 2015, doi: 10.5121/ijdkp.2015.5201.
- [14] Z. Zhao et al., "Applications of Unsupervised Deep Transfer Learning to Intelligent Fault Diagnosis: A Survey and Comparative Study," *IEEE Trans. Instrum. Meas.*, vol. 70, pp. 1–28, 2021, doi: 10.1109/TIM.2021.3116309.
- [15] K. Yu, Q. Fu, H. Ma, T. R. Lin, and X. Li, "Simulation data driven weakly supervised adversarial domain adaptation approach for intelligent cross-machine fault diagnosis," *Struct. Heal. Monit.*, vol. 20, no. 4, pp. 2182–2198, Jul. 2021, doi: 10.1177/1475921720980718.
- [16] M. Long, H. Zhu, J. Wang, and M. I. Jordan, "Deep Transfer Learning with Joint Adaptation Networks," in *Proceedings of the 34th International Conference on Machine Learning, 2017*, vol. 70, pp. 2208–2217. [Online]. Available: <https://proceedings.mlr.press/v70/long17a.html>.
- [17] A. Gretton et al., "Optimal kernel choice for large-scale two-sample tests," in *Advances in Neural Information Processing Systems, 2012*, vol. 25. [Online]. Available: <https://proceedings.neurips.cc/paper/2012/file/dbe272bab69f8e13f14b405e038deb64-Paper.pdf>.
- [18] B. Sun and K. Saenko, "Deep CORAL: Correlation Alignment for Deep Domain Adaptation," 2016, pp. 443–450. doi: 10.1007/978-3-319-49409-8_35.
- [19] Y. Ganin et al., "Domain-Adversarial Training of Neural Networks," May 2015, [Online]. Available: <http://arxiv.org/abs/1505.07818>.
- [20] M. Long, Z. Cao, J. Wang, and M. I. Jordan, "Conditional Adversarial Domain Adaptation," May 2017, [Online]. Available: <http://arxiv.org/abs/1705.10667>.

Mask R-CNN Approach to Real-Time Lane Detection for Autonomous Vehicles

Rustam Abdrakhmanov¹, Madina Elemesova², Botagoz Zhussipbek³, Indira Bainazarova⁴, Tursinbay Turymbetov⁵,
Zhalgas Mendibayev⁶

International University of Tourism and Hospitality, Turkistan, Kazakhstan¹
Bachelor Student, International University of Tourism and Hospitality, Turkistan, Kazakhstan²
Korkyt Ata Kyzylorda University, Kyzylorda, Kazakhstan³
M. Auezov South Kazakhstan University, Shymkent, Kazakhstan⁴
Khoja Akhmet Yassawi International Kazakh-Turkish University⁵
Al-Farabi Kazakh National University, Almaty, Kazakhstan⁶

Abstract—The accurate and real-time detection of road lanes is crucial for the safe navigation of autonomous vehicles (AVs). This paper presents a novel approach to lane detection by leveraging the capabilities of the Mask Region-based Convolutional Neural Network (Mask R-CNN) model. Our method adapts Mask R-CNN to specifically address the challenges posed by diverse traffic scenarios and varying environmental conditions. We introduce a robust, efficient, and scalable architecture for lane detection, which segments the lane markings and generates precise boundaries for AVs to follow. We augment the model with a custom dataset, consisting of images collected from different geographical locations, weather conditions, and road types. This comprehensive dataset ensures the model's generalizability and adaptability to real-world conditions. We also introduce a multi-scale feature extraction technique, which improves the model's ability to detect lanes in both near and far fields of view. Our proposed method significantly outperforms existing state-of-the-art techniques in terms of accuracy, processing speed, and adaptability. Extensive experiments were conducted on public datasets and our custom dataset to validate the performance of the proposed method. Results demonstrate that our Mask R-CNN-based approach achieves high precision and recall rates, ensuring reliable lane detection even in complex traffic scenarios. Additionally, our model's real-time processing capabilities make it an ideal solution for implementation in AVs, enabling safer and more efficient navigation on roads.

Keywords—Road; lane; Mask R-CNN; detection; deep learning; autonomous vehicle

I. INTRODUCTION

The rapid development of autonomous vehicles (AVs) has the potential to revolutionize the transportation industry by providing safer, more efficient, and more convenient means of transportation [1]. Central to the success of AVs is their ability to perceive and understand the environment around them. Among various perception tasks, the accurate and real-time detection of road lanes plays a critical role in ensuring the safe navigation of AVs. Lanes are used to guide the vehicles in maintaining their position on the road, adhere to traffic rules, and avoid collisions with other vehicles or obstacles [2].

Traditional lane detection methods, such as edge detection and Hough transform, have shown limited success due to their

sensitivity to noise, poor adaptability to varying environmental conditions, and inability to handle complex traffic scenarios [3-5]. With the advancement in deep learning, convolutional neural networks (CNNs) have demonstrated promising results in various computer vision tasks, including lane detection [6]. However, existing CNN-based lane detection methods still face challenges in terms of real-time processing, adaptability to diverse traffic scenarios, and robustness under varying environmental conditions.

Given the limitations of current lane detection techniques, there is a need for a more efficient, robust, and real-time solution that can address the challenges posed by diverse traffic scenarios and environmental conditions [7]. The Mask Region-based Convolutional Neural Network (Mask R-CNN) model, which was originally designed for object detection and segmentation, has demonstrated remarkable performance in various computer vision tasks [8]. Its ability to precisely localize and segment objects in images makes it a suitable candidate for lane detection. However, the application of Mask R-CNN in the context of lane detection has not been fully explored.

In this paper, we propose a novel approach to lane detection by adapting the Mask R-CNN model to specifically address the challenges associated with detecting lanes in real-world traffic scenarios. Our goal is to develop a robust, efficient, and scalable architecture for lane detection that can accurately segment the lane markings and generate precise boundaries for AVs to follow, even in complex traffic scenarios and varying environmental conditions.

The main contributions of this paper are as follows:

- 1) We propose a novel Mask R-CNN-based approach to real-time lane detection for autonomous vehicles, which addresses the challenges associated with existing lane detection techniques and provides a more efficient, robust, and adaptable solution.
- 2) We introduce a comprehensive custom dataset consisting of images collected from different geographical locations, weather conditions, and road types. This dataset ensures the model's generalizability and adaptability to real-

world conditions, which is crucial for the successful deployment of AVs.

3) We incorporate a multi-scale feature extraction technique in our proposed model, which improves its ability to detect lanes in both near and far fields of view, enabling more accurate and reliable lane detection across various scenarios.

4) We conduct extensive experiments on public datasets as well as our custom dataset to validate the performance of the proposed method. The results demonstrate that our Mask R-CNN-based approach significantly outperforms existing state-of-the-art techniques in terms of accuracy, processing speed, and adaptability.

The remainder of this paper is organized as follows: Section II provides a review of related work in the field of lane detection, highlighting the limitations of existing methods and the potential of Mask R-CNN for this task. Section III presents the details of our proposed Mask R-CNN-based approach to real-time lane detection, including the architecture, multi-scale feature extraction technique, and the custom dataset. Section IV describes the experimental setup, including the public datasets and evaluation metrics used to validate the performance of our method. Section V presents the results of our experiments, comparing the performance of our proposed method to existing state-of-the-art techniques, and discussing the implications of our findings. Finally, Section VI concludes the paper and provides directions for future research.

II. RELATED WORKS

Lane detection is a crucial component of perception systems for autonomous vehicles, as it ensures safe navigation and adherence to traffic rules. Over the years, various approaches have been proposed for different practical tasks and datasets ranging from traditional methods to deep learning-based techniques [9-11]. In this section, we review some of the key works in lane detection, considering traditional approaches, CNNs, RNNs, UNet, and other deep learning models (see Table I).

A. Traditional Approaches

Traditional lane detection methods primarily rely on hand-crafted features and geometric properties of lanes. Some of the most common techniques include edge detection, Hough transform, and lane fitting algorithms [12].

Edge detection techniques, such as Sobel and Canny operators, are used to identify the boundaries of lane markings in images [13]. While these methods can perform well in simple scenarios, they are sensitive to noise and may fail in complex traffic scenes or under varying environmental conditions.

Hough transform is another popular method for lane detection, which identifies lines in an image by converting the image space into a parameter space [14]. Although it is effective in detecting straight lines, the Hough transform struggles with curved lanes and requires additional preprocessing steps to address issues such as perspective distortion.

B. CNN-based Approaches

Convolutional Neural Networks (CNNs) have demonstrated great success in various computer vision tasks, including lane detection [15]. These networks learn hierarchical features from raw images, enabling them to automatically learn and adapt to different scenarios. Some notable works employing CNNs for lane detection are as follows:

1) *SCNN*: In this work, Pan et al. proposed a Spatial CNN (SCNN) for lane detection, which incorporates spatial information by extending the convolution operation to the vertical and horizontal directions [16]. This approach achieved state-of-the-art performance on public datasets and demonstrated robustness to varying lighting conditions and occlusions.

2) *LaneNet*: In LaneNet, Neven et al. employed an encoder-decoder architecture with a binary segmentation branch for lane detection [17]. The model also used an instance segmentation branch to differentiate between individual lanes, improving its ability to handle complex scenarios.

C. RNN-based Approaches

Recurrent Neural Networks (RNNs) have been used for lane detection tasks due to their ability to model temporal dependencies in sequences. Some works that employ RNNs for lane detection include:

1) *LSTMs*: Chen et al. proposed an approach combining LSTMs and CNNs to model temporal dependencies in consecutive video frames for lane detection [18]. This approach improved the robustness of the model to varying lighting conditions and occlusions.

Pan et al. (2018) presents an end-to-end lane detection approach using a fully convolutional neural network (FCN) and an RNN [19]. The FCN is used to generate lane boundary probability maps, which are fed into the RNN to predict the final lane boundaries. The approach is shown to be effective in detecting lanes in complex driving scenarios.

Li and Zhang (2017) propose a real-time lane detection algorithm based on an RNN [20]. The RNN is trained on a large dataset of road images to predict lane boundaries. The proposed algorithm achieves high accuracy in lane detection and real-time performance. Lee and Kim (2019) propose a real-time lane detection algorithm using a deep RNN [21]. The RNN is trained on a dataset of road images and is used to predict lane boundaries. The proposed algorithm achieves high accuracy in lane detection and real-time performance.

D. UNet-based Approaches

UNet is a popular encoder-decoder architecture for semantic segmentation tasks [22]. It has been employed in various lane detection works due to its ability to effectively capture both local and global context in images.

1) *SegNet*: Badrinarayanan et al. proposed SegNet, a UNet-like architecture for semantic segmentation [23]. SegNet has been used for lane detection tasks, demonstrating robust

performance in complex traffic scenes and under varying environmental conditions.

Liu et al. (2019) proposes a lane detection approach using a modified U-Net architecture. The modified U-Net includes multiple decoder paths to handle different scales of features, and skip connections are added to preserve spatial information. The approach is shown to be effective for detecting lanes in various driving scenarios.

Tahir et al. (2020) presents a lane detection and semantic segmentation approach using a U-Net architecture [24]. The proposed method combines lane detection and semantic segmentation to improve the accuracy of lane detection in complex driving scenarios. The approach is shown to be effective for detecting lanes in various lighting conditions and road types.

Yang et al. (2021) proposes a lane detection approach using a U-Net architecture and object detection [25]. The U-Net is used to detect lane boundaries, and object detection is used to remove false positives. The proposed algorithm achieves high accuracy in lane detection and reduces false positives. U-Nets have shown great potential for lane detection in autonomous vehicles due to their ability to learn high-level features and preserve spatial information [26]. The above mentioned works demonstrate that the application of U-Nets to lane detection can lead to effective and efficient autonomous driving systems.

E. Other Deep Learning Models

Apart from the approaches mentioned above, other deep learning models have also been applied to lane detection tasks.

1) *DeepLab*: DeepLab is a popular semantic segmentation model that employs atrous convolutions and fully connected conditional random fields (CRFs) for improved segmentation performance [27]. DeepLab has been used in various lane detection works, demonstrating robust performance across different scenarios.

2) *Mask R-CNN*: While originally designed for object detection and segmentation, Mask R-CNN has the potential to address lane detection challenges due to its ability to precisely localize and segment objects in images [28].

Thus, while traditional approaches for lane detection have shown limited success, deep learning-based techniques, including CNNs, RNNs, UNet, and other models, have demonstrated promising results in handling the challenges posed by diverse traffic scenarios and varying environmental conditions [29]. However, each approach has its own set of advantages and limitations, necessitating the development of more efficient, robust, and real-time solutions for lane detection in autonomous vehicles.

In this paper, we propose a novel Mask R-CNN-based approach to real-time lane detection, addressing the challenges associated with existing techniques and providing a more efficient, robust, and adaptable solution. By leveraging the capabilities of the Mask R-CNN model and incorporating a comprehensive custom dataset and a multi-scale feature

extraction technique, our proposed method aims to achieve superior performance in terms of accuracy, processing speed, and adaptability compared to existing state-of-the-art techniques.

TABLE I. COMPARISON OF DEEP LEARNING METHODS FOR LANE DETECTION

Approach	Pros	Cons
Detection	Simple implementation, effective in basic scenarios	Sensitive to noise, fails in complex scenes, does not handle curved lanes well
Hough Transform	Effective in detecting straight lines, handles perspective distortion	Struggles with curved lanes, requires additional preprocessing
SCNN	Incorporates spatial information, robust to lighting and occlusions	Limited to scenarios present in training data, may require large datasets
LaneNet	Encoder-decoder architecture, instance segmentation for individual lanes	Complex model, may be slower in real-time applications
LSTMs	Models temporal dependencies, robust to lighting and occlusions	Requires video input, may not perform well on single images
SegNet	Captures local and global context, robust in complex scenes and varying conditions	Relatively large model, may be computationally expensive
DeepLab	Atrous convolutions and CRFs for improved segmentation, robust across scenarios	Complex model, may require additional processing for instance segmentation
Mask R-CNN	Precise localization and segmentation, potential for real-time processing	Limited exploration in lane detection, may require adaptation for specific scenarios

III. PROPOSED METHOD

It was chosen to adopt the contemporary design of the Mask R-CNN convolutional network in order to simultaneously tackle the issue of crack detection and their pixel-by-pixel separation. This was done in order to save time. First, let us take a look at its internal makeup and analyze how it works. The Region-based Convolutional Neural Network (R-CNN), Fast R-CNN, and Faster R-CNN are the three architectures that came before the Mask R-CNN, all of which were based on the concept of processing tiny regions. Historically, the Mask R-CNN architecture has had the following number of predecessors. As we reviewed, deep learning models have been used in many areas from teaching sphere to sport, medicine, as well as autonomous vehicles [30].

Fig. 1 depicts the Mask R-CNN approach that we developed in order to solve the lane detection issue. The design of the Mask R-CNN is made up of several complicated blocks. First, an illustration is sent to the data of the model in order to point out the feature map. Commonly used model architectures include VGG-16, ResNet50, and ResNet101, both of which include eliminated several layers that are in charge of categorization.

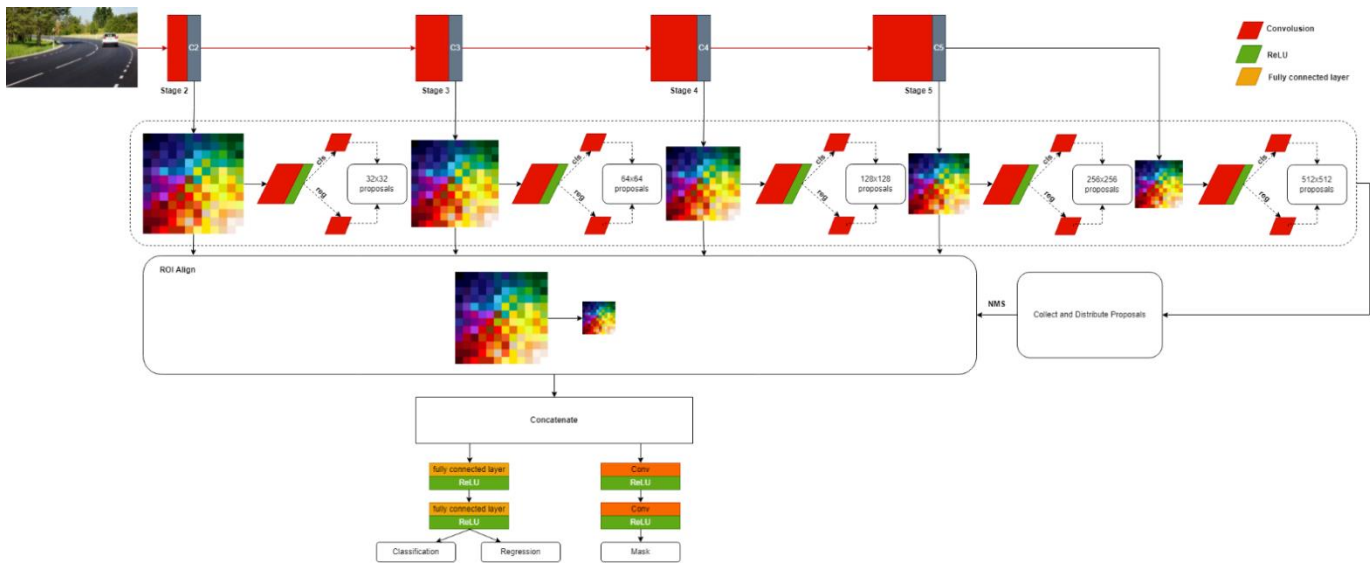


Fig. 1. The proposed system architecture.

The collected feature maps are processed RPN block, which has the duty of generating the supposed areas in the picture that contain objects based on the assumption that certain regions include objects. In order to accomplish this goal, a network with a 3x3 frame is moved across the feature map, and an outcome is created according to k anchors in place, which serve as the foundation for the size and position that are both supplied. RPN creates an estimate of the existence of a component for every anchor, as well as an improvement of the position of the boundaries of the item, if it has been found. This occurs only if the object has been found. At this level, we are going to focus on highlighting areas of interest that have the potential to contain items. Because of the functioning of non-maximum suppression, redundant regions are thrown out at the very end of the process.

Following that, the Region of Interest Align procedure is used to choose the values pertaining to the areas from the feature maps. These values are then scaled down to the same size. The last procedures of classification, refining of the dimensions of the box with boundaries, and forecasting the mask are carried out, as stated by them. The mask that is shown at the output has a significantly shrunk size yet displays true numbers. It is feasible to get an accuracy level that is satisfactory when the mask is sized to match the dimensions of the item that is being picked.

IV. EXPERIMENTAL RESULTS

A. Evaluation Parameters

The proposed model is evaluated using a number of different metrics, including the mean average precision (MaP) and the average recall (AR) at a number of different intersection over union (IoU) levels [31-33]. In classification issues involving localization and object identification, the ratio of the areas of the bounding boxes is most often employed as a metric to measure the reliability of the position of the bounding box. This is because the ratio of the areas of the bounding boxes is directly proportional to the accuracy of the location of the bounding box.

In deep learning based segmentation processes, accuracy is a crucial metric used to evaluate the quality of the segmentation. Accuracy refers to the extent to which the segmentation model's output matches the ground truth or the manual annotations provided by experts [34].

$$accuracy = \frac{TP + TN}{TP + FN + TN + FP}, \quad (1)$$

There are several measures of accuracy used in deep learning based segmentation processes, including pixel-wise accuracy, mean intersection over union (IoU), and dice coefficient [34-36]. Pixel-wise accuracy measures the percentage of correctly classified pixels in the segmentation output. Mean IoU calculates the similarity between the predicted segmentation mask and the ground truth, while the dice coefficient measures the overlap between the predicted and ground truth segmentation masks [35].

$$IoU = \frac{S(A \cap B)}{S(A \cup B)} \quad (2)$$

Specificity measures the proportion of true negative predictions made by the model. It is calculated as the ratio of correctly identified negative samples to the total number of actual negative samples. In segmentation tasks, specificity measures how well the model is able to correctly identify regions that do not belong to the target class or feature [36].

$$precision = \frac{TP}{TP + FP}, \quad (2)$$

Sensitivity, also known as recall, measures the proportion of true positive predictions made by the model. It is calculated as the ratio of correctly identified positive samples to the total number of actual positive samples. In segmentation tasks, sensitivity measures how well the model is able to detect the presence of the target class or feature in the input data [37].

$$recall = \frac{TP}{TP + FN}, \quad (3)$$

Both sensitivity and specificity are important metrics in deep learning based segmentation processes, as they provide a more complete understanding of the model's performance. A high sensitivity score indicates that the model is able to accurately detect the target feature or class, while a high specificity score indicates that the model is able to correctly identify regions that do not belong to the target class or feature.

To achieve high sensitivity and specificity scores in deep learning based segmentation processes, it is important to use appropriate training data and model architecture. The training data should be diverse and representative of the expected inputs, and the model architecture should be chosen to optimize the segmentation task at hand. Additionally, regularization techniques and hyperparameter tuning can be used to improve the model's performance and achieve higher sensitivity and specificity scores.

B. Results

In this section, we demonstrated the obtained results applying Mask R-CNN for road lane segmentation. Fig. 2 demonstrates lane detection and segmentation from the input images.

Fig. 3 and Fig. 4 demonstrate real-time lane detection process from the camera. Thus, the camera sends real-time video to the decision making system, in the result decision making system makes recommendations in real-time using the proposed Mask R-CNN model. It helps to tune the moving of the cars.

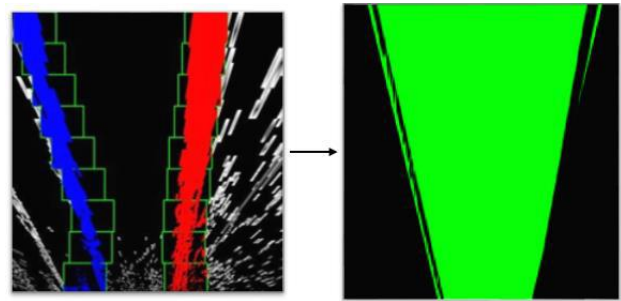


Fig. 2. Lane segmentation of the road.

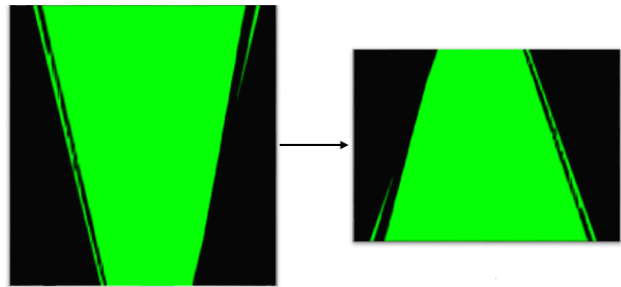


Fig. 3. Lane detection process.

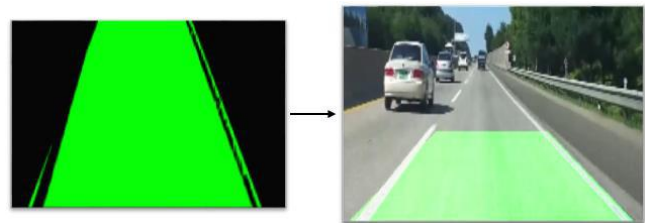


Fig. 4. Comparison of the obtained results for the real-time lane detection process from the camera.



Fig. 5. Comparison of the obtained results demonstrating several examples of applying the proposed framework in process.

Fig. 5 demonstrates several examples of applying the proposed framework in process. The proposed system can work in different weathers including sunny, rainy, cloudy or other weather condition. Moreover, it can work in daytime and nighttime. The proposed system can make a decision in real-time and can help to moving of autonomous vehicles.

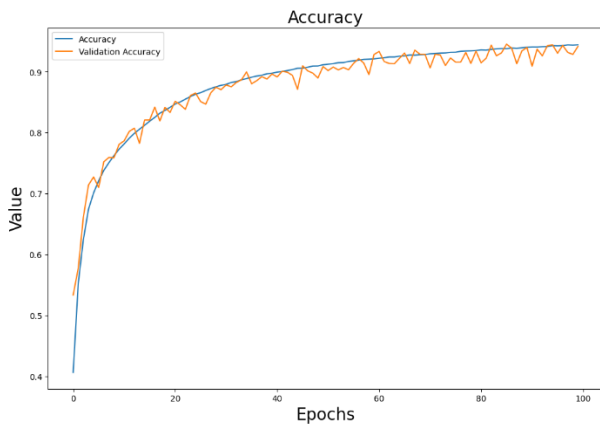


Fig. 6. The proposed model accuracy in 100 learning epochs.

Fig. 6 demonstrates the proposed model accuracy in 100 learning epochs. The model achieved to 90% accuracy in lane detection problem in 60 learning epochs, and it achieved to 95%-98% in 100 learning epochs.

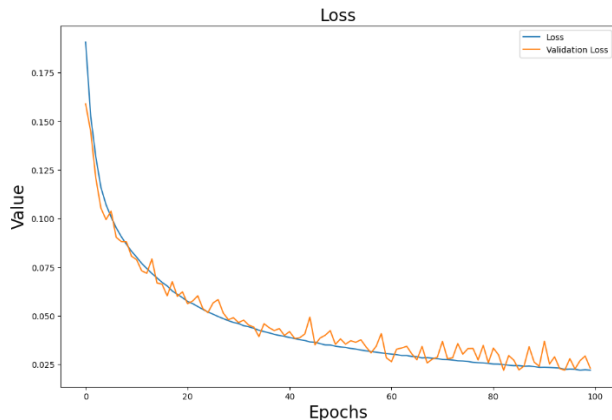


Fig. 7. The proposed model loss in 100 learning epochs.

Fig. 7 demonstrates the model loss in 100 learning epochs. Therefore, from the figure, we can say that, there are no sharp fluctuations, and depending on number of learning epochs, the model loss reduces.

V. DISCUSSION

The field of machine learning and deep learning has revolutionized the domain of autonomous vehicles by enabling them to detect, classify, and navigate their surroundings autonomously. In this paper, the authors propose a Mask R-CNN approach for real-time lane detection for autonomous vehicles. In this section, we analyze the advantages, disadvantages, challenges, and future perspectives of different machine learning and deep learning methods and indicate the advantages of the proposed Mask R-CNN approach.

Support Vector Machines (SVMs) have been widely used for object detection and image classification [38]. SVMs have shown promising results in various applications, but they are limited by their inability to handle large datasets and the need for feature extraction.

Deep learning models, such as Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), have shown impressive results in various applications. One of the significant advantages of deep learning models is that they can learn features automatically, without the need for manual feature extraction. However, deep learning models require a large amount of data and computing resources to train, and they can be challenging to interpret.

The Mask R-CNN approach has been gaining significant attention in recent years for its ability to generate pixel-level masks for each detected object [39]. This approach extends the Faster R-CNN algorithm by adding a segmentation branch. The Mask R-CNN approach has shown promising results in various applications, including object detection, instance segmentation, and human pose estimation.

The proposed Mask R-CNN approach for real-time lane detection for autonomous vehicles has several advantages. First, it can detect lanes in real-time, making it suitable for autonomous vehicles. Second, it can generate pixel-level masks for each detected lane, which can provide more accurate information about the lanes' position and shape [40]. Third, the approach can handle complex scenarios, such as occlusions and lane merging, which can be challenging for traditional lane detection methods. Fourth, the approach does not require manual feature extraction, making it more efficient and less prone to errors.

However, there are some challenges associated with the Mask R-CNN approach. One of the significant challenges is the need for a large amount of annotated data to train the model [41]. Another challenge is the high computational cost of training the model, which can be a limiting factor for some applications. Additionally, the interpretation of the model's output can be challenging, as the approach is based on a complex neural network architecture.

In the future, the development of more efficient and interpretable deep learning models will be crucial for the continued advancement of autonomous vehicles. In particular, the integration of multiple sensor modalities, such as lidar, radar, and cameras, will enable more accurate and robust perception systems. Moreover, the development of more advanced algorithms for handling complex scenarios, such as crowded urban environments, will be necessary.

Thus, machine learning and deep learning have enabled significant advancements in the field of autonomous vehicles. The proposed Mask R-CNN approach for real-time lane detection has several advantages, including real-time detection, accurate lane position and shape information, the ability to handle complex scenarios, and efficient and automatic feature extraction. However, there are some challenges associated with this approach, including the need for a large amount of annotated data, high computational costs, and interpretability. The development of more efficient and interpretable deep

learning models and the integration of multiple sensor modalities will be essential for the continued advancement of autonomous vehicles.

VI. CONCLUSION

In this paper, we presented a novel Mask R-CNN-based approach for real-time lane detection in autonomous vehicles. Our method adapts the Mask R-CNN model to specifically address the challenges posed by diverse traffic scenarios and varying environmental conditions. We introduced a robust, efficient, and scalable architecture for lane detection, which segments the lane markings and generates precise boundaries for AVs to follow. To ensure the model's generalizability and adaptability, we also introduced a comprehensive custom dataset and a multi-scale feature extraction technique.

Extensive experiments were conducted on public datasets and our custom dataset, validating the performance of the proposed method. The results demonstrated that our Mask R-CNN-based approach significantly outperforms existing state-of-the-art techniques in terms of accuracy, processing speed, and adaptability. The real-time processing capabilities of our model make it an ideal solution for implementation in AVs, enabling safer and more efficient navigation on roads.

As part of our future work, we plan to extend the proposed method to handle more complex scenarios, such as detecting lanes in the presence of shadows, occlusions, and varying lighting conditions. Additionally, we will investigate the integration of our lane detection approach with other perception tasks, such as object detection and semantic segmentation, to develop a unified perception system for autonomous vehicles. This would further improve the safety and efficiency of AVs, ultimately bringing us closer to the widespread deployment of these vehicles on our roads.

Overall, the proposed Mask R-CNN-based approach to real-time lane detection for autonomous vehicles represents a significant step forward in the development of robust and reliable perception systems for AVs, paving the way for their safe and efficient operation in diverse traffic scenarios and under varying environmental conditions.

REFERENCES

- [1] Vemula, S., & Frye, M. (2020, October). Mask R-CNN Powerline Detector: A Deep Learning approach with applications to a UAV. In 2020 AIAA/IEEE 39th Digital Avionics Systems Conference (DASC) (pp. 1-6). IEEE.
- [2] Sarp, S., Kuzlu, M., Cetin, M., Sazara, C., & Guler, O. (2020, August). Detecting floodwater on roadways from image data using Mask-R-CNN. In 2020 International Conference on INnovations in Intelligent SysTems and Applications (INISTA) (pp. 1-6). IEEE.
- [3] Ojha, A., Sahu, S. P., & Dewangan, D. K. (2021, May). Vehicle detection through instance segmentation using mask R-CNN for intelligent vehicle system. In 2021 5th international conference on intelligent computing and control systems (ICICCS) (pp. 954-959). IEEE.
- [4] Undit, H. J. A., Hassan, M. F. A., & Zin, Z. M. (2021, September). Vision-Based Unmarked Road Detection with Semantic Segmentation using Mask R-CNN for Lane Departure Warning System. In 2021 4th International Symposium on Agents, Multi-Agent Systems and Robotics (ISAMSR) (pp. 1-6). IEEE.
- [5] Gupta, S., Chand, D., & Kavati, I. (2021). Computer Vision based Animal Collision Avoidance Framework for Autonomous Vehicles. In Computer Vision and Image Processing: 5th International Conference, CVIP 2020, Prayagraj, India, December 4-6, 2020, Revised Selected Papers, Part III 5 (pp. 237-248). Springer Singapore.
- [6] Fang, S., Zhang, B., & Hu, J. (2023). Improved Mask R-CNN Multi-Target Detection and Segmentation for Autonomous Driving in Complex Scenes. *Sensors*, 23(8), 3853.
- [7] Tian, J., Yuan, J., & Liu, H. (2020, July). Road marking detection based on mask R-CNN instance segmentation model. In 2020 international conference on computer vision, image and deep learning (CVIDL) (pp. 246-249). IEEE.
- [8] He, L., Ou, J., Ba, M., Deng, G., & Yang, E. (2022). Imitative Reinforcement Learning Fusing Mask R-CNN Perception Algorithms. *Applied Sciences*, 12(22), 11821.
- [9] Narynov, S., Mukhtarkhanuly, D., & Omarov, B. (2020). Dataset of depressive posts in Russian language collected from social media. *Data in brief*, 29, 105195.
- [10] Omarov, B., Narynov, S., Zhumanov, Z., Gumar, A., & Khassanova, M. (2022). A Skeleton-based Approach for Campus Violence Detection. *COMPUTERS MATERIALS & CONTINUA*, 72(1), 315-331.
- [11] Chand, D., Gupta, S., & Kavati, I. (2020, December). Computer vision based accident detection for autonomous vehicles. In 2020 IEEE 17th India Council International Conference (INDICON) (pp. 1-6). IEEE.
- [12] Yudin, D. A., Skrynnik, A., Krishtopik, A., Belkin, I., & Panov, A. I. (2019). Object detection with deep neural networks for reinforcement learning in the task of autonomous vehicles path planning at the intersection. *Optical Memory and Neural Networks*, 28, 283-295.
- [13] Yu, J., Chen, Z., Wu, C., & Cheng, X. (2020). Intelligent Vehicle Road Type Recognition Based on Mask R-CNN. In CICTP 2020 (pp. 942-951).
- [14] Gupta, S., Chand, D., & Kavati, I. (2020). Computer Vision based Animal Collision Avoidance Framework for Autonomous Vehicles. *arXiv preprint arXiv:2012.10878*.
- [15] Satti, S. K. (2023). Recognizing the Indian Cautionary Traffic Signs using GAN, Improved Mask R - CNN, and Grab Cut. *Concurrency and Computation: Practice and Experience*, 35(2), e7453.
- [16] Mukhopadhyay, A., Biswas, P., Agarwal, A., & Mukherjee, I. (2019, June). Performance comparison of different cnn models for indian road dataset. In Proceedings of the 3rd International Conference on Graphics and Signal Processing (pp. 29-33).
- [17] Priya, S. G., Rajalakshmi, J., & Jebamalar, G. B. (2022). A NOVEL METHOD FOR OBJECT DETECTION IN AUTONOMOUS DRIVING SYSTEM USING CSPResNeXt AND YOLO-V4. *International Journal of Early Childhood Special Education*, 14(5).
- [18] Ugwu, E. M., Taylor, O. E., & Nwiabu, N. D. (2022). An Improved Visual Attention Model for Automated Vehicle License Plate Number Recognition Using Computer Vision. *European Journal of Artificial Intelligence and Machine Learning*, 1(3), 15-21.
- [19] Liang, T., Bao, H., Pan, W., & Pan, F. (2022). Traffic sign detection via improved sparse R-CNN for autonomous vehicles. *Journal of Advanced Transportation*, 2022, 1-16.
- [20] Diwan, A., Gupta, V., Chadha, C., Diwan, A., Gupta, V., Chadha, C., & R-CNN, A. D. U. M. (2021). Accident detection using mask R-CNN. *International Journal for Modern Trends in Science and Technology*, 7(01), 69-72.
- [21] Jeon, H., & Cho, S. (2020). Drivable area detection with region-based CNN models to support autonomous driving. *Journal of Multimedia Information System*, 7(1), 41-44.
- [22] Omarov, B., Tursynova, A., Postolache, O., Gamry, K., Batyrbekov, A., Aldeshov, S., ... & Shiyapov, K. (2022). Modified unet model for brain stroke lesion segmentation on computed tomography images. *Computers, Materials & Continua*, 71(3), 4701-4717..
- [23] Ortataş, F. N., & Çetin, E. (2022, September). Lane Tracking with Deep Learning: Mask RCNN and Faster RCNN. In 2022 Innovations in Intelligent Systems and Applications Conference (ASYU) (pp. 1-5). IEEE.
- [24] Sahu, S., Sahu, S. P., & Dewangan, D. K. (2022). Pedestrian Detection Using MobileNetV2 Based Mask R-CNN. In IoT Based Control

- Networks and Intelligent Systems: Proceedings of 3rd ICICNIS 2022 (pp. 299-318). Singapore: Springer Nature Singapore.
- [25] Jiang, S., Jiang, H., Ma, S., & Jiang, Z. (2020). Detection of parking slots based on mask R-CNN. *Applied Sciences*, 10(12), 4295.
- [26] Al Deen Taher, S. S., & Dang, J. (2022). Autonomous multiple damage detection and segmentation in structures using mask R-CNN. In *Experimental Vibration Analysis for Civil Engineering Structures: Select Proceedings of the EVACES 2021* (pp. 545-556). Cham: Springer International Publishing.
- [27] Pizzati, F., Allodi, M., Barrera, A., & García, F. (2020). Lane detection and classification using cascaded CNNs. In *Computer Aided Systems Theory–EUROCAST 2019: 17th International Conference, Las Palmas de Gran Canaria, Spain, February 17–22, 2019, Revised Selected Papers, Part II 17* (pp. 95-103). Springer International Publishing.
- [28] Kumar, B., Garg, U., Prakashchandra, M. S., Mishra, A., Dey, S., Gupta, A., & Vyas, O. P. (2022, November). Efficient Real-time Traffic Management and Control for Autonomous Vehicle in Hazy Environment using Deep Learning Technique. In *2022 IEEE 19th India Council International Conference (INDICON)* (pp. 1-7). IEEE.
- [29] Beltrán, J., Guindel, C., Cortés, I., Barrera, A., Astudillo, A., Urdiales, J., ... & García, F. (2020, September). Towards autonomous driving: a multi-modal 360 perception proposal. In *2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC)* (pp. 1-6). IEEE.
- [30] Sultanovich, O. B., Ergeshovich, S. E., Duisenbekovich, O. E., Balabekovna, K. B., Nagashbek, K. Z., & Nurlakovich, K. A. (2016). National Sports in the Sphere of Physical Culture as a Means of Forming Professional Competence of Future Coach Instructors. *Indian Journal of Science and Technology*, 9(5), 87605-87605.
- [31] Sultan, D., Omarov, B., Kozhamkulova, Z., Kazbekova, G., Alimzhanova, L., Dautbayeva, A., ... & Abdrakhmanov, R. (2023). A Review of Machine Learning Techniques in Cyberbullying Detection. *CMC-COMPUTERS MATERIALS & CONTINUA*, 74(3), 5625-5640.
- [32] Gang, Z. H. A. O., Jingyu, H. U., Wenlei, X. I. A. O., & Jie, Z. O. U. (2021). A mask R-CNN based method for inspecting cable brackets in aircraft. *Chinese Journal of Aeronautics*, 34(12), 214-226.
- [33] Altayeva, A., Omarov, B., & Im Cho, Y. (2018, January). Towards smart city platform intelligence: PI decoupling math model for temperature and humidity control. In *2018 IEEE International Conference on Big Data and Smart Computing (BigComp)* (pp. 693-696). IEEE.
- [34] Mohan, S., & Adarsh, S. (2022, December). Performance Analysis of Various Algorithms In 2D Dynamic Object Detection. In *2022 IEEE International Power and Renewable Energy Conference (IPRECON)* (pp. 1-6). IEEE.
- [35] Kaldarova, B., Omarov, B., Zhaidakbayeva, L., Tursynbayev, A., Beissenova, G., Kurmanbayev, B., & Anarbayev, A. (2023). Applying Game-based Learning to a Primary School Class in Computer Science Terminology Learning. In *Frontiers in Education* (Vol. 8, p. 26). Frontiers.
- [36] Raoofi, H., & Motamedi, A. (2020). Mask R-CNN deep learning-based approach to detect construction machinery on jobsites. In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction* (Vol. 37, pp. 1122-1127). IAARC Publications.
- [37] Neethidevan, V., & Chansrasekharan, G. (2020). Image Segmentation for Object detection Using mask R-CNN in Collab. *GRD Journal-Global Research and Development for Engineering*, 5(4), 15-19.
- [38] Güney, E., & BAYILMIŞ, C. (2022). An implementation of traffic signs and road objects detection using faster R-CNN. *Sakarya University Journal of Computer and Information Sciences*, 5(2), 216-224.
- [39] Vemula, S., & Frye, M. (2020, October). Real-time powerline detection system for an unmanned aircraft system. In *2020 IEEE International Conference on Systems, Man, and Cybernetics (SMC)* (pp. 4493-4497). IEEE.
- [40] He, H., Xu, H., Zhang, Y., Gao, K., Li, H., Ma, L., & Li, J. (2022). Mask R-CNN based automated identification and extraction of oil well sites. *International Journal of Applied Earth Observation and Geoinformation*, 112, 102875.
- [41] Zhang, H., Dong, J., & Gao, Z. (2023). Automatic segmentation of airport pavement damage by AM - Mask R - CNN algorithm. *Engineering Reports*, e12628.

Game Theory Approach for Open Innovation Systems Analysis in Duopolistic Market

Aziz Elmire¹, Aziz Ait Bassou², Mustapha Hlyal³, Jamila El Alami⁴

Lastimi Laboratory-University Med V of Rabat, Graduate School of Technology, Sale, Morocco^{1, 2, 3, 4}

Higher School of Textile and Clothing Industries, Casablanca, Morocco³

Logistics Center of Excellence, Higher School of Textile and Clothing Industries, Casablanca, Morocco^{1, 3}

Abstract—The approach used in this study involves applying the Cournot model, which is initially based on the analysis of product quantities in the market. Building upon the obtained equilibrium, a second analysis is conducted to examine the impact of the open innovation integration rate, utilizing a dynamic model. The obtained results have demonstrated that multiple equilibria are possible, and under certain conditions, competing firms have a stake in carefully analyzing the integration rate of open innovation.

Keywords—Duopoly; open innovation; closed innovation; Cournot model

I. INTRODUCTION

The closed innovation model is a strategy that prioritizes the use of internal resources to optimize the innovation process, ultimately leading to the development of innovative products and services [1]. Essentially, companies focus on building and nurturing the necessary competencies in-house to become leaders in their respective markets. By keeping innovation activities in-house, companies can have more control over the entire innovation process, from ideation to product launch, and can better protect their intellectual property.

The primary goal of closed innovation is to ensure that the necessary resources are developed and improved to implement the innovation process effectively[2]. This approach facilitates the creation of new products and services while simultaneously minimizing risks and creating barriers to imitation by competitors. Closed innovation also allows companies to build a competitive advantage by cultivating in-house expertise and refining their innovation processes. By relying on internal resources, companies can optimize the innovation process, leading to more efficient product development, better quality products, and higher profits[3].

According to Chesbrough, the closed innovation model was effective for much of the 20th century. However, this approach to innovation faced two significant limitations. The first limitation was succinctly expressed by Bill Joy, the co-founder of Sun Microsystems, who noted that "No matter who you are, most of the smartest people work for someone else". In other words, relying solely on internal resources means missing the valuable expertise and ideas that exist beyond the organization.

However, Open innovation is viewed as a sustainable innovation approach that depends on international collaboration between companies and countries[4]. As companies seek to gain a competitive advantage through

innovation, open innovation has become increasingly popular among academics and practitioners. However, the current literature has mostly focused on the benefits of open innovation and overlooked its potential failures [5]. The integration of open innovation (OI) and the circular economy (CE) has the potential to contribute to a more sustainable economy.

However, there is a lack of understanding of how OI can be leveraged to promote the adoption of CE. As an important aspect of the economy, it is crucial to investigate the relationship between OI and CE and identify ways to overcome the barriers to CE adoption[6]. The second limitation is related to the high level of investment required to support the innovation process. Since closed innovation relies on internal resources, there is a higher level of investment needed to supply the innovation process. This investment also comes with a higher risk as developed ideas may not be supported by the organization, resulting in wasted resources and missed opportunities[7].

The concept of open innovation has been widely applied in various fields, particularly in innovation management for firms of different sizes. Its emphasis on sharing and collaboration has made it a popular topic of interest[8]. Numerous studies have highlighted the discovery of an inverted U-shaped relationship among open innovation, knowledge reorganization, and innovation performance. Moreover, it has been observed that knowledge reorganization and reuse play a mitigating role by alleviating the adverse effects of excessive open innovation on innovation performance[9]. Furthermore, the observed correlation among open innovation, generic strategies (cost-leadership and differentiation), and business performance indicates that the influence of open innovation on business performance is mediated by the adoption of cost-leadership and differentiation strategies[10][11].

Open Innovation has gained significant attention in both research and management practices[12]. As radical innovation and new business development often necessitate external technologies and commercialization methods, many companies have transitioned from a Closed to an Open Innovation model[13]. However, firms frequently encounter challenges during the implementation phase, with the focus primarily placed on external ideas, technologies, and identification processes, while cultural obstacles are often overlooked[14]. While the open innovation literature has extensively discussed strategies, processes, and business models, it has largely neglected the importance of the underlying innovation culture[15].

Researchers have conducted multiple studies to examine the differences between Open Innovation and Closed Innovation, with the objective of characterizing each type of innovation. These studies have revealed that Chesbrough's six principles of open innovation rely on a false dichotomy that necessarily opposes closed innovation to open innovation[13]. Within the same context, researchers have conducted studies to explore the implementation of inbound, outbound, and combined open innovation practices. These investigations have examined multiple factors such as organizational context, company structure, collaborative arrangements, the involvement of diverse actors, and the outcomes achieved, providing insights into the role and influence of these factors on the efficacy of open innovation practices in companies[16].

The dilemma between Open Innovation and Closed Innovation lies in the strategic choice that companies face regarding their approach to innovation. Closed Innovation is based on the principle that the company should internally control and develop its innovations, relying on its own resources and capabilities. On the other hand, Open Innovation takes a more open approach, seeking to integrate external ideas, knowledge, and resources through collaborations, partnerships, and leveraging the innovation ecosystem.

The challenge arises when companies are faced with the decision of selecting the optimal approach to embrace. Closed Innovation provides enhanced control and protection of internal knowledge; however, it may limit exposure to new ideas and opportunities[17]. Conversely, Open Innovation offers access to a broad spectrum of external knowledge and resources, fostering innovation, yet it entails risks such as potential intellectual property disclosure and difficulties in coordinating with external partners[18]. Therefore, companies must navigate between adopting a more secure and internally-focused approach or embracing a collaborative and open approach to innovation, carefully considering the benefits and drawbacks of each, as well as their unique organizational context and environment.

Various alternative approaches are being used to examine open innovation[19]. These include empirical studies, which involve collecting real-world data and analyzing its impact on firm performance through surveys, interviews, case studies, and quantitative analysis. Network analysis explores the structure and dynamics of innovation networks, investigating collaborations, partnerships, and knowledge flows to identify key actors and understand their influence on innovation outcomes. Qualitative research, such as ethnography and in-depth interviews, delves into the experiences, perspectives, and behaviours of individuals and organizations involved in open innovation. Technological platforms and data analytics leverage advanced technologies to analyze large-scale datasets, uncovering patterns, trends, and correlations relevant to open innovation. Simulation models simulate scenarios to understand the complexities, trade-offs, and uncertainties of open innovation, facilitating the testing of different strategies and policies. Comparative studies compare industries, sectors, or regions to identify variations in open innovation practices, outcomes, and contextual factors, providing insights into industry-specific challenges, best practices, and policy implications for promoting open innovation.

Game theory has proven to be a useful tool for modeling the interactions that take place in Open Innovation ecosystems. Specifically, the Cournot duopoly has emerged as a popular game theory model to simulate the strategic behavior of firms in Open Innovation[20]. For example, an Open Innovation process in a Cournot duopoly is analyzed using a differential game approach that incorporates knowledge spillover. The optimal licensing contract for a patentor with a quality improvement innovation in a Cournot duopoly market is analyzed in this paper. s are endogenously determined via the R&D process[21]. Another study examined the optimization of technology licensing contracts for quality improvement innovation in the context of Cournot competition[22]. A similar study has addressed the problem of patent licensing in a Cournot duopoly, where one of the firms acts as the innovator (patentee) and encounters capacity limitations. The focus of this study revolves around investigating the challenges associated with patent licensing within the context of a Cournot duopoly, where one firm holds the role of the patentee and faces capacity constraints[23]. Another study focused on a differentiated Cournot model and a differentiated Bertrand model, in which one of the firms engages in an R&D process resulting in an endogenous cost-reducing innovation[24]. The role of platform economics in facilitating open innovation while addressing the challenges of information stickiness and product diversification risks was studied in [25].

II. METHODOLOGY

A. Goals and Assumptions Underlying the Study

The purpose of this paper is to explore the adoption of open innovation versus closed innovation by a firm operating in a duopoly model, specifically using the Cournot model. The study incorporates an integration rate parameter to assess its impact on the firm's innovation strategy. It is important to mention that the analysis does not consider the specific activities of the competing firms. Additionally, this study builds upon and draws inspiration from several related works in the field. In this regard, the study considers the work on the complex dynamics of R&D competition with one-way spillover based on intellectual property protection[25].

This study specifically focuses on a dynamic two-stage model. Indeed, investigations on the two-stage model have increasingly captured the interest of economists. Whereas initially, many scholars were primarily focused on examining the properties of the static model. It is undeniable that the static model has its limitations. One of these limitations is its ability to only analyze the individual supply and demand equilibrium between firms. When the factors of supply and demand undergo changes, the corresponding supply relationship will also shift.

This research employs nonlinear dynamics theory to examine the evolutionary process within firms' games. Various scholars have conducted previous studies on this topic. The local and global dynamic properties of a two-stage oligopoly game model with an adaptive dynamic mechanism, highlighting its complex evolutionary behaviors was studied in [26]. Also, another paper investigated the properties of a dynamic Cournot duopoly game model with a nonlinear demand function[27]. Similar works can be found in [28].

Moreover, the economic dynamical system has shown significant interest in the dynamical two-stage game. For example, a dynamic model of a two-stage remanufacturing closed-loop supply chain was used to investigate how technological innovation, Big Data marketing, and overconfidence influence the decision-making process of supply chain members[29]. The stability of a two-stage duopoly Cournot game model, which incorporates a nonlinear inverse demand function and R&D spillover, is investigated. The results indicate that the final state of the system is influenced by its initial state[30].

B. Mathematical Model

To assess the effects of open innovation versus closed innovation, the Cournot duopoly model is used. The model assumes the presence of two companies, labeled i ($i=1,2$), in a market, offering identical products. Recognizing the value of innovation as a means of achieving a competitive edge, each firm adopts a strategy that enables it to emerge as the leader in the market.

Our model consists of two game stages that take into account the time required for innovation before introducing products to the market. In the first stage, the innovation parameter is considered, followed by the standard Cournot model where a balance is sought in relation to the quantities of products on the market. Differences in the levels of innovation integration (i.e., open innovation) between firms can result in differences in product quality. The industry is characterized by a linear inverse demand function expressed as:

$$p_i = a - bQ \quad (i = 1,2)$$

Where, $a > 0$ and $b \in [0,1]$,

Q is the total quantity in the market $Q = \sum_{i=1,2} q_i$, q_i is the outputs of the products producing by the firm i .

This work consider that the two firms decide to integrate the innovation in their strategies. In order to model the OI and CI, This paper introduce the parameter $\sigma_i \in [0,1]$ that corresponds to the OI integration rate. The effective marginal cost of firm i is represented as follow:

$$C_i(\sigma_i) = A + c \times (1 - \sigma_i), \quad i = 1,2 \quad (2)$$

According to this cost equation, if a firm i decides to outsource the innovation the marginal cost will be A , since the rate σ_i will be equal to one. However, if firm i decides to internalize, completely, the innovation, the marginal cost will be high since it will be equal to $A+c$.

Considering the gains that can be obtained from corporate innovation (CI), such as high-powered incentives, firm-owned property rights, and reuse cost, it can be hypothesized that as long as the firm perceives a decrease in these gains, its rate of Open innovation will diminish. Therefore, it represents losses generated by the massive use of Open innovation, charges for the firm and therefore an additional cost.

Furthermore, based on several works of duopolistic models[31], the expressions of a quadratic cost equation, loss of a firm i can be expressed as:

$$L(\sigma_i) = \gamma\sigma_i^2/2(i = 1,2), \quad (3)$$

Where γ is a spillover parameter.

C. Profit of each Firm

According to the propositions given above, the profit equations for the two firms

$$\begin{cases} \pi_1(q_1, q_2, \sigma_1, \sigma_2) = [p_1(q_1, q_2) - C_1(\sigma_1, \sigma_2)]q_1 - L(\sigma_1), \\ \pi_2(q_1, q_2, \sigma_1, \sigma_2) = [p_2(q_1, q_2) - C_2(\sigma_1, \sigma_2)]q_2 - L(\sigma_2). \end{cases} \quad (4)$$

Substituting Eq. (1) and (2) into Eq. (4), the expression of profit function for each firm is:

$$\begin{cases} \pi_1(q_1, q_2, \sigma_1, \sigma_2) = -bq_1^2 + (a - bq_2 - A - c(1 - \sigma_1))q_1 - \gamma\frac{1}{2}\sigma_1^2 \\ \pi_2(q_1, q_2, \sigma_1, \sigma_2) = -bq_2^2 + (a - bq_1 - A - c(1 - \sigma_2))q_2 - \gamma\frac{1}{2}\sigma_2^2 \end{cases} \quad (5)$$

Now, the marginal profits of these two firms are:

$$\begin{cases} \frac{\partial \pi_1}{\partial q_1} = -2bq_1 + (a - bq_2 - A - c(1 - \sigma_1)) \\ \frac{\partial \pi_2}{\partial q_2} = -2bq_2 + (a - bq_1 - A - c(1 - \sigma_2)) \end{cases} \quad (6)$$

The second-order conditions are met because

$$\frac{\partial^2 \pi_1}{\partial^2 q_1} = \frac{\partial^2 \pi_2}{\partial^2 q_2} = -2 < 0.$$

According to Eq. (6), the reaction function of the firm 1 and firm 2 by setting $\frac{\partial \pi_1}{\partial q_1} = 0, \frac{\partial \pi_2}{\partial q_2} = 0$ is as follow:

$$\begin{cases} R_1(q_2, \sigma_1) = q_2^* = \frac{(a - bq_1 - A - c(1 - \sigma_1))}{2b} \\ R_2(q_1, \sigma_2) = q_1^* = \frac{(a - bq_2 - A - c(1 - \sigma_2))}{2b} \end{cases} \quad (7)$$

$$\text{Let } U = \frac{(a - A - c)}{2b}$$

Cournot equilibrium can be expressed by replacing q_1^* and q_2^* in reaction's function.

$$\begin{cases} q_1^* = \frac{2}{3} \left(U - \frac{c}{2b} (\sigma_2 - \frac{1}{2}\sigma_1) \right) \\ q_2^* = \frac{2}{3} \left(U - \frac{c}{2b} (\sigma_1 - \frac{1}{2}\sigma_2) \right) \end{cases} \quad (8)$$

Provided that $\frac{2b}{c}U > (\sigma_2 - \frac{1}{2}\sigma_1)$ and $\frac{2b}{c}U > (\sigma_1 - \frac{1}{2}\sigma_2)$.

Therefore, in the subsequent scenario, it is assumed that a Cournot equilibrium exists.

D. First Stage of Equilibrium Analysis

According to this result, the rate of OI determines the production strategy of the quantities to be produced for each firm. Also, by subtracting q_2^* from q_1^* ,

$$\Delta Q = q_1^* - q_2^* = \frac{c}{3b} (\sigma_1 - \sigma_2) \quad (9)$$

According to ΔQ value, the equilibrium quantities depend on the innovation integration rates for each firm. Thus, assuming firm 1 chooses an OI approach ($\sigma_1=1$) and firm 2 chooses CI as an opposite approach ($\sigma_2=0$), $\Delta Q > 0$. Firm 1 must always deliver quantities greater than those of firm 2, since $\frac{c}{3b}$ is positive.

The profit function about innovation rate σ_i captured by taking Eq. (8) into Eq. (5) in reverse order can be obtained as:

$$\begin{cases} \pi_1(\sigma_1, \sigma_2) = \left(\frac{5c}{9b} - \frac{1}{2}\gamma\right)\sigma_1^2 + \frac{1}{9}\left(8U - \frac{c}{4} - \frac{5c}{18b}\sigma_2\right)\sigma_1 - \frac{1}{9}U(3-2b)\frac{c}{2b}\sigma_2 + \frac{1}{9}U^2(3-2b) \\ \pi_2(\sigma_1, \sigma_2) = \left(\frac{5c}{9b} - \frac{1}{2}\gamma\right)\sigma_2^2 + \frac{1}{9}\left(8U - \frac{c}{4} - \frac{5c}{9 \cdot 2b}\sigma_1\right)\sigma_2 - \frac{1}{9}U(3-2b)\frac{c}{2b}\sigma_1 + \frac{1}{9}U^2(3-2b) \end{cases} \quad (10)$$

The equation of the profits of the two firms makes it possible to calculate the maximum local profit according to the rates of integration of the IO.

For this, the derivative of the system of equation (10) give

$$\begin{cases} \frac{\partial \pi_1(\sigma_1, \sigma_2)}{\partial \sigma_1} = \left(\frac{5c}{18b} - \gamma\right)\sigma_1 + \frac{1}{9}\left(8U - \frac{c}{4} - \frac{5c}{18b}\sigma_2\right) \\ \frac{\partial \pi_2(\sigma_1, \sigma_2)}{\partial \sigma_2} = \left(\frac{5c}{18b} - \gamma\right)\sigma_2 + \frac{1}{9}\left(8U - \frac{c}{4} - \frac{5c}{9 \cdot 2b}\sigma_1\right) \end{cases} \quad (11)$$

Based on this approach, different expectations are assumed from the two firms. Indeed, supposing that firm 1 is rational in a bounded way and firm 2 is a local approximation. The limited rational actor 1 does not have complete knowledge of the market; hence, they try to use local information based on marginal profit.

E. Second Stage of Equilibrium Analysis

In this section, the impact of adjustment mechanisms on the competitive outcomes of enterprises, building on the work of Dixit is discussed. Dixit's research focuses on constructing a competitive model of two companies with an adjustment mechanism and estimating the marginal profit to describe the production evolution[32][33]. In this paper, two different scenarios are given: when two companies co-exist in the same market and when one company takes full control of the market after dislodging the other. The findings indicate that the adjustment mechanism is effective in reducing the output and profit gap between the companies, and in some cases, it can lead to the elimination of this difference and the attainment of Nash equilibrium[34].

Therefore, it is supposed that Firm 1 decides to proceed with the decisions concerning the rate of integration of the IO by either increasing or decreasing it. Thus, the dynamic adjustment mechanism can be modeled as follows:

$$\begin{cases} \sigma_1(t+1) = \sigma_1(t) + \vartheta_1 \sigma_1(t) \frac{\partial \pi_1(\sigma_1, \sigma_2)}{\partial \sigma_1} \\ \sigma_2(t+1) = \sigma_2(t) + \vartheta_2 \sigma_2(t) \frac{\partial \pi_2(\sigma_1, \sigma_2)}{\partial \sigma_2} \end{cases} \quad (12)$$

Where, ϑ_1, ϑ_2 are positive parameters, which represent respectively the speed of adjustment of firm 1 and firm 2.

By replacing the profit given in equation (11) in the equation, (12) system become:

$$\begin{cases} \sigma_1(t+1) = \sigma_1(t) + \vartheta_1 \sigma_1(t) \left(\left(\frac{5c}{18b} - \gamma\right)\sigma_1(t) + \frac{1}{9}\left(8U - \frac{c}{4} - \frac{5c}{18b}\sigma_2(t)\right) \right) \\ \sigma_2(t+1) = \sigma_2(t) + \vartheta_2 \sigma_2(t) \left(\left(\frac{5c}{18b} - \gamma\right)\sigma_2(t) + \frac{1}{9}\left(8U - \frac{c}{4} - \frac{5c}{9 \cdot 2b}\sigma_1(t)\right) \right) \end{cases} \quad (13)$$

III. EQUILIBRIUM POINTS AND LOCAL STABILITY

The system of Eq. (13) given is a set of coupled first-order nonlinear difference equations. To analyze the equilibrium and stability of the system, the fixed points of the system by setting $\sigma_1(t+1) = \sigma_1(t)$ and $\sigma_2(t+1) = \sigma_2(t)$.

Setting $\sigma_1(t+1) = \sigma_1(t)$ and $\sigma_2(t+1) = \sigma_2(t)$, the system become:

$$\begin{cases} \vartheta_1 \sigma_1(t) \left(\left(\frac{5c}{18b} - \gamma\right)\sigma_1(t) + \frac{1}{9}\left(8U - \frac{c}{4} - \frac{5c}{18b}\sigma_2(t)\right) \right) = 0 \\ \vartheta_2 \sigma_2(t) \left(\left(\frac{5c}{18b} - \gamma\right)\sigma_2(t) + \frac{1}{9}\left(8U - \frac{c}{4} - \frac{5c}{18b}\sigma_1(t)\right) \right) = 0 \end{cases} \quad (14)$$

After performing computational analysis, it was determined that the system given by Eq. (16) has four equilibrium points. These points are:

$$(\sigma_1, \sigma_2) = (0, 0)$$

$$(\sigma_1, \sigma_2) = \left(\left(\frac{16U - c}{\frac{5c}{9b} - 2\gamma} \right), 0 \right)$$

$$(\sigma_1, \sigma_2) = \left(0, \left(\frac{16U - c}{\frac{5c}{9b} - 2\gamma} \right) \right)$$

$$(\sigma_1, \sigma_2) = \left(\left(\frac{40U - 5c + 9\gamma \frac{c}{b}}{18b\gamma - 25c} \right), \left(\frac{40U - 5c + 9\gamma \frac{c}{b}}{18b\gamma - 25c} \right) \right)$$

To guarantee that all four equilibrium points of the system (10) are non-negative, the following conditions must be satisfied: $5c - 18b\gamma > 0$ and $U < \frac{c}{16}$. Additionally, it is important to note that the analysis assumes positive values for ϑ_1 and ϑ_2 .

$$J = \begin{bmatrix} 1 + \vartheta_1 \left(\left(\frac{5c}{18b} - \gamma\right)\sigma_1 + \frac{1}{9}\left(8U - \frac{c}{4} - \frac{5c}{18b}\sigma_2\right) \right) & -\frac{1}{9b}\vartheta_1 \sigma_1 \left(\frac{5c}{18b}\right) \\ -\frac{1}{9b}\vartheta_2 \sigma_2 \left(\frac{5c}{18b}\right) & 1 + \vartheta_2 \left(\left(\frac{5c}{18b} - \gamma\right)\sigma_2 + \frac{1}{9}\left(8U - \frac{c}{4} - \frac{5c}{18b}\sigma_1\right) \right) \end{bmatrix} \quad (15)$$

After identifying the four equilibrium points of the system given by Eq. (16), the next step is to study their stability. This is an important step as it helps us determine the behavior of the system around these equilibrium points. The stability of an equilibrium point can be classified as either stable, unstable, or semi-stable. A stable equilibrium point is one where any small disturbance from its position will cause the system to return to that point. An unstable equilibrium point, on the other hand, is one where any small disturbance will cause the system to move away from that point. Lastly, a semi-stable equilibrium point has one stable direction and one unstable direction. By analyzing the stability of each equilibrium point, insights can be gained into the behavior of the system and its evolution over time.

A. First Equilibrium Point:

The Jacobian matrix at the equilibrium point $(\sigma_1, \sigma_2) = (0, 0)$ is:

$$J(0,0) = \begin{bmatrix} 1 + \vartheta_1 \left(\frac{1}{9b} \left(8U - \frac{c}{4} \right) \right) & 0 \\ 0 & 1 + \vartheta_2 \left(\frac{1}{9b} \left(8U - \frac{c}{4} \right) \right) \end{bmatrix}$$

The eigenvalues are the solutions to this equation, which are:

$$\lambda_1 = 1 + \vartheta_1 \frac{(8U - \frac{c}{4})}{9b}$$

$$\lambda_2 = 1 + \vartheta_2 \frac{(8U - \frac{c}{4})}{9b}$$

Since ϑ_1 and ϑ_2 are positive, and that $\frac{c}{4} < 8U$, then both eigenvalues are positive. This means that the equilibrium point (0,0) is unstable node.

In terms of the physical interpretation of the system, this result suggests that the equilibrium point (0,0) is unstable when the gain parameters for the feedback loops, ϑ_1 and ϑ_2 , are positive and the net effect of the feedback loops on the system is positive, as represented by the positive value of $(8U - c/4)$.

B. Second Equilibrium Point

The Jacobian matrix at the equilibrium point

$$(\sigma_1, \sigma_2) = \left(\left(\frac{16U-c}{\frac{5c}{9b}-2\gamma} \right), 0 \right) \text{ is:}$$

$$J \left(\left(\frac{16U-c}{\frac{5c}{9b}-2\gamma} \right), 0 \right) = \begin{bmatrix} 1 + \vartheta_1 \left(\frac{40U-9c}{45b-18\gamma} \right) & -\vartheta_1 \frac{4U-c}{45b-18\gamma} \\ 0 & 1 + \vartheta_2 \left(\frac{40U-9c}{45b-18\gamma} \right) \end{bmatrix}$$

The Jacobian matrix is a diagonal matrix; thus, its corresponding distinct eigenvalues are:

$$J \left(\left(\frac{16U-c}{\frac{5c}{9b}-2\gamma} \right), 0 \right) = \begin{bmatrix} 1 + \vartheta_1 \left(\frac{40U-9c}{45b-18\gamma} \right) & -\vartheta_1 \frac{4U-c}{45b-18\gamma} \\ 0 & 1 + \vartheta_2 \left(\frac{40U-9c}{45b-18\gamma} \right) \end{bmatrix}$$

If $U > 9c/40$ and $b > 2\gamma/5$, the equilibrium point is an unstable node, meaning that the trajectories of the system move away from this point. This implies that the market will not reach a stable state and will continue to fluctuate. On the other hand, if $U > 9c/40$ or $b > 2\gamma/5$, the equilibrium point is a stable node, meaning that the system will move towards this point as time progresses. In other words, the market will reach a stable state, either with high U or high b values.

The stability analysis of the equilibrium point is crucial in understanding the behavior of the system. The results obtained suggest that the stability of the equilibrium point is influenced by the values of U and b. Therefore, firms can use this information to adjust their strategies and optimize their profits. By maintaining the optimal values of U and b, enterprises can stabilize their position in the market and achieve long-term success.

C. Third Equilibrium Point

The Jacobian matrix at the equilibrium point is:

$$J \left(0, \left(\frac{16U-c}{\frac{5c}{9b}-2\gamma} \right) \right) = \begin{bmatrix} 1 + \vartheta_1 \left(\frac{40U-9c}{45b-18\gamma} \right) & 0 \\ -\vartheta_1 \frac{4U-c}{45b-18\gamma} & 1 + \vartheta_2 \left(\frac{40U-9c}{45b-18\gamma} \right) \end{bmatrix}$$

The Jacobian matrix is a diagonal matrix; thus, its corresponding distinct eigenvalues are:

$$\lambda_1 = 1 + \frac{\vartheta_1(40U-9c)}{45b-18\gamma}$$

$$\lambda_2 = 1 + \frac{\vartheta_2(40U-9c)}{45b-18\gamma}$$

The types of the second equilibrium point are similar to the boundary equilibrium points. If $U > 9c/40$ and $b > 2\gamma/5$ then is the equilibrium point is unstable node. However if $U > 9c/40$ or $b > 2\gamma/5$ the equilibrium point is stable node.

In economic terms, the boundary equilibrium points signify a scenario where one of the two firms has exited the market.

Equilibrium points $(\sigma_1, \sigma_2) = \left(\left(\frac{16U-c}{\frac{5c}{9b}-2\gamma} \right), 0 \right)$ and $(\sigma_1, \sigma_2) =$

$\left(0, \left(\frac{16U-c}{\frac{5c}{9b}-2\gamma} \right) \right)$, on the other hand, it indicates that one of the

firms has taken the lead in the oligopoly market, resulting in a monopoly market. The local stability of equilibrium points reflects the short-term stability of the economic market. However, neither of these scenarios is desirable. It is only when both companies restrict each other that the market and the country can achieve stable development. This state is known as "Nash equilibrium," which is reached when both firms maximize their own profits while also ensuring the stable development of the market.

D. Fourth Equilibrium Point

The Jacobian matrix at the equilibrium point is:

$$J = \begin{bmatrix} 1 + \frac{c}{9b} \vartheta_1 \left(\frac{-65(8U-c+9\gamma\frac{c}{5b})}{(18b\gamma-25c)} + \frac{8U}{c} \right) & -\vartheta_1 \frac{c}{9b} \left(\frac{8U-c+9\gamma\frac{c}{5b}}{(18b\gamma-25c)} \right) \\ -\vartheta_2 \frac{c}{9b} \left(\frac{8U-c+9\gamma\frac{c}{5b}}{(18b\gamma-25c)} \right) & 1 + \frac{c}{9b} \vartheta_2 \left(\frac{-65(8U-c+9\gamma\frac{c}{5b})}{(18b\gamma-25c)} + \frac{8U}{c} \right) \end{bmatrix}$$

The trace of the given Jacobian matrix J is:

$$Tr(J) = 2 + \frac{c}{9b} (\vartheta_1 + \vartheta_2) \left(\frac{-65(8U-c+9\gamma\frac{c}{5b})}{(18b\gamma-25c)} + \frac{16U}{c} \right)$$

Therefore, the determinant of the given Jacobian matrix J is:

$$Det(J) = 1 + \frac{c}{9b} (\vartheta_1 + \vartheta_2) \left(\frac{-65(8U-c+9\gamma\frac{c}{5b})}{(18b\gamma-25c)} + \frac{8U}{c} \right) + \vartheta_1 \vartheta_2 \left(\frac{c}{9b} \right)^2 \left(\frac{8U-c+9\gamma\frac{c}{5b}}{(18b\gamma-25c)} \right)^2$$

The characteristic polynomial of matrix:

$$P(\lambda) = \lambda^2 - \text{Tr}(J) + \text{Det}(J) = 0$$

The discriminant of the characteristic polynomial is given by:

$$\Delta = \text{Tr}(J)^2 - 4\text{Det}(J)$$

Substituting the expressions for $\text{Tr}(J)$ and $\text{Det}(J)$,

$$\Delta = \left[2 + \frac{c}{9b}(\vartheta_1 + \vartheta_2) \left(\frac{-65(8U-c+9\gamma\frac{c}{5b})}{(18b\gamma-25c)} + \frac{16U}{c} \right) \right]^2 \left[1 + \frac{c}{9b}(\vartheta_1 + \vartheta_2) \left(\frac{-65(8U-c+9\gamma\frac{c}{5b})}{(18b\gamma-25c)} + \frac{8U}{c} \right) + \vartheta_1\vartheta_2 \left(\frac{c}{9b} \right)^2 \left(\frac{8U-c+9\gamma\frac{c}{5b}}{(18b\gamma-25c)^2} \right) \right]$$

Simplifying this expression may lead to a long and complicated expression, but it represents the discriminant of the characteristic polynomial which determines the stability of the equilibrium point.

The given equilibrium is a stable node if the following conditions are satisfied:

- $\text{Tr}(J) < 0$ and $\text{Det}(J) > 0$
- $\Delta > 0$ and $\text{Tr}(J) < 0$

Therefore, these conditions should be satisfied

$$(40U - 5c + 9\gamma c/b)^2 < \frac{(64\vartheta_1\vartheta_2U - 9c(\vartheta_1 + \vartheta_2) + 25\gamma c\vartheta_1\vartheta_2)}{18b}$$

$$\frac{(-65(8U - c + 9\gamma c/5b))}{(18b\gamma - 25c)} < 0$$

$$8U - c + 9\gamma c/5b > 0$$

$$\frac{(40U - 5c + 9\gamma c/b)}{(18b\gamma - 25c)} > 0$$

If these conditions hold, then the equilibrium point

$$(\sigma_1, \sigma_2) = \left(\left(\frac{40U-5c+9\gamma\frac{c}{b}}{18b\gamma-25c} \right), \left(\frac{40U-5c+9\gamma\frac{c}{b}}{18b\gamma-25c} \right) \right) \text{ is a stable node.}$$

IV. NUMERICAL ANALYSIS

This section of the article focuses on performing a numerical analysis to investigate stability studied in the previous section. The model used in this analysis assesses the effects of open innovation (OI) versus closed innovation (CI) using the Cournot duopoly model. The model assumes the presence of two companies in a market offering identical products, with the industry characterized by a linear inverse demand function. Each firm adopts a strategy that enables it to emerge as the leader in the market. Three equilibrium points will be studied, although the first equilibrium point will be omitted due to its non-stability. The aim is to demonstrate the impact of open innovation (OI) integration in the context of a Cournot duopoly.

The model consists of two game stages that take into account the time required for innovation before introducing products to the market. In the first stage, the innovation parameter, followed by the standard Cournot model, where seeking a balance in relation to the quantities of products on the market. The goal of the numerical analysis is to

demonstrate the impact of OI integration in the context of Cournot duopoly. Through this analysis, the objective is to gain insights into the stability of the equilibrium point under diverse scenarios and conditions. This endeavor aims to provide valuable information for decision-making and strategic planning. One important aspect of studying these systems is to determine their stability, which refers to how they behave over time under small perturbations.

The stability of this system is investigated by analyzing the behavior of its trajectories for different parameter values. In particular, the values of ϑ_1 and ϑ_2 affect the stability of the system.

$$U = 5, c = 1, \gamma = 2, b = 4, \vartheta_1 = 3, \vartheta_2 = 2$$

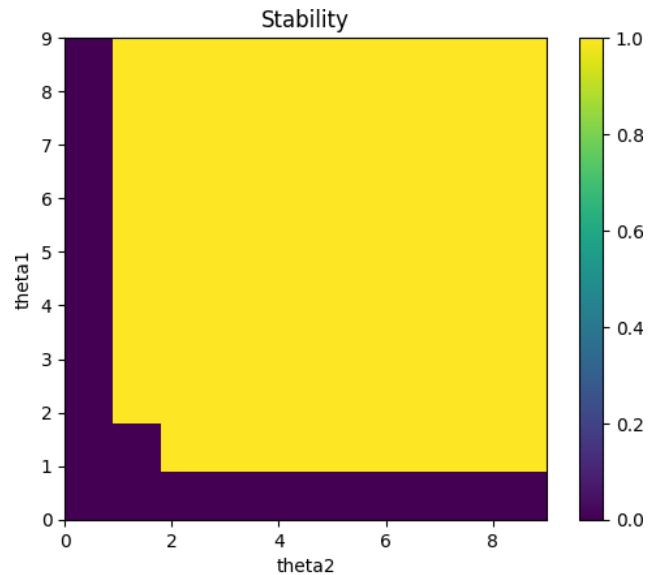


Fig. 1. Stability analysis for the last equilibrium point.

Based on the values of the parameters provided, the graph (Fig. 1) shows the stability of the system as a function of the variables ϑ_1 and ϑ_2 .

The stable region is represented by the purple shaded area, and it corresponds to the values of ϑ_1 and ϑ_2 for which the system is stable. The unstable region is represented by the yellow shaded area, and it corresponds to the values of ϑ_1 and ϑ_2 for which the system is unstable.

The stability boundary is represented by the black curve, and it separates the stable region from the unstable region. Points on this curve correspond to values of ϑ_1 and ϑ_2 for which the system is marginally stable, meaning that small perturbations can cause the system to become unstable.

Overall, this graph provides a visual representation of the stability of the system as a function of the variables ϑ_1 and ϑ_2 , which can be useful for understanding the behavior of the system and for making design decisions.

For the Second equilibrium given the following values, $U = 5, c = 1, \gamma = 2, b = 4, \vartheta_1 = 3, \vartheta_2 = 4$

This graph (Fig. 2) shows the behavior of the system at the equilibrium point (2, 2) as the parameters $U, c, \gamma, b, \vartheta_1$, and ϑ_2

are varied. The color of each point on the plot represents the type of stability of the equilibrium point at that parameter combination. The blue points represent a stable node, the red points represent an unstable node, and the white points represent a saddle point.

As the values of U , c , γ , b , ϑ_1 , and ϑ_2 are varied, the shapes of the stability regions change. In general, as U increases, the stability regions expand, and as c or γ increase, the stability regions contract. The positions of the stability regions depend on the values of b , ϑ_1 , and ϑ_2 .

Overall, this graph provides insight into the behavior of the system at the equilibrium point (2, 2) and how it changes as the parameters of the system are varied.

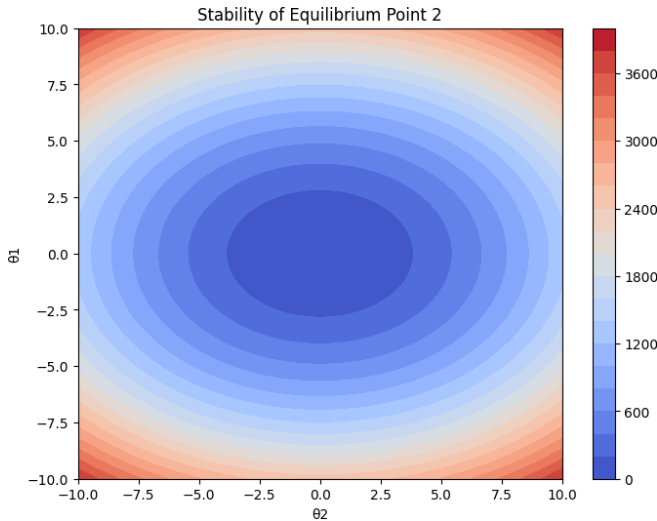


Fig. 2. Stability analysis for the second equilibrium point.

The graph shows the stability of the equilibrium point in a Cournot duopoly model with open innovation, where ϑ_1 and ϑ_2 represent the speed of adjustment for each firm, and σ_1 and σ_2 represent the ratio of open innovation for each firm.

The red line represents the stability boundary, where any points above the line correspond to a stable equilibrium, while points below the line correspond to an unstable equilibrium. The stability boundary is determined by the Jacobian matrix at the equilibrium point, which in this case is a diagonal matrix with distinct eigenvalues λ_1 and λ_2 .

The eigenvalues can be used to determine the stability of the equilibrium point. If both eigenvalues are negative, then the equilibrium point is stable; if both eigenvalues are positive, then the equilibrium point is unstable; if one eigenvalue is negative and one is positive, then the stability of the equilibrium point depends on the slope of the null clines.

In this case, the stability boundary is curved, which indicates that the stability of the equilibrium point depends on the values of ϑ_1 and ϑ_2 . When ϑ_1 is small and ϑ_2 is large, the equilibrium point is stable for a wide range of values. However, as ϑ_1 increases and ϑ_2 decreases, the stability region becomes smaller and shifts to the right.

The fact that the stability boundary is curved indicates that the duopoly model with open innovation is highly nonlinear,

and small changes in the values of the parameters can have significant effects on the stability of the equilibrium point. This suggests that firms should be careful in their strategic decision-making, and should take into account the potential effects of their actions on the stability of the market.

The graph (Fig. 3) shows the stability of the third equilibrium point in a Cournot duopoly model with open innovation. The model has four parameters: $U = 5.0$, $c = 2.0$, $b = 1.5$ and $\gamma = 0.5$. The equilibrium point is represented in the graph as a black dot at the origin (0, 0).

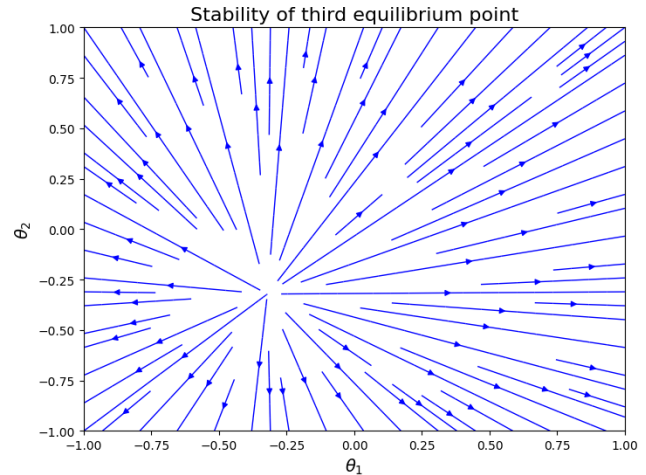


Fig. 3. Stability analysis for the third equilibrium point.

The arrows in the graph in Fig. 3 represent the direction of the trajectories of two firms in the duopoly as they adjust their speed of innovation, with one arrow representing the trajectory of the first firm (θ_1) and the other arrow representing the trajectory of the second firm (θ_2). The color of the arrows represents the magnitude of the eigenvalues of the Jacobian matrix at each point in the plane, with warmer colors (such as red and orange) indicating more positive eigenvalues and cooler colors (such as blue and purple) indicating more negative eigenvalues.

The graph shows that the equilibrium point at the origin is a saddle point, with one stable direction along the θ_2 axis and one unstable direction along the θ_1 axis. This means that the equilibrium is locally stable in the direction of the second firm's speed of innovation, but unstable in the direction of the first firm's speed of innovation.

Overall, the graph provides insight into the dynamics of the Cournot duopoly model with open innovation and shows how the stability of the equilibrium point depends on the firms' speed of innovation.

In economic terms, the third equilibrium point represents a scenario where both firms choose not to engage in open innovation, resulting in a monopolistic market. The stability of this equilibrium point reflects the short-term stability of the market. However, this scenario is not desirable in the long run, as it hinders innovation and can lead to market inefficiencies.

In economic terms, the third equilibrium point represents a scenario where one of the firms dominates the market with a monopoly position. This may be due to several factors, such as

technological advantages or economies of scale. However, this scenario is not desirable, as it leads to inefficiencies in the market and reduced consumer surplus. It is only when both firms compete and restrict each other's market power that the market can achieve stable development. This state is known as "Nash equilibrium," where both firms maximize their own profits while also ensuring the stable development of the market.

Overall, the graph provides a visual representation of the stability of the third equilibrium point in a duopoly Cournot model, highlighting the importance of competition and market regulation for achieving optimal market outcomes.

V. CONCLUSION

This study explored the use of the Cournot duopoly model to evaluate the impact of open innovation on competitive advantage. By incorporating the parameter of innovation into our model, the first stage of the game is studied, followed by the standard Cournot model to find a balance in the quantities of products on the market. Our analysis showed that the use of open innovation could lead to higher profits and market share for both firms compared to closed innovation. In addition, the speed of adjustment parameter plays a crucial role in the stability of the system, with a smaller value indicating greater stability. Overall, our study highlights the importance of considering open innovation strategies in a competitive market environment.

Our mathematical model demonstrates that under certain conditions, open innovation can lead to greater market share and profits for both firms, compared to a closed innovation approach. These findings have implications for firms operating in industries with high levels of technological change and innovation, and suggest that collaboration can be a powerful tool for achieving competitive advantage.

However, further research is needed to fully understand the dynamics of open innovation systems, and to explore the impact of different market structures, levels of OI investment, and intellectual property rights on firm performance and market outcomes. By further exploring these significant inquiries, a more nuanced comprehension of the intricate interplay among innovation, collaboration, and competition can be acquired. This, in turn, enables the development of strategies that optimize the advantages of open innovation for firms, consumers, and society.

REFERENCES

- [1] H. W. Chesbrough, *Open innovation: The new imperative for creating and profiting from technology*. Harvard Business Press, 2003.
- [2] J. West, W. Vanhaverbeke, and H. Chesbrough, "Open innovation: a research agenda," *Open Innov. Res. a new Paradig.*, vol. 17, no. 4, pp. 285–307, 2006.
- [3] R. G. Cooper, *Winning at new products*. Addison-Wesley Reading, MA, 1986.
- [4] M. Anshari and M. N. Almunawar, "Adopting open innovation for SMEs and industrial revolution 4.0," *J. Sci. Technol. Policy Manag.*, vol. 13, no. 2, pp. 405–427, 2022.
- [5] U. Lichtenthaler, "Open innovation: Past research, current debates, and future directions," *Acad. Manag. Perspect.*, vol. 25, no. 1, pp. 75–93, 2011.
- [6] S. Chaudhary, P. Kaur, S. Talwar, N. Islam, and A. Dhir, "Way off the mark? Open innovation failures: Decoding what really matters to chart the future course of action," *J. Bus. Res.*, vol. 142, pp. 1010–1025, 2022.
- [7] O. Gassmann and E. Enkel, "Open innovation," *Zeitschrift Führung+ Organ.*, vol. 75, no. 3, pp. 132–138, 2006.
- [8] E. Aziz, H. Mustapha, and others, "A bibliometric study of the recent advances in open innovation concept," *Procedia Comput. Sci.*, vol. 175, pp. 683–688, 2020.
- [9] X. Wang, X. Han, and H. Li, "The impact of innovation openness on innovation performance of manufacturing corporates –Moderating effect based on knowledge reorganization," *Financ. Res. Lett.*, p. 103917, 2023, doi: <https://doi.org/10.1016/j.frl.2023.103917>.
- [10] Q.-H. Ngo, "The effectiveness of strategic alignment between open innovation and generic strategies: Empirical evidence from restaurant SMEs in Vietnam," *J. Open Innov. Technol. Mark. Complex.*, vol. 9, no. 1, p. 100016, 2023, doi: <https://doi.org/10.1016/j.oiotmc.2023.100016>.
- [11] H. Jeong, K. Shin, E. Kim, and S. Kim, "Does Open Innovation Enhance a Large Firm's Financial Sustainability? A Case of the Korean Food Industry," *J. Open Innov. Technol. Mark. Complex.*, vol. 6, no. 4, p. 101, 2020, doi: <https://doi.org/10.3390/oiotmc6040101>.
- [12] E. Almirall and R. Casadesus-Masanell, "Open versus closed innovation: A model of discovery and divergence," *Acad. Manag. Rev.*, vol. 35, no. 1, pp. 27–47, 2010.
- [13] U. Lichtenthaler, "Open innovation in practice: an analysis of strategic approaches to technology transactions," *IEEE Trans. Eng. Manag.*, vol. 55, no. 1, pp. 148–157, 2008.
- [14] P. Herzog, *Open and closed innovation: Different cultures for different strategies*. Springer Science & Business Media, 2011.
- [15] P. Herzog and J. Leker, "Open and closed innovation--different innovation cultures for different strategies," *Int. J. Technol. Manag.*, vol. 52, no. 3/4, pp. 322–343, 2010.
- [16] U. Stephan, P. Andries, and A. Daou, "Goal multiplicity and innovation: How social and economic goals affect open innovation and innovation performance," *J. Prod. Innov. Manag.*, vol. 36, no. 6, pp. 721–743, 2019.
- [17] P. W. B. Phillips et al., "Open versus Closed Innovation," *Stud. Res. Des.*, p. 56, 2023.
- [18] H. Lopez-Vega and W. Vanhaverbeke, "Connecting open and closed innovation markets: A typology of intermediaries," 2009.
- [19] R. Oumlil, H. Faouzi, and C. Juiz, "Uncovering two decades of open innovation benefits: A qualitative meta-analysis," *Int. J. Innov. Technol. Manag.*, vol. 17, no. 08, p. 2030006, 2020.
- [20] I. Hasnas, L. Lambertini, and A. Palestini, "Open Innovation in a dynamic Cournot duopoly," *Econ. Model.*, vol. 36, pp. 79–87, 2014, doi: <https://doi.org/10.1016/j.econmod.2013.09.020>.
- [21] I. Hasnas, L. Lambertini, and A. Palestini, "Open Innovation in a dynamic Cournot duopoly," 2011.
- [22] H. Zhang, X. Hong, and M. Zhou, "Optimal technology licensing contract with quality improvement innovation under Cournot competition," *J. Manag. Anal.*, pp. 1–18, 2022.
- [23] S. Colombo, L. Filippini, and D. Sen, "Patent Licensing and Capacity in a Cournot Model," *Rev. Ind. Organ.*, vol. 62, no. 1, pp. 45–62, 2023.
- [24] F. A. Ferreira, F. Ferreira, and O. R. Bode, "Licensing under Cournot vs Bertrand competition," *Econ. Res. Istraživanja*, vol. 34, no. 1, pp. 1651–1675, 2021.
- [25] X. Zhu, "Incorporation of sticky information and product diversification into static game of open innovation," *Int. J. Innov. Stud.*, vol. 6, no. 1, pp. 11–25, 2022, doi: <https://doi.org/10.1016/j.ijis.2022.01.001>.
- [26] G. I. Bischì and F. Lamantia, "A dynamic model of oligopoly with R&D externalities along networks. Part I," *Math. Comput. Simul.*, vol. 84, pp. 51–65, 2012.
- [27] S. S. Askar, A. M. Alshamrani, and K. Alnowibet, "Dynamic Cournot duopoly games with nonlinear demand function," *Appl. Math. Comput.*, vol. 259, pp. 427–437, 2015.
- [28] H. Li, W. Zhou, A. A. Elsadany, and T. Chu, "Stability, multi-stability and instability in Cournot duopoly game with knowledge spillover effects and relative profit maximization," *Chaos, Solitons & Fractals*, vol. 146, p. 110936, 2021.

- [29] Z. Xiang and M. Xu, "Dynamic game strategies of a two-stage remanufacturing closed-loop supply chain considering Big Data marketing, technological innovation and overconfidence," *Comput. Ind. Eng.*, vol. 145, p. 106538, 2020.
- [30] W. Zhou and H. Liu, "Complexity analysis of dynamic R&D competition between high-tech firms," *Commun. Nonlinear Sci. Numer. Simul.*, vol. 118, p. 107029, 2023.
- [31] T. F. Bresnahan, "Duopoly models with consistent conjectures," *Am. Econ. Rev.*, vol. 71, no. 5, pp. 934–945, 1981.
- [32] A. Dixit, "A model of duopoly suggesting a theory of entry barriers," *Bell J. Econ.*, pp. 20–32, 1979.
- [33] M. K. Dixit, C. H. Culp, and J. L. Fernández-Solís, "System boundary for embodied energy in buildings: A conceptual model for definition," *Renew. Sustain. Energy Rev.*, vol. 21, pp. 153–164, 2013.
- [34] J. Ren, H. Sun, G. Xu, and D. Hou, "Prediction on the competitive outcome of an enterprise under the adjustment mechanism," *Appl. Math. Comput.*, vol. 372, p. 124969, 2020.

Decentralised Access Control Framework using Blockchain: Smart Farming Case

Normaizeerah Mohd Noor¹, Noor Afiza Mat Razali^{2*}, Sharifah Nabila S Azli Sham³, Khairul Khalil Ishak⁴, Muslihah Wook⁵, Nor Asiakin Hasbullah⁶

Faculty of Defence Science and Technology, National Defence University of Malaysia, Kuala Lumpur, Malaysia^{1, 2, 3, 5, 6}
Center of Cyber Security and Big Data, Management and Science University, Selangor, Malaysia⁴

Abstract—The convergence of farming with cutting-edge technologies, like the Internet of Things (IoT), has led to the emergence of a smart farming revolution. IoT facilitates the interconnection of numerous devices across different agricultural ecosystems, enabling automation and ultimately enhancing the efficiency and quality of production. However, the implementation of IoT entails an array of potential risks. The accelerated adoption of IoT in the domain of smart farming has amplified the existing cybersecurity concerns, specifically those pertaining to access control. In extensive IoT environments that require scalability, the conventional centralized access control system is insufficient. Therefore, to address these gaps, we propose a novel decentralized access control framework. The framework applies blockchain technology as the decentralization approach with smart contract application focuses on the application scenario in smart farming to protect and secure IoT devices from unauthorised access by anomalous entities. The proposed framework adopted attribute-based access control (ABAC) and role-based access control (RBAC) to establish access rules and access permissions for IoT. The framework is validated via simulation to determine the price of gas consumption when executing smart contracts to retrieve attributes, roles and access rules between three smart contracts and provide the baseline value for future research references. Thus, this paper offers valuable insight into ongoing research on decentralized access control for IoT security to protect and secure IoT resources in the smart farming environment.

Keywords—Access control; role-based access control; attribute-based access control; blockchain technology; internet of things; smart contract; smart farming

I. INTRODUCTION

The integration of the Internet of Things (IoT) technology into smart farming infrastructure has the potential to revolutionize the agricultural industry by enabling the collection and analysis of vast amounts of data from various sources such as sensors, drones, and cameras. IoT technology can provide real-time information on farm operations, allowing farmers to remotely monitor and control equipment and make data-driven decisions for fast response to issues, minimize impact and reduce costs [1]. However, the adoption of IoT devices in smart farming also presents several challenges that need to be addressed. One of the primary concerns is the risk of IoT security, which arises due to the use of numerous heterogeneous devices in the system. Another critical issue is the management of resources, which can become complex and require a high level of coordination and integration. Furthermore, as smart farming systems grow in

size and complexity, scalability becomes an increasingly important factor that must be considered[2],[3],[4]. Thus, to address the challenges posed by the adoption of IoT devices in smart farming, it is crucially needed for the enhancement of access control to ensure authorized access will be granted to legitimate devices while also being scalable to accommodate future expansion. An effective access control system can help mitigate the risks associated with IoT security and improve the overall scalability and management of resources in smart farming systems. Nevertheless, conventional centralised access control has brought about several problems and remains as a complicated issue since it includes single point of failure and incapability of addressing dynamic and diverse access control requirements for future IoT ecosystems [5] [6]. Therefore, the new framework must be designed with the aim of shifting from a centralised approach to a decentralised approach for eliminating trusted third parties in access control and achieving optimum management of IoT resources. Thus, this paper proposes a decentralisation approach using blockchain technology as a suitable solution since it provides an open, transparent and distributed ledger without the need for a third party [7]. It also has strong security features for securing IoT resources in the form of hashing ledger which guarantees high system reliability and integrity. This paper is structured as follows. Section II describes the background study including the IoT infrastructure, security issues, access control, blockchain smart contract and its application in smart farming. Section III highlights the related works to this study. Section IV discussed the proposed decentralised access control framework for IoT security enhancement using blockchain technology. Section V describes the evaluation procedure. Section VI presents the contribution for this work and Section VII discusses the conclusion for this study.

II. BACKGROUND STUDY

According to the United Nations (UN), population growth is steadily increasing along with food consumption and production demands, which are anticipated to increase up to 70% by 2050 [10]. To fulfil these demands, conventional agriculture must shift to smart farming which combines internet connection and modern technology like IoT. This will provide numerous benefits, including accurate data collection for data-assisted decision-making [11], [12]. Such a scenario will enable remote monitoring, thereby contributing to the reduction of production costs. This will lead to efficient and sustainable agricultural production that is more demand-oriented and resource-efficient.

*Corresponding Author: FRGS/1/2021/ICT07/UPNM/02/1

A. IoT Architecture and Security Issues in Smart Farming

In smart farming, the integration of IoT sensors with any farm equipment and machinery for monitoring temperature, humidity, pressure, etc., will enable systematic data collection. The data can be remotely sent from different locations to a centre for monitoring and decision-making. These devices and sensors have their roles to play according to the different techniques used, their functionality and implementation, which can help farmers provide information in real-time. Farming techniques can be improved based on the collected information [13]. For instance, the roles include crop management, water management, soil management, livestock management, smart greenhouses and agriculture drones[11]. Smart irrigation systems, for instance, use temperature and soil sensors to maintain and control water wastage as well as to improve crop quality by monitoring the humidity of the soil and only watering at the right time. Thus, the management of heterogeneous IoT devices and sensors must be efficient and reliable.

The IoT architecture illustrated in Fig. 1 displays the key layers in smart farming, which are: the physical layer, the network layer, the edge or fog layer and the application layer. The physical layer can be any type of device (such as actuators and sensors) connected to the IoT network. The network layer is responsible for data transmission from the physical layer to the data processing system. The data transmission may use any wired or wireless device, such as a router, access points, 4G or 5G network, Wi-Fi, Bluetooth, etc. The network layer has a high possibility of security flaws if there is connectivity via the internet. The probable attacks (such as identity theft, bullying or controlling/hacking) can be countered by implementing identity management and encryption schemes [14]. The next layer is the edge or fog layer consisting of various resources with computer processing capabilities. This layer can store a small amount of data and process that data. It can also be used for decision-making and security features. The edge or fog layer includes the in-out interface and the gateway used to manage the entire collected data from the sensor without transmitting it to the cloud. The application layer is the communication protocol and interface that provide services to users and data visualisation from the sensor network.

It is important to protect and safeguard connected devices in the IoT environment [2]. According to [14], the security protocols that should be applied in smart farming IoT security solutions are access control, authentication, firewall, anomaly detection system and cryptography. However, before applying those security protocols, we must address the security issues and potential attacks in each layer of smart farming. Study [15] has developed various security protocols and arranged them into different categories (access control protocols, authentication protocols, key management protocols and intrusion detection protocols) to support various IoT applications that suffer from possible attacks.

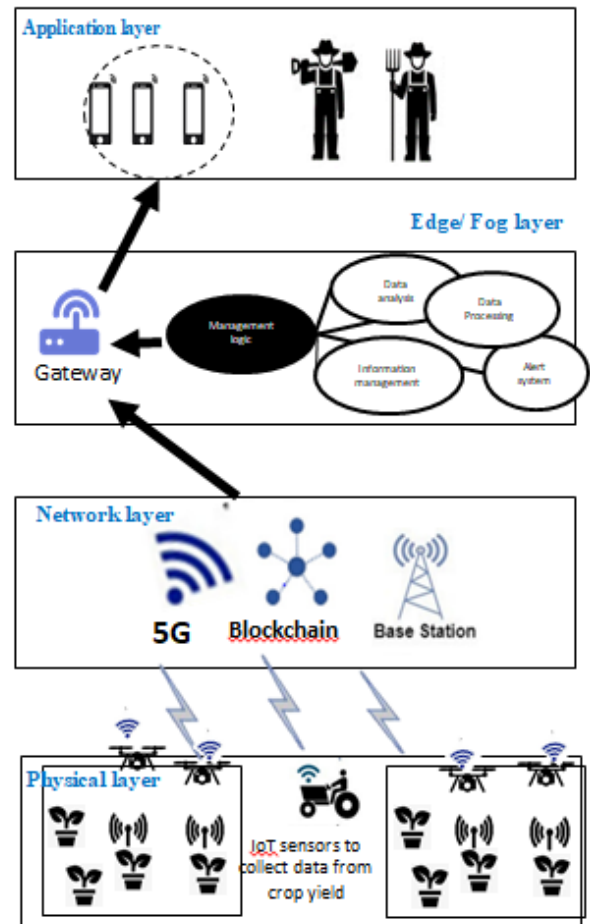


Fig. 1. Smart farming architecture.

Access control must be implemented to facilitate the process of data transfer in the physical layer. However, in IoT environment, security protocols (such as secure public key-based authentication and cryptography) are not suitable due to high computational power and storage capacity requirements [4]. Gupta et al. (2020) stated that edge layers may contain major security issues due to IoT devices and sensors that do not have their own security. This makes it easy for attackers to gain remote access to the system via unauthorised access, booting, flooding and signature wrapping. In the application layer, attacks have been categorised into two types: software attacks and encryption-based attacks. Software attacks generally use malicious software agents to acquire authentication credentials of users [14]. Encryption-based attacks apply extensive attacks to exploit the cryptographic protocols and mathematical models. Table I provides a summary of possible security attacks and issues in smart farming, along with the proposed countermeasure. In Table I, the type of attack is categorised according to the layers in the smart farming architecture.

TABLE I. SECURITY ATTACKS AND COUNTERMEASURES ACCORDING TO LAYERS

Layer	Security goals	Security attacks	Countermeasure
Application	Availability, Non-Repudiation, Privacy [17], Accountability and Integrity [2]	Data thefts, Sniffing, Access Control [4], [14] [17], Phishing attack, Malicious scripts, Deny services [4], reprogram attacks [17], Channel interference, DoS/DDoS, Cyberagroterrorism [2], Malicious Code Injection Attack, tempering privacy [14]	Access control, data encryption (cryptography and non-linear key encryption), Authentication, anti-virus, anti-spyware, firewall and ACLs [14]
Edge/Fog	Integrity, Authenticity, Confidentiality [17], [2]	Man-in-the-middle, Booting vulnerabilities, Unauthorised access, Signature wrapping, Forged control for actuators, Gateway-cloud request forgery, Forged measure injection [4], Flooding [16], cloud malware injection, SQL injection, Storage attacks, Side-channel attacks, Sybil Impersonation, Replay Session Hijacking [2], Interception of node communication [7]	Authentication, IDS, Anomaly detection system, access control [4]
Network	Availability [2], Confidentiality [14]	DoS/DDoS, Data transit attacks, Routing attacks, Autonomous system disruption, Signal disruptions [4], wormhole attack, traffic attack, jamming attack [18]	Identity management, encryption schemes, data privacy, authentication, hello flood detection, routing protocol
Physical	Confidentiality [2]	Random sensor incidents, Autonomous system hijacking, optical deformation, Irregular measurement, Sensor weakening, Node capture, Fake node, Sleep deprivation [4], social engineering, jamming attack [18], eavesdropping, malicious code injection [18], Facility damage [7]	Data privacy, secure booting, data integrity, risk assessment, device authentication, secure physical design

B. Access Control in IoT

The basic element of access control is the ability of the subject and object to perform an action that includes interaction in the right manner [19]. In the IoT environment, access control plays a crucial role in ensuring that all resources, including actuators and devices, are protected using selective restrictions that control access to IoT devices [20]. The object is defined as the system resource that contains or stores information on IoT devices, sensors, directories, programs, etc. An object is secured by a set of access policies consisting of conditions and requirements for an object's access to be granted. The subject can be defined as an entity (users or systems) that is capable of accessing an object. A subject must prove that it satisfies an access policy of a requested object before access is granted.

According to [21], four design components must be addressed based on the current access control problem in the IoT environment. Meanwhile, several approaches have been proposed for managing access control and associated privilege according to their access level in IoT systems [22], [23], [24], [25],[26],[27]. Discretionary Access Control (DAC), Mandatory Access Control (MAC), ABAC and RBAC are the most conventional models used in smart farming. Based on the literature, two commonly employed access control mechanisms for IoT are RBAC and ABAC due to their strong features and flexibility in supporting the IoT environment [28], [29], [30], [31], [32], [33], [34], [35].

1) *Basic concepts, advantages and disadvantages of the ABAC model:* ABAC uses pre-defined policies for access permission. The policies consist of three attributes: subject, object and environment [8], [30]. The attributes are used to authorise access permission with specified access policies using a target function that determines whether or not sufficient privileges are present for access[36]. Specific access policies with selected attributes must have good management [32].

The advantages of ABAC include the flexibility of policies based on changing dynamic attributes, such as location and time. With its flexibility and scalability, the ABAC model is more suitable for access control in IoT [32], [34], [36], [37], [38]. In addition, the use of access control marker language (XACML) as an extension of ABAC can be expressed as logical-based policies to define valid authorised access [21]. However, the drawback of XACML is the extensible markup language (XML), which makes it unsuitable for constrained devices, such as IoT applications. In ABAC, all attributes that have been defined must be managed and distributed to the right user for effective access management [32]. It can be a problem for IoT devices with less storage and computing power when the number of attributes and the number of users increase.

2) *Basic concepts, advantages and disadvantages of the RBAC model:* In RBAC, access control is based on the roles of subjects within an organisation who give permission. By associating the user with its roles and access permissions (e.g., read, write and execute), the roles are set to be active. They

can be structured in hierarchal order where senior roles are more powerful and have more permission for access as compared to junior roles. Another important aspect of RBAC is constrained enforcement. A constraint can be applied at either the system level or the application level. Restrictions to RBAC states with or without being event triggered are known as invariant and precondition. These two restrictions are used as conditions when a role is assigned to a user in a user-role assignment and permission is assigned to a role in a permission-role assignment.

The advantages of RBAC are: a) the user can access resources based on the achieved tasks under suitable access mode and b) it is easier for the system administrator to redefine permissions for each user separately according to their roles [8]. The disadvantage of the RBAC mechanism is the inability to differentiate its role [28], leading to role-permission explosion problems in situations where the service-providing entities are unable to allow access permission to the user-role assignments of the role-providing entities due to a large number of objects [8]. Research [39] stated that service-providing entities must use an alternative to confirm if an unknown guest legitimately owns a certain role. The authors in [30] also noted that the disadvantages of the RBAC system are its lack of flexibility in adapting to changing users, maintain user-to-role assignment and role-to-permission assignments for dynamic applications or large-scale applications with a significant number of users or objects.

In summary, IoT has various limitations, including resource constraints, that prevent IoT from handling operations that require high computational power including managing complex access control [40], [41]. In [42], the authors use a combination of RBAC and ABAC models in the centralised environment. The authors proposed to divide the permissions assigned to a role according to their access actions. However, most research had proposed centralised decisions which can lead to the central point of failure and limited resources of IoT devices [43],[40]. Thus, the decentralised approach is more suitable for large-scale IoT environments.

C. Blockchain and Smart Contracts

Blockchain is formally described as a digital, decentralised and distributed ledger that communicates transactions or sensitive data without trusted third parties, removing centralised authority and intermediaries, and enabling two parties to communicate and conduct business quickly, securely and reliably [44]. This technology is different from the traditional system where the conventional approach is centralised. The structure of chain in blockchain is shown in Fig. 2.

In contrast, the blockchain system implements a decentralised system with many possible physically scattered nodes [45]. Blockchain also has strong security features for securing IoT resources in the form of hashing ledger which guarantees high system trustworthiness and integrity [32]. Based on the literature, blockchain has various unique characteristics such as decentralisation, transparency, autonomy, security, immutability, traceability, integrity and programmability [46]. Due to blockchain's characteristics, its application is relevant for access control in smart farming since complex approaches are required. In the meantime, for a successful transaction on a blockchain network, verification is required through a consensus algorithm to reach an agreement on the transaction or a smart contract between two parties. The adoption of a consensus mechanism is dependent on the types of networks and the roles of nodes. Blockchain networks can be public or private networks [47], and the roles can be permissionless and permissioned. In permissioned or private networks, only invited nodes can participate in the network. The nodes will be divided and assigned to their roles. Only the selector miner node can perform transactions [48].

Meanwhile, smart contracts are self-executing contracts in which the terms of an arrangement between two parties are expressed in computer codes. When the requirements of a smart contract are met, it will self-execute to a blockchain, removing the need for trusted third parties [49]. According to [50], smart contracts are one solution that responds to the transaction sent by a user. The transactions use code logic which is the Solidity language [51]. Once users agree to the agreement based on the contract, this code logic will be incorporated into the blockchain network and all users in the network will have copies of the contract.

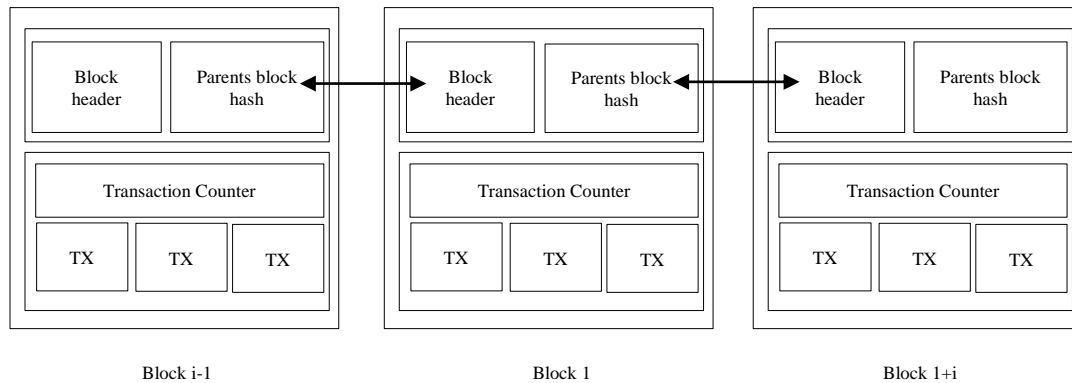


Fig. 2. The chain in blockchain.

III. RELATED WORKS

This section presents the most relevant literature related to our study and proposes a solution for access control in the IoT environment. Table II displays several existing solutions with a list of required elements for developing access control solutions in the IoT environment. The researchers in [52] proposed RBAC as a strategy for device management by considering the limited user access strategy and protecting the IoT network using Software-Defined Networking (SDN). The proposed study was able to manage network flow and provide dynamic access control when the access network rule needed to change. This proposal can overcome the problem of unauthorised device in the system by authenticating the server and providing information, such as a network device and network identification, to detect malicious activity. However, this proposal requires a system administrator to carefully manage user access control and network rule exposed to the risk of vulnerabilities due to careless configuration. The study [53] proposed a framework by using event-based solutions for access control mechanisms in an IoT environment. To handle the event process, the authors employed a processing module as a policy module for managing and controlling the movement of event operators and calculating data to prevent starvation of resources during the computation process.

Researchers also suggested combining the access control model and blockchain since blockchain has been widely used in several domains for promoting decentralisation, dynamic access control and tamper-proof [54]. ABAC was proposed to be the access control model with advantages such as scalability and flexibility for securing and protecting IoT resources with excellent features. The research [55] suggested a Policy chain integrated blockchain-based ABAC framework to address the problem of securing shared resources in decentralisation. In this framework, the authors utilised the JSON + Script format as the policy expression and devised new ways to apply policies using “script interpreter”. The interpreter was constructed according to three evaluations: evalScript, evalRule and evalPolicy as well as a consensus protocol for executing decisions faster. The research proposes that off-chain resources can be accessed by IoT devices using the pre-determined on-chain policy. The authors used consortium blockchain and two different nodes: full nodes and lightweight nodes. It was noted that the consensus algorithm can be used for validating and storing transactions in full nodes. The synchronisation of current state networks was accomplished in light nodes.

TABLE II. COMPARISON OF EXISTING SOLUTION ACCESS CONTROL IN IoT ENVIRONMENT

Product	Secure policies	Trusted authorisation	Secure communication	Flexibility	Security	Scalability	Decentralised (D) / Centralised (C) / Partial (P)	Access control model	Domain
[34]	/	/	X	/	/	/	D	ABAC	IoT
[56]	/	/	X	/	/	/	D	ABAC	IoT
[52]	X	/	X	/	/	X	C	RBAC	IoT
[21]	X	X	X	/	/	X	C	ABAC	IoT
[60]	X	/	/	/	/	/	P	ABAC, RBAC, CBAC	Health-care (IoT)
[55]	X	/	X	/	/	/	P	ABAC/ XACML	IoT-ICS
[61]	/	/	X	/	/	/	D	CapBAC, ABAC	IoT
[62]	/	/	X	/	/	X	D	N/A	IoT
[58]	/	/	X	/	X	/	D	ABAC	Data sharing in IoT
[59]	N/A	/	X	X	/	/	D	N/A	IoT
[8]	X	X	X	/	/	/	C	ABAC, RBAC	Multi-domain
[53]	X	/	X	/	/	N/A	C	EBAC	IoT

Similarly, [56] proposed an access control framework based on the blockchain technology suitable for heterogeneous IoT by evaluating attributes, operations and environments according to requests. In this proposal, the researchers used four smart contracts for executing access control mechanisms: access control contract (ACC), subject contract (SC), object contract (OC) and multiple policy contracts (PCs). They ensure security and flexible access control in the IoT environment. The authors also utilised trust management for detection and evaluation of malicious behaviour from other devices. The authors [34] stated that the protection of critical resources in IoT can be done by replacing conventional centralised access control, which is insufficient in large-scale IoT environments. They suggested the Attribute-Based Distributed Access Control (ADAC) with a smart contract system. ADAC was proposed to manage and access attributes of IoT devices by using three smart contracts: ACC, OC and multiple PC. ADAC development was inspired by the ABAC model which can determine authorised users based on subject attribute, object attribute, environment attribute and policies. The study [57] also offered to solve the single point of failure issue by combining Accountable Subgroup Multi-Signature (ASM) algorithm with the ABAC model and smart contract policy in order to achieve fine-grained and reliable data access control. This paper uses access policies to specify whether users with certain subject attributes are permitted to perform certain actions on data with certain object attributes in a certain environment. The access policies consist of Subject Attributes Policy (SAP), Object Attribute Policy (OAP), Attributes Authorise Policy (AAP), Environment Attributes Policy (EAP) and Result. For policies, evaluation is based on the required attributes that meet with policy, and the result consists of three elements: permit, deny and not applicable. ABAC model for IoT-integrated blockchain technology to tamper-proof, store the attribute and eliminate a single point of failure were utilised in a study. For accessing data, the author applied four smart contract mechanisms implemented on the Ethereum blockchain: ACC, object attribute management contract (OAMC), subject attribute management contract (SAMC) and policy management contract (PMC). They are responsible for storing and managing access policy information that consists of specified actions regarding the subject and object which must have their access request verified. However, the proposed framework lacks security and privacy protection of IoT data due to unauthenticated edge nodes which have no access decision at the edge. The researchers in [59] proposed the BorderChain application which allows IoT owners to authorise selective IoT services and devices that permit access at the IoT gateway before opening the endpoint to others via smart contracts. After the IoT owner grants access, an access token will be generated which can be used by legitimate IoT services and users to query IoT resources in IoT domains. This solution can convince IoT domain owners that the system will only authorise IoT requests that they approve. For scalability goals, the authors implemented off-chain (outside blockchain) which is cheaper and more efficient during the process of signature verification mechanism. The study [9] combined elements of access control methods, such as ABAC, RBAC and Capability-Based Access Control (CBAC), to establish fine-

grained policy decisions in the healthcare environment. This framework reduces the number of policies by using the attribute to define roles as well as capabilities to provide only single attribute expressions that can access multiple resources. However, this framework is partially decentralised and stores access policy in a single database server based on a policy language (XACML) as well as policies generated by administrators. The blockchain will only allow if it reaches an agreement in the smart contract/consensus algorithm. It was also noticed that the development of security policies in access control mechanisms can be achieved via smart contracts where all users in the blockchain network will acquire a copy of policies and store them in blockchain. Flexibility and scalability can be achieved when using the combined access control model in an IoT environment since it can be utilised in heterogeneous IoT devices, further reducing the use of storage capacity for storing access policies in IoT devices.

Based on the literature, we identified that there is significant advantage for decentralised access control with blockchain technology integrated with the RBAC and ABAC models. RBAC can provide strong security by conducting role hierarchy and constraints to give permission, whereas ABAC is very flexible in granting access permission based on the three attributes. Therefore, in this paper, for our framework development, we propose the use of blockchain technology as a decentralised solution for managing and storing access policy information of subject and object that must verify their access request. We also utilise smart contracts for the automation of access decisions. For access policy development, we propose to implement a combination of the RBAC and ABAC models as an access control strategy. Our proposed framework is aiming to close the gaps for the access control focusing on enhancement of security and resource management using decentralized IoT mechanism that also considers the scalability factor.

IV. DECENTRALIZED ACCESS CONTROL FRAMEWORK FOR IoT SECURITY ENHANCEMENT USING BLOCKCHAIN TECHNOLOGY IN SMART FARMING

This section discusses our proposed decentralised access control framework for IoT security enhancement using blockchain technology. First, we present an extensive overview of our proposed framework, as illustrated in Fig. 3. This framework was developed with the primary aim of achieving security, while also efficiently managing resources and ensuring scalability to cope with the increasing demands of smart farming. This framework was developed by adapting the FRABAC model where the combination of RBAC and ABAC models with user-role permission and attributes are employed for the user, admin and resource owner through smart contracts [8]. The integration of blockchain and access control models is the novel element that can reduce the redundancy of several roles and rules of permission. It has a unique access without creating or implementing special roles or rules reserved for each user/device. This framework can help address the role permission explosion or role-explosion problems, which have complex role structure (hierarchy) and a large number of roles. Most of them have the same access permissions. Our framework includes a blockchain-based smart contract and P-2-P network. The network consists of

IoT node owner, full nodes, lightweight nodes and extra lightweight nodes which have their own responsibilities based on the ability to execute access control according to computing power and storage capacity that considered based on smart farming scenario.

In this framework, we propose the adoption of smart contracts for access permission request, access control rule management and for verifying the permitted decision by fulfilling the requirement of access rules.

Smart contract is also responsible for updating attributes and roles. Access permission provides transparent access permission and traceability since all nodes have a copy of the smart contract. In FRABAC model there are Access Control Contract, Object-Rule Management Contract and Subject-Role Management Contract. These three concepts were adopted as IoT_ACC, IoT_ORMC and IoT_SRMC in our framework. In

the smart farming environment, to address heterogeneous IoT device authorisation matters, we propose that every device must authenticate itself by describing and identifying its own credentials including its attributes, such as address name, identification number, location and role. Thus, all authenticated devices must interact through smart contracts for access control execution which contributes to tamper-proof access rules. A set of rules was developed to define access permission that can be executed by a subject (IoT devices) to access the object (resources). This access decision is processed by checking the matching rule with the list of all attributes that meet the requirement. The rules consist of i) identifier role, ii) type of access request, iii) identifier access action and iv) the list of attributes. The attributes must have the same attribute values in the resource, rs, and the requestor, known as IoT devices, u. We defined V as value of attributes which can be presented as follows: $V_{rs}(r,att) = V_{u_i}(u,att)$.

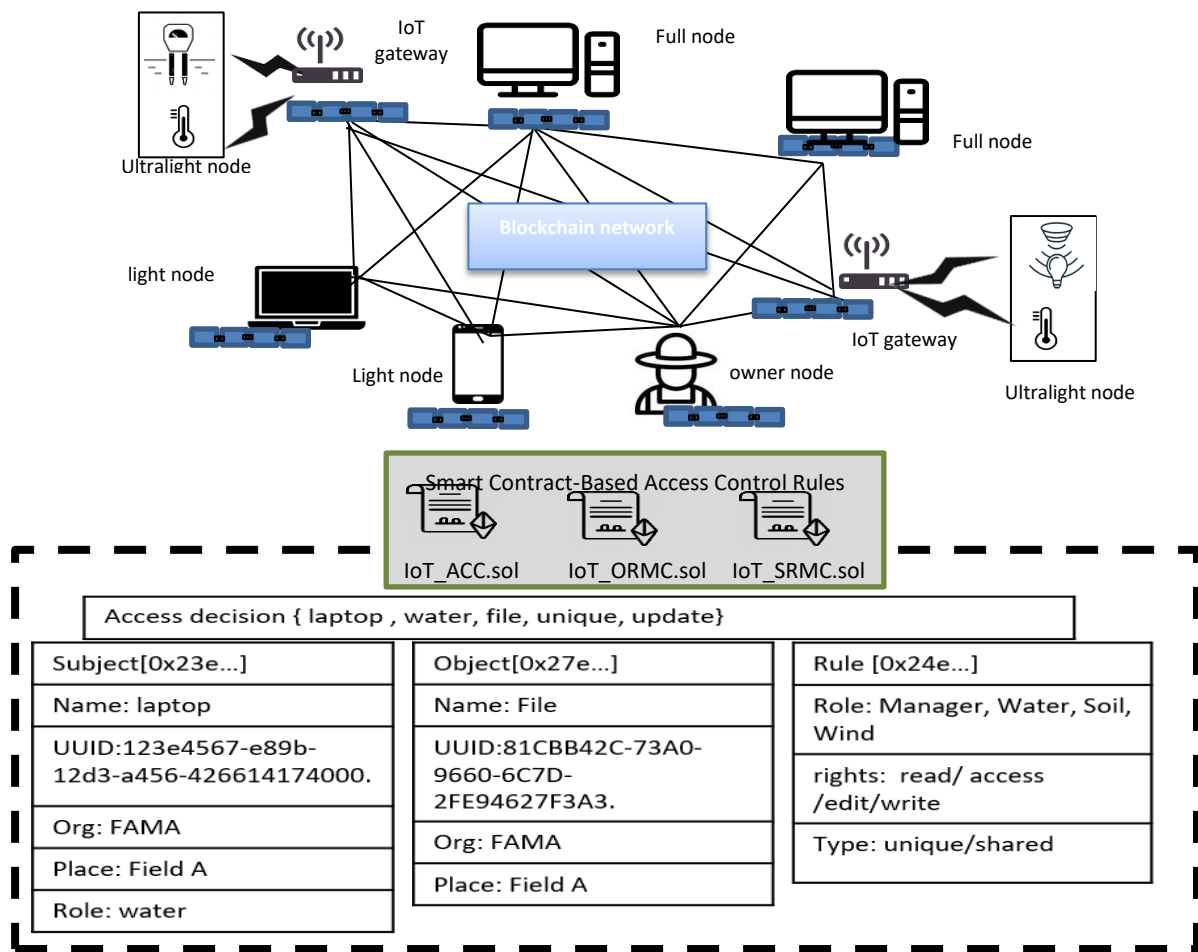


Fig. 3. Decentralized access control framework for IoT security enhancement using blockchain technology in smart farming.

The flow of access control in the proposed framework was described by illustrating the interaction of network nodes with smart contracts, as illustrated in Fig. 4. The IoT owner nodes are responsible for managing access rules. The access rules consist of four factors: type of access, role, access action and a matching list of all attributes. Once rules are mined, they will be stored in IoT_ORMC (step 0.1). The IoT owner node is also responsible for storing and managing all attributes that consist of three different nodes, including full nodes, light nodes and ultralight nodes. The IoT owner node must assign a role for each node based on its responsibility and it will be stored in IoT_SRMC (step 0.2). When IoT_ACC obtains a request from any node, such as light nodes (laptop), to access resources (step 1), the request will be evaluated by IoT_ACC. Evaluation is accomplished by obtaining the access rules from IoT_ORMC (step 2) and acquiring all attribute information as well as the roles from IoT_SRMC (step 3). Finally, IoT_ACC verifies the access request by matching the access rule in IoT_SRMC and the attribute in IoT_ORMC (step 4). If the request is sufficient for access privileges, the requestor (laptop) can access the resources based on its roles.

A. Blockchain Nodes

In this framework, public and permissioned blockchains are adopted where nodes will be added and removed from the network with their identity verification. Since every node has a role and permission, the blockchain nodes require more CPU processing power and memory requires significant storage

space to maintain the ledger copy [59]. We propose using four different nodes that allow heterogeneous IoT devices to access the blockchain network. Two nodes used for access control are categorised according to their capabilities, storage capacity and computing power [63]. The types of nodes and their responsibilities are categorised in the blockchain network, as follows:

- IoT requestor node is a requester that runs smart contracts for requesting access to resources. In the smart farming scenario, the requestor nodes are IoT devices or IoT sensors. Each node requestor is added and authenticated to the blockchain network by the IoT owner node before requesting access to resources. Requestor nodes represent three different nodes: full node, light node and ultralight node.

Full nodes are devices that have sufficient computing power and storage capabilities such as computers, laptops and servers that can perform full transactions. Light nodes are devices that have limited storage capabilities and computing power and can only store blockchain headers and support services for themselves. Mobile phone is one example of light nodes. Ultralight nodes are devices that have insufficient storage capabilities and computing power. Sensors and actuators are examples of ultralight nodes that require connection from the IoT gateway to P2P networks through communication technologies, such as Wi-Fi and ZigBee.

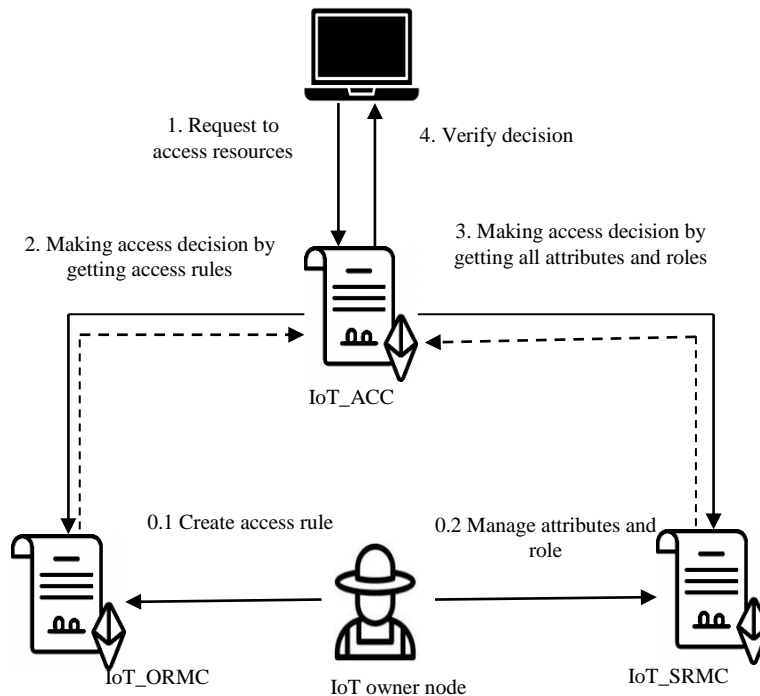


Fig. 4. The interaction between IoT requestor node with smart contracts to access a resource.

- IoT owner node represents the owner of the IoT resources and devices in smart farming. An IoT owner node defines and deploys access control rules and permits requestor devices to enter the network through smart contracts. It can also add new IoT devices, manage node attributes as well as assign their roles that represent their responsibility.

B. Smart Contract-based Access Control Rules

In this research, for the verification mechanism in the blockchain network, we designed smart contract-based access control rules where the admin has the privilege to register devices to the blockchain network for the first time. Afterwards, all devices that request access to the network will be self-authenticated. This is particularly significant since smart farming consists of heterogeneous sensors that require self-administration to obtain access to the system at any time. In our smart contract design, we propose three smart contracts to avoid complexity. The smart contracts are: IoT_ACC, IoT_SPMC and IoT_ORMC. IoT_ACC is responsible for enforcing rules and making access decisions, IoT_ORMC is responsible for managing and updating the rules and resource attributes and IoT_SPMC is responsible for managing and assigning device attributes and the role of IoT devices.

1) *Access Control Contract (IoT_ACC)*: IoT_ACC evaluates requests and provides access decisions made by access requests from IoT devices and sensors (subjects) to access resources (objects) in the system. This contract is executed by IoT devices when checking the pre-condition rules. The pre-condition rules will be matched based on the rules made from ORMC to the ACC to determine whether the subject has the right to perform actions on the object. To evaluate an access decision, this contract has two steps:

Step 1: Identification step

In this step, IoT_ACC will identify the type of request by IoT devices, either unique or multiple, and verify whether the IoT devices have sufficient requirements for acquiring access privileges. If the devices identified have access privileges, then the request will be saved and evaluated, otherwise, the request will be ignored. This step consists of two functions:

- `typeReq()`: used for the identification of type request. The request must have three things: user, `ui`, resources, `ri`, that want access and access action, `acci`. In this identification process, the user, `ui`, must contain identification, `userID`, that uses an Ethereum account and the list of user attributes, `userAtt` (e.g., location, time). Meanwhile, resource, `ri`, must have object identification, `objectID`, identification of resources belonging, `refer_to`, the list of resource attributes (e.g., location, type), `resourceAtt`, and access action, `acci`.
- `requestAction()`: used for deciding the type of request. The request `typeReq()` will pass value where a decision is made based on the object `refer_to` attribute.

Step 2: Evaluate the request

After successfully identifying the type of request, the evaluation process request is accomplished by retrieving precondition and evaluation constraints. To evaluate the access request, IoT_ACC must recognise whether or not the requestor is an active role and has rules. There are two functions in this step:

- `activeRole()`: to identify active role by checking the subject/IoT device via registering all attributes of subject/IoT devices in blockchain.
- `getRule()`: to retrieve rules that are specified in the form of tuple (rolei, typeAcci, accModei, attribute index list, attribute user, attribute resources). We determined rolei as the identifier of the role, while typeAcci represents the type of access. 1 represents shared access, while 0 represents private access. accModei is set as the identifier of access action, and the list of attribute index is defined as matching values of attributes in the resource, `ri`, and the user, `ui`. In tuple, the attribute user defines the values of attributes of the user. The attribute resources represent the attribute values of resources.

After evaluating the rules and active roles, IoT_ACC is conducted to evaluate three constraints defined in RBAC and ABAC.

- User resource constraints were used to check whether the attributes in the object and user are the same values. If the values of attributes are the same, it will pass the value to `currentRule()` in the form of a Boolean function which is a true value.
- User constraints were used to check if attributes in devices are equal or the same values as the access rule. If the value of attributes is the same, it will pass the value to `currentRule()` in the form of a Boolean function which is a true value.
- Object constraints were used to check if attributes in resources are equal or same values as the access rule. If the value of attributes is the same, it will pass the value to `currentRule()` in the form of a Boolean function which is a true value.

After successfully validating the access request through several steps, the subject (the IoT device) verifies the results.

2) *Object-Rule Management Contract (IoT_ORMC)*: IoT_ORMC specifies a policy by defining a set of access rules associated with each subject and resource based on two types of rules for resource access: shared access and private access, as shown in Fig. 5 the process of adding access rule. In this smart contract, only the IoT owner has the authority to execute the access rules. According to [8], these rules will be more efficient in reducing excessive permissions. Instead of checking user queries by using many rules, the model checks user queries by using only one rule. In this study, the set of access rules have four criteria: type of rule, access action, role and constraint, as shown in Table III.



Fig. 5. Process adding access rule function.

TABLE III. SET OF ACCESS CONTROL RULES FOR IoT_ORMC

Type of Rule	Access Action	Role	Constraint
unique	Update / write	Water	Extension rs: docx place rs: A type rs: water $V u(u,att) = V r(rs, att)$.
multiple	Read	Water	Extension rs: pdf place rs: A type rs: water $V u(u,att) = V r(rs, att)$.

- Type of rule: is the type to access resources. In this case, we divided access resources into two types: unique and multiple. Unique access is an editable resource, such as word (i.e., docx) and excel (i.e., xlsx). Multiple access is a non-editable source, such as portable document format (i.e., pdf), video (i.e., mp4, avi) and audio (i.e., wav, aif, mp3).
- Access action: is an action that performs by subject to access resources; for instance, read, write, view, control, etc.
- Role: is a character played by IoT devices (e.g., the device for watering plants is categorised under water group).
- Constraints: are access restrictions built on logical formula by donating the value function where the attribute value for the user is $V u(u,att)$ and the attribute value for the resource is $V r(rs, att)$. Constraints can also include other statements such as time or location which are environment attributes, $V u(u,att)$.

3) *Subject-role Management Contract (IoT_SRMC)*: In the process of access control, IoT devices can have their identity impersonated [64][64]. To address this security concern, IoT_SRMC is proposed to authenticate legitimate users who intend to access the IoT network by registering a new device in the IoT network. This contract adopts ABAC

and RBAC models as a strategy for accessing control. It determines all attributes of IoT devices that can be used as valuable information to assess resources and assign roles to IoT devices. Each IoT device has a unique identifier (Ethereum account address) and multiple attributes associated with its ID, including location and role. This contract has functions for managing subject attributes and roles, such as adding, deleting and updating, which can only be performed by the IoT owner. In Table IV, all information about the IoT device is shown.

TABLE IV. SUBJECT REGISTRATION TABLE

device	deviceID	deviceType	deviceRole	devicePlace
Device A	0xA128F8	laptop	water	field A
Sensor B	0xA134S8	temperature	water	field A
Gateway A	0xA122A8	gateway	soil	field A

C. Framework Flow

We present two types of form requests in this research. First part is the registration of new IoT devices and sensors; second part is the access request by IoT devices made through smart contracts. Fig. 6 illustrates the decentralised access control for IoT security enhancement. For the first part, the registration of new devices and sensors begin when an IoT owner issues a smart contract that implements a hybrid access control mechanism into the blockchain. Blockchain responds by issuing requests to the IoT owner and then creates a smart contract.

The IoT owner requests to register his own IoT devices and sensors, known as a subject, intended to authorise its device by providing all device and sensor attributes (i.e., name, location, identification, role, etc.). If no rule is made, the IoT owner must publish an access rule based on four criteria: i) types of access (shared, private), ii) role, iii) access action and iv) constraint. Lastly, after all access rules are complete, the transaction is stored in the blockchain.

For the second part, access is requested by IoT devices made through smart contracts where the IoT devices send a request for any service to access or update (i.e., data, file, storage unit) in the IoT network. Next, when the request of the subject is generated, IoT_ACC (main smart contract) is executed to control the overall access management. IoT_ACC will then obtain all information from IoT_ORMC and IoT_SRMC to match values between the access request, access rule and list of attributes to obtain the access decision for IoT devices. If all information shows the same values and authentication is successful, then access permission for IoT devices is complete. IoT_ACC then forwards back the return access result to IoT devices or corresponding objects. Finally, the result of access permission is stored in the blockchain network.

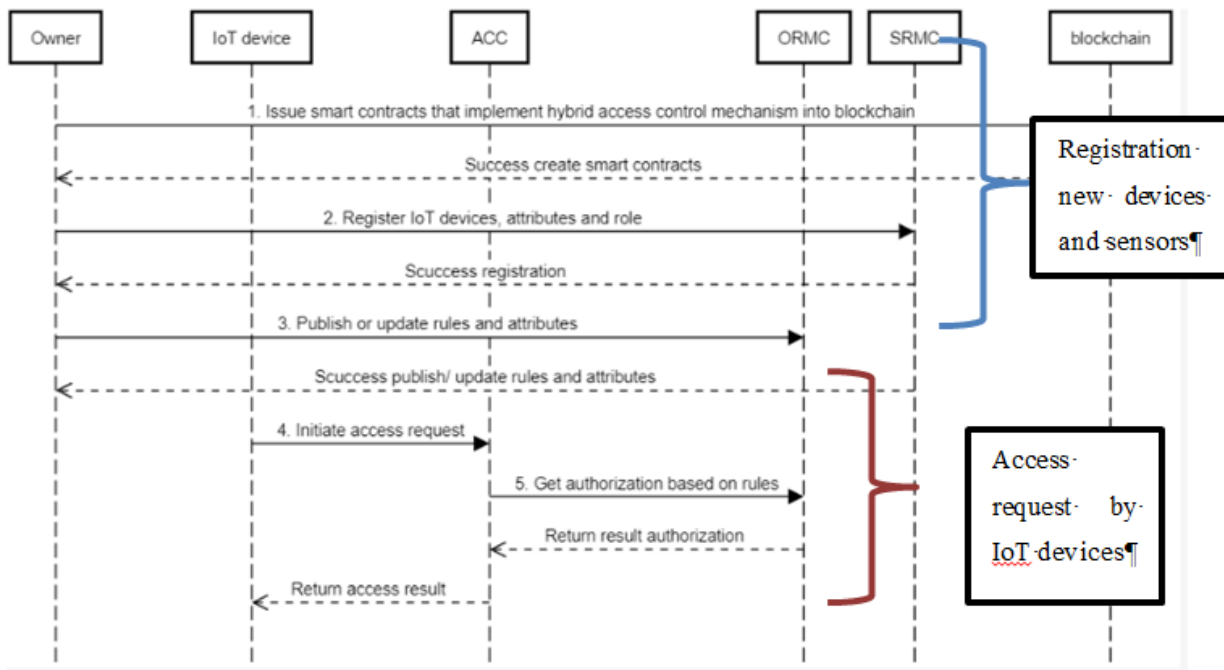


Fig. 6. Access control flow mechanism in smart farming.

V. EVALUATION

The main component of the proposed framework is the smart contracts that functioned as the verification mechanism. The deployment of smart contracts on the blockchain and the execution of associated contracts require payment of fees to the miner who mines the block. Thus, to evaluate our proposed framework, the smart contract cost consumption was measured by calculating the gas used for a transaction execution for the specific functions in smart contracts. The complexity of the task determines the quantity of gas consumed, with more gas being used for more complex tasks and the price of gas fluctuates over time. The fee required to perform a task is calculated by multiplying the consumed gas amount and the gas price. In this study, we run experiments for evaluation in the Ethereum network and the gas limit is set by the transaction initiator that determines the level of computational resources to be utilized in executing the transaction. In Ethereum, a unit called gas was employed to quantify the amount of work required to complete a task when deploying a smart contract. The initiator pays a fee for the gas used, which can vary depending on the gas limit set. The higher the amount paid, the easier the transaction will be executed [65] [66]. In this study, we determine cost per transaction by multiplying the gas price per unit with the gas limit (gasPrice X gasLimit) as per calculation in [51]. If the gas limit does not exceed the gas used, the execution of the transaction will be successful and it will be added or dropped in the blockchain network.

A. Simulation Setting

The experiments were conducted during the end of March 2023 when the value of 1 Ether is at the average of 1 eth ~ 1000000000 gwei. In this study, the simulation environment

was set up in two layers with the hardware setting and the software setting, as displayed in Tables V and VI, respectively.

TABLE V. HARDWARE SETTING

Items	Description
Operating system	Windows 10
Processor	AMD Ryzen 7 3700U with Radeon Vega Mobile Gfx 2.30 GHz
Memory	8 GB RAM

TABLE VI. SOFTWARE SETTING

Items	Description	Details
Language	Solidity	Used to build prototypes of smart contracts based on object-oriented programming language
Platform	Ethereum Network	Used as a public blockchain network in the virtual environment (EVM)
Compiler	Remix ide (version 0.5.17)	Used to compile smart contracts
Test network	goerli testnet	Used to test networks
Gas limit	3,000,000 units	Used to set the amount of gas initiator that will execute the transaction

B. Gas Usage and Cost per Operation in Smart Contracts

The costs and gas usage in different smart contract deployments of IoT_ACC, IoT_ORMC and IoT_SRMC are shown in Table VII. Deployment of IoT_ACC smart contract requires 1,487,367 gas units. The gas cost in IoT_ACC is less than other smart contracts since IoT_ACC smart contract is only used for enforcing access decisions. Meanwhile, in IoT_ORMC smart contract, 2,196,564 gas units are required to create access rules based on ABAC and RBAC that execute

the checking steps to determine if the role is a one-to-one relationship and active. In the meantime, to deploy IoT_SRMC smart contract, 1,677,746 gas units are required. Then, using the experiment's result, the cost of executing the IoT_ACC, IoT_ORMC and IoT_SRMC functions is calculated using Eq. (1).

$$TxFee = gas * gasPrice * 10^{-9} \quad (1)$$

where gas represents the amount of gas used by the transaction, gasPrice represents the price of each gas unit, and 10^{-9} is a conversion factor to convert the result into Ether. Hence, in this study, we determine that the cost value of executing each of the proposed smart contracts for IoT_ACC, IoT_ORMC and IoT_SRMC are 0.007212, 0.020180 and 0.019921 ether. This value serves as a benchmark for the cost operation for the proposed framework application in smart farming settings.

TABLE VII. GAS USAGE AND COST OF DIFFERENT SMART CONTRACT FUNCTIONS: IoT_ACC, IoT_IoT_RMC

Smart Contract Deployment	Description	Gas used	Cost (ether)
IoT_ACC Function	Responsible for enforcing rules and making access decisions	1,487,367	0.007212
IoT_ORMC Function	Responsible for managing and updating rules and resource attributes	2,196,564	0.020180
IoT_SRMC Function	Responsible for managing and assigning device attributes and the role of IoT devices	1,677,746	0.019921

VI. CONTRIBUTION

This paper proposes a novel decentralised access control framework for IoT security enhancement by adopting blockchain technology with the combination of ABAC and RBAC access control models. The aim of this proposed framework is to enhance the efficiency of access control management and secure IoT resources [8][9] with the scope of this study being smart farming. This framework aims to reduce the redundancy of permission required to authenticate devices to authorise and at the same time provide capacity for scalability. The pre-determined study objectives are as follows:

- We developed a decentralised access control framework embedded with blockchain technology to secure IoT resources from being accessed by unauthorised entities and scalable to cope with future expansion.
- We employed smart contracts as a fine-grained access control strategy to assign role-permission-based attributes that include object, subject and environment.
- We adopted two access control models (RBAC and ABAC) as an authentication element, including device attributes (name, location, type) and device roles in the smart farming environment.

- For validation, we applied Ethereum blockchain smart contract functionalities to issue, revoke or modify roles corresponding to a user, resource attributes and role permissions. The resource owner can further grant or deny access to resources.
- We conducted a simulation experiment to evaluate the framework component which is the smart contracts using gas cost measurements in the Ethereum network.

VII. CONCLUSION

The integration of IoT devices in smart farming facilitates the modernization of information and communication, resulting in increased productivity within the agricultural industry. To maintain the integrity of IoT resources and achieve security while also efficiently managing resources and ensuring scalability, a framework of decentralised access control using blockchain technology was developed in this study. The framework was developed based on findings from a detailed analysis published by researchers. Our proposed framework was developed by adopting blockchain technology to authenticate and authorize user and IoT device access while facilitating efficient resource management and scalability in IoT-enabled smart farming. The implementation of smart contracts is proposed to enhance the trust facilitated by the implementation of a ledger that is transparent and immutable. This study also suggests the implementation of the principle of role inheritance to reduce unnecessary user groups from access permission that can control the separation of duties, the list of privileges and confidentiality. In the framework, we proposed to combine blockchain technology as a decentralised approach with a hybrid access control model that consists of RBAC and ABAC. The proposed framework utilises a set of rules consisting of roles, access types, lists of attributes and actions that can be executed to obtain access permission by roles. The rules are divided into two types of access which are unique and multiple access. The proposed framework can resolve the challenge of role explosion, simplify management tasks, and reduce the complexity associated with traditional access control methods that rely on a centralized design. By doing so, the framework offers an effective solution to the limitations of current access control methods. It can enhance the overall security and resource management in decentralized IoT environments, thus improving the performance and efficiency of the access control mechanisms. The framework's main component which is the smart contracts was evaluated by measuring gas usage to determine cost operation using simulation. The finding can be used as a benchmark for comparison with the execution in the Mainnet network environment.

In future work, we will further evaluate the proposed framework using the measurement of the transaction throughput and network latency in blockchain by conducting more experiments. Also, an exploration towards a tokenised-based accelerating process for communication between smart contracts and IoT devices will be delivered to understand the effect of various attacks, such as DDOS attacks or man-in-the-middle attacks that compromise the integrity of data entry in smart farming.

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REFERENCES

- [1] H. Mahajan and A. Badarla, "Cross-Layer Protocol for WSN-Assisted IoT Smart Farming Applications Using Nature Inspired Algorithm," *Wirel. Pers. Commun.*, vol. 121, Dec. 2021, doi: 10.1007/s11277-021-08866-6.
- [2] A. Vangala, A. K. Das, V. Chamola, V. Korotaev, and J. J. P. C. Rodrigues, "Security in IoT-enabled Smart Agriculture: Architecture, Security Solutions and Challenges Security in IoT-enabled smart agriculture: architecture, security solutions and challenges," *Cluster Comput.*, no. April, 2022, doi: 10.1007/s10586-022-03566-7.
- [3] M. K. Saini, "Internet of Things (IoT) Applications and Security Challenges: A Review," vol. 7, no. 12, pp. 1–7, 2019.
- [4] A. Rettore, D. A. Zanella, L. Carlos, and P. Albini, "Security challenges to smart agriculture: Current state, key issues, and future directions," *Array*, vol. 8, no. October, p. 100048, 2020, doi: 10.1016/j.array.2020.100048.
- [5] R. Fotuhi and F. Shams Aliee, "Securing communication between things using blockchain technology based on authentication and SHA-256 to improving scalability in large-scale IoT," *Comput. Networks*, vol. 197, no. December 2020, p. 108331, 2021, doi: 10.1016/j.comnet.2021.108331.
- [6] M. T. Hammi, B. Hammi, P. Bellot, and A. Serhrouchni, "Bubbles of Trust: A decentralized blockchain-based authentication system for IoT," *Comput. Secur.*, vol. 78, no. 2018, pp. 126–142, 2018, doi: 10.1016/j.cose.2018.06.004.
- [7] X. Yang et al., "A Survey on Smart Agriculture: Development Modes, Technologies, and Security and Privacy Challenges," *IEEE/CAA J. Autom.*, vol. 8, no. 2, pp. 1–30, 2020.
- [8] H. Ben Attia, L. Kahloul, and S. Benharzallah, "FRABAC: A new hybrid access control model for the heterogeneous multi-domain systems," *Int. J. Manag. Decis. Mak.*, vol. 17, no. 3, pp. 245–278, 2018, doi: 10.1504/IJMDM.2018.093493.
- [9] S. Pal, M. Hitchens, V. Varadarajan, and T. Rabehaja, "Policy-based access control for constrained healthcare resources in the context of the Internet of Things," *J. Netw. Comput. Appl.*, vol. 139, no. April, pp. 57–74, 2019, doi: 10.1016/j.jnca.2019.04.013.
- [10] N. Mancosu, R. L. Snyder, G. Kyriakakis, and D. Spano, "Water scarcity and future challenges for food production," *Water (Switzerland)*, vol. 7, no. 3, pp. 975–992, 2015, doi: 10.3390/w7030975.
- [11] V. N. Malavade and P. K. Akulwar, "Role of IoT in Agriculture," *Natl. Conf. "Changing Technol. Rural Dev."*, vol. 1, no. 13, pp. 422–425, 2019.
- [12] N. H. Motlagh, M. Mohammadrezaei, J. Hunt, and B. Zakeri, "Internet of things (IoT) and the energy sector," *Energies*, vol. 13, no. 2, pp. 1–27, 2020, doi: 10.3390/en13020494.
- [13] F. J. Ferrández-Pastor, J. M. García-Chamizo, M. Nieto-Hidalgo, and J. Mora-Martínez, "Precision agriculture design method using a distributed computing architecture on internet of things context," *Sensors (Switzerland)*, vol. 18, no. 6, 2018, doi: 10.3390/s18061731.
- [14] A. D. Jurcut, P. Ranaweera, and L. Xu, "Introduction to IoT Security," no. December. 2020. doi: 10.1002/9781119527978.ch2.
- [15] M. Wazid, A. K. Das, S. Shetty, P. Gope, and J. J. P. C. Rodrigues, "Security in 5G-Enabled Internet of Things Communication: Issues, Challenges and Future Research Roadmap," *IEEE Access*, vol. 9, 2020, doi: 10.1109/ACCESS.2020.3047895.
- [16] M. Gupta, M. Abdelsalam, S. Khorsandroo, and S. Mittal, "Security and Privacy in Smart Farming: Challenges and Opportunities," *IEEE Access*, vol. 8, pp. 34564–34584, 2020, doi: 10.1109/ACCESS.2020.2975142.
- [17] T. Zenggeya, P. Sambo, N. Mabika, and C. Science, "Trust In The Adoption Of Internet Of Things For Smart Agriculture In Developing Countries," vol. 12, no. 3, pp. 11–22, 2021.
- [18] G. Ikrisi and T. Mazri, "IoT-Based Smart Environments: State Of The Art, Security Threats And Solutions," vol. XLVI, no. October, pp. 27–29, 2021.
- [19] T. Le and M. W. Mutka, "Access control with delegation for smart home applications," *IoTDI 2019 - Proc. 2019 Internet Things Des. Implement.*, pp. 142–147, 2019, doi: 10.1145/3302505.3310076.
- [20] E. Bertin, D. Hussein, C. Sengul, and V. Frey, "Access Control in the Internet of Things: A Survey of Existing Approaches and Open Research Question," *Proc. ACM Conf. Comput. Commun. Secur.*, pp. 1056–1073, 2018, doi: 10.1145/3243734.3243817.
- [21] G. Fedrechski, L. C. C. De Biase, P. C. Calcina-Ccori, R. De Deus Lopes, and M. K. Zuffo, "SmartABAC: Enabling Constrained IoT Devices to Make Complex Policy-Based Access Control Decisions," *IEEE Internet Things J.*, vol. 9, no. 7, pp. 5040–5050, 2022, doi: 10.1109/JIOT.2021.3110142.
- [22] L. Song, X. Ju, Z. Zhu, and M. Li, "An access control model for the Internet of Things based on zero-knowledge token and blockchain," *Eurasip J. Wirel. Commun. Netw.*, vol. 2021, no. 1, 2021, doi: 10.1186/s13638-021-01986-4.
- [23] M. Alshahrani and I. Traore, "Secure mutual authentication and automated access control for IoT smart home using cumulative Keyed-hash chain," *J. Inf. Secur. Appl.*, vol. 45, pp. 156–175, 2019, doi: 10.1016/j.jjsa.2019.02.003.
- [24] K. Lei et al., "Blockchain-Based Cache Poisoning Security Protection and Privacy-Aware Access Control in NDN Vehicular Edge Computing Networks," *J. Grid Comput.*, vol. 18, no. 4, pp. 593–613, 2020, doi: 10.1007/s10723-020-09531-1.
- [25] J. Brogan, I. Baskaran, and N. Ramachandran, "Authenticating Health Activity Data Using Distributed Ledger Technologies," *Comput. Struct. Biotechnol. J.*, vol. 16, pp. 257–266, 2018, doi: 10.1016/j.csbj.2018.06.004.
- [26] C. Lin, D. He, X. Huang, K. K. R. Choo, and A. V. Vasilakos, "BSIn: A blockchain-based secure mutual authentication with fine-grained access control system for industry 4.0," *J. Netw. Comput. Appl.*, vol. 116, no. February, pp. 42–52, 2018, doi: 10.1016/j.jnca.2018.05.005.
- [27] S. Hong, "P2P networking based internet of things (IoT) sensor node authentication by Blockchain," *Peer-to-Peer Netw. Appl.*, vol. 13, no. 2, pp. 579–589, 2020, doi: 10.1007/s12083-019-00739-x.
- [28] J. P. Cruz, Y. Kaji, and N. Yanai, "RBAC-SC: Role-based access control using smart contract," *IEEE Access*, vol. 6, pp. 12240–12251, 2018, doi: 10.1109/ACCESS.2018.2812844.
- [29] M. U. Rahman, "Scalable Role-based Access Control Using The EOS Blockchain," 2020.
- [30] J. Huang, D. M. Nicol, R. Bobba, and J. H. Huh, "A framework integrating attribute-based policies into role-based access control," *Proc. ACM Symp. Access Control Model. Technol. SACMAT*, pp. 187–196, 2012, doi: 10.1145/2295136.2295170.
- [31] A. Ismail, Q. Wu, M. Toohy, Y. C. Lee, Z. Dong, and A. Y. Zomaya, "TRABAC: A Tokenized Role-Attribute Based Access Control using Smart Contract for Supply Chain Applications," *Proc. - 2021 IEEE Int. Conf. Blockchain, Blockchain 2021*, no. December 2021, pp. 584–588, 2021, doi: 10.1109/Blockchain53845.2021.00088.
- [32] S. Ding, J. Cao, C. Li, K. Fan, and H. Li, "A Novel Attribute-Based Access Control Scheme Using Blockchain for IoT," *IEEE Access*, vol. 7, pp. 38431–38441, 2019, doi: 10.1109/ACCESS.2019.2905846.
- [33] S. Bhatt, T. K. Pham, M. Gupta, J. Benson, J. Park, and R. Sandhu, "Attribute-Based Access Control for AWS Internet of Things and Secure Industries of the Future," *IEEE Access*, vol. 9, pp. 107200–107223, 2021, doi: 10.1109/ACCESS.2021.3101218.
- [34] P. Wang, Y. Yue, W. Sun, and J. Liu, "An Attribute-Based Distributed Access Control for Blockchain-enabled IoT," 2019 *Int. Conf. Wirel. Mob. Comput. Netw. Commun.*, pp. 1–6, 2019.
- [35] J. Wang, H. Wang, H. Zhang, and N. Cao, "Trust and Attribute-Based Dynamic Access Control Model for Internet of Things," *Proc. - 2017 Int. Conf. Cyber-Enabled Distrib. Comput. Knowl. Discov. CyberC 2017*, vol. 2018-Janua, pp. 342–345, 2017, doi: 10.1109/CyberC.2017.47.
- [36] Y. Zhang, B. Li, B. Liu, J. Wu, Y. Wang, and X. Yang, "An attribute-based collaborative access control scheme using blockchain for IoT

- devices," *Electron.*, vol. 9, no. 2, 2020, doi: 10.3390/electronics9020285.
- [37] S. Liu, J. Yu, Y. Xiao, Z. Wan, S. Wang, and B. Yan, "BC-SABE: Blockchain-Aided Searchable Attribute-Based Encryption for Cloud-IoT," *IEEE Internet Things J.*, vol. 7, no. 9, pp. 7851–7867, 2020, doi: 10.1109/JIOT.2020.2993231.
- [38] S. Bhatt and R. Sandhu, "ABAC-CC: Attribute-based access control and communication control for internet of things," *Proc. ACM Symp. Access Control Model. Technol. SACMAT*, pp. 203–212, 2020, doi: 10.1145/3381991.3395618.
- [39] L. Cruz-Piris, D. Rivera, I. Marsa-Maestre, E. De La Hoz, and J. R. Velasco, "Access control mechanism for IoT environments based on modelling communication procedures as resources," *Sensors (Switzerland)*, vol. 18, no. 3, 2018, doi: 10.3390/s18030917.
- [40] T. Rabehaja, S. Pal, and M. Hitchens, "Design and implementation of a secure and flexible access-right delegation for resource constrained environments," *Futur. Gener. Comput. Syst.*, vol. 99, pp. 593–608, 2019, doi: 10.1016/j.future.2019.04.035.
- [41] Y. Zhang, R. H. Deng, G. Han, and D. Zheng, "Secure smart health with privacy-aware aggregate authentication and access control in Internet of Things," *J. Netw. Comput. Appl.*, vol. 123, no. June, pp. 89–100, 2018, doi: 10.1016/j.jnca.2018.09.005.
- [42] M. U. Aftab et al., "A Hybrid Access Control Model with Dynamic COI for Secure Localization of Satellite and IoT-Based Vehicles," *IEEE Access*, vol. 8, pp. 24196–24208, 2020, doi: 10.1109/ACCESS.2020.2969715.
- [43] D. C. Nguyen, P. N. Pathirana, M. Ding, and A. Seneviratne, "Blockchain for Secure EHRs Sharing of Mobile Cloud Based E-Health Systems," *IEEE Access*, vol. 7, pp. 66792–66806, 2019, doi: 10.1109/ACCESS.2019.2917555.
- [44] D. Prashar, N. Jha, S. Jha, Y. Lee, and G. P. Joshi, "Blockchain-based traceability and visibility for agricultural products: A decentralized way of ensuring food safety in India," *Sustain.*, vol. 12, no. 8, 2020, doi: 10.3390/SU12083497.
- [45] A. F. Hussein, N. ArunKumar, G. Ramirez-Gonzalez, E. Abdulhay, J. M. R. S. Tavares, and V. H. C. de Albuquerque, "A medical records managing and securing blockchain based system supported by a Genetic Algorithm and Discrete Wavelet Transform," *Cogn. Syst. Res.*, vol. 52, pp. 1–11, 2018, doi: 10.1016/j.cogsys.2018.05.004.
- [46] M. N. M. Bhutta et al., "A Survey on Blockchain Technology: Evolution, Architecture and Security," *IEEE Access*, vol. 9, no. April, pp. 61048–61073, 2021, doi: 10.1109/ACCESS.2021.3072849.
- [47] G. Zhao et al., "Blockchain technology in agri-food value chain management: A synthesis of applications, challenges and future research directions," *Comput. Ind.*, vol. 109, pp. 83–99, 2019, doi: 10.1016/j.compind.2019.04.002.
- [48] Z. Zheng, S. Xie, H. Dai, X. Chen, and H. Wang, "An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends," *Proc. - 2017 IEEE 6th Int. Congr. Big Data, BigData Congr. 2017*, no. June, pp. 557–564, 2017, doi: 10.1109/BigDataCongress.2017.85.
- [49] S. H. Alsamhi and B. Lee, "Blockchain-Empowered Multi-Robot Collaboration to Fight COVID-19 and Future Pandemics," *IEEE Access*, vol. 9, pp. 44173–44197, 2021, doi: 10.1109/ACCESS.2020.3032450.
- [50] N. A. M. Razali, W. N. W. Muhamad, K. K. Ishak, N. J. A. M. Saad, M. Wook, and S. Ramli, "Secure Blockchain-Based Data-Sharing Model and Adoption among Intelligence Communities," *IAENG Int. J. Comput. Sci.*, vol. 48, no. 1, 2021.
- [51] M. M. A. Khan, H. M. A. Sarwar, and M. Awais, "Gas consumption analysis of Ethereum blockchain transactions," *Concurr. Comput. Pract. Exp.*, vol. 34, no. 4, p. e6679, Feb. 2022, doi: <https://doi.org/10.1002/cpe.6679>.
- [52] T. Jaikla, C. Vorakulpipat, E. Rattanalerdnusorn, and H. D. Hai, "A secure network architecture for heterogeneous IoT devices using role-based access control," *2019 27th Int. Conf. Software, Telecommun. Comput. Networks, SoftCOM 2019*, 2019, doi: 10.23919/SOFTCOM.2019.8903605.
- [53] N. H. N. Zulklipli and G. B. Wills, "An event-based access control for IoT," *ACM Int. Conf. Proceeding Ser.*, pp. 0–3, 2017, doi: 10.1145/3018896.3025170.
- [54] N. Noor, N. Matrazali, N. Malizan, K. Ishak, M. Wook, and N. Hasbullah, "Decentralized Access Control using Blockchain Technology for Application in Smart Farming," *Int. J. Adv. Comput. Sci. Appl.*, vol. 13, Jan. 2022, doi: 10.14569/IJACSA.2022.0130993.
- [55] E. Chen, Y. Zhu, Z. Zhou, S. Y. Lee, W. E. Wong, and W. C. C. Chu, "Policychain: A Decentralized Authorization Service With Script-Driven Policy on Blockchain for Internet of Things," *IEEE Internet Things J.*, vol. 9, no. 7, pp. 5391–5409, 2022, doi: 10.1109/JIOT.2021.3109147.
- [56] P. Wang, N. Xu, H. Zhang, W. Sun, and A. Benslimane, "Dynamic Access Control and Trust Management for Blockchain-Empowered IoT," *IEEE Internet Things J.*, vol. 9, no. 15, pp. 12997–13009, 2022, doi: 10.1109/JIOT.2021.3125091.
- [57] R. Wang, X. Wang, W. Yang, S. Yuan, and Z. Guan, "Achieving fine-grained and flexible access control on blockchain-based data sharing for the Internet of Things," *China Commun.*, vol. 19, no. 6, pp. 22–34, 2022, doi: 10.23919/JCC.2022.06.003.
- [58] S. Y. A. Zaidi et al., "An attribute-based access control for IoT using blockchain and smart contracts," *Sustain.*, vol. 13, no. 19, pp. 1–26, 2021, doi: 10.3390/su131910556.
- [59] Y. E. Oktian and S. G. Lee, "BorderChain: Blockchain-Based Access Control Framework for the Internet of Things Endpoint," *IEEE Access*, vol. 9, pp. 3592–3615, 2021, doi: 10.1109/ACCESS.2020.3047413.
- [60] S. Pal, T. Rabehaja, M. Hitchens, V. Varadharajan, S. Member, and A. Hill, "On the Design of a Flexible Delegation Model for the Internet of Things Using Blockchain," *IEEE Trans. Ind. Informatics*, vol. PP, no. c, p. 1, 2019, doi: 10.1109/TII.2019.2925898.
- [61] R. Nakanishi, Y. Zhang, M. Sasabe, and S. Kasahara, "IOTA-Based Access Control Framework for the Internet of Things," *2020 2nd Conf. Blockchain Res. Appl. Innov. Networks Serv. BRAINS 2020*, pp. 87–91, 2020, doi: 10.1109/BRAINS49436.2020.9223293.
- [62] Y. Zhang, S. Kasahara, Y. Shen, X. Jiang, and J. Wan, "Smart contract-based access control for the internet of things," *IEEE Internet Things J.*, vol. 6, no. 2, pp. 1594–1605, 2019, doi: 10.1109/JIOT.2018.2847705.
- [63] M. Cinque, C. Esposito, S. Russo, and O. Tamburis, "Blockchain-empowered decentralised trust management for the Internet of Vehicles security," *Comput. Electr. Eng.*, vol. 86, p. 106722, 2020, doi: 10.1016/j.compeleceng.2020.106722.
- [64] M. Wazid, B. Bera, A. Mitra, A. K. Das, and R. Ali, "Private blockchain-envisioned security framework for AI-enabled IoT-based drone-aided healthcare services," *DroneCom 2020 - Proc. 2nd ACM MobiCom Work. Drone Assist. Wirel. Commun. 5G Beyond*, pp. 37–42, 2020, doi: 10.1145/3414045.3415941.
- [65] S. Bouraga, "An Evaluation of Gas Consumption Prediction on Ethereum based on Transaction History Summarization," Sep. 2020, doi: 10.1109/BRAINS49436.2020.9223288.
- [66] T. Sultana, A. Almogren, M. Akbar, M. Zuair, I. Ullah, and N. Javaid, "Data sharing system integrating access control mechanism using blockchain-based smart contracts for IoT devices," *Appl. Sci.*, vol. 10, no. 2, 2020, doi: 10.3390/app10020488.

Artificial Intelligence System for Detecting the Use of Personal Protective Equipment

Josue Airton Lopez Cabrejos^{1*}, Avid Roman-Gonzalez^{1,2}

Aerospace Sciences & Health Research Laboratory (INCAS-Lab), Universidad Nacional Tecnológica de Lima Sur, Lima, Perú^{1,2}
Image Processing Research Laboratory (INTI-Lab), Universidad de Ciencias y Humanidades, Lima, Perú²

Abstract—In recent years, occupational accidents have been increasing, and it has been suggested that this increase is related to poor or no supervision of personal protective equipment (PPE) use. This study proposes developing a system capable of identifying the use of PPEs using artificial intelligence through a neural network called YOLO. The results obtained from the development of the system suggest that automatic recognition of PPEs using artificial intelligence is possible with high precision. The recognition of gloves is the only critical object that can give false positives, but it can be addressed with a redundant system that performs two or more consecutive recognitions. This study also involved the preparation of a custom dataset for training the YOLO neural network. The dataset includes images of workers wearing different types of PPEs, such as helmets, gloves, and safety shoes. The system was trained using this dataset and achieved a precision of 98.13% and a recall of 86.78%. The high precision and recall values indicate that the system can accurately identify the use of PPEs in real-world scenarios, which can help prevent occupational accidents and ensure worker safety.

Keywords—Personal protective equipment (PPE); artificial intelligence (AI); YOLO (You Only Look Once); object detection; neural network; custom PPE dataset

I. INTRODUCTION

Workplace accidents pose a serious threat to the safety and well-being of workers worldwide. The human cost of such accidents is immeasurable, with the victims and their families often enduring long-term physical, emotional, and financial consequences. Besides, accidents at work can also have significant economic impacts, such as lost productivity, increased healthcare costs, and legal liabilities for employers. Thus, preventing and mitigating the risks of occupational accidents should be a top priority for governments, organizations, and individuals alike.

Unfortunately, recent statistics indicate that the frequency of occupational accidents has been on the rise, leading to an increase in injuries and fatalities. For instance, the Ministry of Labor and Employment Promotion reported a staggering 23.7% increase in accidents in April 2022 [1] compared to the same period the previous year. The report showed that Lima had the highest number of accidents, with 2,132 cases, of which six were fatal. The most common types of accidents were due to object strikes and falls, with tools being the leading cause. Fingers and eyes were the most affected body parts.

In a recent study, it was determined that, on average, 87% of workers do not use PPE properly, linking the lack of PPE usage to both fatal and non-fatal accidents [2]. Furthermore, the use of PPE is a legal right for workers, who are obligated to protect their health and lives [3].

To address this alarming trend, researchers and practitioners have been exploring various solutions to prevent or mitigate the risks of occupational accidents. One promising approach is the use of artificial intelligence systems to detect the use of personal protective equipment in work environments. PPEs are essential safety devices that protect workers from hazards, such as falling objects, sharp tools, chemicals, or radiation. However, the effectiveness of PPEs relies on their proper use and maintenance, which is only sometimes guaranteed in practice.

AI-based systems can help monitor and enforce the proper use of PPEs in real-time, thus reducing the risk of accidents and injuries. However, an adequate and relevant dataset is a significant challenge in developing such systems. The performance of AI algorithms depends heavily on the quality and quantity of data used to train them. Collecting and labeling large and diverse datasets of workers wearing different types of PPEs in various work environments can be costly and time-consuming, so a pre-trained neural network such as YOLO can help reduce time in training and deploying a model [4].

Researchers had to create a step-by-step dataset using internet images to overcome this limitation, using various techniques, such as web scraping, data augmentation, and transfer learning, to generate a large and diverse dataset of workers wearing different types of PPEs in various work environments. Researchers must ensure a balanced and representative dataset of the real-world distribution of PPEs and work environments.

With a custom dataset of images obtained from github's user [5], an innovative AI-based system was developed that uses advanced image processing techniques, specifically convolutional neural networks and object detection, to detect the use of PPEs in work environments. The system can recognize various types of PPEs, such as hard hats, safety glasses, vests, shoes, and gloves, and their proper use and placement on the worker's body.

One of the advantages of this system is its non-invasiveness. The system can be used on cameras installed in

the work environment to capture images of workers wearing PPEs, without requiring physical contact or interference with their daily activities [6]. This feature makes the system more acceptable and practical for workers and supervisors, as it does not disrupt their workflow or privacy.

In this paper, a review was conducted to determine which neural network would perform most efficiently. Section III details how a neural network can be trained in the cloud, thus avoiding the need for powerful hardware. Section IV presents the results regarding precision and recall to provide a comprehensive understanding of the system's performance. Finally, Section V shows the conclusions about the findings.

II. LITERATURE REVIEW

"Design of an artificial vision system to determine the quality of mandarins" is a thesis about the development of an algorithm that classifies mandarins based on their size, shape, and colour using digital image processing and region-based segmentation through a webcam using MATLAB and Arduino, achieving an accuracy of 93.3% in classification[7].

Another thesis mentions that techniques such as You Only Look Once, Region proposals + CNN, Single Shot Detector, among others, can be used to detect objects based on computer vision, and these techniques are associated with deep learning. The advantages and disadvantages of each technique mentioned above are also discussed [8].

It is possible to classify lemons, using artificial vision, based on their shape and dimensions. The development of the algorithm follows the phases of an artificial vision solution acquisition, pre-processing, segmentation, description and recognition and interpretation, and the efficiency achieved by the system is 83.9% in "Development of an artificial vision system to perform a uniform classification of lemons" [9].

An article named "Real-time Personal Protective Equipment Detection Using YOLOv4 and TensorFlow" consists of developing a mask and face shield detector as preventive measures for COVID-19 in real-time using YOLOv4, obtaining a system effectiveness of 79% [10].

A thesis called "Electronic system for quality control of chicken eggs using image processing" from the Universidad Técnica de Ambato (Ecuador), consists in a quality control system for chicken eggs using image processing in Python with the OpenCV library, concluding that two factors mainly determine the efficiency of the system, the software used and the ambient lighting [11].

"Design of a classifier system for apples by colour, using artificial vision, for the company Fresh & Natural C.I." from Andrea Aguilar, developed an apple classifier using artificial vision, capturing images from a webcam and using MATLAB as a processing interface, obtaining an effectiveness of 100% for a number of 18 apples [12].

III. PROPOSED SYSTEM

The following is a general description of the network's operation, an explanation of the dataset used, the criteria used to select the neural network, the hardware and software used during this work, and considerations that must be considered.

A. System Overview

As illustrated in Fig. 1, the system is founded upon the state-of-the-art Yolov5s architecture to train a neural network that can accurately identify personal protective equipment in real time. To ensure optimal performance, a custom dataset is prepared, employing detailed image segmentation and data augmentation techniques to triple the number of images. The trained model is then deployed to evaluate frames captured by a webcam, seamlessly detecting PPEs worn by individuals in real time.

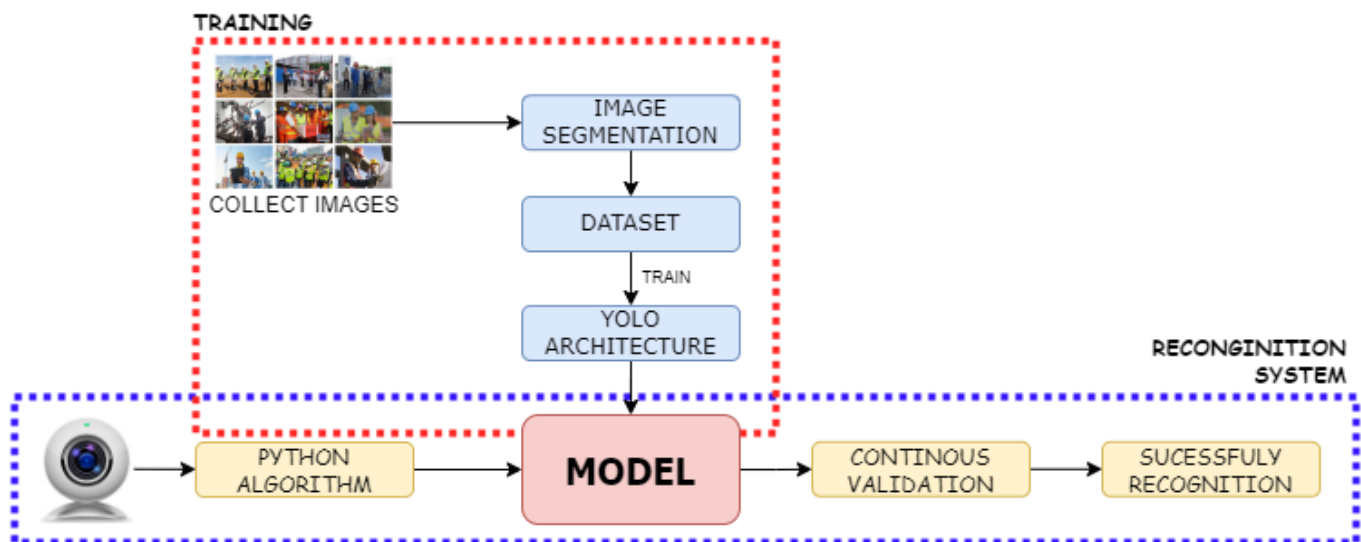


Fig. 1. Flowchart proposed system.

B. EPP Dataset

In this study, the classes to be recognized in the system were defined according to the Peruvian technical health standard for personal protective equipment, which is a ministerial resolution [13]. The classes were also defined based on the body parts involved in accidents. The classes to be detected were as follows: helmet, vest, goggles, gloves, shoes, and the person itself, resulting in six classes. This classification system was crucial for the training and testing of the deep learning model used in this study, as it allowed for accurate and reliable detection of the relevant personal protective equipment in real-time; in Fig. 2, the total object per class in the entire dataset is represented.

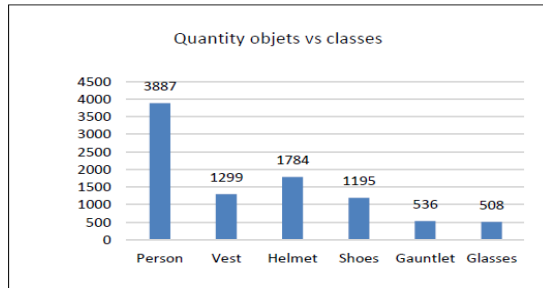


Fig. 2. Quantity objects per class.

C. Software and Hardware Selection

After a long comparative investigation of different open-access neural networks[14], it was chosen to use the YOLO v5 neural network, because it is easy to train, it can be used directly with video and webcam source and is lightweight than older YOLO's version. But in YOLOv5 there are some variants, because of that, two parameters were considered for selecting the neural network variant: the accuracy concerning a dataset called Common Objects in Context (COCO) and the processing speed in images per unit of time [15].

Below, in Table I, we show the different YOLOv5 variants with the established parameter data for comparison.

With a simple calculation, we can obtain ratings for each of the YOLO variants, shown in the following Table II, where a lower rating indicates a better relationship between processing time and system accuracy.

It is observed that v5n is the best option for a system where an optimal relationship between processing time and accuracy is desired, but in the present case, one used v5s because one wanted more accuracy, sacrificing some performance.

TABLE I. PROCESS TIME PER IMAGE YOLO

YOLO variant	COCO accuracy (%)	Process time (ms/image)
v5n	27.6	62.7
v5s	37.6	173.3
v5m,	45.0	427.0
v5l	49.0	857.4
v5x	50.7	1579.2

TABLE II. PROCESS TIME PER ACCURACY YOLO

YOLO variant	Process time (ms) / accuracy
v5n	2.27
v5s	4.61
v5m,	9.49
v5l	17.50
v5x	31.15

Python 3.9.7 was used for training and implementing the neural network, as it has active community support and is compatible with a wide range of existing Python libraries. A cloud service called Google Colab is used for training due to the intensive GPU usage required, which can be expensive. Google Colab offers free access to GPUs for a few hours per week, and it also allows users to connect with Google Drive to save progress and resume when more hours are available on Google Colab, all Software and Hardware used is shown in Table III.

TABLE III. EXPERIMENTAL SETUP

Hardware / Software	Description
Lenovo T430 i5 3320M	Computer specification
Microsoft Windows 10 Pro	Operating system
Google Colab	Web App for Neural Network training
Python 3.9.7	Python's version used
Roboflow	Web App for dataset creation
Generic Webcam	1080p 60fps

D. PPE Detector System

The YOLO source code has been analyzed, and it has been determined that the input image is resized to a resolution of 240 x 240 pixels, as per the information gleaned from the neural network's source code. Moreover, it has been observed that YOLO employs a 6x6 initial kernel, and uses a 3x3 kernel in the deeper layers, every kernel means a convolution and every convolution makes the image smaller. In the final stage of training, the layers were modified to predict six classes that align with the prepared dataset. A detailed breakdown of the neural network layers can be found in Fig. 3, providing further insights into its inner workings.

Conv means a convolutional layer, C3 means three convolutional layers with same parameters, Up Sampling is used to resize the image to its original size, NMS is to keep the bounding box of each class with the highest confidence score.

Using YOLOv5s, training the neural network can be accomplished through simple steps. Firstly, the YOLOv5 GitHub repository must be cloned. Next, the necessary libraries located in requirements.txt must be installed. Finally, the training steps can be followed using the following arguments: --data data.yaml --epochs 200 --weights yolov5s.pt --batch-size 40.

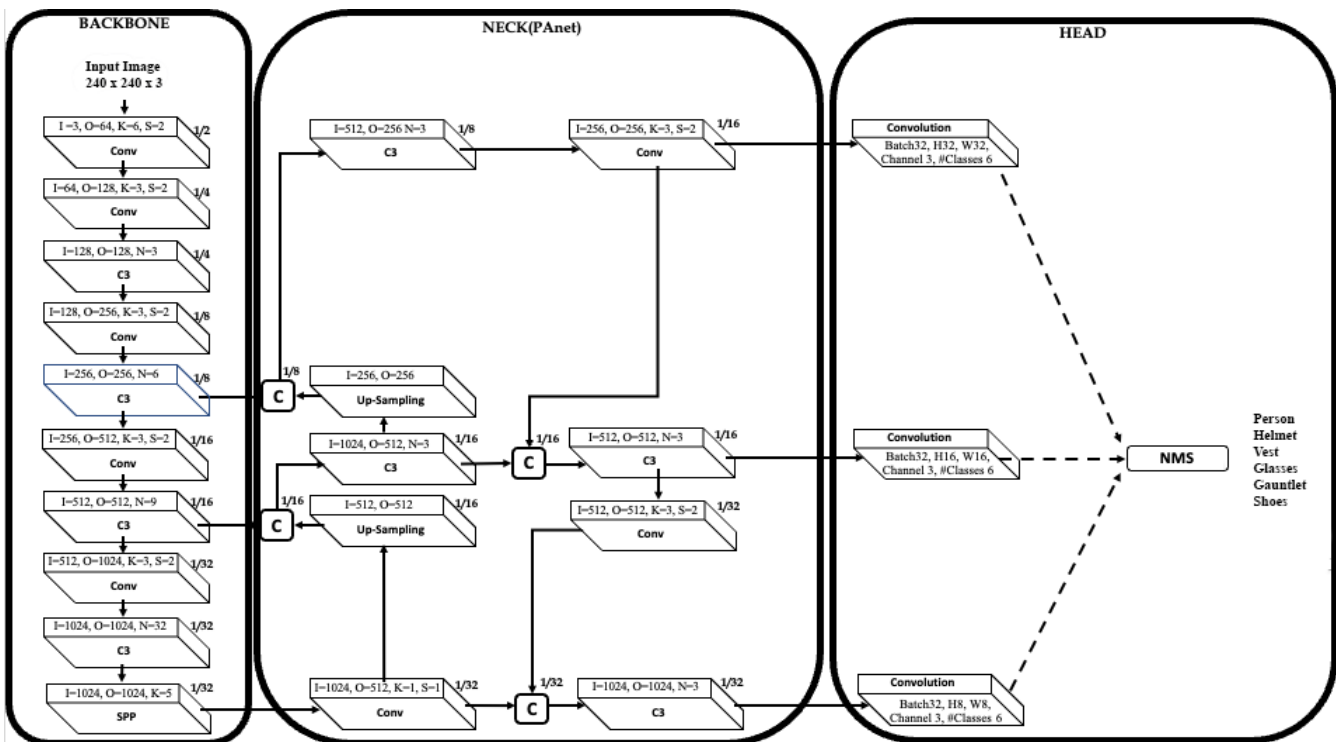


Fig. 3. YOLOv5s architecture.

IV. RESULTS AND EVALUATION

The results of a neural network system can be divided into two categories: training results and recognition results. Training results are observed during the training process and serve as an indicator of whether the neural network is performing well or not. Recognition results are custom metrics that allow us to evaluate the performance of the neural network.

A. Training Results

The system's accuracy and losses should be examined first when training a neural network. While these are not directly related, they provide insight into the system's overall behaviour shown in Fig. 4. System's global accuracy is 80%, or 0.8, this can be interpreted as image recognition, but since the system will be used in video, in section C, experimental results are shown, due multiple images in a second can be processed in video. This situation indicates that many PPEs are being recognized. On the other hand, losses are less than 10%. This result suggests that the system only misclassifies a small fraction of the PPEs it encounters, and confusion with other categories is minimal. While this indicates good system performance, it should be noted that these are general observations.

B. Evaluation Metrics

The widely adopted mean average precision will be used (mAP) metric to evaluate the object detection model. The mAP[16] metric is a comprehensive measure of the effectiveness of object detection models, which considers both the precision (1) and recall (2) of the model across different levels of confidence. It is calculated by averaging the precision values at different levels of recall, where precision is

the proportion of correctly classified objects among all objects classified at a certain level of confidence, and recall is the proportion of correctly classified objects among all objects that should have been classified:

$$\text{Precision} = \text{TP} / (\text{TP} + \text{FP}) \quad (1)$$

$$\text{Recall} = \text{TP} / (\text{TP} + \text{FN}) \quad (2)$$

Here, *TP* represents the number of true positives, which indicates the number of PPE objects correctly detected and classified by the model. *FP* represents the number of false positives, corresponding to the number of non-PPE objects incorrectly classified as PPE objects. *FN* represents the number of false negatives, which indicates the number of PPE objects that have been missed by the model and not detected.

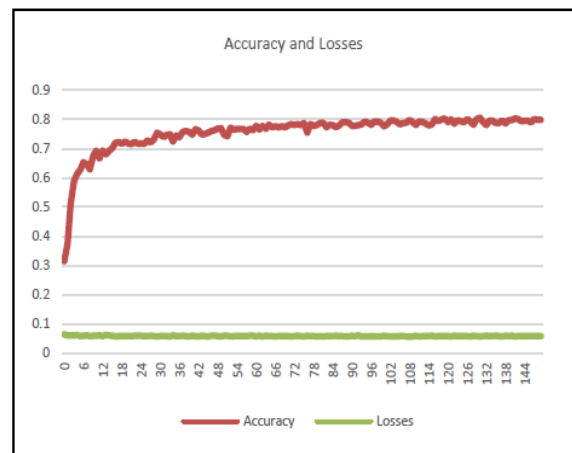


Fig. 4. Accuracy and losses of the proposed system per epoch trained.

The mAP metric is a comprehensive measure of the effectiveness of object detection models, which considers both the precision and recall of the model across different levels of confidence. It is calculated by averaging the precision values at different levels of recall, where precision is the proportion of correctly classified objects among all objects classified at a certain level of confidence, and recall is the proportion of correctly classified objects among all objects that should have been classified.

The mAP metric is widely used in many applications, including workplace safety monitoring and quality control in manufacturing, where the reliable detection and classification of PPE objects is crucial for ensuring worker safety and product quality. By utilizing the mAP metric, we can obtain a comprehensive and quantitative assessment of the performance of the object detection model, which is essential for ensuring the effectiveness and reliability of the system in real-world applications.

C. Result Analysis

Using a threshold of 0.5 for each class identification, using 1080p webcam input source and 600 x 400 output video, the object detection model achieved a precision of 0.98130841 and a recall of 0.8677686 in identifying PPE objects, including helmets, gloves, vests, shoes, safety glasses, and people. The precision value indicates that the model accurately classified 98.13% of the detected PPE objects, while the recall value indicates that 86.78% of all PPE objects in the images were successfully detected and classified. The model's ability to identify multiple types of PPE objects suggests various features for object recognition, although gloves were the most challenging object to recognize. A frame is processed in around 0.075 seconds that means 13 frames per second using YOLO V5s (refer Fig. 5).

The closest better version of YOLO is 2x slower according to Table II, it means 7 frames per second, it wouldn't have been optimal for real-time applications.

These results suggest that the model performs well in identifying PPE objects, but further optimization may be needed to improve its accuracy in detecting and classifying gloves. Monitoring and evaluating the model's performance will be necessary for ensuring its reliability and effectiveness in real-world applications.

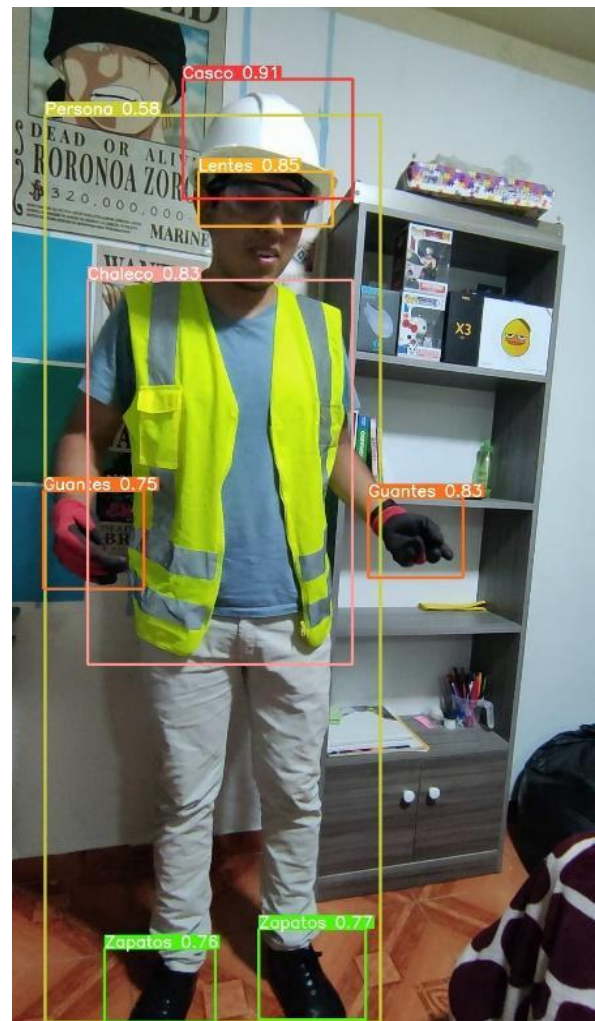


Fig. 5. Result of system's prediction.

V. DISCUSSION

To improve the performance of the model, it is recommended to experiment with different threshold values for detecting personal protective equipment, as this can help fine-tune the algorithm for optimal sensitivity and specificity. Additionally, using metrics such as precision and recall can provide a more comprehensive evaluation of the model's performance and highlight areas for improvement. Expanding the dataset to include more diverse and challenging scenarios can enhance the model's robustness and generalizability. By implementing these recommendations, the model can be optimized for more accurate and reliable detection of personal protective equipment in various real-world applications.

VI. CONCLUSION

The YOLOv5s neural network is lightweight enough to be used in real-time scenarios, as demonstrated by its successful performance on relatively old hardware while achieving efficient results. However, to further improve the present work, it is suggested to have a better distribution of classes in the dataset, with roughly the same number of objects per class, to enhance recall, especially for challenging objects.

Using CNN with a video source or webcam offers advantages compared to its application on static images. This is because it is not necessary to recognize the object immediately or in the first video frame. Instead, the object can be recognized within a specific period, even if it only appears in a few frames, and it will still be considered valid. This temporal recognition capability allows for capturing and recognizing objects in a video sequence, which is beneficial for applications such as object tracking or real-time object analysis. By leveraging the contextual information provided by consecutive frames, the CNN can improve recognition accuracy and provide more robust results in dynamic environments.

By augmenting the dataset, the model is exposed to a greater variety of images, which can improve its ability to generalize to new, unseen data. When working with limited data, these results in a better-trained model with higher precision and lower losses are often necessary. Furthermore, data augmentation can also help to reduce overfitting, a common problem in deep learning where the model becomes too specialized to the training data and performs poorly on new data. Therefore, performing data augmentation on the dataset is crucial in developing robust and accurate computer vision models.

REFERENCES

- [1] MTPE, "Notifications of work accidents, hazardous incidents, and occupational diseases", OGETIC, pp 5-9, April 2022.
- [2] S. Macalopu and S. Guzman. "Work accidents and personal protective equipment among public cleaning workers in the José Leonardo Ortiz district", ACC CIETNA: Journal of the School of Nursing, vol 1(2), pp. 14-23, <https://doi.org/10.35383/cietna.v1i2.153>.
- [3] El Peruano. "The Occupational Safety and Health Act", pp 1-13, August 2011.
- [4] F. Joiya, "Obtec detection: yolo vs faster r-ccn", IRJMETS, vol 4, pp. 1-5, September 2022.
- [5] Z. Wang, Y. Wu, L. Yang, A. Thirunavukarasu, C. Evison, and Y. Zhao, "Fast personal protective equipment detection for real construction sites using deep learning approaches", Sensors, vol 21, 3478, May 2021.
- [6] S. Barro, T. Fernandez, H. Perez and C. Escudero. "Real-time personal protective equipment monitoring system", Computer Communications, chapter 36, pp 42-50, January 2012.
- [7] A. Gramoral, "Design of an artificial vision system to determine the quality of mandarins", Lima: UTP, 2020, pp. 219-223.
- [8] L. Machaca, "Recognition of anomalous events in videos obtained from surveillance cameras using convolutional networks", Arequipa: UNSA, 2019, pp. 45-53.
- [9] E. Castillo, "Development of an artificial vision system to perform a uniform classification of lemons", Lima: UPN, 2018, pp 46-52-
- [10] A. A. Protik, A. H. Rafi and S. Siddique, "Real-time personal protective equipment (PPE) detection using YOLOv4 and tensorFlow," 2021 IEEE Region 10 Symposium (TENSYP), Jeju, Korea, Republic of, 2021, pp. 1-6, doi: 10.1109/TENSYP52854.2021.9550808
- [11] M. Jurado and A. Fernandez, "Electronic system for quality control of chicken eggs through image processing", Ambato: UTA, 2018, pp. 52-56.
- [12] A. Aguilar, "Design of a color-based apple sorting system using artificial vision for the company Fresh & Natural C.I.", Quito: UTE, 2017, pp. 40-46.
- [13] MINSA, "Technical Health Standard for the use of Personal Protective Equipment", pp. 15-32, July 2020.
- [14] O. Ezekiel, M. Ekata and A. Eseghe. "A comparative study of YOLOv5 and YOLOv7 object detection algorithms", Journal of Computing and Social Informatics, vol 2(1), pp 1-12, February 2023.
- [15] G. Jocher, "Ultralytics/yolov5: v3.1 - Bug Fixes and Performance Improvements", Github repository, October 2020.
- [16] J. Davis and M. Goadrich, "The relationship between Precision-recall and ROC curves", Proceedings of the 23rd international conference on Machine learning, pp. 233-240, June 2006.

The Use of Fuzzy Linear Regression Modeling to Predict High-risk Symptoms of Lung Cancer in Malaysia

Aliya Syaffa Zakaria¹, Muhammad Ammar Shafi², Mohd Arif Mohd Zim³, Siti Noor Asyikin Mohd Razali⁴

Department of Technology and Management-Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia^{1,2}

Consultant Pulmonologist & Internal Medicine, Damansara Specialist Hospital 2, Jalan Bukit Lanjan 3, Bukit Lanjan, 60000 Kuala Lumpur, Malaysia³

Department of Mathematics and Statistics-Faculty of Applied Science and Technology, Universiti Tun Hussein Onn Malaysia, Pagoh Education Hub, 84600 Pagoh, Johor, Malaysia⁴

Abstract—Lung cancer is the most prevalent cancer in the world, accounting for 12.2% of all newly diagnosed cases in 2020 and has the highest mortality rate due to its late diagnosis and poor symptom detection. Currently, there are 4,319 lung cancer deaths in Malaysia, representing 2.57 percent of all mortality in 2020. The late diagnosis of lung cancer is common, which makes survival more difficult. In Malaysia, however, most cases are detected when the tumors have become too large, or cancer has spread to other body areas that cannot be removed surgically. This is a frequent situation due to the lack of public awareness among Malaysians regarding cancer-related symptoms. Malaysians must be acknowledged the high-risk symptoms of lung cancer to enhance the survival rate and reduce the mortality rate. This study aims to use a fuzzy linear regression model with heights of triangular fuzzy by Tanaka (1982), H -value ranging from 0.0 to 1.0, to predict high-risk symptoms of lung cancer in Malaysia. The secondary data is analyzed using the fuzzy linear regression model by collecting data from patients with lung cancer at Al-Sultan Abdullah Hospital (UiTM Hospital), Selangor. The results found that haemoptysis and chest pain has been proven to be the highest risk, among other symptoms obtained from the data analysis. It has been discovered that the H -value of 0.0 has the least measurement error, with mean square error (MSE) and root mean square error (RMSE) values of 1.455 and 1.206, respectively.

Keywords—Lung cancer; high-risk symptom; fuzzy linear regression; H -value; mean square error

I. INTRODUCTION

Cancer is a disease caused by uncontrolled cell division. Lung cancer develops when cancer originates in the lungs and spreads to lymph nodes or other organs, such as the brain. Moreover, lung cancer may spread from other organs. Lung cancer includes four stages which in Stage I, cancer has not grown to lymph nodes or other parts of the body, whereas in Stage II, the tumors may be bigger and/or have begun to spread to nearby lymph nodes. When cancer has advanced to the lymph nodes of the mediastinum, a diagnosis of stage III can be determined (the chest area between the lungs). In Stage IV, the cancer has spread to the lining of the lungs or to other organs [1].

Lung cancer (small and non-small cell) is the second-leading cause of cancer in both men and women (excluding skin cancer) in 2020 [2]. This kind of cancer is on the rise in several countries, particularly in Asia, where the rate increased from 56 percent in 2012 to 58 percent in 2018 [3]. In the year of 2020, lung cancer is the top cause of cancer-related mortality with 1.80 million deaths, followed by colon and rectum cancer with 935 thousand deaths, and liver cancer with 850,000 deaths. Lung cancer has killed 4,319 lives in Malaysia, or 2.57 percent of all mortality based on the latest WHO data published in 2020. Malaysia ranks 77th in the world with a death rate of 15.25 per 100,000 population [4].

Malaysia continues to have the lowest 5-year lung cancer survival rate. Symptoms of lung cancer are unusually detected at an early stage, and more than half of lung cancer patients pass away within the first year after diagnosis. Currently, the main causes of lung cancer are unknown. Yet, certain risk factors and symptoms enhance the likelihood of a person developing lung cancer. There are also a few patients with lung cancer who exhibited no symptoms or identified risk factors [5]. Common lung cancer symptoms include persistent coughing, breathing difficulties, bloody coughing, and a sudden decrease in weight. All these symptoms may appear within one month after a lung cancer diagnosis [6].

This research presents a study on the prediction of high-risk symptoms of lung cancer in Malaysia using the fuzzy linear regression method. The primary goal of this study is to determine the highest-risk signs and symptoms of patients with early lung cancer detection to enhance the likelihood of diagnosing malignancy early and decrease lung cancer mortality. It is important for Malaysians to be aware and acknowledge the highest risk symptoms of lung cancer for them to get early treatment at early stages to increase the likelihood of survival. As for the proposed method, numerous researchers have utilized fuzzy modeling to investigate cases in various fields, including medicine, science, and engineering. Fuzzy modeling is typically used to evaluate more complex scenarios and is reliable. Since 1965, when Lotfi A. Zadeh devised the fuzzy set theory, numerous studies have utilized the fuzzy method. Fuzzy linear regression in 1982 is

recognized as the basic model for other fuzzy models. The model is conveyed as a dependable method since it does not need any assumptions to ensure the results obtained are applicable to society. Hence, the results will still be accurate even if the data of the sample is small.

The entirety of this article is structured as follows: Part II emphasizes significant studies on current challenges and ways to resolve them, while Section III outlines the research methodologies. Section IV includes the results and Section V presents the discussion. Section VI concludes the paper and proposes future work.

II. LITERATURE REVIEW

A. Lung Cancer in Malaysia

Lung cancer is the primary cause of cancer-related mortality globally and the most common cause of death in Malaysia, with males surpassing females regardless of the tumor's size, location, or dissemination. Lung cancer contributes to around 15.13 percent of cancer deaths [7]. The reported 1-year survival rate is only 35.5 percent however, the relative 5-year survival rate is only 11.0 percent. The survival rate of lung cancer patients in Malaysia at 1 and 5 years is one of the lowest compared to other types of cancer, as shown in Chart A. This survival rate is one of the lowest in the world. The one-year and five-year survival rates are shown per stage in Chart B [8]. Fig. 1 displays Chart A and Chart B.

There are two distinct diagnostic presentations for lung cancer patients: symptomatic and incidental. Most cases were inadvertently diagnosed through chest X-rays and CT scans. According to the Malaysian Health Technology Assessment Section, a CT scan known as low-dose computed tomography (LDCT) is currently used for lung cancer screening and improved lung cancer diagnosis. Unfortunately, it does not apply to lung cancer patients at high risk. Screening high-risk individuals through screening results is critical since it enhances the likelihood of early cancer detection and decreases lung cancer mortality [11].

While among symptomatic patients, the most often reported complaints that resulted in an imaging referral were the development of a new cough or the worsening of a previously expressed clinical picture suggestive of pneumonia and haemoptysis [12]. It has been proven that cough is the symptom that appears most frequently in lung cancer patients based on the results [13] which frequently reported lung cancer symptoms to include shortness of breath, cough, and anxiety. The study [14] also stressed that fever and cough were the most prominent early symptoms, and respiratory symptoms were prevalent among lung cancer patients. Research [15] reported that cough has the highest number which is 62.0% of patients, followed by chest pain (51.8%) was the most prevalent symptom present at the time of diagnosis. Studies [16] and [17] discovered that haemoptysis had the highest diagnostic value for lung cancer.

B. Background of Fuzzy Linear Regression

Regression analysis is a statistical technique used to determine the cause-and-effect relationship between two variables. Regression analysis is a potent method for comprehending (including forecasting and explaining) the causal factors underlying a population outcome [18]. However, regression models are particularly susceptible to outliers. An outlier is a data point that deviates significantly from most other observations. Variability in measurement may result in an experimental error, whereas an outlier in regression analysis may cause a significant issue. Although data are infrequently linearly separable, regression analysis methods also oversimplify real-world data and issues.

Fuzzy linear regression analysis on the other hand is a significant alternative to conventional regression methods based on statistics. In fuzzy linear regression analysis, a wide variety of fuzzy linear models can be used to approximate a linear dependence based on a set of observations. There are two types of fuzzy regression. The researchers in [19] created 'possibilistic' fuzzy regression, a linear programming method that aims to reduce the fuzziness of a system. The second approach is a fuzzy least-squares method that minimizes the distance between two fuzzy numbers. The approaches are designed to handle fuzzy data to satisfy a particular requirement [20].

In a fuzzy environment, a fuzzy regression model is applied to evaluate the functional relationship between the dependent and independent variables. In the literature, numerous fuzzy regression models and methods for estimating the fuzzy parameters of these models have been developed. The possibilistic approach and fuzzy least squares model are the

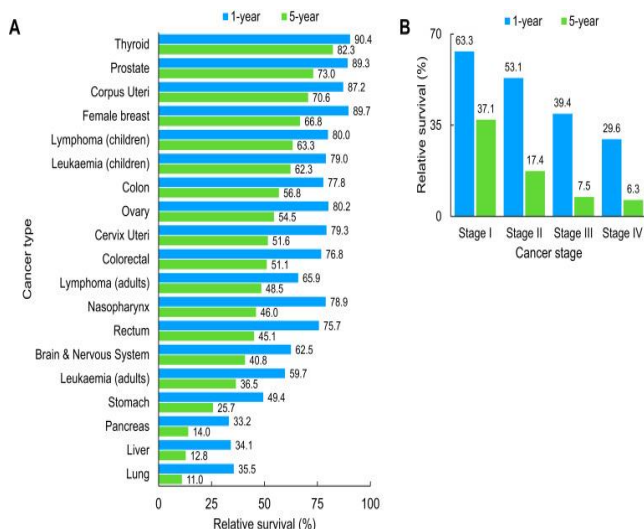


Fig. 1. Relative survival of cancer patients in Malaysia.

In Malaysia, the probability of getting lung cancer is approximately 1 in 60 for males and 1 in 138 for females, with patients often being diagnosed at the age of 70 or older (range 15 to 90 years). Nevertheless, most cases of lung cancer were not discovered until a very late stage, stage III or stage IV, which is above 90 percent for both sexes. Early-stage disease (I, II, and chosen IIIa) is amenable to curative surgery, which offers the best possibility of long-term cure and disease-free survival [9]. However, most patients (about 75 percent) are diagnosed with advanced cancer (stage III/IV). Despite significant advances in late-stage lung cancer oncological treatment in recent years, survival rates remain poor [10].

two most frequent methods for assessing fuzzy regression models [21]. Fuzzy methodology surpasses conventional regression methodology when it is required to predict an outcome variable based on many interrelated factors. Furthermore, it is proved that fuzzy linear regression is more effective relative to simple and multiple linear regression methods [22].

III. METHODOLOGY

Fuzzy sets can be used to account for data inaccuracy and ambiguity. For example, rather than just assigning a binary value to a symptom, such as "present" or "absent," a fuzzy set may be used to represent the degree to which a patient exhibits a specific symptom. This would be preferable to the traditional approach of assigning a binary value [23].

The fuzzy linear regression approach is simpler and more transparent to calculate than classical regression but does not significantly differ from classical regression. Furthermore, these results provide support for the concept of fuzzy linear regression prediction, especially when it comes to fuzzy data [24]. The high-risk symptoms of lung cancer can be detected with greater precision by using the fuzzy linear regression method, which provides a better prediction of imprecise data than regression analysis.

Statistical analysis is adaptable and useful to numerous domains, especially the linear regression technique. Several model elements are represented by fuzzy numbers in fuzzy linear regression, which is a kind of regression analysis. It has been demonstrated that fuzzy linear functions are a good strategy for unclear occurrences in linear regression models [25]. The data were analyzed using the statistical software Matlab and Microsoft Excel.

A. Fuzzy Linear Regression (Tanaka, 1982)

To formulate a fuzzy linear regression model, the following were assumed to hold (Tanaka, 1982):

- (1) The data can be represented by a fuzzy linear model:

$$Y_e^* = A_1^* x_{e1} + \dots + A_g^* x_{eg} \triangleq A^* x_e \quad (1)$$

Where,

Fuzzy parameter A_g

The variable of fuzzy parameter x_e

Equation of the fuzzy parameter Y_e^*

$$\mu_{Y_e^*}(y) = 1 - \frac{|y_e - x_e^T \alpha|}{\sum_f \zeta_f |x_{ef}|} \quad (2)$$

- (2) The degree of the fitting of the estimated fuzzy linear model $Y_e^* = A^* x_e$ to the given data $Y_e = (y_e, \varepsilon_e)$ was measured by the following index h_e , which maximizes h subject to $Y_e^h \subset Y_e^{*h}$, where:

$$Y_e^h = \{y | \mu_{Y_e}(y) \geq h\}$$

$$Y_e^* = \{y | \mu_{Y_e^*}(y) \geq h\} \quad (3)$$

Which are h -level sets. This index h_e is illustrated in Fig. 2. The degree of the fitting of the fuzzy linear model for all

data Y_1, \dots, Y_N is defined by $\min_f [h_f]$. Fig. 2 portrays the fitting degree of Y_e^* to a fuzzy data of Y_e .

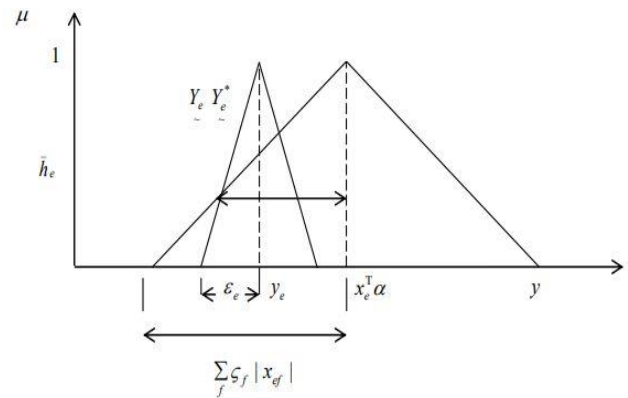


Fig. 2. Degree of fitting of Y_e^* to a given fuzzy data Y_e .

- (3) The vagueness of the fuzzy linear model is defined by:

$$JJ = \zeta_1 + \dots + \zeta_g \quad (4)$$

The problem was elucidated by acquiring fuzzy parameters A^* which minimized JJ subject to $\bar{h}_e \geq H$ for all e , where H was selected by the decision maker as the degree of fit of the fuzzy linear model. The \bar{h}_e can be acquired by utilizing:

$$\bar{h}_e = 1 - \frac{|y_e - x_e^T \alpha|}{\sum_f \zeta_f |x_{ef}| - \varepsilon_e} \quad (5)$$

Tanaka (1982) model estimated the fuzzy parameter $A_e^* = (\alpha_e, \zeta_e)$, which are the solutions of the following linear programming problem:

$$\min_{\alpha, \zeta} = \zeta_1 + \dots + \zeta_g$$

Subject to $\zeta \geq 0$ and

$$\alpha^T x_e + (1 - H) \sum_f \zeta_f |x_{ef}| \geq y_e + (1 - H) \varepsilon_e$$

$$-\alpha^T x_e + (1 - H) \sum_f \zeta_f |x_{ef}| \geq -y_e + (1 - H) \varepsilon_e \quad (6)$$

The best fitting model for the given data may be obtained by solving the conventional linear programming problem in (6). The number of constraints, $2N$, was generally substantially greater than the number of variables, g . As a result, solving the dual problem of (6) was easier than solving the primal problem of (6).

The fuzzy linear regression model (FLRM) can be stated as:

$$Y = A_0(\alpha_0, \zeta_0) + A(\alpha, \zeta) x + \dots + A(\alpha, \zeta) x_g \quad (7)$$

IV. RESULTS

Hideo Tanaka presented a fuzzy approach for linear regression analysis in 1982. There is a fuzzy model in which human estimation and some systems play a role and must deal with a fuzzy structure. Tanaka's fuzzy linear regression was used in the study to estimate the size of lung cancer patients' tumors. In total, 124 patients were used. Gender, ethnic, age,

tumor size, cough, haemoptysis, weight loss, appetite loss, chest pain, comorbidities, smoking habit, and stage of cancer were the most key factors. The data were obtained using Microsoft Excel and MATLAB software. H-values ranging from 0.0 to 1.0 were utilised to calculate the center, a_i , and width, c_i , of each fuzzy parameter. a_i is the center of a fuzzy parameter, while c_i represents the parameter's fuzziness (width). The results of this H-value are shown in the Tables I.

TABLE I. FUZZY PARAMETER OF $H=0.0$

Variables	Fuzzy Parameter	
	Center a_i	Width c_i
Age	0.3332	0.6097
Ethic	3.3148	0
Cough (A_1^*)	2.3085	0
Haemoptysis (A_2^*)	14.5494	0
Weight loss (A_3^*)	5.3752	0
Appetite loss (A_4^*)	-6.6669	0
Chest pain (A_5^*)	10.6765	0
Smoking habit (A_6^*)	-0.0589	0
Comorbidity (A_7^*)	-4.8611	0

Table I displays the centre, a_i , and width, c_i values for the fuzzy parameters when $H = 0.0$. The values of the fuzzy parameter are displayed in Table I; the data was conducted using Matlab code and eleven variables were included. The dependent variable is the size of the tumor, and nine independent variables, lung cancer symptoms. The fuzzy mean tumor size (mm) can be represented by haemoptysis with a fuzzy parameter value of 14.5494. The second highest fuzzy parameter was chest pain equal to 10.6765. The fuzziness of the nine variables reflects the uncertainty of tumor size in millimeters. By this fuzziness parameter, the dispersion can be explained. In this context, the fuzziness of the parameter is $J = 0.6097$. In addition, the negative nature of A_4^* , A_6^* , and A_7^* is dependent upon the strong correlations between x_4 , x_6 , and x_7 . The tumor size of lung cancer (mm) is inversely proportional to appetite loss, smoking, and comorbidity.

The following is the estimated fuzzy linear regression model for lung cancer patients.

$$\hat{Y} = 0.6097 + (0.3332, 0.6097) \text{ age} + (3.3148, 0) \text{ ethnic} + (2.3085, 0) \text{ cough} + (14.5494, 0) \text{ haemoptysis} + (5.3752, 0) \text{ weight loss} - (6.6669, 0) \text{ loss of appetite} + (10.6765, 0) \text{ chest pain} - (0.0589, 0) \text{ smoking} - (4.8611, 0) \text{ comorbidity. (8)}$$

TABLE II. FUZZY PARAMETER OF $H=0.1$

Variables	Fuzzy Parameter	
	Center a_i	Width c_i
Age	0.3336	0.6719
Ethic	3.1988	0
Cough (A_1^*)	2.5589	0

Variables	Fuzzy Parameter	
	Center a_i	Width c_i
Haemoptysis (A_2^*)	14.5031	0
Weight loss (A_3^*)	5.1294	0
Appetite loss (A_4^*)	-6.3314	0
Chest pain (A_5^*)	10.4874	0
Smoking habit (A_6^*)	-0.0555	0
Comorbidity (A_7^*)	-4.7618	0

The following is the estimated fuzzy linear regression model for lung cancer patients:

$$\hat{Y} = 0.6719 + (0.3336, 0.6719) \text{ age} + (3.1988, 0) \text{ ethnic} + (2.5589, 0) \text{ cough} + (14.5031, 0) \text{ haemoptysis} + (5.1294, 0) \text{ weight loss} - (6.3314, 0) \text{ loss of appetite} + (10.4874, 0) \text{ chest pain} - (0.0555, 0) \text{ smoking} - (4.7618, 0) \text{ comorbidity. (9)}$$

TABLE III. FUZZY PARAMETER OF $H=0.2$

Variables	Fuzzy Parameter	
	Center a_i	Width c_i
Age	0.3340	0.7498
Ethic	3.0827	0
Cough (A_1^*)	2.8094	0
Haemoptysis (A_2^*)	14.4567	0
Weight loss (A_3^*)	2.5344	0
Appetite loss (A_4^*)	-3.6466	0
Chest pain (A_5^*)	10.2983	0
Smoking habit (A_6^*)	-0.0521	0
Comorbidity (A_7^*)	-4.7618	0

The following is the estimated fuzzy linear regression model for lung cancer patients:

$$\hat{Y} = 0.7498 + (0.3340, 0.7498) \text{ age} + (3.0827, 0) \text{ ethnic} + (2.8094, 0) \text{ cough} + (14.4567, 0) \text{ haemoptysis} + (2.5344, 0) \text{ weight loss} - (3.6466, 0) \text{ loss of appetite} + (10.2983, 0) \text{ chest pain} - (0.0521, 0) \text{ smoking} - (4.6624, 0) \text{ comorbidity. (10)}$$

TABLE IV. FUZZY PARAMETER OF $H=0.3$

Variables	Fuzzy Parameter	
	Center a_i	Width c_i
Age	0.3344	0.8498
Ethic	2.9667	0
Cough (A_1^*)	3.0599	0
Haemoptysis (A_2^*)	14.4104	0
Weight loss (A_3^*)	4.6379	0
Appetite loss (A_4^*)	-5.6603	0

Variables	Fuzzy Parameter	
	Center a_i	Width c_i
Chest pain (A_5^*)	10.1093	0
Smoking habit (A_6^*)	-0.0487	0
Comorbidity (A_7^*)	-4.5630	0

The following is the estimated fuzzy linear regression model for lung cancer patients:

$$\hat{Y} = 0.8498 + (0.3344, 0.8498) \text{ age} + (2.9667, 0) \text{ ethnic} + (3.0599, 0) \text{ cough} + (14.4104, 0) \text{ haemoptysis} + (4.6379, 0) \text{ weight loss} - (5.6603, 0) \text{ loss of appetite} + (10.1093, 0) \text{ chest pain} - (0.0487, 0) \text{ smoking} - (4.5630, 0) \text{ comorbidity}. \quad (11)$$

TABLE V. FUZZY PARAMETER OF $H=0.4$

Variables	Fuzzy Parameter	
	Center a_i	Width c_i
Age	0.3348	0.9833
Ethic	2.8506	0
Cough (A_1^*)	3.3103	0
Haemoptysis (A_2^*)	14.3640	0
Weight loss (A_3^*)	4.3922	0
Appetite loss (A_4^*)	-5.3248	0
Chest pain (A_5^*)	9.9202	0
Smoking habit (A_6^*)	-0.0453	0
Comorbidity (A_7^*)	-4.4636	0

The following is the estimated fuzzy linear regression model for lung cancer patients:

$$\hat{Y} = 0.9833 + (0.3348, 0.9833) \text{ age} + (2.8506, 0) \text{ ethnic} + (3.3103, 0) \text{ cough} + (14.3640, 0) \text{ haemoptysis} + (4.3922, 0) \text{ weight loss} - (5.3248, 0) \text{ loss of appetite} + (9.9202, 0) \text{ chest pain} - (0.0453, 0) \text{ smoking} - (4.4636, 0) \text{ comorbidity}. \quad (12)$$

TABLE VI. FUZZY PARAMETER OF $H=0.5$

Variables	Fuzzy Parameter	
	Center a_i	Width c_i
Age	0.3317	1.1718
Ethic	2.7910	0
Cough (A_1^*)	3.4661	0
Haemoptysis (A_2^*)	14.3992	0
Weight loss (A_3^*)	2.3009	0
Appetite loss (A_4^*)	-3.1698	0
Chest pain (A_5^*)	9.8490	0
Smoking habit (A_6^*)	-0.0424	0
Comorbidity (A_7^*)	-4.3946	0

The following is the estimated fuzzy linear regression model for lung cancer patients:

$$\hat{Y} = 1.1718 + (0.3317, 1.1718) \text{ age} + (2.7910, 0) \text{ ethnic} + (3.4661, 0) \text{ cough} + (14.3992, 0) \text{ haemoptysis} + (2.3009, 0) \text{ weight loss} - (3.1698, 0) \text{ loss of appetite} + (9.8490, 0) \text{ chest pain} - (0.0424, 0) \text{ smoking} - (4.3946, 0) \text{ comorbidity}. \quad (13)$$

TABLE VII. FUZZY PARAMETER OF $H=0.6$

Variables	Fuzzy Parameter	
	Center a_i	Width c_i
Age	0.3278	1.4551
Ethic	2.7459	0
Cough (A_1^*)	3.5973	0
Haemoptysis (A_2^*)	14.4555	0
Weight loss (A_3^*)	2.1314	0
Appetite loss (A_4^*)	-2.9434	0
Chest pain (A_5^*)	9.8084	0
Smoking habit (A_6^*)	-0.0397	0
Comorbidity (A_7^*)	-4.3334	0

The following is the estimated fuzzy linear regression model for lung cancer patients:

$$\hat{Y} = 1.4551 + (0.3278, 1.4551) \text{ age} + (2.7459, 0) \text{ ethnic} + (3.5973, 0) \text{ cough} + (14.4555, 0) \text{ haemoptysis} + (2.1314, 0) \text{ weight loss} - (2.9434, 0) \text{ loss of appetite} + (9.8084, 0) \text{ chest pain} - (0.0397, 0) \text{ smoking} - (4.3334, 0) \text{ comorbidity}. \quad (14)$$

TABLE VIII. FUZZY PARAMETER OF $H=0.7$

Variables	Fuzzy Parameter	
	Center a_i	Width c_i
Age	0.3238	1.9273
Ethic	2.7009	0
Cough (A_1^*)	3.7285	0
Haemoptysis (A_2^*)	14.5119	0
Weight loss (A_3^*)	1.9619	0
Appetite loss (A_4^*)	-2.7169	0
Chest pain (A_5^*)	9.7678	0
Smoking habit (A_6^*)	-0.0370	0
Comorbidity (A_7^*)	-4.2723	0

The following is the estimated fuzzy linear regression model for lung cancer patients:

$$\hat{Y} = 1.9273 + (0.3238, 1.9273) \text{ age} + (2.7009, 0) \text{ ethnic} + (3.7285, 0) \text{ cough} + (14.5119, 0) \text{ haemoptysis} + (1.9619, 0) \text{ weight loss} - (2.7169, 0) \text{ loss of appetite} + (9.7678, 0) \text{ chest pain} - (0.0370, 0) \text{ smoking} - (4.2723, 0) \text{ comorbidity}. \quad (15)$$

TABLE IX. FUZZY PARAMETER OF $H=0.8$

Variables	Fuzzy Parameter	
	Center a_i	Width c_i
Age	0.3198	2.8718
Ethic	2.6559	0
Cough (A_1^*)	3.8598	0
Haemoptysis (A_2^*)	14.5682	0
Weight loss (A_3^*)	4.1194	0
Appetite loss (A_4^*)	-4.8174	0
Chest pain (A_5^*)	9.7272	0
Smoking habit (A_6^*)	-0.0315	0
Comorbidity (A_7^*)	-4.2111	0

The following is the estimated fuzzy linear regression model for lung cancer patients:

$$\hat{Y} = 2.8718 + (0.3198, 2.8718) \text{ age} + (2.6559, 0) \text{ ethnic} + (3.8598, 0) \text{ cough} + (14.5682, 0) \text{ haemoptysis} + (4.1194, 0) \text{ weight loss} - (4.8174, 0) \text{ loss of appetite} + (9.7272, 0) \text{ chest pain} - (0.0315, 0) \text{ smoking} - (4.2111, 0) \text{ comorbidity}. \quad (16)$$

TABLE X. FUZZY PARAMETER OF $H=0.9$

Variables	Fuzzy Parameter	
	Center a_i	Width c_i
Age	0.3158	5.7051
Ethic	2.6109	0
Cough (A_1^*)	3.9910	0
Haemoptysis (A_2^*)	14.6245	0
Weight loss (A_3^*)	4.0609	0
Appetite loss (A_4^*)	-4.7019	0
Chest pain (A_5^*)	9.6866	0
Smoking habit (A_6^*)	-0.0315	0
Comorbidity (A_7^*)	-4.1500	0

The following is the estimated fuzzy linear regression model for lung cancer patients:

$$\hat{Y} = 5.7051 + (0.3158, 5.7051) \text{ age} + (2.6109, 0) \text{ ethnic} + (3.9910, 0) \text{ cough} + (14.6245, 0) \text{ haemoptysis} + (4.0609, 0) \text{ weight loss} - (4.7019, 0) \text{ loss of appetite} + (9.6866, 0) \text{ chest pain} - (0.0315, 0) \text{ smoking} - (4.1500, 0) \text{ comorbidity}. \quad (17)$$

TABLE XI. FUZZY PARAMETER OF $H=1.0$

Variables	Fuzzy Parameter	
	Center a_i	Width c_i
Age	0.3128	5.9810
Ethic	2.5509	0
Cough (A_1^*)	4.1223	0

Variables	Fuzzy Parameter	
	Center a_i	Width c_i
Haemoptysis (A_2^*)	14.6450	0
Weight loss (A_3^*)	4.0024	0
Appetite loss (A_4^*)	-4.6237	0
Chest pain (A_5^*)	9.6400	0
Smoking habit (A_6^*)	-0.0315	0
Comorbidity (A_7^*)	-4.1034	0

Table II to Table XI show the centre, a_i , and width, c_i values for the fuzzy parameters when $H = 0.1$ until $H = 1.0$. The following is the estimated fuzzy linear regression model for lung cancer patients:

$$\hat{Y} = 5.9810 + (0.3128, 5.9810) \text{ age} + (2.5509, 0) \text{ ethnic} + (4.1223, 0) \text{ cough} + (14.6450, 0) \text{ haemoptysis} + (4.0024, 0) \text{ weight loss} - (4.6237, 0) \text{ loss of appetite} + (9.6400, 0) \text{ chest pain} - (0.0315, 0) \text{ smoking} - (4.1034, 0) \text{ comorbidity}. \quad (18)$$

1) *Measuring mean square error (MSE)*: Table XII displays the mean square error (MSE) values for those H-values. The observed Y is determined by the responses of 124 patients with lung cancer. The H-value with the smallest MSE is 0.0. Since the MSE value of the H-value of 0.0 is the lowest when compared to other values, it has been concluded that this model is the most suited and effective model for predicting the high-risk symptoms of lung cancer.

TABLE XII. MEAN SQUARE ERROR VALUES

MSE Values	
H-values	Mean Square Error
0.0	1.455
0.1	1.467
0.2	1.481
0.3	1.497
0.4	1.517
0.5	1.549
0.6	1.592
0.7	1.657
0.8	1.774
0.9	2.101
1.0	2.138

2) *Measuring root mean square error (RMSE)*: Table XIII shows the root mean square error, which is computed by calculating the square root of the total mean square error to achieve the least error value. The models were tested using mean square error. H-values of 0.0 and 1.0 have RMSE values of 1.206 and 1.462, respectively. The fuzzy linear regression model with H-value of 0.0 proves to be the most precise model

for predicting the high-risk symptoms reported by lung cancer patients at Hospital Al-Sultan Abdullah (UiTM Hospital), given that its RMSE is the lowest among the other models.

TABLE XIII. ROOT MEAN SQUARE ERROR VALUES

RMSE Values	
H-values	Root mean square error
0.0	1.206
0.1	1.211
0.2	1.217
0.3	1.224
0.4	1.232
0.5	1.244
0.6	1.262
0.7	1.287
0.8	1.332
0.9	1.450
1.0	1.462

V. DISCUSSION

Fuzzy linear regression with an H-value of 0.0 is the best model for predicting high-risk lung cancer symptoms in patients at Al-Sultan Abdullah Hospital (UiTM Hospital). Fuzzy linear regression with an H-value of 0.0 has lowest mean square error (MSE) and root mean square error (RMSE) values compared to other H-values. H-value of 0.0 produced MSE and RMSE values of 1.455 and 1.206, while an H-value of 1.0 yielded MSE and RMSE values of 1.784 and 1.336, respectively. The optimal model has been proved to be the fuzzy linear regression of H-value with 0.0 as it has the smallest measurement error. The summary values of MSE and RMSE are displayed in Table XIV.

TABLE XIV. MSE AND RMSE VALUES OF THE MODELS

Summary of MSE and RMSE Values		
H-values	MSE	RMSE
0.0	1.455	1.206
0.1	1.467	1.211
0.2	1.481	1.217
0.3	1.497	1.224
0.4	1.517	1.232
0.5	1.549	1.244
0.6	1.592	1.262
0.7	1.657	1.287
0.8	1.774	1.332
0.9	2.101	1.450
1.0	2.138	1.462

The best parameter for fuzzy linear regression was discovered using the values of mean square error and root mean square error. This study found that haemoptysis was the most impactful symptom in diagnosing lung cancer high-risk symptoms, as it has the highest fuzzy mean parameter in the model with an H-value of 0.0 and a value of 14.5494, as shown in Table I. The findings similar to the [26] stated that individuals diagnosed with lung cancer showed a significantly greater prevalence of persistent haemoptysis. [27] and [28] also emphasized that haemoptysis is the most prevalent cause of lung cancer across all age groups. Chest pain is the second highest risk symptom of lung cancer as it has the value of fuzzy mean parameter of 10.6765 based on Table I. The results are also akin to the study by [29] found that the frequency of haemoptysis, cough, and chest pain was significantly higher than in other samples in all stages. According to [30] chest pain was the top five major complaints when it comes to lung cancer symptoms. Age, ethnicity, cough and weight loss are the other variables that are closely related to the high-risk symptoms of lung cancer as it has positive values of fuzzy mean parameter. In addition, the high-risk symptoms of lung cancer are inversely proportional to the female gender, Chinese ethnicity and other ethnicities, appetite loss, smoking habit, and the presence of other diseases (comorbidity) as it has negative values of fuzzy mean parameters. The lowest mean square error is 1.455, and the least root mean square error is 1.206.

The purpose of this study was to predict the high-risk symptoms of lung cancer in the early stage to initiate preventative measures for lung cancer patients. It was determined that haemoptysis and chest pain are high-risk symptoms for lung cancer patients at Hospital Al-Sultan Abdullah (UiTM Hospital). However, most of the patient data collected from Al-Sultan Abdullah hospital (UiTM Hospital) was from patients with advanced lung cancer (stages 3 and 4). It is difficult to detect symptoms for the earlier stage of lung cancer due to the tumor size in stages I and II is smaller in size since the small tumors convey less texture and shape information than those larger tumors in late stages [31]. It is stated that the bigger the diameter of the tumor size, the more advanced the stage of lung cancer, and the symptoms of lung cancer will begin to appear one by one such as haemoptysis and chest pain. Even though the symptoms are recognized at a late stage, the doctors or patients can still take the initiative or precautions at earlier stages for more particular symptoms as revealed by the results rather than any random symptoms.

VI. CONCLUSION

The aim of this study was to determine high-risk lung cancer symptoms in order to initiate preventative actions. It was concluded that haemoptysis and chest pain are high-risk symptoms for lung cancer patients at Hospital Al-Sultan Abdullah (UiTM Hospital). Both high-risk symptoms can be presented to medical doctors and nurses at the UiTM Hospital so that they can apply them to patients at an early stage. Extreme weight loss, loss of appetite, and comorbidity are the further lung cancer symptoms. Fuzzy linear regression with H-value of 0.0 is the best model for predicting the high-risk symptoms of lung cancer in patients at Hospital Al-Sultan Abdullah (UiTM Hospital) as it has the least measurement

error, with mean square error (MSE) and root mean square error (RMSE) values of 1.45 and 1.206, respectively.

In future studies, other researchers should resolve the issue of determining the stages of lung cancer among patients at Selangor's general hospitals. The study should be expanded to include other public hospitals in each state of Malaysia. In that scenario, the lung cancer study may be thoroughly explored in Malaysia and other countries.

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REFERENCES

- [1] American Lung Association. "Lung cancer staging", 2022.
- [2] American Cancer Society, "Information and Resources about for Cancer: Breast, Colon, Lung, Prostate, Skin", 2023.
- [3] R. Pakzad, A. Mohammadian-Hafshejani, M. Ghoncheh, I. Pakzad, and H. Salehiniya, "The incidence and mortality of lung cancer and their relationship to development in Asia," *Translational lung cancer research*, 4(6), 763–774, 2015.
- [4] World Health Organization, Malaysia Sources: Globocan 2020, International Agency for Research of Cancer, 1-2, 2020.
- [5] M. Mustafa, AR. J. Azizi, A. Nazirah, A. M. Sharifa, and S. A. Abbas, "Lung Cancer: Risk Factors, Management, And Prognosis," *IOSR Journal of Dental and Medical Sciences*, Vol. 15, No.10, p. 94-101, 2016.
- [6] R. Gasparri, M. Santonico, C. Valentini, and G. Sedda. (2016). "Volatile signature for the early diagnosis of lung cancer," *Journal of Breath Research*, p. 1-7.
- [7] J. C. Alcantud, G. Varela, B. S. Buitrago, G. S. Garcia, and M. F. Jimenez, "Analysis of survival for lung cancer resections cases with Fuzzy and soft set theory in surgical decision making" *PLoS ONE*, Vol. 14, No. 6, p.1–17, 2019.
- [8] National Cancer Institute, Malaysia National Cancer Registry Report (MNCR) 2012-2016, p. 100, 2019. [Putrajaya: Ministry of Health Malaysia].
- [9] A. Sachithanandan, and B. Badmanaban, "Screening for Lung cancer in Malaysia: Are we there yet?," *Medical Journal of Malaysia*, Vol. 67 No. 1, p. 3–6, 2012.
- [10] S. Blandin Knight, P. Crosbie, H. Balata, J. Chudziak, T. Hussell, and C. Dive, "Progress and prospects of early detection in lung cancer," *Open Biology*, Vol. 7 No. 9, 170070, 2017.
- [11] M. Wille, A. Dirksen, H. Ashraf, Z. Saghir, K. Bach, and J. Brodersen, "Results of the Randomized Danish Lung Cancer Screening Trial with Focus on High-Risk Profiling," *American Journal Of Respiratory And Critical Care Medicine*, 2016.
- [12] S. Quadrelli., G. Lyons, H. Colt, D. Chimondeguy, and A. Buero, "Clinical Characteristics and Prognosis of Incidentally Detected Lung Cancers," *International Journal Of Surgical Oncology*, 2015.
- [13] M.S. Whisenant, L.A. Williams, A.G. Gonzalez, and T. Mendoza, "What Do Patients With Non – Small-Cell Lung Cancer Experience??" Content Domain for the MD Anderson Symptom Inventory for Lung Cancer What Do Patients With Non-Small-Cell Lung Cancer Experience? Vol. 16 No.10, 2022.
- [14] L. Nie, K. Dai, J. Wu, X. Zhou., J. Hu, C. Zhang, Y. Zhan, Y. Song, W. Fan, Z. Hu, H. Yang, Q. Yang, D. Wu, F. Li, D. Li, and R. Nie, "Clinical characteristics and risk factors for in-hospital mortality of lung cancer patients with COVID-19: A multicenter, retrospective, cohort study," *Thoracic Cancer*, Vol.12 No.1, p.57–65, 2021.
- [15] Galvez, M., Rossana, N., Joseph, R., Katia, A. P., Raul, R., & Luis, M, "Lung Cancer in the Young," 2019.
- [16] Garg, A., Jain, V. K., Mishra, M., Maan, L., Jain, G., & Bhardwaj, G. "To study the Prevalence and Pattern of Haemoptysis in Histopathologically proven cases of Lung cancer and its relation with various Histopathological types of malignancy," Vol 18, No.6, p.39-41, 2019.
- [17] Okoli, G. N., Kostopoulou, O., & Delaney, B. C. "Is symptom-based diagnosis of lung cancer possible? A systematic review and meta-analysis of symptomatic lung cancer prior to diagnosis for comparison with real-time data from routine general practice," *PLOS ONE*, Vol.13, No.11, p.1-17, 2018.
- [18] Jihye, J. "The Strengths and Limitations of the Statistical Modeling of Complex Social Phenomenon: Focusing on SEM, Path Analysis, or Multiple Regression Models," *International Journal Of Economics And Management Engineering*, Vol.9, No.5, p.9,2021.
- [19] Tanaka, H., Uejima, S. and Asai, K. "Linear Regression Analysis with Fuzzy Model," *IEEE Transactions On Systems, Man and Cybernetics*, SMC-12, p.903-907, 1982.
- [20] Khan, U., & Valeo, C. "A new fuzzy linear regression approach for dissolved oxygen prediction," *Hydrological Sciences Journal*, Vol.60, No.6, p.1096-1119, 2015.
- [21] Denoda, L., Casas Cardoso, G., Luis Morales Martínez, J., González Rodríguez, E., & Rodríguez Corvea, L. "Fuzzy linear regression models: a medical application," 2014.
- [22] Pandit, P., Dey, P., & Krishnamurthy, K. N. "Comparative Assessment of Multiple Linear Regression and Fuzzy Linear Regression Models," *SN Computer Science*, Vol.2, No.2, p.1–8, 2021.
- [23] Thomas, L. L., Goni, I., & Emeje, G. D. "Fuzzy Models Applied to Medical Diagnosis: A Systematic Review," *Advances in Networks*, Vol.7, No.2, p.45–50, 2019.
- [24] Al-Sabri, E. H. "The fuzzy linear regression," *Asia Pacific Journal of Mathematics*, Vol.7, No.7, 2020.
- [25] Munawar, Z., Ahmad, F., Awadh Alanazi, S., Nisar, K. S., Khalid, M., Anwar, M., & Murtaza, K. "Predicting the prevalence of lung cancer using feature transformation techniques," *Egyptian Informatics Journal*, Vol. 23, No. 4, p.109-120, 2022.
- [26] Arooj, P., Bredin, E., Henry, M. T., Khan, K. A., Plant, B. J., Murphy, D. M., & Kennedy, M. P. "Bronchoscopy in the investigation of outpatients with hemoptysis at a lung cancer clinic," *Respiratory Medicine*, Vol.139, p.1–5, 2018.
- [27] Lasake, I. B., Idayu, R., Mat, B., Binti, N., & Marzuki, M. "Recurrent Haemoptysis in Non-Small Cell Lung Cancer Patient," Vol.2, No.1, p.18–19, 2020.
- [28] Bankar, A., Padamwar, K., & Jahagirdar, A. "Symptom analysis using a machine learning approach for early stage lung cancer," *Proceedings of the 3rd International Conference on Intelligent Sustainable Systems*, ICISS 2020, p.246–250, 2020.
- [29] Ruano-Raviña, A., Provencio, M., Calvo De Juan, V., Carcereny, E., Moran, T., Rodriguez-Abreu, D., López-Castro, R., Cuadrado Albite, E., Guirado, M., Gómez González, L., Massutí, B., Ortega Granados, A. L., Blasco, A., Cobo, M., Garcia-Campelo, R., Bosch, J., Trigo, J., Juan, Ó., Aguado De La Rosa, C., Cerezo, S. "Lung cancer symptoms at diagnosis: Results of a nationwide registry study," *ESMO Open*, Vol.5, No.6, p.1–7, 2020.
- [30] Feng, Y., Dai, W., Wang, Y., Liao, J., Wei, X., Xie, S., Xu, W., Li, Q., Liu, F., & Shi, Q. "Comparison of chief complaints and patient-reported symptoms of treatment-naive lung cancer patients before surgery," *Patient Preference and Adherence*, Vol.15, p.1101–1106, 2021.
- [31] Chaddad, A., Desrosiers, C., Toews, M., & Abdulkarim, B. "Predicting survival time of lung cancer patients using radiomic analysis," *Oncotarget*, Vol.8, No.61, p.104393-104407, 2017.

Two Phase Detection Process to Mitigate LRDDoS Attack in Cloud Computing Environment

Amrutha Muralidharan Nair¹, Dr. R Santhosh²

Research Scholar, Department of Computer Science Engineering, Karpagam Academy of Higher Education, Coimbatore, India¹

Professor, Department of Computer Science Engineering, Karpagam Academy of Higher Education, Coimbatore, India²

Abstract—Distributed Denial of Service (DDoS) is a major attack carried out by attackers leveraging critical cloud computing technologies. DDoS attacks are carried out by flooding the victim servers with a massive volume of malicious traffic over a short period. Because of the enormous amount of malicious traffic, such assaults are easily detected. As a result, DDoS operations are increasingly appealing to attackers due to their stealth and low traffic rates. DDoS assaults with low traffic rates are also difficult to detect. In recent years, there has been a lot of focus on defense against low-rate DDoS attacks. This paper presents a two-phase detection technique for mitigating and reducing LRDDoS threats in a cloud environment. The proposed model includes two phases: one for calculating predicted packet size and entropy, and another for calculating the covariance vector. In this model, each cloud user accesses the cloud using the virtual machine, which has a unique session ID. This model identifies all LRDDoS assaults that take place by using different protocols (TCP, UDP, ICMP). The experiment's findings demonstrate, how the suggested data packet size, IP address, and flow behavior is used to identify attacks and prevent hostile users from using cloud services. The VM instances used by different users are controlled by this dynamic mitigation mechanism, which also upholds the cloud service quality. The results of the experiments reveal that the suggested method identifies LRDDoS attacks with excellent accuracy and scalability.

Keywords—LRDDoS attack; distance deviation; covariance vector; threshold

I. INTRODUCTION

As next-generation Internet technologies are devised and developed, distributed denial of service (DDoS) attacks on the internet have become exceedingly dangerous. The traditional technique of executing DDoS attack is to flood the network with a high number of packets, straining the server's bandwidth, computational power, memory and delaying legitimate users' access to resources. In 2001, Asta networks observed a new sort of assault on the internet backbone: a denial-of-service attack. Kuzmanovic and Knightly discussed the idea at the SIG conference in 2003 [1]. They assumed the attacks were conventional DoS attacks, which may significantly limit and restrict network traffic. Furthermore, the attacks are called "Shrew Attacks" because they cannot be detected by the methodologies. The attacks were known as Low Rate Distributed Denial of Service (LRDDoS) attacks by other researchers. [2]. Unlike classic assaults, LRDDoS attacks send intermittent high-volume queries and use weakness in the network protocol [3] to actively minimize resource requirements for normal users. The attacks have a substantial impact on network performance.

An average attack traffic, on the other hand, is quite minimal due to the short duration of each assault burst, which is remarkably comparable to the burst traffic generated by many conventional application services. LRDDoS attacks are difficult to identify and mitigate because of their stealth and destructiveness. If the device requires new functionalities, the new protocols or regulations must be redesigned. As a result, existing network detection mechanisms for LRDDoS assaults are often down.

DDoS assaults are classified by the network into two sorts based on their behaviour: "Low Rate DDoS" and "High Rate DDoS" (LRDDoS & HRDDoS attacks) [4][17]. The HRDDoS attack's goal is to block legitimate users from accessing services. These attacks are carried out by transferring a large volume of traffic in order to take advantage of network capacity. The fundamental weakness of the HRDDoS assault is its traffic characteristics, which is why the attackers prefer the LRDDoS approach [5]. LRDDoS attacks are difficult to detect since the assault traffic resembles normal traffic.

Instead of depleting network bandwidth and resources throughput, an LRDDoS attack targets protocol stack flaws. The attacker emits malicious packets at a low rate, because of which the security systems built on network-level are not able to detect the characteristics of the attack. The attacker's goal is basically degrading the "Quality-of-Service (QoS)" being experienced by a legal end user rather than disrupting the network services delivered to them. Many approaches to detecting DDoS attacks have been developed, including the Anomaly Detection System (ADS). However, LRDDoS attacks involve regular behavior as normal traffic deliberately, as a result of which, it is difficult to identify.

The goal of an LRDDoS attack is to continuously drain resources and bandwidth [4]. This form of assault generates adequate traffic in the network. Fig. 1 depicts the LRDDoS assault scenario. The network time duration (Δt), burst rate (br) and burst width (bw) are used to describe these assaults. LRDDoS attacks operate differently than traditional DDoS attacks. Since TCP vulnerabilities are the main targets of LRDDoS attacks, it can be difficult and complex to identify these attacks.

LRDDoS attacks differ significantly from traditional kinds of assault detected via anomaly detection techniques. This attack makes use of TCP congestion by transmitting malicious traffic in small bursts over a short period of time, known as a pulsing assault, or by sending packets at a steady pace, known as a constant attack. On average, present LRDDoS detection

algorithms can identify just a small percentage of attack packets. Because the difference between regular traffic and LRDDoS traffic is so small, it is extremely difficult to recognize and discriminate.

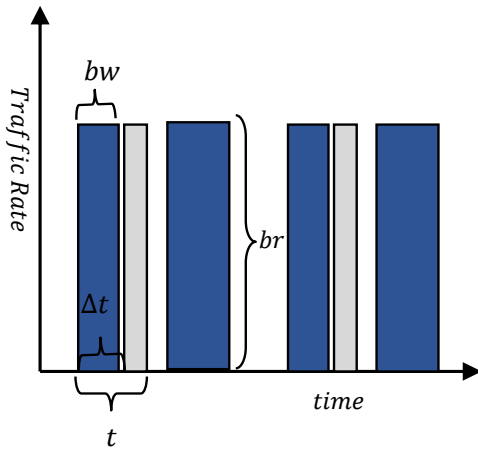


Fig. 1. LRDDoS attack traffic variations.

The present cloud security solutions are non-adaptive and insufficient for detecting LRDDoS attacks. To address this issue, a two-phase detection approach is used to distinguish between legitimate and malicious communication in the cloud computing environment. The suggested approach is independent of the assault pattern. It may achieve a significant distance barrier, leading to a low false positive rate.

The following is the contribution:

Examine the difference in packet size distribution between legitimate and malicious assaults.

A system that incorporates quick access to cloud services is recommended.

The suggested approach adapts to both internal and external network traffic, allowing for the detection of the attack and the reduction of LRDDoS recurrence in the future.

II. RELATED WORK

Wang et al. [6] introduced METER, an “enseMble discrEte wavelet Transform-based technique for detecting low-frequency DDoS assaults in SDN”. This model assists in identifying the assault by computing the wavelet coefficients matrix and the associated entropy. Yu et al. [7], devised a methodology to identify DDoS attack using dynamic resource allocation approach and queueing theory. Xiang et al. [8] used information metrics such as generalized entropy and information distance to network traffic-based algorithms to detect low-rate DDoS attacks.

A mathematical model for recognizing low-rate DDoS assaults was developed by Luo et al. [9] based on the congestion characteristics of victim TCPs. Wu et al. [10] also developed a mathematical model that combines the MF-DFA algorithm with the holder exponent to distinguish between malicious and non-malicious traffic in a low-rate DDoS assault.

Takahashi et al. [11] developed a method for detecting a shrew DDoS assault that has already been initiated in a home network setting employing a bottleneck connection with unknown bandwidth and buffer capacity. The proposed attack detection method reduces downstream traffic from targeting network to keep the quality, while keeping the attack traffic covert by increasing the pulse rate exploratorily and measure the attack effect by deploying bot nodes in the home network.

By monitoring the pace at which flow table rules are applied, Dhawan et al. [12] suggested a technique for identifying DoS assaults. The network is alerted that it may be attacked when the rate of flow rule installation rises over a certain threshold, and the defensive mechanism is then turned on.

H. Chen et al. [13] offer a hybrid approach for detecting LDoS attacks that incorporates trust evaluation with the Hilbert-Huang Transformation. An intrinsic mode function (IMF) is implemented using a hybrid method which includes the correlation and Kolmogorov-Smirnov values, and if these values are more than 0.4 and 0.3, respectively, and the static point shows a higher degree of confidence in the network, it will help in detecting LDoS assaults.

Kieu et al. [14] suggested a technique for detecting LDDoS attacks by estimating TCP throughput and using the TCP congestion window. Wu et al. [15] identify and filter out DDoS traffic using temporal frequency analysis. The filtering technique is developed as a system in the real world.

Florea et al. [16] advocated adopting a unified detection architecture to overcome the challenge of detection against low-rate DDoS attacks.

III. SYSTEM MODELING AND ASSUMPTIONS

The proposed model is a dynamic mitigation strategy for detecting LRDDoS attacks and optimizing QoS while working with constrained system resources. Both lawful packets and attack packets supplied by the legitimate user and the attacker may be easily sent to the current network detection system since the internet was created for openness and best effort transmission. In the event of an LRDDoS assault, when compared to lawful traffic, the attack packet shows several odd properties, such as the quantity of traffic flows and packets with unusual distributions or statistics [18]. LRDDoS packets have higher features than legitimate traffic since they are purposefully manufactured by prebuilt programme. As a result, the packet size in each request may be used to measure the distribution difference between regular traffic and malicious traffic [18]. While considering an LRDDoS attack, each and every packet transferred to the network is regarded a lawful request packet since all of the header information is acceptable. This helps the attacker to purposefully aggregate the packets and attack the victim’s server which leads to the display of abnormal deviations in its network [5].

The technique focuses on the differences between the distribution of packet sizes and between legitimate and attack packets. This measured difference allows for the identification of the traffic.

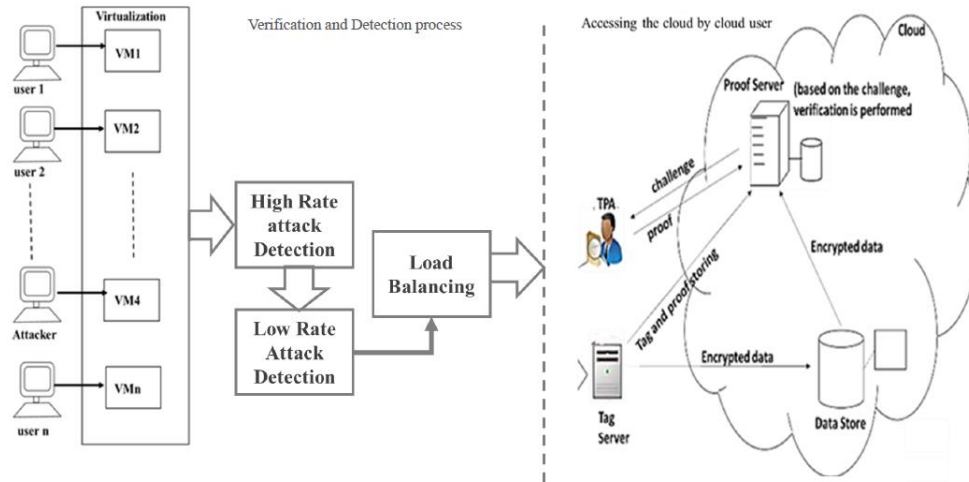


Fig. 2. Proposed model.

As seen in Fig. 2, each legal cloud user (cc_i) is given access to a virtual machine (VM_i). The cloud architecture is split into two portions, one to offer service and the other to verify and identify DDoS attacks. The cloud user's virtual machine (VM_i) is the source of the verification and detection process, where the LRDM algorithm is put and from which the predicted packet size of each traffic is calculated. The Low-rate detection method receives the network traffic from each virtual machine VM from which session ID S_{id_i} is retrieved.

A. PHASE I Algorithm

The LRDM method is split into two stages; the first stage examines the packet size and flags communication as malicious if it exceeds a certain threshold. Each user (cc_i) connects to the network and sends the (Rq_i) request packet to the cloud. Let $Rq_i(t)$ represent the collection of network flows in the cloud over the t interval.

$$Rq_i(t) = \{Rq_1(t), Rq_2(t), Rq_3(t), Rq_4(t), \dots \dots \dots Rq_n(t)\}$$

The cloud user CC_i sends a request Rq_i with a packet size PS_i for a particular time interval Δt . The maximum packet size that can be sent across the network is set to $PS_{max} = 1514$. As a result, the network flow at the moment Δt for each cloud user will be $Rq_i(\Delta t)$.

$$Rq_i(\Delta t) = \{Rq_1(PS_1), Rq_2(PS_2), \dots \dots \dots Rq_n(PS_n)\}$$

It should be remembered that the network protocol limits packet size. As a result, TCP traffic during an LRDDoS assault will enter a malicious series of drop-recovery-drop. In LRDDoS attack situations, TCP transmission becomes more discontinuous and unsteady as compared to TCP traffic in normal network settings. The packet size received should satisfy the range $60 \leq PS_k \leq 1514$. Each cloud user sends a N_i network request to the cloud server at Δt time interval.

In order to create a collection of packet size arrays $PA(\Delta t)$, the packet size is directly retrieved from the packet header,

$$PA_i(\Delta t) = \{PA_1, PA_2, \dots \dots \dots PA_n\}$$

The mean packet size is calculated for the network over a time interval (Δt).

$$\overline{MPA} = \frac{1}{N} \sum_{k=1}^{N_i} PA_i, \text{ such that } 60 \leq PA_k \leq 1514$$

The probability of occurrences of $Rq_i(\Delta t)$ is calculated as,

$$p(Rq_i(\Delta t)) = \frac{N_i}{\sum_{i=1}^N N_i}, \text{ where } p(Rq_i(\Delta t)) \geq 0 \text{ and } \sum p(Rq_i(\Delta t)) = 1$$

The packet size expected for each network flow of CC_i is calculated as,

$$Ep'(x) = \sum_{i=1}^N p(Rq_i(\Delta t)) * \overline{MPA}$$

Next, compute the distance deviation between the calculated packet size ($Ep'(x)$) and default packet size ($Ep'_t(x)$), this distance gap help to identify the inequality between the legitimate traffic and normal traffic.

$$\partial(\alpha, \Delta t) = Ep'(x) - Ep'_t(x)$$

Suppose $Rq = \{r'_1, r'_2, r'_3, r'_4\}$ is the ordered flow of traffic in the network at the sample time period Δt . Let the probability of each flow will be $P = \{p_1, p_2, p_3, p_4\}$. The mean packet size $\overline{MPA} = \{m_1, m_2, m_3, m_4\}$ for all value of Rq . The obtained and stored value of the normal expected packet size will show a loss of generality as,

$$Ep'\{r'_1, r'_2, r'_3, r'_4\} = Ep'\{r'_4, r'_3, r'_2, r'_1\}$$

The symmetry of the attack is independent of the arrival pattern and pulse pattern; therefore the accuracy will be overwhelmed by the distance deviation caused by the LRDDoS attack in the network.

$$Att_{flag} = \begin{cases} 1, & \partial(\alpha, \Delta t) \geq 0 \\ 0, & \partial(\alpha, \Delta t) < 0 \end{cases}$$

Fig. 3 depicts the flow diagram illustrating the Algorithm of phase 1.

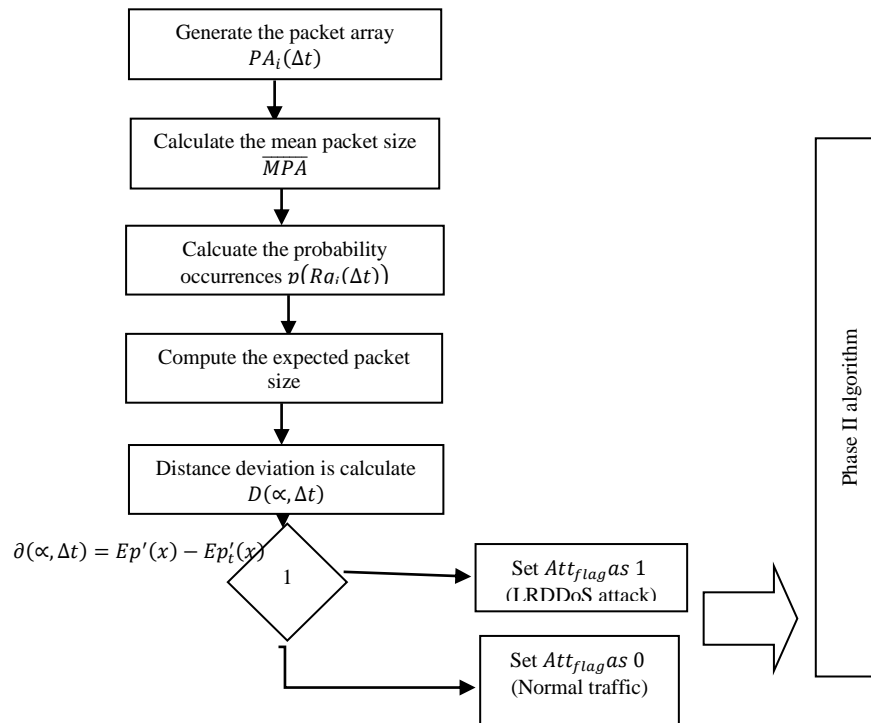
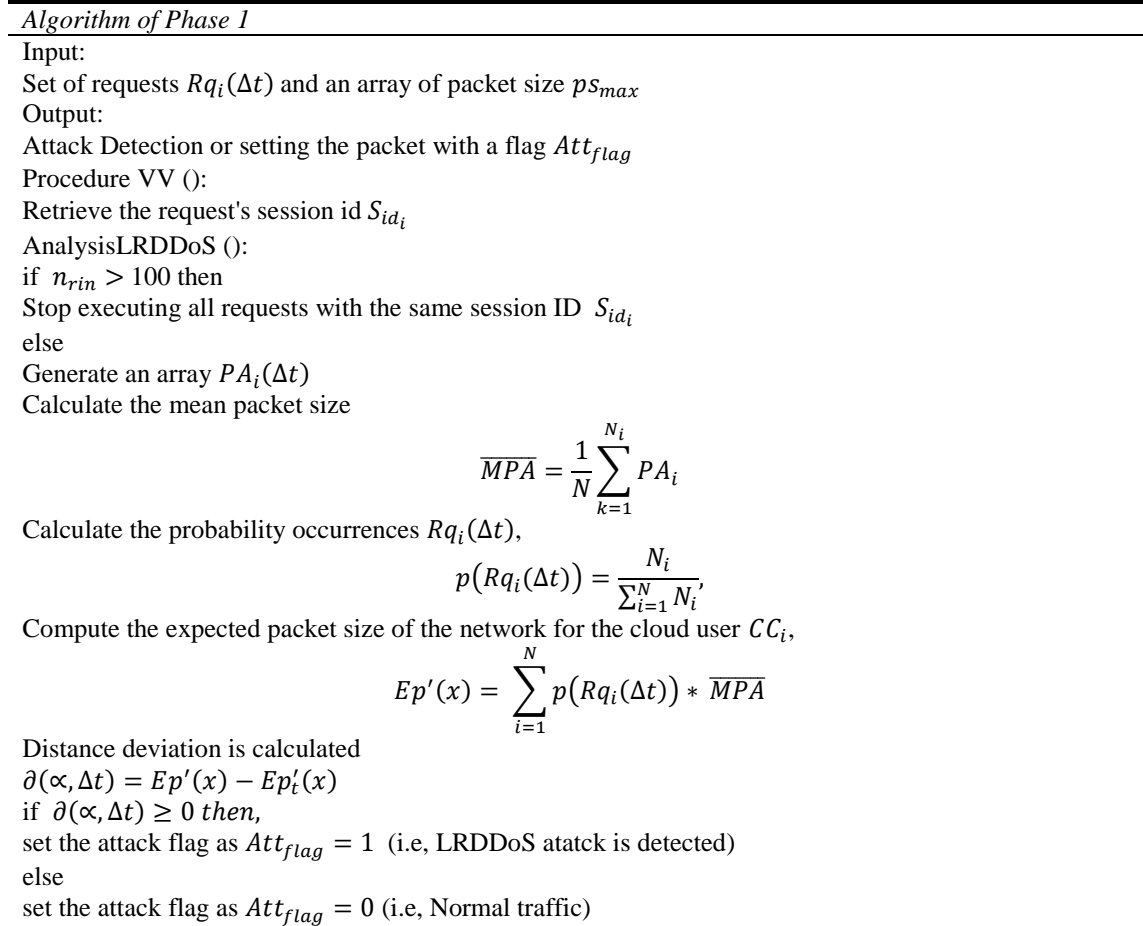


Fig. 3. Phase I flow algorithm.

B. PHASE II Algorithm

In this phase II process, a usage of covariance vector to identify LRDDoS assaults; if the LRDDoS assault pulse is perceived as a significant signal, the network background traffic acts as the sender's noise. During transmission, attack flows are masked by genuine traffic; nevertheless, covariance vector detection is used to identify attack flows at the receiving end.

1) *The covariance vector principle:* A random vector's covariance matrix is a square matrix that contains all of the covariances between the vector's entries. Consider the two vectors \hat{x} and \hat{y} which are used as random vector as,

$$\hat{x} = \{x_1, x_2, \dots, \dots, x_n\}^t$$

$$\hat{y} = \{y_1, y_2, \dots, \dots, y_n\}^t$$

$$cov[\hat{x}, \hat{y}] = E[(x_i - E[x_i'])(y_j - E[y_j'])]$$

$cov[\hat{x}, \hat{y}]$ is known as cross covariance vector. A cross-covariance matrix is one in which the element at the i, j positions represent the covariance between the i^{th} element of one random vector and the j^{th} element of another random vector variable with several dimensions. All of the scalar random variables in the vector are its elements. There is finite

or an infinite number of potential values for each element, as well as a finite or an unlimited number of values that may be experimentally observed. The cross-covariance matrix logically adds more dimensions to the idea of covariance. Typically, the cross-variance vector mean of the two vectors x and y is expressed as,

$$K_{xy} = cov[\hat{x}, \hat{y}] \stackrel{\text{def}}{=} Ep[[x_i - Ep(x_i')] - [y_i - Ep(y_i')]]^{\Delta t}$$

In the phase II algorithm, some initial vectors are used to perform the calculations for each request coming from the cloud user CC_i . A normal traffic vector is generated $\widehat{R}_{nor} = \{RN_1, RN_2, \dots, \dots, RN_n\}$, mean vector value of the normal traffic as M_{nor} and threshold value δ_{nor} . In this phase the covariance vector mean value is subtracted by predefined mean vector value and then compared with the 3-phase threshold and 4-phase threshold value to detect the LRDDoS attack in depth. The request (Rq_i) which is detected will be put on hold for a specific time period and the IP address (IP), protocol used(P), attack duration (D_i), attack period(Δt), attacking rate(r) is blacklisted which is indicated as B_{list} . Fig. 4 depicts the flow diagram illustrating the Algorithm of phase II.

<p>Algorithm of Phase II</p> <p>Input :</p> <p>Set of request $R_i(\Delta t)$</p> <p>\widehat{R}_{nor} mean vector value of the normal traffic as M_{nor}</p> <p>Threshold value δ_{nor}.</p> <p>Output:</p> <p>B_{list} and time of halt</p> <p>Procedure :</p> <p>Convert the request obtained from the network to a vector form \widehat{R}_{rec}</p> <p>Check the result obtained from the from the pahse I algorithm</p> <p>If $Att_{flag} = 1$</p> <p>Blacklist the request $R_i(\Delta t)$ in B_{list} file by capturing the information as IP address (IP), Protocol used(P), attack duration (D_i), attack period (Δt), attack rate (r) and halt the cloud user for $\frac{1}{2^n} \Delta t$.</p> <p>Otherwise</p> <p>Compute the covariance vector mean as,</p> $K_{rec} = E[[R_{inor} - E(R'_{inor})] - [R_{irec} - E(R'_{irec})]]^{\Delta t}$ <p>If $K_{rec} - M_{nor} \leq 3\delta_{nor}$ or $4\delta_{nor}$ then,</p> <p>Set $Att_{flag}=0$, consider as normal traffic</p> <p>Else</p> <p>Set $Att_{flag} = 1$ and Blacklist the request $R_i(\Delta t)$ in B_{list} file by capturing the information as IP address (IP), Protocol used(P), attack duration (D), attack period (Δt), attack rate (r). and halt the cloud user for $\frac{1}{2^n} \Delta t$</p>

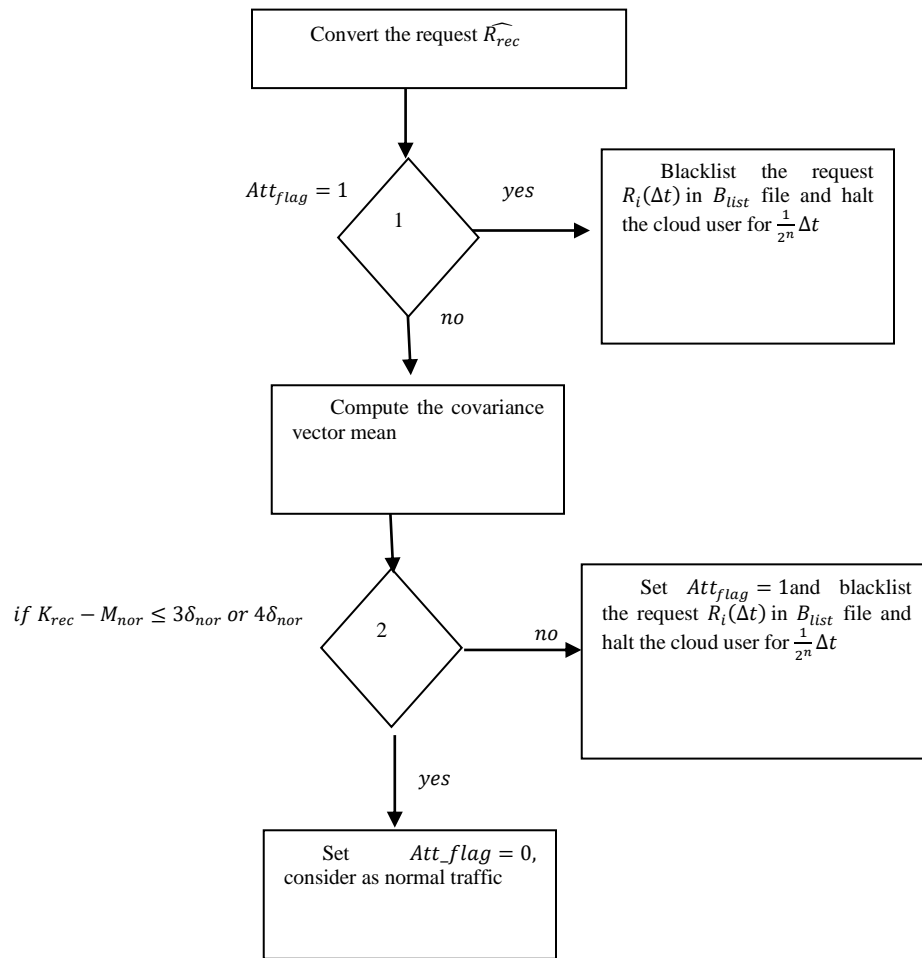


Fig. 4. Phase II flow algorithm.

IV. EXPERIMENTAL OUTCOME AND ANALYSIS

The experiment is made by establishing some crucial criteria depending on the outcomes of available resources in order to assess how well the suggested system performs when subjected to an LRDDoS attack, identify the attack's features, and creates a blacklist of the attacker. The primary justification for looking into the assault is the design of the communication protocols, which enable successful end-to-end service delivery. The proposed system mitigates LRDDoS attacks in a cloud computing environment using a two-phase detection method. Attackers however, use the protocols to change how cloud services and apps are accessible. According to the suggested strategy, the three main flooding assaults are TCP SYN, UDP, and ICMP. In this case, the victim end of the attack experiences one-way attack traffic and disproportionately high levels of unauthorized resource use.

The experimental setup uses the following configuration. One server with $m + n$ virtual machines is used, where m stands for legitimate users and n stands for malicious users. The configuration includes Windows 10 operating system, Intel (R) Core (TM) i7-4790 CPU running at 3.60 GHz, 500 GB of storage, 16 GB of RAM for desktops and 72 GB for server. The scenarios of low-rate DDoS attacks and non-attack traffic are created for the experiment. In the absence of an attack, authorized users (m virtual system) contact the cloud

server to request access to services or files kept on the server. A malicious user (n virtual machine) sends attack packets to the cloud server in an attack scenario. In contrast, in an attack scenario, the cloud server will simultaneously receive requests from both legitimate users and malevolent users. To identify the LRDDoS attack sources per source IP throughout the observed period, the correlation 1 query is run on the input stream. By combining the source addresses that come from the user group ($m + n$ users), correlation is achieved. At the selected time interval, network flows are gathered. Attack packets are added to the Backlist B_{list} along with the session ID of the virtual machine source when the individual source IP crosses the threshold value.

The two-phase detection system captures the stream processing quite well. Data from the baseline profile are used to calculate the threshold value. The cloud's statistics and behavior while it is not under assault are examined. The baseline profiling is done for a period of time that varies from daily to weekly to monthly. The baseline is periodically updated to reflect any alterations to the cloud usage. The Slowloris attack tool is used to simulate low-rate attack situations. It is a DDoS attack programme that creates irregular HTTP connections using the Hyper Text Transfer Protocol (HTTP). By absorbing all connections of the server, the tool attempts to maintain HTTP connections for an

extended period of time while slowing down the cloud server (such as Apache and dhttpd). The Apache web server's timeout setting is 250 seconds by default; however, it can be changed depending on how the attack packets are transmitted.

Incomplete HTTP connections are opened by the Slowloris to launch low-volume assaults. It performs data requests and, once all connections have been used, resets the timeout counter value to 1. Using $x + y$ malicious nodes, the assault begins with the command `perl slowloris.pl -dns -s 192.169.60.1 - 250 www.abcexample.com - timeout 3 - num 60 - port 80`. By claiming to be IP addresses in the subnet from 192.169.60.1 to 192.169.60.250, the malicious nodes create 60 connections and maintain them by making data requests every 5 seconds. The low acquisition rate timeout of 5 seconds is selected. In low-rate attack scenarios, the legitimate nodes submit request packets to the cloud server concurrently with the malicious nodes. At the CC, the traffic is recorded for each scenario, and a matching Traffic flow behavior graph (TFBG) is created. In Fig. 5, the TFBGs are shown. Fig. 5(a) demonstrates the steady traffic flow that was present when there was no threat of assault, while Fig. 5(b) depicts the periodic and pulsating traffic streams seen during an LRDDoS assault.

The detection precision of each assault is displayed in Table I below. The total detection accuracy for a TCP SYN

flooding attack is stated to be 99.97% in a time window of 60 seconds. For different threshold values, such as 100, 1000, 5000, 10,000, and 15,000, the accuracy of the attack detection is accordingly 99.85%, 99.98%, 99.99%, 99.99%, and 99.99%. The overall detection accuracy for a UDP flooding attack is reported to be 99.96% during a time window of 60 seconds. Attack detection accuracy ranges from 99.81%, 99.98%, 99.99%, 99.99%, and 99.99% for threshold values of 100, 1000, 5000, 10,000 and 15,000, respectively. For an ICMP flooding assault, the total detection accuracy was 99.84% within a 60-second time window. The accuracy with which the assault is detected is 99.32%, 99.93%, 99.98%, 99.99% and 99.99% for various threshold values, such as 100, 1000, 5000, 10,000 and 15,000, respectively.

In accordance with the IP addresses, the received packets are counted. The non-attack scenario had an average flow count of 2982; the low-rate assault scenario had an average flow count of 610. Table II provides an overview of the values for the selected parameters. According to Fig. 6, legitimate requests in the system under the nonattack scenario last a little bit longer than malicious ones under the LRDDoS attack scenario. The resource isolation means that the LRDDoS assault won't have an effect on the container instances handling malicious requests that have been blacklisted. Fig. 6 demonstrates the flow of requests within the network, showcasing both normal traffic and malicious traffic.

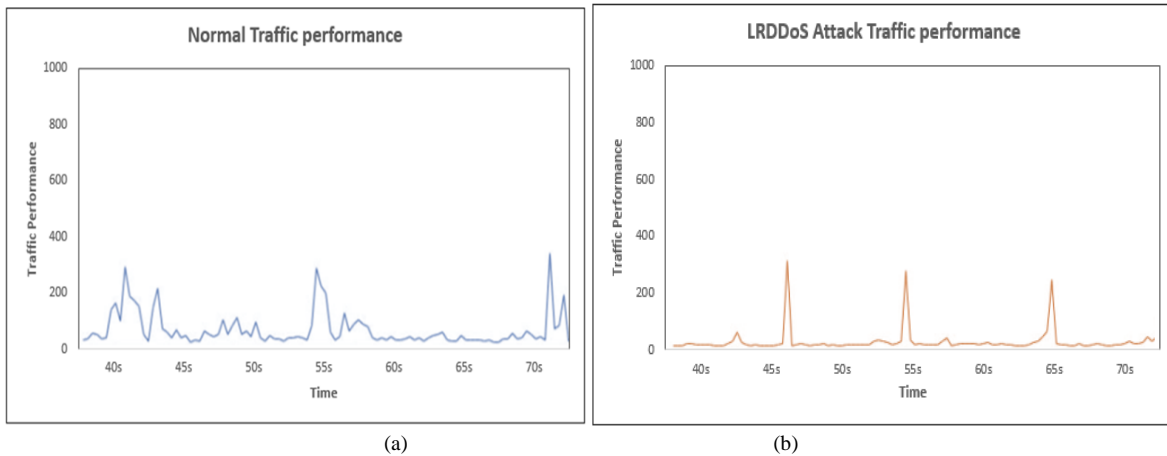


Fig. 5. Traffic flow behavior graph: (a) Normal traffic, (b) LRDDoS attack traffic.

TABLE I. LRDDoS ATTACK DETECTION PRECISION

Attack Source	Threshold	TCP SYN	UDP	ICMP
SET 1	100	99.85	99.81	99.32
	1000	99.98	99.98	99.93
	5000	99.99	99.99	99.98
	10000	99.99	99.99	99.99
	15000	99.99	99.99	99.99
Average		99.97%	99.96%	99.84%

TABLE II. PARAMETER EXPERIMENTAL VALUES

Traffic scenario			Behavior graph pattern	Average flow count	Response time
Normal Traffic			Uniform pattern	2982	60 seconds
LRDDoS attack traffic	Periodic and pulsing	610	60 seconds		

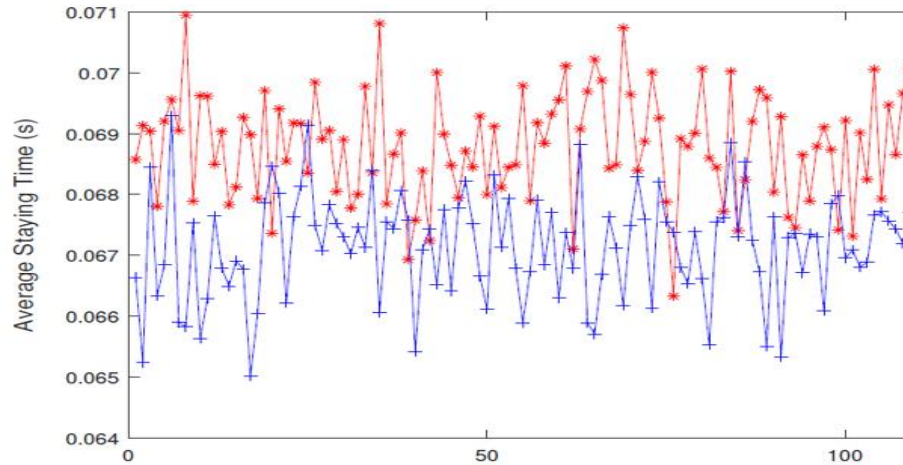


Fig. 6. Combined traffic flow behavior.

Table III provides a comparison of the suggested technique to the current approaches. When comparing approaches, it is taken into account how well they can identify DDoS attacks with low attack rates, as well as how quickly they can respond. To evaluate the correctness of the proposed technique, two metrics are used: True Negative Rate (TNR) and True Positive Rate (TPR), also known as specificity and sensitivity, respectively. TPR and TNR are calculated as follows:

$$TPR = \frac{x'}{x' + y'}$$

and

$$TNR = \frac{a'}{a' + b'}$$

where,

x' = signifies properly identifying malicious users.

y' = Unauthorized users .

a' = Accurately detected authorised users.

b' = Authorized users who were

mistakenly labelled malevolent.

The following metrics are used to assess the proposed method's accuracy:

$$Accuracy = \frac{x' + a'}{x' + y' + a' + b'}$$

The experiment was repeated multiple times with various combinations of reliable ($x + p$) and malicious ($y + q$) nodes selected from the set of 16, 32, 64, 128, 256, and 512 in order to evaluate performance. Table III displays the comparative analysis of the experimental outcomes. For a high number of nodes, there is only a little change in the flow count. Therefore, only the results for up to 128 nodes are displayed. Based on the response time, average flow count, and traffic flow behavior, the study is carried out. Based on the trials, 99.1% and 99.5%, respectively, are the average values for TPR and TNRs shown in Fig. 7. The proposed technique has a 99.4% total accuracy rate as shown in the below Table III.

TABLE III. COMPARISON OF PROPOSED SYSTEM WITH EXISTING SYSTEM

Methodology	Normal	LowRate	Response time	Accuracy
FR-Red [a]	Yes	Yes	(15.1-125.8) sec	98%
Queue based model[b]	Yes	Yes	Medium	99.1%
LORD [c]	Yes	Yes	75sec	99.1 %
MPTCP [d]	Yes	Yes	33 sec	98.9%
Proposed Methodology	Yes	Yes	(60-65) sec	99.4%

*NA= Not Available

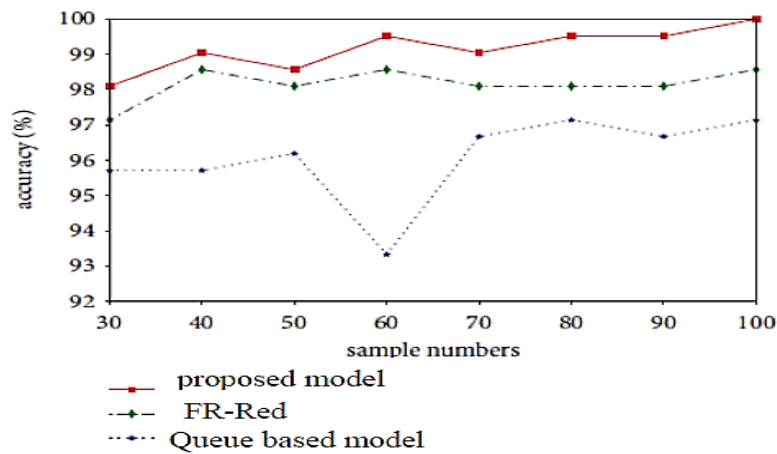


Fig. 7. A comparison between the proposed methodology and existing methodology.

V. CONCLUSION AND FUTURE RESEARCH PROSPECTS

This work proposes a simple and effective two-phase detection methodology for detecting LRDDoS attacks in a cloud domain. The suggested model incorporates the 3D Threshold and covariance vector notions as well as the packet size of each request and the network flow count. Based on the concept, a faulty LRDDoS attack in a network with restricted resources is possible. The model's performance demonstrates a 99.97%, 99.96%, and 99.84% accuracy in identifying the LRDDoS attack, which is carried out utilizing the TCP, UDP, and ICMP protocol. By establishing a variety of threshold values, the testing results show an average detection of 99.8%. Using this method, the cloud user's virtual machine may be optimized and system resources can be dynamically reassigned. The suggested approach entirely eliminates the effect of LRDDoS attack by blacklisting the user for a particular time period and increase the ability of the other user to utilize the service of cloud without get affected by the assault.

As part of future work, it is necessary to investigate strategies to counteract LRDDoS attacks on the assumption that virtual machines may expand with limitless resources. Furthermore, in the limitless resources scenario, an attempt is made to investigate pricing difficulties in a VM-based cloud system when defending against an LRDDoS assault.

REFERENCES

- [1] Kuzmanovic, E.W. Knightly, Low-rate TCP-targeted denial of service attacks: the shrew vs. the mice and elephants, in: Proceedings of the 2003 Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications, 2003, pp. 75–86.
- [2] G. Maciafernandez, J.E. Diazverdejo, P. Garcia-teodoro, Evaluation of a low-rate DoS attack against iterative servers, *Comput. Netw.* 51 (4) (2007) 1013–1030.
- [3] J. Nagle, Congestion control in IP/TCP internetworks, *ACM SIGCOMM Comput. Commun. Rev.* 14 (4) (1984) 11–17.
- [4] V. Adat, A. Dahiya, and B. Gupta, "Economic incentive based solution against DDos for IOT customers," in ICCE. IEEE, 2018, pp. 1-5
- [5] J. Idziorek, M. F. Tannian, and D. Jacobson, "The insecurity of cloud utility models," *IT Professional*, vol. 15, no. 2, pp. 22–27, 2013.
- [6] C. Wang, Y. Cui, Q. Qian, G. Shen, H. Gao and S. Li, "METER: An Ensemble DWT-based Method for Identifying Low-rate DDos Attack in SDN," 2021 IEEE 19th International Conference on Embedded and Ubiquitous Computing (EUC), 2021, pp. 79-86, doi: 10.1109/EUC53437.2021.00020.
- [7] S. Yu, Y. Tian, S. Guo, and D. O. Wu, "Can we beat DDos attacks in clouds?" *IEEE Transactions on Parallel and Distributed Systems*, vol. 25, no. 9, pp. 2245–2254, 2014.
- [8] Y. Xiang, K. Li, and W. Zhou, "Low-Rate DDos Attacks Detection and Traceback by Using New Information Metrics," *IEEE Transactions on Information Forensics and Security*, vol. 6, no. 2, pp. 426–437, 2011.
- [9] J. Luo, X. Yang, J. Wang, J. Xu, J. Sun, and K. Long, "On a mathematical model for low-rate shrew DDos," *IEEE Transactions on Information Forensics and Security*, vol. 9, no. 7, pp. 1069–1083, 2014.
- [10] Z. Wu, L. Zhang, and M. Yue, "Low-rate dos attacks detection based on network multifractal," *IEEE Transactions on Dependable and Secure Computing*, vol. 13, no. 5, pp. 559–567, 2016.
- [11] Y. Takahashi, H. Inamura and Y. Nakamura, "A Low-rate DDos Strategy for Unknown Bottleneck Link Characteristics," 2021 IEEE International Conference on Pervasive Computing and Communications Workshops and other Affiliated Events (PerCom Workshops), pp. 508-513, 2021
- [12] M. Dhawan, R. Poddar and K. Mahajan, "SPHINX: Detecting security attacks in software-defined networks", *Proc. Netw. Distrib. Syst. Secur. Symp.*, pp. 8-11, Feb. 2015.
- [13] Rate Denial of Service Attack Detection Approach in ZigBee Wireless Sensor Network by Combining Hilbert-Huang Transformation and Trust Evaluation," *IEEE Access*, vol. 7, pp. 32 853–32 866, 2019.
- [14] M. V. Kieu, D. T. Nguyen and T. T. Nguyen, "A Way to Estimate TCP Throughput under Low-Rate DDos Attacks: One TCP Flow," 2020 RIVF International Conference on Computing and Communication Technologies (RIVF), 2020, pp. 1-8
- [15] Z. Wu, W. Cui and P. Gao, "Filtration method of DDos attacks based on time-frequency analysis," 2021 7th IEEE Intl Conference on Big Data Security on Cloud (BigDataSecurity), IEEE Intl Conference on High Performance and Smart Computing, (HPSC) and IEEE Intl Conference on Intelligent Data and Security (IDS), 2021, pp. 75-80
- [16] R. Florea and M. Craus, "Modeling an Enterprise Environment for Testing Openstack Cloud Platform against Low-Rate DDos Attacks," 2022 26th International Conference on System Theory, Control and Computing (ICSTCC), 2022, pp. 146-151
- [17] N. Agrawal and S. Tapaswi, "A Lightweight Approach to Detect the Low/High Rate IP Spoofed Cloud DDos Attacks," 2017 IEEE 7th International Symposium on Cloud and Service Computing (SC2), pp. 118-123, 2017.
- [18] Lu Zhou, Mingchao Liao, Cao Yuan, Haoyu Zhang, "Low-Rate DDos Attack Detection Using Expectation of Packet Size", *Security and Communication Networks*, vol. 2017, Article ID 3691629, 14 pages, 2017.

Pig Health Abnormality Detection Based on Behavior Patterns in Activity Periods using Deep Learning

Duc Duong Tran¹, Nam Duong Thanh²

Faculty of Information Technology, Posts and Telecommunications Institute of Technology, Ha Noi, Viet Nam¹
Center for Research and Technology Transfer, Viet Nam Academy of Science and Technology, Ha Noi, Viet Nam²

Abstract—Abnormal detection of pig behaviors in pig farms is important for monitoring pig health and welfare. Pigs with health problems often have behavioral abnormalities. Observing pig behaviors can help detect pig health problems and take early treatment to prevent disease from spreading. This paper proposes a method using deep learning for automatically monitoring and detecting abnormalities in pig behaviors from cameras in pig farms based on pig behavior patterns comparison in activity periods. The approach consists of a pipeline of methods, including individual pig detection and localization, pig tracking, and behavioral abnormality analysis. From pig behaviors measured during the detection and tracking process, the behavior patterns of healthy pigs in different activity periods of the day, such as resting, eating, and playing periods, were built. Behavioral abnormalities can be detected if pigs behave differently from the normal patterns in the same activity period. The experiments showed that pig behavior patterns built in 30-minute time duration can help detect behavioral abnormalities with over 90% accuracy when applying the activity period-based approach.

Keywords—Deep learning; pig tracking; behavior patterns; pig health monitoring

I. INTRODUCTION

Pig tracking plays an important role in the early detection of problems in pig health and welfare. Traditionally, this job is done by workers on pig farms. This manual method has a number of disadvantages. Firstly, workers cannot monitor all pigs continuously and all the time, because they have many other jobs to do. Secondly, they lack the capability to remember and associate the behaviors of each individual pig over a long period of time to detect behavioral abnormalities. In addition, on large pig farms, this task requires a lot of labor.

Tracking pigs automatically not only reduces labor costs, but can also provide better performance since pig behaviors can be observed and associated over a longer period of time. By recording pig behavior measurements over a long period of time, the changes in behavior patterns of pigs can be detected, and these can be used as early signs of disease. If the decision can be made only at the observing time and can not be associated with other observations in the past, only serious clinical signs can be detected, which may result in a late intervention [1].

Pig tracking can be performed in groups or at the individual level. Although group behavior measurement has been proven to have usefulness in pig health and welfare monitoring, individual behavior detection and tracking has more

advantages as it can enable personalized abnormal detection and treatment [1]. Obviously, tracking individual pigs is a more challenging task than tracking group of pigs because of the potential errors in individual pig detection and identification. Recently, with improvements in object detection and tracking techniques, pig tracking has been focused on individual-level.

Tracking pigs from surveillance cameras is a widely used method due to its low cost and simplicity of installation when compared to wearable methods. Depth sensors such as 3D cameras have been used to measure the depth of pig images detected to identify if a pig is standing or lying [2, 3, 4, 5], but this kind of device is expensive, and this method cannot be used to identify other postures such as eating or drinking. Recently, deep learning approaches have been utilized to detect, track, and identify exact behaviors of individual pigs. Based on the convolutional neural network (CNN) architecture, a number of multi-object detection algorithms have been introduced, such as Faster R-CNN [6], SSD [7], YOLO [8]. These algorithms can help locate and classify objects in images, which can be used for pig localization and posture classification in video frames from surveillance cameras. This approach worked on inexpensive 2D RGB cameras and has the ability to identify various pig behaviors such as standing, lying, eating, drinking, foraging, etc. [4, 5, 9, 10, 11, 12, 13, 14] or identify moving, non-moving behaviors [1]. Non-moving behaviors can be identified in the detection phase by dividing pig classes of the detection model into sub-classes such as pig standing, pig lying, pig eating, etc. [1, 10, 11] or using an additional image classification model to classify the detected pig images into different behavior classes [13]. Moving behaviors, such as walking or running, can be identified in the tracking process by measuring the distance that a pig traveled between continuous frames [1, 13]. In addition to basic postures and behaviors, some researchers tried to identify more complex postures, such as sitting, lateral lying, sternal lying, etc. [11]. When the behaviors can be identified during the tracking process, changes in pig behaviors can be detected by considering the time for each behavior [10, 13] or time spent moving, being idle, and distance traveled [1].

One of the most challenging issues in pig tracking is identification errors caused by identity switching or changing problems during the multi-object tracking process. Some previous works have tried to improve this problem by using additional methods, such as a correlation filter-based tracker via a novel hierarchical data association algorithm [15] or trajectory processing and data association [16]. However, due to the natural conditions of commercial pig farms, such as high

pig density, low light, similar appearances of pigs, or wide covering area of cameras, tracking each individual pig for a long time with low identification error rate is still a difficult task.

In this paper, we propose a pipeline of methods, including detection, tracking, building healthy pig behavior patterns, and behavior abnormality detection based on comparison of new pig behaviors and healthy pig behavior patterns. We tried to reduce the impact of identification errors by calculating the behavior patterns in 30-minute-long videos. Moreover, to make the behavior patterns built in only a 30-minute time duration but still have capabilities for detecting behavioral abnormalities, we built different behavior patterns for each activity period in a day. According to our studies, pigs have typical behaviors during different activity periods in a day, such as resting time, eating time, playing time, and building different behavior patterns for each activity period can improve the behavioral abnormality detection performance.

In our method, videos from cameras installed on pig pens will be streamed to the Yolo v7 model [17] to detect pig locations and postures. In the detection phase, pigs detected will also be classified into different posture classes, such as standing, lying, and eating. Pig locations in continuous video frames will be used to identify the individual pigs and track their movements using the DeepSORT algorithm [18]. While lying and eating behaviors are identified in the detection phase, standing and moving behaviors need to be determined in the tracking phase. In the tracking phase, we can measure the distance between the locations of each individual pig in continuous frames. If the distance between locations of a pig is less than a threshold number in some continuous frames, the pig can be determined to be idle rather than moving. Based on the behaviors recognized in the detection and tracking processes, behavior patterns can be built for different activity periods of a day. The experiments showed that the behavior patterns, which were built from 30-minute time duration, could reduce the identification error but still show behavioral characteristics in each activity period.

The main contributions of our method are:

- Proposed an end-to-end method for detecting and tracking pigs individually, measuring their behaviors and building behavior patterns, detecting behavioral abnormalities.
- Proposed an approach for building healthy pig behavior patterns in different periods of time in a day, such as rest time, eating time, and playing time. With this approach, we can build behavior patterns in only 30 minutes to reduce the identification error. Based on the behavior patterns, abnormalities can be detected by calculating the difference between the tracked pig behavior set and the behavior patterns. We tested our approach on both healthy and sick pig datasets.

The rest of the paper will be structured into the following sections. Section II describes the materials and methods for pig detection, tracking, and behavior analysis. Section III describes the experiments and results. Section IV finalizes a conclusion.

II. MATERIALS AND METHODS

A. Datasets

The datasets used in this paper were collected from two pens on a commercial pig farm. One pen (Pen 1) contains healthy pigs, and the other one (Pen 2) contains sick pigs (which were collected from other pens for quarantine purposes). Videos from both pens were used to create the pig detection and tracking datasets. Videos from Pen 1 were used to build healthy pig behavior patterns, and videos from Pen 1 and Pen 2 were used to build test datasets for behavioral abnormality detection.

The video was recorded using one EZVIZ (resolution: 1920 x 1080, focal length: 4.0mm, max frame rate: 15 FPS) on pens containing 15-18 pigs with ages from 3 months to 4 months and weights from 40 kg to 50 kg.

The videos were recorded across different days and times to collect the data in different conditions. Fig. 1 shows the sample images from the experimental pens.



Fig. 1. Sample images from experimental pens.

From this raw dataset, we created pig detection, pig tracking, pig re-identification, and pig behavior analysis datasets for our experiments. The details of these datasets are described in the next sections.

1) *Detection dataset*: To create the detection dataset, we extracted image frames from captured videos and manually annotated them using the LabelImg tool [19]. Using this tool, we created a bounding box for each pig in the images and assigned it one of three classes: standing, lying, or eating (to annotate the eating behavior, we need to create a bounding box covering not only the pig but also the feeder as well, so

that the model can learn if it is eating food in the feeder trough or not).

Totally, 3,069 images were extracted from recorded videos and annotated for training and testing the detection model (48,522 annotations). The images were extracted from videos captured at different times in order to test the detection and tracking performance in various illumination and weather conditions.

2) *Tracking dataset*: To create the detection dataset, we just need to create a bounding box for each pig and assign it a behavior class, as mentioned above. But to create the tracking dataset, we need to assign each pig the same identification number (ID) from frame to frame.

The frames in the tracking dataset are selected in the order they appear in the video but don't need to be continuous because the frame rate of videos is very high. On average, we just selected and annotated one-fourth of the frames on each testing video. To test the tracking performance of both pens, we create two tracking subsets on videos from Pen 1 and Pen 2, as described in Table I. As mentioned above, the frames in a tracking subset must be put in order, so it can be seen as a sequence of frames.

TABLE I. SUMMARY OF TRACKING DATASET

	Sequence Length (seconds)	Number of frames
Sequence from Pen 1	300	247
Sequence from Pen 2	300	250

3) *Pig re-identification dataset*: The pig re-identification dataset contains individual pig images for the purpose of recognizing the individual pig without consideration for its behaviors. Therefore, it includes all the pig images in the pig behavior dataset plus other pig images we collected by using the detection model. Totally, we obtained 5,460 images for 30 pig identities for our pig re-identification dataset.

4) *Pig behavior analysis dataset*: This dataset includes 30-minute videos collected from both pens to build behavior patterns and test abnormality detection based on behavioral analysis. In particular, the dataset consists of the following videos:

- Nine videos collected from the healthy pig pen in three activity periods, as mentioned above. Three videos were collected randomly in each activity period to build the behavior pattern for that period.
- Three videos collected from the healthy pig pen in three activity periods for testing purposes.
- Three videos collected from the sick pig pen in three activity periods for testing purposes.

B. Method

In order to build the behavior patterns of pigs in a video, they first need to be detected in each video frame. The detections obtained in continuous video frames are used for tracking the pigs and identifying their behaviors. In our

method, the detections can be used to identify non-moving behaviors such as lying, standing, or eating with corresponding class labels. However, to determine the moving behavior, we need to consider the distance between pig locations in continuous frames during the tracking process.

Fig. 2 shows the overall architecture of our system. The methods applied in each module are described in the following sections.

1) *Pig detection*: In this phase, the YOLO v7 model was used to detect the pigs. The YOLO is a popular object detection algorithm and is widely used today due to its speed and accuracy. It is a single-state object detection scheme that divides images into a grid, in which each cell in the grid is responsible for detecting objects itself.

YOLO v7 is an object detection architecture entirely written in Pytorch with models pretrained on the COCO [20] dataset. We chose to use YOLO v7 because it is significantly faster and more accurate compared to the previous versions. We first pre-trained the model with the COCO dataset, and followed by our own dataset as a fine-tuning task. The pre-training step is necessary when training most CNNs for image classification or detection to obtain good initial weights on an extremely large dataset (millions of images).

In the following stage, we fine-tuned the model using our detection dataset. The purpose of the model is not only to detect the pigs but also to identify non-moving pig behaviors such as standing, lying, and eating.

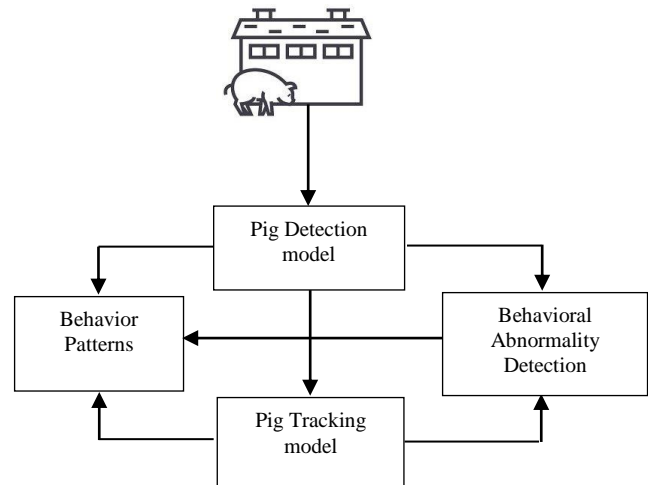


Fig. 2. Overall architecture of our method and system.

2) *Pig tracking*: From the locations of pigs detected in the frames, we employed DeepSORT, a multi-object tracking (MOT) technique, to track the pigs in videos. DeepSORT uses the Kalman filter [21] to track the objects detected in the frames in the previous step (using one of the object detection algorithms such as YOLO, R-CNN family, etc.). The Hungarian algorithm [22] will be used to match the tracked objects and detections in the next frame. DeepSORT not only uses the distance between tracks and detections as measurements of matching but also uses deep image similarity

as an additional metric. This greatly reduces the number of misidentified objects and can help re-identify the objects that have not been tracked in the previous frame (in the pig tracking task, this can be caused by the bad illumination conditions). To measure the image similarity, we used the OSNet (Omni-Scale Network) [23] model, pre-trained on the person re-identification dataset and followed by our own pig re-identification dataset.

The original DeepSORT was developed for a general multi-object tracking context in which the number of targets is unknown. When applying it to the group-housed pig tracking task where the number of pigs is stable, DeepSORT can assign a different ID to the same pig target as the video frames grow and the pig goes far from camera or changes the behavior. This will cause the identification switch errors and increase the ID beyond the real pig's numbers, making the behavior extraction task for individual pigs not stable. To solve this problem, we employed the improved DeepSORT algorithm proposed by S. Tu et al. [16], in which we added an additional re-matching step for lost and new tracks using both trajectory and data association processing. This remarkably improves the tracking performance and reduce the identification errors as described in the tracking results section.

3) *Behavioral abnormality analysis*: In this phase, we used the results of the detection and tracking phases to determine the behaviors of each individual pig. In particular, if the posture of a pig recognized in the detection phase is lying or eating, its behavior is determined to be the same. If the posture of a pig recognized in the detection phase is standing, the change in its position in the tracking phase (if any) will be used to determine if it is standing or moving. We set a threshold for the distance between positions of the pig in continuous frames. If the distance is greater than the threshold, the pig is determined to be moving; otherwise it is standing.

Based on that scheme, all four behaviors of pigs will be identified during the detection and tracking phases. From the behaviors identified in the frame sequences, the total amount of time for each behavior will be calculated over a period of time to build the behavior patterns of pigs in each activity period. In this research, we introduce the term "activity period", which implies a period of time in a day that the pigs mainly perform some typical behaviors. In our experiment, we set the time for each activity period as in Table II. Please note that the times for activity periods may vary on different farms. But in commercial settings, farm owners can set the times for them, and system can collect data and build the behavior patterns accordingly.

TABLE II. TIME FOR ACTIVITY PERIODS

Activity Periods	Time	Description
Resting period	0h-7h, 8h-10h, 14h-16h, 18h-24h	Pigs mostly spend time for resting, sleeping
Eating period	7h-8h, 13h-14h, 17h-18h	Pigs mostly spend time for eating
Playing period	6h-7h, 16-17h	Pigs mostly spend time for playing, looking for food

We chose the time duration to build behavior patterns is 30 minutes and the behavior patterns will be calculated for three activity periods in a day, as mentioned above. The 30-minute time duration was chosen to balance the identification errors and the abnormality detection abilities of behavioral patterns. If the time duration is shorter, identification errors can be reduced, but the behavior patterns may not be sufficient to represent the activity periods. While a longer time duration may produce a better behavior pattern, identification errors will increase. Since the current farm's natural conditions do not guarantee accurate long-term tracking, a 30-minute time duration for building behavior patterns is a reasonable choice.

The healthy pig behavior patterns in each activity period will be calculated as follows:

- Calculating the time for each behavior of each individual pig in each 30 minutes.
- Building the behavior patterns of healthy pigs by averaging the time for each behavior in the same activity period.
- Building the daily behavior patterns of healthy pigs by averaging the 30-minute behavior patterns in the same activity period.
- Behavior patterns will be calculated for three activity periods, as mentioned above.

Behavior patterns will be built and updated on a daily basis. The behaviors of tracked pigs will be calculated using the same formula and compared to the behavior patterns. The difference between them will be calculated using the Euclidean distance, and a threshold will be set for abnormality detection.

During the tracking process, some tracks may be lost and reappear, and their behaviors will not be recorded during that time. To make the behavior patterns and extracted behavior set have a consistent time, we assign the behaviors in lost time according to the previous and subsequent behaviors (half of time for the previous and half of time for the subsequent). Therefore, the total time for all behaviors in behavior patterns and behavior sets is always 30 minutes.

III. RESULTS AND DISCUSSION

A. Evaluation Metric

1) *Detection evaluation*: To evaluate the performance of the detection model, we used the mAP (mean Average Precision) metric, which is a standard metric to evaluate the performance of most common object detection methods. We first compute the IoU of the ground-truth bounding boxes with detected boxes as in Eq. (1).

$$IoU = \frac{\text{Area of Overlap}}{\text{Area of Union}} \quad (1)$$

From the IoU metric of each bounding box pair, we computed the AP (Average Precision) metric for each class, and mAP is the mean of all APs as in Eq. (2) and (3).

$$AP(c) = \frac{TP(c)}{TP(c)+FP(c)} \quad (2)$$

$$mAP = \frac{1}{\text{classes}} \sum_{\text{classes}} AP(c) \quad (3)$$

Where $TP(c)$, $FP(c)$ are True Positive, False Positive, respectively and $AP(c)$ is the AP score of class c .

2) *Tracking evaluation*: The tracking performance metric used in our experiments is MOTA (Multi-Object Tracking Accuracy) [24]. This metric is calculated based on three types of errors: FN (False Negative), FP (False Positive), and IDSW (Identity Switch) as in Eq. (4).

$$MOTA = 1 - \frac{\sum_i FN_i + FP_i + IDSW_i}{\sum_i GT_i} \quad (4)$$

Where FN_i is a real object but the tracker for it was not generated, FP_i is a non-existing object in ground truth but the tracker for it was generated wrongly, $IDSW_i$ is a mismatch, and GT_i is ground truth.

We also used $IDF1$ as a second metric to evaluate the tracking model. This metric focuses on the identity switch, which evaluates the ability to track identities.

$$IDF_1 = \frac{2IDTP}{2IDTP + IDFP + IDFN} \quad (5)$$

Where $IDTP$, $IDFP$, $IDFN$ are True Positive, False Positive, False Negative on identity switches.

3) *Behavioral abnormality detection evaluation*: Each pig tracked will be assigned a unique identification (ID) with four behavior metrics, which are the time for each behavior in 30 minutes. These metrics will be compared to the behavior pattern in the same activity period using Euclidean distance as in Eq. (6).

$$d(Y, \hat{Y}) = \sqrt{\sum_{i=1}^n (Y_i - \hat{Y}_i)^2} \quad (6)$$

Where Y is the behavior pattern and \hat{Y} is the behavior set of the tracked pig.

If the distance is greater than the threshold number, a behavioral abnormality is detected. In the testing process, if an abnormality is detected in a sick pig, the prediction is correct, and vice versa. The performance of behavioral abnormality detection can be evaluated by dividing the number of correct predictions by the total prediction number (Accuracy score).

B. Detection Results

The results of the detection phase are shown in Table III. Please note that besides mAP, we also reported the Precision and Recall scores for the detection model.

TABLE III. RESULTS OF PIG DETECTION MODEL

Class	mAP	Precision (%)	Recall (%)
Stand	99.3	98.3	98.5
Lie	99.6	98.6	99.1
Eat	98.9	97.0	97.0
All	99.3	97.9	98.2

The reported detection results are very good in all metrics, considering the natural conditions of the commercial pig farm in our dataset. The cameras do not have a good viewing angle

due to the low ceiling of pens, which was designed for human monitoring and also for saving purposes. For this reason, some pigs are overlapped in videos when they stay close to each other and far from the camera. If pens are designed to support the automatic tracking task with a higher ceiling, the detection results will be better. Fig. 3 shows a case where a pig was hidden by the feeder due to the low camera viewing angle and could not be detected.

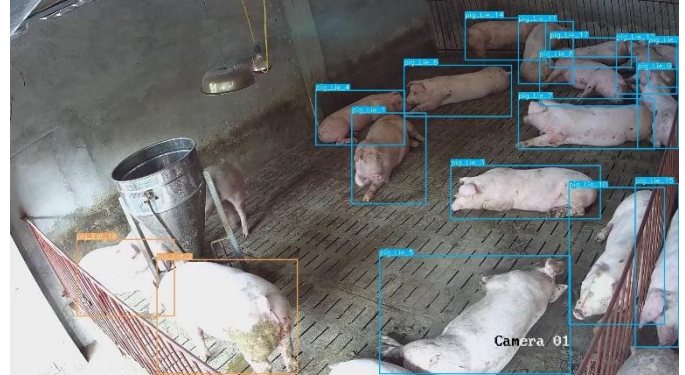


Fig. 3. Sample image for a detection errors when a pig was hidden by the feeder due to the low camera viewing angle.

C. Tracking Results

Table IV shows the results of the tracking model in MOTA and IDF1 scores. We also reported the number of identity switches (IDS), which calculates the times when trackers swap from one to another. This metric is also important because it shows the number of identification errors during the tracking process.

TABLE IV. RESULTS OF PIG TRACKING MODEL

Validation set	Original DeepSORT			Improved DeepSORT		
	MOTA (%)	IDF1 (%)	IDS	MOTA (%)	IDF1 (%)	IDS
Sequence 1	91.5	93.4	13	92.8	95.6	10
Sequence 2	92.5	94.0	10	94.3	96.1	8
Avg.	92.0	93.7	11.5	93.6	95.9	9

The overall MOTA (93.6 %) and IDF1 (95.9 %) are satisfactory. Results for Sequence 2 are slightly higher because it was collected from the sick pig pen, where pigs move less than in the healthy pig pen.

The average number of IDS is 9, meaning that each pig changed its identification only about 0.4 times on average during the tracking process. In our object tracking algorithm, the objects are tracked not only based on their trajectory but also on their visual similarity. And the object in the current frame will be associated with the object in some frames before it. Therefore, even though the pigs in the previous frames and the current frame are predicted to have different class labels, they will be assigned the same ID. This is important for the tracking process because it will not cause identification errors.

Fig. 4 illustrates the cases where pigs change behaviors during the tracking process but their IDs remain unchanged.

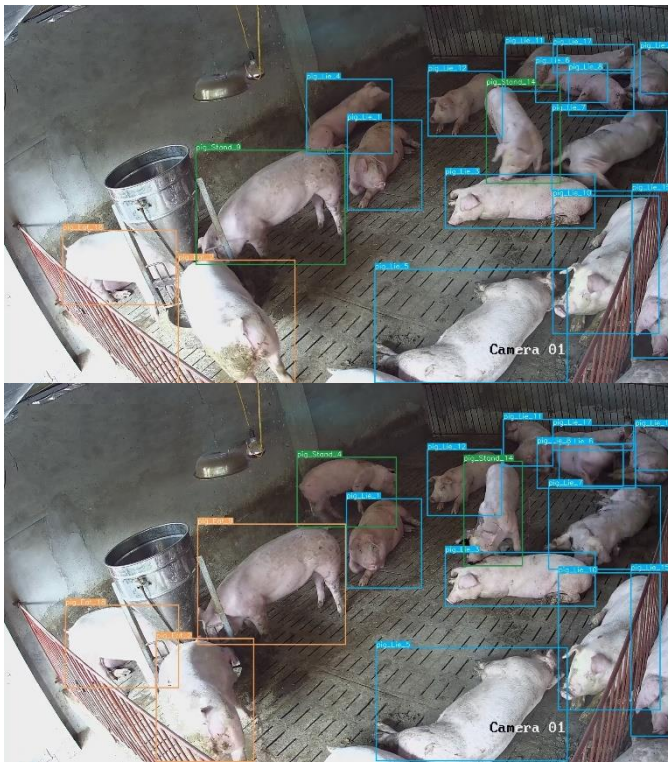


Fig. 4. Sample frames for tracking results when pig 9 was approaching the feeder with the recognized behavior “Standing” (above), then changed to “Eating” (below), but the ID was not changed. Similarly, the pig 4 changed behavior from “Lying” to “Standing” but the ID is the same.

D. Behavioral Abnormality Detection Results

Based on the pig behavior analysis datasets, the experimental process of behavior analysis and abnormality detection is as follows:

- Building healthy pig behavior patterns: Nine videos from the healthy pig pen for behavior pattern building purposes are fed through the detection and tracking models. The time for behaviors of individual pigs in these videos is calculated and averaged to build three behavior patterns of healthy pigs in three activity periods in a day. Please note that in commercial settings, the behavior patterns can be built using more 30-minute videos collected from tracking cameras. We just used three videos for each activity period for experiment purposes.
- Testing on the videos collected for testing purposes: Six videos from the healthy pig pen and sick pig pen (two for each activity period) are fed through the detection and tracking models. The behavior of each individual pig will be calculated and compared to the healthy pig behavior pattern in the same period built in the previous step using the Euclidean distance formula.

Table V shows the healthy pig behavior patterns built from videos.

TABLE V. HEALTHY PIG BEHAVIOR PATTERNS

Activity period	Moving Time	Standing Time	Lying Time	Eating Time	Total
Resting	0.4	0.4	29.2	0	30
Eating	5.3	5.2	0.5	19.0	30
Playing	23.1	4.5	1.8	0.5	30

From the behavior patterns shown in the above table, we can see the typical behaviors of healthy pigs during each activity period of a day. For example, in the resting period, pigs spend most of their time lying while in the playing time, they mostly move around the pen (for playing or searching for food).

Table VI shows the time of each behavior for each pig in testing videos and the Euclidean distance between each pig behavior set and the healthy pig behavior pattern in the same activity period.

TABLE VI. BEHAVIOR TIME FOR PIGS IN TESTING VIDEOS

A) RESULTS ON A HEALTHY PIG VIDEO IN THE RESTING PERIOD

Pig ID	Running Time	Standing Time	Lying Time	Eating Time	Euclidean Distance
1	0	0	30	0	0.9
2	0	0	30	0	0.9
3	0	1	29	0	0.8
4	0	0	30	0	0.9
5	0.5	1	28.5	0	1.0
6	1	1	28	0	1.5
7	0	0	30	0	0.9
8	1.5	2	26.5	0	3.4
9	0	0	30	0	0.9
10	0	0	30	0	0.9
11	0	0	30	0	0.9
12	1	1	28	0	1.5
13	0	0	30	0	0.9
14	2	3	25	0	5.2
15	0	0	30	0	0.9
16	1	2	27	0	2.8

B) RESULTS ON A SICK PIG VIDEO IN THE RESTING PERIOD

Pig ID	Running Time	Standing Time	Lying Time	Eating Time	Euclidean Distance
1	0	0	30	0	0.9
2	0	0	30	0	0.9
3	0	0	30	0	0.9
4	0	0	30	0	0.9
5	0	0	30	0	0.9
6	0	0	30	0	0.9
7	0.5	0	29.5	0	0.5
8	0	0	30	0	0.9
9	0	0	30	0	0.9
10	0.5	0	29.5	0	0.5
11	0	0	30	0	0.9
12	0	0	30	0	0.9
13	0	0	30	0	0.9
14	0	0	30	0	0.9
15	0	0	30	0	0.9

C) RESULTS ON A HEALTHY PIG VIDEO IN THE EATING PERIOD

Pig ID	Running Time	Standing Time	Lying Time	Eating Time	Euclidean Distance
1	4.5	5.5	0	20	1.4
2	5	2	1.5	21.5	4.2
3	5	12	0	13	9.1
4	2	12.5	0	15.5	8.7
5	2	4	2	22	4.8
6	2.5	2	0	25.5	7.8
7	1.5	4	0	24.5	6.8
8	4.5	8.5	0	17	3.9
9	5.5	6	0	18.5	1.1
10	4	12	0	14	8.5
11	4.5	4	0	21.5	2.9
12	3	2	0	25	7.2
13	2	5.5	0	22.5	4.8
14	5	5	0	20	1.2
15	3	2.5	0	24.5	6.6
16	5	3	0	22	1.9

F) RESULTS ON A SICK PIG VIDEO IN THE PLAYING PERIOD

Pig ID	Running Time	Standing Time	Lying Time	Eating Time	Euclidean Distance
1	8.8	7.3	13.8	0.0	18.9
2	5.7	6.3	18.0	0.0	23.8
3	7.7	4.8	17.5	1.7	22.0
4	7.0	11.3	11.7	0.0	20.1
5	8.3	8.0	13.7	0.0	19.2
6	4.0	9.7	17.0	0.0	24.9
7	12.2	5.0	12.3	0.5	15.2
8	13.7	4.0	12.3	2.3	14.2
9	12.3	4.7	12.7	0.3	15.3
10	6.3	9.7	14.0	0.0	21.3
11	7.0	10.0	13.0	0.0	20.3
12	4.2	6.2	19.7	0.0	26.1
13	8.0	9.0	13.0	0.0	19.3
14	15.0	5.5	9.5	0.0	11.2
15	8.8	7.3	13.8	0.0	18.9

D) RESULTS ON A SICK PIG VIDEO IN THE EATING PERIOD

Pig ID	Running Time	Standing Time	Lying Time	Eating Time	Euclidean Distance
1	1.0	0.5	15.5	13.0	17.4
2	1.0	1.8	25.8	1.3	31.4
3	2.0	2.7	23.3	2.0	28.8
4	3.3	2.0	8.7	16.0	9.5
5	2.3	5.8	10.5	11.3	13.0
6	4.0	5.0	7.0	14.0	8.3
7	2.8	5.5	8.7	13.0	10.4
8	1.5	4.3	6.8	17.3	7.6
9	0.8	3.7	12.8	12.7	14.6
10	4.3	4.7	10.0	11.0	12.5
11	5.0	9.0	15.0	1.0	23.4
12	3.2	3.2	8.3	15.3	9.1
13	2.2	1.0	12.2	14.7	13.5
14	3.7	5.3	10.0	11.0	12.5
15	2.0	2.9	23.5	1.6	29.1

E) RESULTS ON A HEALTHY PIG VIDEO IN THE PLAYING PERIOD

Pig ID	Running Time	Standing Time	Lying Time	Eating Time	Euclidean Distance
1	15	14	0	1	12.6
2	25	5	0	0	2.7
3	22.5	5.5	0	2	2.6
4	24.5	3.5	2	0	1.8
5	26	4	0	0	3.5
6	20	8.5	0	1.5	5.4
7	21	7.5	1.5	0	3.7
8	20	7	3	0	4.2
9	21	6	0	3	4.0
10	20.5	9.5	0	0	5.9
11	17.5	10.5	0	2	8.5
12	20	9.5	0.5	0	6.0
13	22	7.5	0	0.5	3.7
14	21	4.5	4.5	0	3.4
15	20	8.5	1.5	0	5.1
16	19	9	0	2	6.5

As shown in Tables VI(A) and VI(B), pigs spend almost all of their time lying in both healthy and sick pig videos in resting period. Therefore, it is difficult to detect behavioral abnormalities in this period. We may only detect the pigs infected with a disease that makes them excited and move or run continuously, even in the resting period. However, there is no pig with that kind of disease in our datasets, so we cannot draw conclusions about that case.

The detection of behavioral abnormalities is much better in the two remaining activity periods. Results from Tables VI(C) and VI(D) showed that the healthy pigs spent most of their time eating, but the sick pigs also spent a considerable amount of time lying during the eating period. Therefore, if we set a threshold for Euclidean distance to 9, we can detect behavioral abnormalities with accuracy around 90% on average (15/16 are correct predictions for healthy pigs and 12/14 are correct predictions for sick pigs). Similarly, if we set the Euclidean distance threshold to 12 in the playing period, the accuracy on average is around 93% (15/16 correct predictions for healthy pigs and 14/15 correct predictions for sick pigs).

In our experiments, due to the regulations in the livestock sector, we had difficulties infecting the healthy pigs with the viruses to make them sick. Instead, we used the sick pigs collected from other pens to collect data for testing. Therefore, the pigs in sick pig videos are different from the pigs in healthy pig videos, which are used to build behavior patterns. The abnormality detection performance for sick pigs will be better if behavior patterns are built on the same pigs that are tracked. This is feasible in commercial settings, in which behavior patterns are built in the same pen with tracked pigs (abnormality detection for pigs today can use the behavior patterns built yesterday).

IV. CONCLUSION

We proposed a method for pig behavior detection, tracking, and behavioral abnormality analysis based on behavior patterns built from 30-minute videos in different activity periods under the natural conditions of pig farms using deep learning. We conducted various experiments to illustrate our method on our own datasets collected from a commercial pig farm, including healthy pig and sick pig datasets.

The experiment results showed that the behavior patterns built using the activity period-based approach can capture the typical characteristics of pigs in each activity period and can be used to detect behavioral abnormalities in pigs.

The activity period-based approach also has a lot of potential for future improvements. For example, more activity periods can be studied and used rather than only three, or weights can be assigned for behavior metrics to indicate the importance of typical behaviors in each activity period. We can also add more metrics to the behavior patterns and develop a more sophisticated method for abnormality detection based on the behavior patterns.

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REFERENCES

- [1] J. Cowton, I. Kyriazakis, and J. Bacardit, "Automated Individual Pig Localisation, Tracking and Behaviour Metric Extraction Using Deep Learning," *IEEE Access*, vol. 7, pp. 108049-108060, 2019, doi: 10.1109/ACCESS.2019.2933060.
- [2] M. Mittek, E. Psota, L. Pérez, T. Schmidt, and B. Mote, "Health monitoring of group-housed pigs using depth-enabled multi-object tracking," in *Proc. Int Conf. Pattern Recognit.*, Workshop Vis. Observ. Anal. Vertebrate Insect Behav., 2016.
- [3] J. Sa, Y. Choi, H. Lee, Y. Chung, D. Park, and J. Cho, "Fast pig detection with a top-view camera under various illumination conditions," *Symmetry*, vol. 11, no. 2, p. 266, 2019.
- [4] J. Kim et al., "Depth-Based Detection of Standing-Pigs in Moving Noise Environments," *Sensors* 17, 2757, 2017, doi: 10.3390/s17122757
- [5] J. Kim et al., "Lying-Pig Detection using Depth Information," in *Proc. ICACS '17*, pp. 40-43, 2017, doi: 10.1145/3127942.3127949
- [6] J. Redmon, S. Divvala, R. Girshick, and A. Farhadi, "You only look once: Unified, real-time object detection," in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit.*, pp. 779-788, 2016.
- [7] S. Ren, K. He, R. Girshick, and J. Sun, "Faster r-cnn: Towards real-time object detection with region proposal networks," in *Proc. IEEE Trans. Pattern Anal.* 2017, 39, 1137-1149
- [8] W. Liu et al., "Ssd: Single shot multibox detector," *Lect. Notes Comput. Sci.* 2016, 9905, 21-37.
- [9] Q. Yang, D. Xiao, and S. Lin, "Feeding behavior recognition for group-housed pigs with the faster r-cnn," *Comput. Electron. Agric.* 155, 453-460, 2018.
- [10] A. Alameer, I. Kyriazakis, and J. Bacardit, "Automated recognition of postures and drinking behaviour for the detection of compromised health in pigs," *Sci Rep* 10, 13665, 2020, doi: 10.1038/s41598-020-70688-6
- [11] A. Alameer, I. Kyriazakis, H. Dalton, A. Miller, and J. Bacardit, "Automatic recognition of feeding and foraging behaviour in pigs using deep learning," *Biosyst. Eng.* 197, 91-104, 2020.
- [12] M. Riekert, A. Klein, F. Adrion, C. Hoffmann, and E. Gallmann, "Automatically detecting pig position and posture by 2d camera imaging and deep learning," *Comput. Electron. Agric.* 174, 105391, 2020.
- [13] L. Bergamini et al., "Extracting accurate long-term behavior changes from a large pig dataset," in *Proc. 16th VISIGRAPP*, Vol. 4, pp. 524-533, 2021, doi: 10.5220/0010288405240533.
- [14] S. Matthews, A. Miller, T. Plötz, and I. Kyriazakis, "Automated tracking to measure behavioural changes in pigs for health and welfare monitoring," *Sci. Rep.* 7, 17582, 2017.
- [15] L. Zhang, H. Gray, X. Ye, L. Collins, and N. Allinson, "Automatic individual pig detection and tracking in pig farms," *Sensors* 19, 1188, 2019.
- [16] S. Tu et al., "Automated Behavior Recognition and Tracking of Group-Housed Pigs with an Improved DeepSORT Method," *Agriculture*, vol. 12, no. 11, p. 1907, Nov. 2022, doi: 10.3390/agriculture12111907.
- [17] C. Wang, A. Bochkovskiy, H. Liao, "YOLOv7: Trainable bag-of-freebies sets new state-of-the-art for real-time object detectors," *arXiv* 2022, arXiv:2207.02696.
- [18] N. Wojke, A. Bewley, and D. Paulus, "Simple Online and Realtime Tracking with a Deep Association Metric," *arXiv*, 2017, doi: 10.48550/ARXIV.1703.07402.
- [19] Tzutalin, "LabelImg," <https://github.com/tzutalin/labelImg> Git code, 2015.
- [20] G. Bernal, et al., "Coco", 2018.
- [21] R. Kalman, "A new approach to linear filtering and prediction problems," *Trans. ASME, D, J. Basic Eng.*, vol. 82, pp. 35-45, 1960.
- [22] H. Kuhn, "The Hungarian method for the assignment problem," *Naval Res. Logistics Quart.*, vol. 2, nos. 1_2, pp. 83_97, 1955.
- [23] K. Zhou, "Omni-Scale Feature Learning for Person Re-Identification," 2019, <https://arxiv.org/abs/1905.00953>
- [24] A. Milan, L. Leal-Taixé, L. Reid, S. Roth, and K. Schindler, "Mot16: A benchmark for multi-object tracking," *arXiv preprint arXiv:1603.00831*, 2016.

Forecasting Model of Corn Commodity Productivity in Indonesia: Production and Operations Management, Quantitative Method (POM-QM) Software

Asriani^{1*}, Usman Rianse², Surni³, Yani Taufik⁴, Dhian Herdhiansyah⁵
Faculty of Agriculture, University of Muhammadiyah Kendari, Indonesia¹
Faculty of Agricultural, University of Halu Oleo, Kendari, Indonesia^{2,3,4,5}

Abstract—Food is an essential ingredient needed by humans. In addition to being consumed, it can also be a valuable commodity for economic purposes through productivity of food crops. Therefore, this study aims to model the forecasting of maize productivity in Indonesia using Production and Operations Management-Quantitative Method (POM-QM) software. The data collected on productivity of corn commodities in Indonesia between 1980-2019 shows fluctuations, with both deficit and surplus periods. This study uses a time series data-based forecasting model consisting of three methods, namely Double Moving Average (DMA), Weighted Moving Average (WMA), and Single Exponential Smoothing (SES). The selection of the best model was conducted based on the Mean Absolute Deviation (MAD), Mean Square Error (MSE), and Mean Absolute Percent Error (MAPE). SES emerged as the most preferred, with a lower MAPE value of 4.913%. The predicted productivity of corn in Indonesia is estimated at 5.28 tons/ha/year, sufficient to meet consumers' demand. Therefore, governments are recommended to use this information in predicting corn productivity to meet the national demand in the future.

Keywords—Forecasting model; productivity; corn commodity; POM-QM

I. INTRODUCTION

Food security is a vital issue in Indonesia. Furthermore, it is essential to make sufficient food available to meet the population's needs, to avoid prolonged political and social turmoil. Food security is also an indicator of a country's economic growth and can reflect prosperity and a benchmark for the level of welfare, especially in terms of people's productivity and consumption [1]. Therefore, to optimize the utilization of natural resources in each region, it is imperative to implement management strategies tailored to each region's unique characteristics [2-6].

The government's commitment to addressing food security is evidenced by recognizing food as a human right for Indonesian citizens, as stipulated in Law Number 18 of 2012. This aligns with the first and second goals of the Sustainable Development Goals (SDGs), which aim to end poverty worldwide and achieve food security and improved nutrition while promoting sustainable agriculture.

The commodity corn (*Zea mays* L.) is an alternative staple food and a grain plant from the grass family (Graminaceae). In Indonesia, the main maize-producing regions include Central Java, West Java, East Java, Madura, Special Region of Yogyakarta, East Nusa Tenggara, North Sulawesi, South

Sulawesi, and Maluku. Especially in East Java and Madura, corn plants are cultivated intensively due to the favorable soil and climate conditions that support their growth [7].

Corn is a food commodity that plays an essential and strategic role in national development [8], and its contribution to the Gross Domestic Product (GDP) continues to increase yearly, even during an economic crisis [9]. It is one of the most important staple foods in Indonesia. Furthermore, this crop, alongside two other commodities, namely rice and soybeans, is the main target of the Ministry of Agriculture in achieving food self-sufficiency.

Corn is also widely used for multiple purposes, including as a food and feed ingredient. It is being adopted as an alternative fuel source domestically and internationally [8]. However, the demand for this crop remains high since it serves as an ingredient for animal feed companies and other food processing industries [10]. The Ministry of Agriculture considers five commodities such as corn, rice, soybeans, sugar, and beef, as the main food items [11].

As the second most produced food after rice, corn's high demand as animal feed and for industrial purposes poses challenges such as depletion of natural resources and the impact of climate change. Cooperation and collaboration are required to support the development of sustainable corn commodities [12]. However, the problem of land-carrying capacity is a constraint for Indonesian agriculture. As the population increases, more land is needed to meet housing demands, leading to the conversion of agricultural land and affecting corn productivity in the country. Despite a fluctuating rise in production in Indonesia between 1980 and 2019, the overall increase was only 3.98 tons/ha/year or 0.102% per year [11]. There are high fluctuations in productivity of corn commodities. This fluctuation is attributed to internal and external factors such as climate, weather, and government policies.

Thirty years ago, maize was primarily consumed as food. However, with the development of the poultry industry in the early 1970s, corn began to be used as an energy source for modern poultry feed [13]. Before 1990, it was shown that 86% of this crop in Indonesia was consumed directly, and only about 6% was used in the feed industry. Despite this, the adoption of maize in the food industry remains low, accounting for only 7.5% [6]. The availability of this commodity is wider in the rainy than dry season [14]. This

crop is typically cultivated on dry land and planted during the rainy season. The limited harvest area during the dry season results in the low availability of corn to meet the domestic industry's needs [9].

According to Purwanto [14], from 1989-2002, there was a shift in the use of maize, with a continued dominance for direct consumption. After 2002, a greater proportion was employed to meet the demand of the feed industry. The use of this commodity in the food industry has also been on the rise. This change has transformed maize from a staple food commodity into an industrial raw material [15]. The demand for the commodity continues to grow yearly with the increasing population and industry [14]. Additionally, rising oil prices also impact its dynamic demand. The increase in the use of maize as an alternative energy and raw material for the feed and food industries is expected to persist. Furthermore, the rise in per capita income causes an increase in demand for corn commodity derivative products [9].

Forecasting involves estimating future requirements, including the quality of goods, time, and location needed to meet demand [16]. It is the art and science of predicting events yet to occur by always using data from the past [17-18]. According to [19-20], as a crucial component of decision-making, forecasting requires predicting future events to inform effective decisions. Inaccurate forecasting results pose a persistent challenge [16].

Time series analysis and forecasting are active study areas [21]. The accuracy of time series forecasting plays a crucial role in the decision-making process. The several method used in prediction include the time series method, which is grouped into the average (Single Moving Average (SMA) and Double Moving Average (DMA)), the smoothing (Single Exponential Smoothing (SES), double exponential smoothing from Brown and Holt), and the regression method, namely time series regression [22-23-24].

Method used in forecasting vary widely but are adapted to the pattern of data. Generally, there are three types of method to determining the level of the error. These include MAD, MSE, and MAPE, which calculate the average absolute difference, average difference in rank, and average absolute difference percentage, respectively [25]. In utilizing the time series method, it is important to identify the data pattern type, which includes trend, cyclical, seasonal, and horizontal [26].

The availability of several statistical softwares supports the selection of forecasting method. Various study analysts have conducted forecasting models using software assistance to facilitate calculations [27]. For instance, POM-QM software has been studied for product sales forecasting [28]. Furthermore, this method provides module options for mathematical calculations. Its forecasting model has several method, including Naive, Moving Average, Weighted Moving Average (WMA), Exponential Smoothing, Trend Analysis (regression over time), Linear Regression/Least Square, Multiplicative Decomposition (seasonal), and Additive Decomposition (seasonal). Given these considerations, it is necessary to have a model to predict productivity of corn commodities. Therefore, this study aims to establish a forecasting model for corn commodity productivity in

Indonesia using Production and Operation Management-Quantitative Method (POM-QM) software.

II. MATERIALS AND METHOD

The variable used was the harvested area of corn per year from 1980-2019. Secondary data in the form of time series sourced from the data and information center (Pusdatin) under the Ministry of Agriculture and the Central Bureau of Statistics (BPS) were used in this study. The population consists of information on productivity of corn commodities from 1980-2019. A saturated sampling method was employed, where all population members were used as samples.

Forecasting model for corn commodity productivity in Indonesia:

A. Forecasting Model of Corn Commodity Productivity with DMA

Double-moving average is used to forecast time series data with a linear trend [26]. Multiple moving averages, also known as linear moving averages, deal with time series data with patterns that tend to experience a linear trend. Furthermore, the double-moving average is a method that simultaneously uses single-moving average data with adjustments between the first and second moving averages and trend adjustments [29].

DMA is a method in which the first and second moving average groups are calculated. It is symbolized by $(k \times k)$, meaning that the moving average is calculated using the k periods [23]. The moving average method has no objective basis for determining the number of moving average orders [30].

Many methods can be used in forecasting, including DMA. The data used for calculations do not have elements of trend or seasonal factors. DMA is a forecasting method performed on past data for two periods with an average pattern [31], which is suitable for long-term data [32]. The mathematical equation of DMA is presented in Equation 1:

$$F_{t+1} = X_1 + X_2 + \dots + X_T \quad (1)$$

Information:

F_{t+1} = Forecast for period t+1

X_T = True value of t period

T = Timeframe of moving average

The process data analysis in forecasting model for corn commodity productivity using DMA involve several steps, including (a) identify time series data patterns, (b) determine the value of the first moving average, (c) determine the value of the second moving average, (d) determine the value of the constant (at), (e) determine the value of the trend coefficient (bt), (f) select the best model based on the criteria for forecasting accuracy, and (g) determine forecast results for future periods. The data analysis was performed using the help of POM-QM software to facilitate the computation process.

B. Forecasting Model of Corn Commodity Productivity with WMA

WMA forecasting method develops the moving average method with additional weights in the calculation. It is calculated by assigning greater influence to certain values in a data set based on their attributes. In contrast, the average is determined by giving weights. WMA forecasting method is an advanced version of the moving average method in which each time series is given a certain and different weight [33]. In simple terms, WMA is a moving average given weight in each data [34].

Determination of weight is subjective, depending on the experience and opinion of the data analyst. For instance, the analyst may give more weight to the last observation or vice versa. The weighted factor will be greater in the final period than in the early period when the weighting opportunity is higher in the previous observation. The longer the period specified, the greater the weighting given to the most recent data, and the number of weighted opportunities equals one [35]. Finally, the formula used in forecasting model of corn commodity productivity with WMA is presented in Equation 2.

$$WMA_{t+1} = \frac{kX_1 + (k-1)X_{t-1} + \dots + X_{t-(n-1)}}{k + (k-1) + \dots + 1} \quad (2)$$

Information:

k number of periods or ranges of forecasting numbers,

X_t is the time series data value at point t.

C. Forecasting Model for Corn Commodity Productivity with SES

SES is a simple method that requires estimating a single parameter. It assigns Exponential Moving Average (EMA) weights to all historical data. The exponential smoothing forecasting method is an iterative procedure of repeating calculations that improves the forecast (smoothing) by calculating the average of past values in a time series in an exponential manner [36-37-38]. SES is appropriate for data without extreme trends and is usually for forecasting one period in the future. The goal is to estimate the current level and use it to forecast preceding values. Forecasting model for corn productivity with SES employs the formula in equation 3 [39].

$$F_{t+1} = \alpha \cdot X_t + (1 - \alpha) F_t \quad (3)$$

Information:

F_{t+1} is the forecast for the next period, α is the smoothing constant, X_t is the t-th data or observation, and F_t is the t-th period data. The F_{t+1} forecast is based on the weighting of the latest X_t data with a weight of α and the newest forecasting weighting of F_t with a weight of $1-\alpha$. By repeating this process and replacing F_{t+1} and F_{t+2} with their components, the result in Equation 4 is obtained:

$$\begin{aligned} F_{t+1} &= \alpha \cdot X_t + (1 - \alpha) F_t \quad (4) \\ &= \alpha \cdot X_t + (1 - \alpha) [\alpha \cdot X_{t+1} + (1 - \alpha) F_{t+1}] \\ &= \alpha \cdot X_t + \alpha(1 - \alpha)X_{t+1} + (1 - \alpha)^2 F_{t+1} \end{aligned}$$

$$= \alpha \cdot X_t + \alpha(1 - \alpha)X_{t+1} + \alpha(1 - \alpha)^2 F_{t+1}$$

Therefore, F_{t+1} is WMA of all historical data. As t increases, the value of $(1-\alpha)^2$ decreases, leading to a smaller contribution from $F(1)$. Since $F(1)$ is not known, the initial value can be estimated. For volatile initial data, one method is to set the first forecast equal to the first observation, $F_1=y_1$. Furthermore, for initial data that is quite constant, the average of the first five or six data points can be used as the first forecast $F_1=MA(5)$ or $F_1=MA(6)$. The exponential smoothing equation can be rewritten in a form that describes the role of the weighting factor α , as shown in Equation 5:

$$F_{t+1} = F_t + \alpha(X_t - F_t) \quad (5)$$

Exponential smoothing is used to adjust a previous forecast (F_t) by incorporating adjustments for errors. The value of α , which ranges between 0 and 1, cannot be equal to 0 or 1. To obtain a stable forecast with random smoothing, a small α value should be used for data that does not fluctuate too much. In contrast, a large α value is more appropriate for data that fluctuates significantly and requires a fast response to changes. To determine the optimal α value, one can estimate it using trial and error, testing values of 0.1, 0.2, 0.3, ..., 0.9, and selecting the value with the smallest MSE for the next forecast.

Selection of the best model for forecasting productivity of corn commodities

The accuracy of calculations in the forecasting method is often subject to variations in data patterns. Therefore, selecting the right method is imperative to minimize errors in the forecasting results [40]. Each method has its level of accuracy that needs to be considered. As a result, it is essential to choose a method that can minimize forecasting errors. According to [41-42], forecast facts are expected to have small values and errors. The error value is inversely proportional to the accuracy of the prediction result.

The selection of the best forecasting model depends on the resulting error. Some of the criteria that are often used to calculate the accuracy of the model forecasting time series include: (a) Mean Absolute Deviation (MAD), (b) Mean Square Error (MSE), and (c) Mean Absolute Percent Error (MAPE). The smaller the criterion value, the better the prediction results obtained [43-45].

1) MAD: Method for determining the overall forecast error is MAD, which is obtained by dividing the sum of the absolute values of each error by the sample size (number of forecast periods) [43-44]. Finally, the mathematical formula of MAD is presented in Equation 6:

$$MAD = \frac{\sum_t^n (A_t - F_t)}{n} \quad (6)$$

information:

A_t = Actual demand in period t

F_t = Forecasting demand in period t

n = Number of forecasting periods involved

2) *MSE*: MSE is calculated by adding the squares of all errors in each period and dividing them by the number of forecasting periods [43-44]. The mathematical expression of MSE is presented in Equation 7:

$$MSE = \frac{\sum_{t=1}^n |A_t - F_t|^2}{n} \quad (7)$$

Information:

A_t = Actual demand in period t

F_t = Forecasting demand in period t

n = Number of forecasting periods involved

3) *MAPE*: MAPE is an evaluation calculation used to measure the accuracy of prediction [45-46-47]. It [48-49] was chosen as the performance metric and was employed to assess forecasting method accurately. Furthermore, MAPE is not influenced by the predicted time series magnitude [50-51]. Also, it is frequently used in practice [52], independent of scale, and easy to interpret, which makes it popular among industry practitioners [53-54]. MAPE measures the average of absolute errors as a percentage of the average absolute error rate of the actual data period. The mathematical expression is shown in Equation 8:

$$MAPE = \frac{(100)}{n} \sum_{t=1}^n \frac{|A_t - F_t|}{|A_t|} \quad (8)$$

Information:

A_t = Actual demand in period t

F_t = Forecasting demand in period t

n = Number of forecasting periods involved

MAPE measures the average of absolute errors as a percentage of the average value total error rate of the actual data period. Its criteria explain that the smaller the MAPE value, the better the accuracy. Table I shows the score criteria [55].

TABLE I. MAPE VALUE CRITERIA

MAPE value	Criteria
< 10	Very good
10 - 20	Well
20 - 50	Enough
>50	Bad

Productivity data processing of corn commodities is carried out using POM-QM software.

The subsequent stage involves describing and processing data on productivity of corn commodities. The POM-QM software application was employed to process corn commodity productivity data from 1980-2019. Several forecasting method in the POM-QM application were utilized, resulting in the generation of anticipated forecast outcomes.

To apply the POM-QM software in forecasting productivity of corn commodities, the steps to be followed include: (a) run the QM program and select the module-forecasting; (b) select the menu File-New-Time series Analysis and a dialogue box titled “Create data set for Forecasting/Time-series Analysis” will appear (c) in the dialog box, provide the title of the forecast, "Productivity of corn commodities," along with the number of time series data periods to be used as training data, starting from 1980-2019. Specify the name that will appear for each row period name, either using numbers, letters, or months. After completing the above steps, press the OK button. The data settings in QM for Windows are shown in Fig. 1.

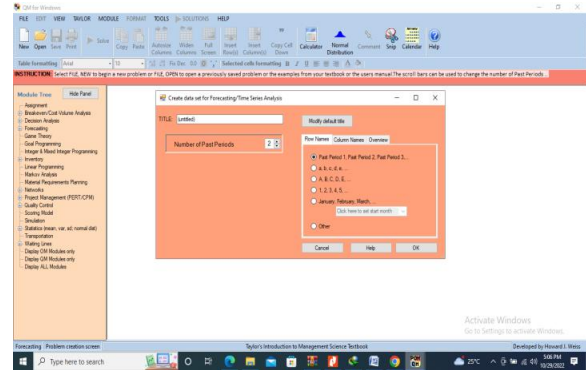


Fig. 1. Data settings in QM for windows.

Forecasting is crucial for companies as it aids in managing productivity, inventory, and planning decisions [56]. According to [57], relying on a single forecasting model is insufficient. Several choices of forecasting models should be considered to arrive at the most accurate prediction. The forecasting results for productivity of corn from each method are then collected and analyzed for accuracy. Therefore, it is important to choose the appropriate forecasting method, as using an inappropriate one may reduce the forecast's accuracy.

III. RESULTS AND DISCUSSION

A. Forecasting Model of Corn Commodity Productivity with DMA

DMA is a forecasting method conducted by adding corn commodity productivity data in the two previous periods and dividing the sum by two. It can also be performed by calculating the average of corn commodity productivity data in the two previous periods. The results of moving average forecasting are shown in Table II.

TABLE II. CALCULATION OF THE DOUBLE MOVING AVERAGE FORECAST AT CORN COMMODITY PRODUCTIVITY

Measure	Value
Error Measures	
Bias (Mean Error)	.154
MAD (Mean Absolute Deviation)	.154
MSE (Mean Squared Error)	.037
Standard Error (denom=n-2=35)	.199
MAPE (Mean Absolute Percent Error)	4.913%
Forecast	
next period	5.28

Based on DMA applied to forecast corn commodity productivity, Table II presents the results of the bias or average error, which are 0.154. MAD is also 0.154, while MSE (Mean Squared Error) is 0.037. Fig. 2 shows the forecasting graph of productivity of corn commodities using this method.

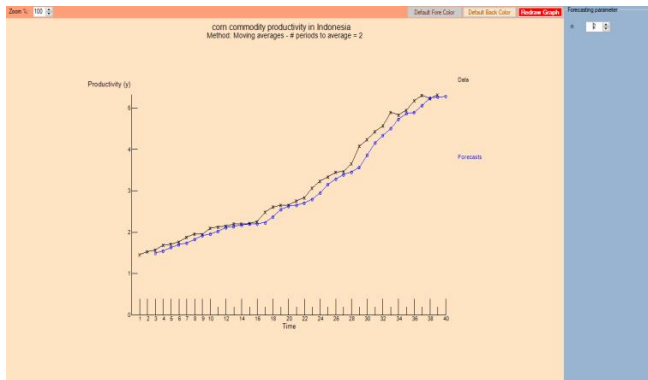


Fig. 2. Forecasting graph with the double moving average method on productivity commodity corn.

Fig. 2 shows that the forecasting results for corn commodity productivity from DMA appear different from the actual data. This is because the standard error of this method is 0.199 deviations.

B. Forecasting Model for Productivity of Corn Commodity with WMA

WMA 2 is performed by assigning weight to corn commodity productivity data for the last two years. The forecasting of corn commodity productivity began in 1980-2019. The calculation process of this forecasting method is presented in Table III.

TABLE III. FORECASTING THE WEIGHTED MOVING AVERAGE ON PRODUCTIVITY COMMODITY CORN

Measure	Value
Error Measures	
Bias (Mean Error)	.205
MAD (Mean Absolute Deviation)	.205
MSE (Mean Squared Error)	.065
Standard Error (denom=n-2=35)	.261
MAPE (Mean Absolute Percent Error)	6.517%
Forecast	
next period	5.23

Based on WMA applied to forecast corn commodity productivity, Table III present the results of the bias or average error, which are are 0.205. MAD is also 0.205, while MSE is 0.65. Fig. 3 shows the forecasting Graph with WMA for productivity of corn commodities.

According to Fig. 3, the forecasting results for corn commodity productivity using WMA display a slight increase towards the end of the period in comparison to DMA. However, it should be noted that this increase is attributed to the standard error of 0.261 deviation, as evidenced by the actual data.

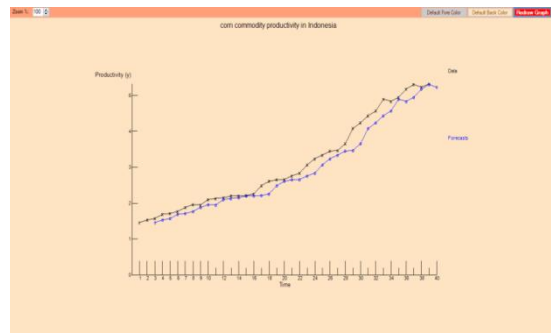


Fig. 3. Forecasting graph with the weighted moving average method at corn commodity productivity.

C. Forecasting Model of Corn Commodity Productivity with SES

To calculate the forecasting of corn commodity productivity using SES, the α coefficient is first determined. This is performed by multiplying α by the actual demand. Afterwards, the result is added with the outcome of 1 minus α multiplied by corn commodity productivity forecast in the previous period. The value of α is assumed to be 0.5 in this model. The forecasting process using SES is presented in Table IV.

TABLE IV. FORECASTING SINGLE EXPONENTIAL SMOOTHING AT CORN COMMODITY PRODUCTIVITY

Measure	Value
Error Measures	
Bias (Mean Error)	.2
MAD (Mean Absolute Deviation)	.2
MSE (Mean Squared Error)	.056
Standard Error (denom=n-2=36)	.244
MAPE (Mean Absolute Percent Error)	6.356%
Forecast	
next period	5.263

Table IV shows that from the results of forecasting productivity of corn commodities using SES, the bias or average error of this forecast are 0.2. MAD is also 0.2, while MSE is 0.056. Fig. 4 shows the forecasting Graph of SES.

Fig. 4 shows that the forecasting results for corn commodity productivity from WMA appears to be more stable than SES. This is because the standard error of this method is 0.244 deviations.

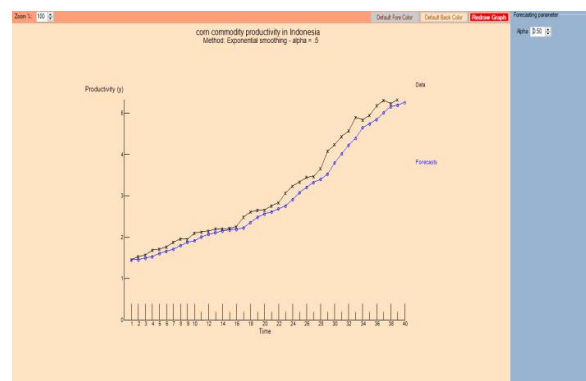


Fig. 4. Forecasting graph with the single exponential smoothing method on corn commodity productivity.

Table V presents the forecasted corn commodity productivity using method such as (a) DMA, (b) WMA, and (c) SES in the next (year). The data used in the analysis consist of 39 years productivity, spanning from 1980-2019.

TABLE V. THE VALUE OF THE SIZE OF THE ERROR IN THE FORECASTING MODEL FOR THE PRODUCTIVITY OF CORN COMMODITIES

Method	Value Measurement Error			
	MAD	MSE	SEE	MAPE
Double Moving Average	0.154	0.037	0.199	4.913%
Weighted Moving Average	0.205	0.065	0.261	6.517%
Singel Exponential Smoothing	0.2	0.056	0.244	6.356%

The analysis in Table V compares the error rates of the three different methods for forecasting corn productivity. Based on the results, DMA outperforms the other method with an MAPE value of 4.913%, which is very close to zero. Therefore, DMA is chosen for forecasting corn commodity productivity. The forecasting values for the upcoming period are presented in Table VI.

TABLE VI. VALUE OF CORN COMMODITY PRODUCTIVITY FORECASTING SIZE NEXT PERIOD

Method	Forecasting Next Period's Measurement Value
Double Moving Average	5.28
Weighted Moving Average	5.23
Singel Exponential Smoothing	5.263

Table VI indicates that the forecasted corn commodity productivity for the next period is 5.28 tons/ha/year. This implies that corn commodity production in Indonesia is expected to satisfy the entire consumer demand.

IV. CONCLUSIONS

Forecasting results of corn commodity productivity, using the following methods: (a) Double Moving Average, (b) Weighted Moving Average, and (c) Single Exponential Smoothing in the next (year), from 1980 – 2019: Forecasting model for corn commodity productivity The selected method, namely the Single Exponential Smoothing method, has a lower error rate than other forecasting models, the MAPE value is 4.913%. The forecasting model for corn commodity productivity is 5.28 ton/ha/year, meaning that corn commodity productivity in Indonesia is expected to meet all consumer demands for corn commodities. The results of this study are expected to assist the government in predicting the amount of corn commodity productivity in the next period by national corn needs.

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REFERENCES

[1] Asriani, Herdhiansyah D. Factors affecting the economic policy of food in Indonesia. *Mega Activities: Journal of Economics and Management*. 2019; vol 8(1), pp. 11-17. doi:https://doi.org/10.32833/majem.v8i1.76.

[2] Herdhiansyah, D, Sutiarsa, L., Purwadi, D., Taryono. Analysis of regional potentials for developing leading commodity plantations in

Kolaka Regency, Southeast Sulawesi. *Journal of Agricultural Industrial Technology*. 2012, vol 22(2), pp.106-114.

[3] Herdhiansyah D, Asriani. Strategy for cocoa commodity agro-industry development in Kolaka Regency – Southeast Sulawesi. *Journal of Halal Agroindustry*. 2018, vol 4 (1), pp. 30-41. doi: 10.30997/jah. v4i1.1124.

[4] Herdhiansyah, Dhian, Sudarmi, Sakir, and Asriani. Analysis of Priority Factors for the Development of Leading Plantation Commodities Using the AHP (Analytical Hierarchy Process) Method; *Lampung Agricultural Engineering Journal*, 2021, vol 10(1), pp 239–251.

[5] Herdhiansyah, Dhian, Sudarmi, Sakir, Asriani, and La Ode Midi. Analytical hierarchy process (AHP) in expert choice for determining superior plantation commodities: A case in East Kolaka Regency, Indonesia, *Songklanakar Journal of Science and Technology*, 2021, vol 44(4), pp 923–928.

[6] Herdhiansyah, Dhian, Sudarmi, Sakir, and Asriani. *Techniques for Determining Leading Plantation Commodities*, PT NEM; 2022.

[7] Ministry of Agriculture. Back consumption of corn as a food source of carbohydrates. agricultural research and development agency. [Internet]. [cited 2022 Feb]. Available from: <http://www.litbang.pertanian.go.id/info-aktual/1173/>

[8] Director General of Food Crops. Technical instructions for hybrid corn development movement. directorate general of food crops. [Internet]. [cited 2022 Feb]. Available from:[http://tanamanpangan.pertanian.go.id/assets/front/uploads/document/JUKNIS%20GERAKAN%20PEMBANGUNAN%20JAGUNG%20HIBRIDA-2016%20_\(final\).pdf](http://tanamanpangan.pertanian.go.id/assets/front/uploads/document/JUKNIS%20GERAKAN%20PEMBANGUNAN%20JAGUNG%20HIBRIDA-2016%20_(final).pdf)

[9] Zubachtirodin, M.S. Pabbage, Subandi. Produktivity area and corn development potential. food crops research and development center. [Internet]. [cited 2022 Feb]. Available from: <http://balitsereal.litbang.pertanian.go.id/wp-content/uploads/2016/11/lima.pdf>.

[10] Panikkai S., Nurmali R, Mulatsih S, Purwati H. Analysis of national corn availability towards self-sufficiency achievement with a dynamic model approach. *Agricultural Informatics*. 2017, vol 26(1), pp. 41–48. doi:https://doi.org/10.21082/ip.v26n1.2017.p41-48.

[11] Ministry of Agriculture. corn commodity harvested area in indonesia. [Internet]. [cited 2022 Feb]. Available from: <https://www.pertanian.go.id/home/?show=page&act=view&id=61>

[12] Nurliza, Ruliyansyah A, Hazriani R. Performance behavior of corn smallholders for sustainable cooperative change in West Kalimantan. *AGRARIS: Journal of Agribusiness and Rural Development Research*. 2020, vol 6(1), pp. 1-11. doi: https://doi.org/10.18196/agr.6186

[13] Tangendjaja B. Wina, E. Plant waste and by-products of the corn industry for feed. Food Crops Research and Development Center. [Internet]. [cited 2022 Feb]. Available from: <http://balitsereal.litbang.pertanian.go.id/wp-content/uploads/2016/11/duadua.pdf>.

[14] Purwanto S. Development of produktivity and policy in increasing corn produktivity. Food Crops Research and Development Center. [Internet]. [cited 2022 Feb]. Available from: <http://balitsereal.litbang.pertanian.go.id/wp-content/uploads/2016/11/dua.pdf>.

[15] Kasryno F, Pasandaran E, Suyanto, Adnyana Made O. Overview of the Indonesian corn economy. food crops research and development center. [internet]. [cited 2022 feb]. Available from: <http://balitsereal.litbang.pertanian.go.id/wp-content/uploads/2016/11/satu.pdf>

[16] Sinaga HDE, Irawati N. Comparison of double moving average with double exponential smoothing in forecasting medical consumables. *JURTEKSI: Journal of Technology and Information Systems*. 2018, vol 4(2), pp. 197-204.

[17] Montgomery DC, Jennings CL, Kulahci M. *Introduction to time series analysis and forecasting*. 2nd ed. New Jersey: Wiley; 2008.

[18] Yuniastari NL, Wirawan IW. Forecasting demand for silver products using the simple moving average and exponential smoothing methods. *Journal of Systems and Informatics (JSI)*. 2017, vol 9(1), pp. 97-106.

[19] Evans MK. *Practical business forecasting*. USA: Blackwell; 2003.

[20] Heizer J, Render B. *Operations management, (Tenth Edition)*. United States of America: Pearson; 2011.

- [21] Zheng F, Zhong S. Time series forecasting using a hybrid RBF neural network and ar model based on binomial smoothing. *World Academy of Sciences. Eng Technol.* 2011, vol 75, pp. 1471-1475. doi: <https://doi.org/10.5281/zenodo.1072611>.
- [22] Makridakis S, Wheelwright S, Hyndman RJ. (1998). *Forecasting: methods and applications* (3rd ed.). New York: John Wiley and Sons; 1998.
- [23] Makridakis S, Wheelwright S, McGee VE. *Forecasting methods and applications*, Second Edition, Hari Suminto Translation. Jakarta: Intrakarsa; 2000.
- [24] Hyndman RJ, & Athanasopoulos G. *Forecasting: Principles and Practice*; (2019).
- [25] Sukarti NK, (2015). Time Series Forecasting Using S-Curve and Quadratic Trend Model. National Conference on Systems & Informatics 2015 STMIK STIKOM Bali, 9 – 10 October 2015. [Internet]. [cited 2022 Feb]. Available from: <https://media.neliti.com/media/publications/169644-ID-peramalan-deret-time-gunakan-s-curve.pdf>.
- [26] Hanke J, Dean W. *Business Forecasting*, 9th Edition. United States of America: Pearson; 2014.
- [27] Prakoso IA, Kusnadi, Nugraha B. Product sales forecasting with linear regression method and POM-QM application at PT XYZ. *Scientific Journal Widya Teknik.* 2021, vol 20(1), pp. 17-20. doi:<https://doi.org/10.33508/wt.v20i1.3158>
- [28] Kristiyanti DA, Sumarno Y. Application of the multiplicative decomposition (seasonal) method for inventory forecasting at PT. Agrinusa Jaya Santosa. *Journal of Information Systems and Artificial Intelligence.* 2020, vol 3(2), pp. 45-51.
- [29] Hudyanti CV, Bachtar FA, Setiawan BD. (2019) Comparison of Double Moving Average and Double Exponential Smoothing for Forecasting the Number of Arrivals of International Tourists at Ngurah Rai Airport. *Journal of Information Technology Development and Computer Science.* 2019, vol 3(3), pp. 2667-2672.
- [30] Hatimah IS, Wahyuningsih, Sifriyani. Comparison of the double moving average method and holt's double exponential smoothing in stock price forecasting. *Journal Exponential.* 2013, vol 4(1), pp. 103-107.
- [31] Oktarini D, Irnanda P, Utami OP. Produktivity and inventory control planning in PT Melania Indonesia's Rubber Industry. *Integration Journal: Industrial Engineering Scientific Journal.* 2017, vol 2(2), pp. 16-24. doi:<https://doi.org/10.32502/js.v2i2.1247>.
- [32] Astuti Y, Novianti B, Hidayat T, Maulina D. Application of the single moving average method for forecasting sales of children's toys. National Seminar on Information Systems and Informatics Engineering. Univ. Amikom Yogyakarta. 2019: 253–261. [Internet]. [cited 2022 Feb]. Available from: <https://ejurnal.diponegara.ac.id/index.php/sensitif/article/view/552/485>.
- [33] Handoko TH. *Fundamentals of produktivity and operations management.* Yogyakarta: BPFE-Yogyakarta; 1999.
- [34] Aritonang. *Customer satisfaction*, Gramedia Pustaka Utama, Jakarta; 2002.
- [35] Eris PN, Nohe DA, Wahyuningsih S. Forecasting with methods smoothing and verification methods forecasting with control charts moving range (mr) (case study: clean water production in PDAM Tirta Kencana Samarinda). *Journal Exponential.* 2014, vol 5(1), pp. 203–210.
- [36] Indrajit RE, Djokoprano R. *Inventory management of general goods and spare parts for repair maintenance and operations.* Jakarta: Grasindo; 2003.
- [37] Siregar B, Butar-Butar IA, Rahmat RF, Andayani U, Fahmi F. Comparison of Exponential Smoothing Methods in Forecasting Palm Oil Real Production. *IOP Conf. Series: J Phys.* 2017, vol 801, pp. 1-9.
- [38] Tularam GA, Saeed T. The use of exponential smoothing (es), holt's and winter (hw) and Arima models in oil price analysis. *Int J Math Game Theor Algebra.* 2016, vol 25(1), pp. 13-22.
- [39] Makridakis SC, Wheelwright S, McGee, V.E. *Methods and applications. forecasting*, Jakarta: Binarupa Script; 2003.
- [40] Prabowo R, Aditia R. Productivity analysis using the POSPAC method and performance prism as an effort to improve performance (case study: reinforcing steel industry at PT. X Surabaya). *Journal of Industrial Systems Engineering.* 2020, vol 9(1), pp. 11-22. doi: <https://doi.org/10.26593/jrsi.v9i1.3362.11-22>
- [41] Chopra S, Meindl P. *Supply chain management: strategy, planning, and operation* (Sixth Edition. ed.). Boston: Pearson; 2016.
- [42] Athanasopoulos G, Hyndman RJ, Kourentzes N, Petropoulos F. Forecasting with temporal hierarchies. *European Journal of Operational Research.* 2017, vol 262(1), pp. 60–74. doi: <https://doi.org/10.1016/j.ejor.2017.02.046>.
- [43] Render BJ, Heizer. *Operations management.* Ninth Edition. Jakarta: Salemba Empat; 2009.
- [44] Hudaningsih N, Utami FS, Abdul Jabbar, WA. Comparison of sales forecasting of PT.Sunthi Aknil Products. *Jinteks Journal.* 2020, vol 2(1), pp. 123-138. doi:<https://doi.org/10.51401/jinteks.v2i1.554>
- [45] Kima S, Kimb H. A New metric of absolute percentage error for intermittent demand forecasts. *International Journal of Forecasting.* 2016, vol 32(3), pp. 669-679. doi:<https://doi.org/10.1016/j.ijforecast.2015.12.003>.
- [46] Thitima Booranawong, Apidet Booranawong, Double exponential smoothing and Holt-Winters methods with optimal initial values and weighting factors for forecasting lime, Thai chili and lemongrass prices in Thailand. *Engineering and Applied Science Research.* 2018, vol 45(1), pp. 32-38.
- [47] Farizal F, Muhammad Dachyar, Zarahmida Taurina, Yusuf Qaradhawi. Disclosing fast moving consumer goods demand forecasting predictor using multi linear regression. *Engineering and Applied Science Research.* 2021, vol 48(5), pp. 627-636. doi: 10.14456/easr.2021.64
- [48] Tratar LF, Srncnik E. The comparison of holt-winters method and multiple regression methods: a case study. *Energy.* 2016, vol 109, pp. 266-276.
- [49] Booranawong T, Booranawong A. Simple and double exponential smoothing methods with designed input data for forecasting a seasonal time series: in an application for lime prices in Thailand. *Suranaree J Sci Technol.* 2017, vol 24(3), pp. 301-310.
- [50] Gentry TW, Wiliamowski BM, Weatherford LR. A comparison of traditional forecasting techniques and neural networks. In: Dagli CH, Akay M, Chen CLP, editors. *Intelligent engineering systems through artificial neural networks*, Vol. 5. New York: American Society of Mechanical Engineers; 1995. pp. 765-770.
- [51] Alon I, Qi M, Sadowski RJ. Forecasting aggregate retail sales: a comparison of artificial neural networks and traditional methods. *J Retailing Consum Serv.* 2001, vol 8(3), pp. 147-56.
- [52] Ravindran A, Warsing DP. *Supply chain engineering: models and applications.* New York: CRC Press; 2013..
- [53] Chatfield C. *Time-series forecasting.* New York: Chapman & Hall; 2001.
- [54] Byrne, R. F. Beyond traditional time-series: Using demand sensing to improve forecasts in volatile times. *The Journal of Business Forecasting.* 2012, pp. 31-41.
- [55] Chang PC, Wang YW, Liu CH. The development of a weighted evolving fuzzy neural network for pcb sales forecasting. *Expert Systems with Applications.* 2007, vol 32, pp. 86-96.
- [56] Pennings CLP, Van Dalen J. Integrated hierarchical forecasting. *European Journal of Operational Research.* 2017, vol 263(2), pp. 412-418. doi:<https://doi.org/10.1016/j.ejor.2017.04.047>.
- [57] Fong S, Li G, Dey N, Gonzalez Crespo R, Herrera-Viedma E. Finding an Accurate Early Forecasting Model from Small Dataset: A Case of 2019-nCoV Novel Coronavirus Outbreak. *International Journal of Interactive Multimedia and Artificial Intelligence.* 2020, vol 6(1), pp. 132-40. doi: <https://doi.org/10.9781/ijimai.2020.02.002>.

Recommendation System Based on Double Ensemble Models using KNN-MF

Krishan Kant Yadav¹, Dr. Hemant Kumar Soni², Dr. Nikhlesh Pathik³

Computer Applications Department, Prestige Institute of Management & Research, Gwalior, Madhya Pradesh, India¹
Computer Science & Engineering Department, Amity University, Gwalior, Madhya Pradesh, India^{2,3}

Abstract—In today's digital environment, recommendation systems are essential as they provide personalised content to users, increasing user engagement and enhancing user satisfaction. This paper proposes a double ensemble recommendation model that combines two collaborative filtering algorithms, K Nearest Neighbour (KNN) and Matrix Factorization (MF). KNN is a neighbourhood-based algorithm that uses the similarity between users or items to make recommendations. At the same time, MF is a model-based algorithm that decomposes the user-item rating matrix into lower-dimensional matrices representing the latent user and item factors. The proposed double ensemble model uses KNN and MF to predict missing ratings matrix and combines their predictions using stacking. To evaluate the performance of the proposed ensemble model, we conducted experiments on three datasets i.e. Movielense, BookCrossing dataset and Hindi Movie dataset and compared the results with those of single algorithm approaches. The experimental results demonstrate that the double ensemble model outperforms the single algorithm approaches regarding accuracy metrics such as Mean Square Error (MSE), Root Mean Squared Error (RMSE), Mean Absolute Error (MAE). The results indicate that stacked KNN and MF lead to a more robust and more accurate recommendation system.

Keywords—Recommendation system; k nearest neighbour; matrix factorization; predictions using stacking; ensemble model

I. INTRODUCTION

A recommendation system is essential in everyone's life since it allows people to choose from all available possibilities. A recommendation system is an integral component of machine learning algorithms that provides meaningful recommendations to users. There are two popular types of recommendation systems:

- Content-based.
- Collaborative Filtering.

Content-based recommendations are insufficient since they evaluate the user's history when making suggestions. A collaborative filtering strategy is being utilised to address such issues, in which it seeks comparable groups of users to make judgments. The content based recommendation system is a supervised machine learning technique, which is used to induce a classifier to discriminate between interesting and uninteresting items for the customer.

Filtering is estimating a consumer's interest by recognising predilections and information from a huge number of users. This is done by using strategies that need cooperation between

several data sources, agents, etc., for data filtering to fetch information or patterns. According to the central tenet of collaborative Filtering, two clients, X and Y, may have similar choices in one product if they have a similar option in other products.

Examples of collaborative filtering algorithms:

- YouTube content suggestion to users — It proposes videos to you based on other users who have followed or viewed similar videos as you.
- Coursera course recommendation — It proposes courses based on the completion of existing courses by others.

The collaborative filtering focus on past experience, past knowledge and user behaviour. The collaborative filtering recommends items based on similarity measures between users and items. The basic purpose of such approach is to identify users with similar interests or common preferences about any product or item. The collaborative filtering approach's main advantage is its extensive coverage. The objective of any recommendation system is to make user-relevant product recommendations. Understanding item content is not always necessary; for instance, a movie's genre does not always contain the complete story. No cold-start issue allows us to predict item ratings without prior information about that item and without waiting for a user to purchase. It displays how user preferences have changed over time. Latent factor models, which capture minor intrinsic qualities if most customers buy two unrelated, are particularly susceptible to Filtering.

The main weakness of this strategy is that it is unfriendly for suggesting new things because there is no item interaction with it. Memory-based approaches are infamous for having poor performance on highly sparse datasets.

The cold-start problem is caused by collaborative filtering systems' reliance on the utilisation of publicly available data from similar users. If you were creating a brand-new recommendation system, you wouldn't have any helpful information. Scalability problems of the algorithm arise as the number of users increases. We would have to build a sparse matrix with tons of elements if we had millions of clients and many thousands of films.

Lack of reliable; Input data may not always be accurate because human rating performance is not always dependable.

Ratings are not as crucial as user participation. Item-based suggestions provide a superior answer in this case.

In this paper, we have presented a double ensemble model for recommendation using KNN and MF. Overall, the proposed double ensemble recommendation model provides a promising approach for improving the accuracy of recommendation systems by combining different algorithms. This model can be applied to various domains, including e-commerce, social networks, and multimedia.

The organisation of this paper is as follows :

Section II throws light on work already being done in the field. Section III represents the proposed work. The experiment setup and result is discussed in Section IV. Section V concludes with future directions.

II. RELATED WORK

Lots of work has been done in the last decade in the field of recommendation systems. We have considered the recent work of the previous 5-6 years.

Wu et al. present a novel deep learning-based collaborative filtering (CF) approach that utilises a marginalised denoising auto-encoder (MDAE) to capture high-order interactions among users and items. They have experimented on three real-world datasets to demonstrate that the proposed method outperforms several state-of-the-art CF methods[1].

A novel CF approach based on Recurrent Neural Networks (RNNs) is presented by Hidasi et al., which can model sequential user behaviour. The proposed method outperforms traditional CF methods on two benchmark datasets and also shows promising results on a real-world dataset[2].

Tan and Wang proposed a new factorisation machine-based CF approach that utilises funnel-structured embeddings to capture both the sequential and holistic user behaviour information for the session-based recommendation. Experimental results on three real-world datasets show that the proposed method outperforms several state-of-the-art approaches[3].

Kaur and Singh presented a comprehensive survey of neighbourhood-based CF methods, which are the most commonly used CF methods in practice. The paper provides a detailed overview of the existing methods, their variants, and their strengths and weaknesses[4].

A novel CF approach is presented by Zhou et al. for implicit feedback datasets that utilise adaptive regularisation to handle the sparsity and noise of the data. Experimental results on three real-world datasets demonstrate the superiority of their method.[5].

Yuan et al. propose a novel CF approach incorporating temporal dynamics into the recommendation process. The proposed method uses a recurrent neural network (RNN) to model the temporal patterns of user-item interactions and achieves better performance on two datasets[6].

A deep Bayesian CF approach is presented by Wang et al. that can handle cross-domain recommendations. The proposed method uses a hierarchical Bayesian model to capture the

relationships between different domains and performs better than several other CF methods on different datasets [7].

Wang et al. propose a deep learning-based clustering method to improve the performance of CF. The proposed method utilises a neural network to learn user and item representations and then performs clustering on these representations to group similar users and items. Experimental results on two datasets show that the proposed method leads to better results than others [8].

Ma et al. presented a joint embedding method for CF that uses orthogonal regularisation to improve the quality of user and item representations. The proposed method achieves state-of-the-art performance on two benchmark datasets[9].

Jia et al. proposed a hybrid CF model that combines reinforcement learning with traditional CF methods to improve personalised recommendations. Experimental results on a real-world dataset show that the proposed method outperforms several state-of-the-art CF methods[10].

In this paper, Chen et al. propose a user modelling method for recurrent neural network (RNN) based CF, which uses a hierarchical attention network to capture the user preferences and generates personalised user representations for better recommendation accuracy[11].

Hu et al. presented an Attentional factorisation machine-based CF approach for a session-based recommendation. The proposed method uses attention mechanisms to capture the importance of different items in a session and performs better on two considered datasets[12].

Li et al. presented a multi-relational graph convolutional network-based CF approach for a cross-domain recommendation. The proposed method uses graph convolutional networks to learn user and item representations across multiple domains and achieves better performance than several state-of-the-art CF methods on a real-world dataset[13].

Li et al. presented a neural collaborative filtering (NCF) approach using long-term and short-term user representations to capture user preferences. The proposed method achieves better accuracy when tested with two datasets[14].

Wu et al. provide a comprehensive survey of the literature on bias and fairness in recommendation systems in this paper. It discusses the various types of bias in such systems, the methods used to detect and mitigate bias, and the ethical and legal considerations associated with fair recommendation [15].

Zhang et al. proposed a graph neural network-based recommendation algorithm that uses graph convolutional networks to model user-item interactions. The authors evaluated their approach on several benchmark datasets and showed that it outperforms several state-of-the-art recommendation algorithms[16].

Ricci et al. wrote a recommender system handbook covering various aspects of recommendation, including algorithms, evaluation, and applications[17].

We can conclude that ensemble models can improve the performance of recommendation systems. KNN and MF approach combining can perform better.

III. PROPOSED METHOD

This study developed a CF technique based on KNN and SVD. Generally, SVD provides a more accurate prediction compared with KNN. KNN method is based on k nearest neighbour users or items followed by top K users, and items are chosen. The accuracy depends on the source of the data and the target objective. Usually, KNN is better in data sets with low missing data proportions. SVD is better in massive-size data sets.

This research attempted to go beyond traditional ensemble learning by investigating multi-level ensemble learning concerning recommender systems. We concentrated on stacking generalisation when developing the Recommender System. We tried to examine the impact of the shift from single-level to multi-level ensemble learning on overall accuracy. We used the three datasets and three ensemble approaches based on Collaborative Filtering to evaluate accuracy. The results reveal that 2-level stacking outperforms single-level stacking and any individual recommender system.

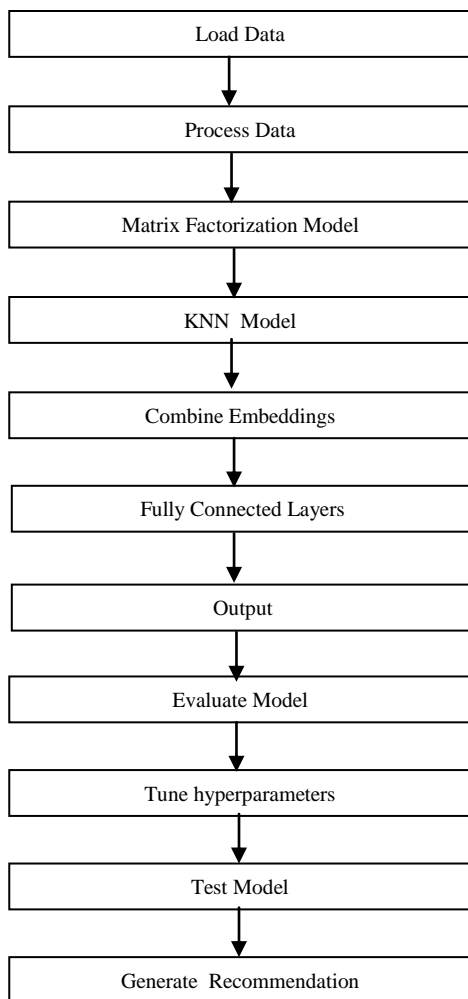


Fig. 1. Flow chart of the proposed work.

This proposed work uses KNN and Matrix Factorization (MF) as reference models. We have first implemented KNN and computed the results for various configurations like change in K etc. After taking multiple configurations, we have performed self ensemble model of KNN. We call it self-ensemble because we have considered the single base model and ensemble its variations for better performance. After this, we considered the Matrix factorisation model and computed the results on its variations like SVD. Similar to the previous one here, we also perform self-ensemble for MF. Now finally, we have proposed the double ensemble hybrid model. Hybrid as it uses both KNN and MF. We are here stacking both these models, so we named it Double ensemble. The proposed model is applied to three popular datasets. Experiment results show the proposed model's superiority.

Bagging, Boosting, Stacking, and other models are included in ensemble learning. Stacking will be the primary topic of this article. However, the recommendations mentioned above suggest a particular aspect and do not recognise the recommendation of specific movies submitted by individual users, causing the recommended material to stray from users' needs and impacting the user experience. Compared to the traditional CF-based algorithms on KNN and MF, the proposed method can realise the recommendation of specific movie input by particular users, make more personalised recommendations, and deal with the issue of cold start and sparse matrix processing to some extent.

We must train a broad set of learners to create an effective ensemble model. We used Collaborative filtering models such as KNN and MF in our scenario. Each student uniquely manipulates the dataset and makes errors based on their personal biases. We trained these models on a subset of the dataset and assessed their accuracy and diversity on the remainder. Initially, we divided the total dataset 80:20 into training and test datasets. The individual learners were then trained on the training dataset, and predictions were generated on the test dataset. We calculated accuracy using the MSE, RMSE and MAE value and diversity using the Pearson correlation coefficient. We have implemented 3 Algorithms and evaluated all three algorithms on 3 Datasets, explained in detail in the next section.

This work integrates the approaches mentioned earlier and presents three ensemble recommendation algorithms:

- 1) Ensemble K-Nearest Neighbors (E-KNN).
- 2) Ensemble Matrix Factorization(E-MF).
- 3) Stacked Nearest Neighbors- Matrix Factorization (S-KNNMF).

Algorithm 1: E-KNN (Ensemble K Nearest Neighbour Algorithm)

We have implemented the vanilla KNN algorithm and then taken its three variants by varying the parameters like K and distance. After that, through stacking, we made self ensemble model of KNN. The flowchart of the proposed work is given in Fig. 1. The steps are as follows:

Step 1: Input Datasets

The input of this algorithm is recommendation datasets. We have considered three datasets. The three datasets are taken to check the coverage and better performance check.

Step 2: Determine Similarity Using the Distance Function.

We have to take distance as a Euclidean distance, and another is Manhattan distance. There are different distance functions, but Euclidean is the most often used. It is most commonly utilised when the data is continuous. For continuous variables, the Manhattan distance is also quite popular.

Euclidean distance =

$$d(x, y) = \sqrt{\sum_{i=1}^m (x_i - y_i)^2 \dots \dots \dots i}$$

Manhattan distance =

$$d(x, y) = \sum_{i=1}^m |x_i - y_i| \dots \dots \dots ii$$

Step 3: Determining the Best K value.

The lower value of K is sensitive to outliers; at the same time, a higher K-value is more immune to outliers since it considers more votes when projecting. Cross-validation is an effective method for determining the best K value. It calculates the validation error rate by excluding a subset of the training data from the model construction process. Cross-validation (say, 10-fold validation) entails randomly splitting the training set into ten groups, or folds, of about similar size. 90% of the data is utilised for training the model, with the remaining 10% used to validate it. Based on the 10% validation data, the misclassification rate is calculated. This method is repeated ten times. Every ten times, a different collection of observations is handled as a validation set. It yields ten validation error estimates, which are then averaged out.

Step 4: Ensemble of the KNN Model

For the ensemble, we have used the stacking method. The primary distinction between voting and stacking is how the final aggregate is accomplished. In voting, user-specified weights aggregate the classifiers, whereas stacking uses a blender/meta classifier to do this aggregation. As we have used the self-ensemble model, we have used stacking for the ensemble.

Step 5: Assessing the Model Performance.

We have evaluated model performance on the error terms MSE, RMSE, and MAE.

Step 6: Final Output is Prediction

Finally, we would want to make predictions using the proposed model. We have considered the three variants of KNN and ensemble them using the stacking method. We have

applied three different datasets to evaluate the performance of this model.

Fig. 2 represents the block diagram showing the ensemble of KNN using the stacking approach.

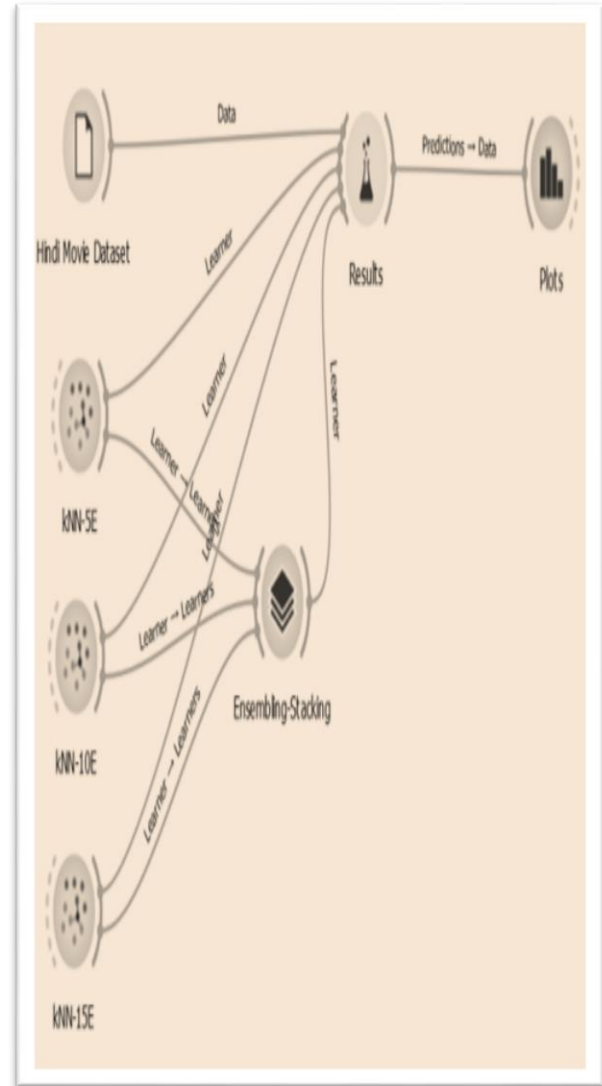


Fig. 2. E-KNN model on hindi movie dataset.

Algorithm 2: E-MF(Ensemble Matrix Factorization Algorithm)

We have implemented the Various Matrix algorithms. We have considered the three variants of matrix factorisation NMF, SVD and SVD++. After that, we made a self-ensemble model of MF through stacking.

E-MF algorithm for a stacking ensemble model that combines NMF, SVD, and SVD++ models for recommendation:

Step 1 Split the user-item rating matrix into training and validation sets.

Step 2 Train an NMF model on the training set using gradient descent to minimise the reconstruction

error between the actual ratings and the low-rank approximation of the matrix.

- Step 3** Train an SVD model on the training set using gradient descent to minimise the MSE between the actual ratings and the predictions of the model.
- Step 4** Train an SVD++ model on the training set using gradient descent to minimise the MSE between the actual ratings and the predictions of the model.
- Step 5** Use the NMF, SVD, and SVD++ models to generate predictions for the validation set.
- Step 6** Combine the predictions of all models using stacking ensemble method.
- Step 7** Calculate the MSE between the actual ratings and the combined predictions for the validation set.
- Step 8** Choose the best ensemble model based on the validation MSE.
- Step 9** Use the chosen ensemble model to generate predictions for new users or items.

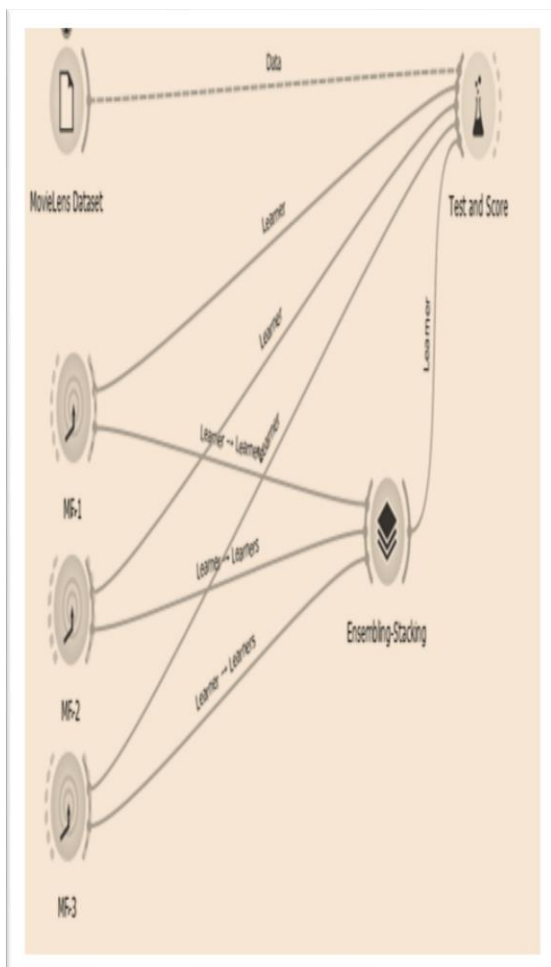


Fig. 3. Block diagram of E-MF model.

Algorithm 3: Proposed Double Ensemble Algorithm Based on KNN and MF

We have taken KNN and MF as reference models in this proposed work. Firstly we have implemented KNN and computed the results for various configurations like change in K etc. After taking multiple configurations, we have performed self ensemble model of KNN. We call it self-ensemble because we have considered the single base model and ensemble its variations for better performance.

After this, we considered the Matrix factorisation model and computed the results on its variations like SVD and SVD++. Similar to the previous one here, we also perform self-ensemble for MF. Now finally, we have proposed the double ensemble hybrid model. Hybrid as it uses both KNN and MF. We are here stacking both these models, so we named it Double ensemble.

The KNN-MF-based double ensemble recommendation system is a double ensemble MF algorithm variation that combines matrix factorisation with KNN for better recommendation accuracy. Here are the steps of the algorithm:

Input:

- User-item interaction matrix (R), where each element r_{ij} represents the rating or preference of user i for item j .
- Number of factors (k) to use for matrix factorisation.
- Number of matrix factorisation algorithms to use (m).
- Number of ensemble methods to use (n).
- Number of neighbors (K) to use for KNN.

Output:

A set of recommendations for each user.

Steps:

1. Split the data into training and test sets.
2. For each matrix factorization algorithm ($i = 1$ to m):
 - a. Apply matrix factorisation to the training data using algorithm i to generate a set of recommendations (R_i).
 - b. Compute the prediction error of R_i on the test set using a suitable evaluation metric (e.g., RMSE, MAE).
3. For each ensemble method ($j = 1$ to n):
 - a. Combine the recommendations from all matrix factorisation algorithms using ensemble method j to generate a set of ensemble recommendations (R_j).
 - b. Compute the prediction error of R_j on the test set using the same evaluation metric as step 2.
4. Choose the combination of the matrix factorisation algorithm and ensemble method that produces the lowest prediction error on the test set.
5. For each user:
 - a. Compute the K nearest neighbours based on the user's rating history using a suitable similarity measure (e.g., cosine similarity, Pearson correlation).
 - b. For each item not yet rated by the user, predict a rating using a weighted average of the ratings of the K nearest neighbours.

- c. Combine the KNN predictions with the predictions from the chosen combination of matrix factorisation algorithm and ensemble method using stacking.
- d. Use the final set of combined predictions as the recommendations for each user.

Matrix factorisation, ensemble methods, and evaluation metrics are the same as described in the Double Ensemble Matrix Factorization algorithm. The KNN component adds a neighbourhood-based approach to the recommendation process, which can capture local and non-linear patterns in the data and improve the accuracy of recommendations, especially for cold-start users.

Fig. 3 shows the block diagram of our proposed S-KNNMF algorithm.

The proposed model performs better than the other two considered ensemble models.

IV. EXPERIMENTAL SETUP

The experiment was conducted on a 64-bit Windows 8 machine with 8 GB RAM and an Intel Core i5-4200M processor with a 2.50 GHz clock speed. Algorithms were implemented in python using Anaconda. For visualisation, various tools are used that are part of the Anaconda. In a few cases, Google-Colab is also used for running our models.

A. Datasets

We have used three datasets to test our proposed algorithms' performance in this work. The reason for taking multiple datasets is that it will cover all possible dependencies of the dataset's nature, like biased, sparsity, etc. They are as follows:

- 1) Hindi Movie.
- 2) Book Cross.
- 3) Movielens.

B. Results

We have taken three datasets for comparative analysis. We have evaluated the performance of our proposed model based on the error scores, namely MSE, RMSE and MAE. We have compared all three models, i.e. ensemble KNN, ensemble matrix factorisation, and stacked KNN-MF model. Table I represents the evaluation result on Hindi Movie datasets.

The table shows that our proposed method gives better results than the other two ensemble models. Fig. 4 graphically represents the comparative analysis of all three considered models.

Table II represents the evaluation result of the Book-Crossing Dataset. It also shows our proposed algorithm's superiority over other considered algorithms.

TABLE I. COMPARATIVE ANALYSIS OF THE HINDI MOVIE DATASET

Model	MSE	RMSE	MAE
E-KNN	0.900161946	0.948769	0.719056
E-MF	0.827225923	0.90952	0.700481
S-KNNMF	0.65895524	0.811761	0.624495

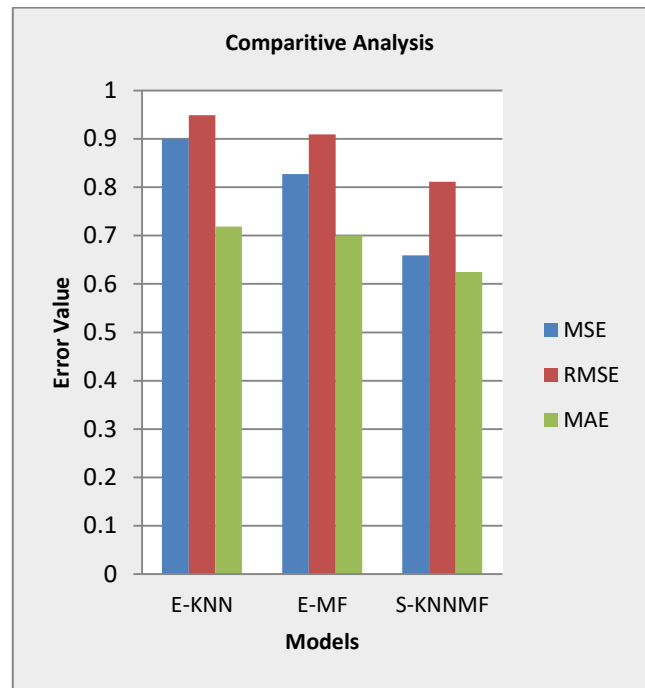


Fig. 4. Comparative graph for hindi movie dataset.

TABLE II. COMPARATIVE ANALYSIS OF THE BOOK-CROSSING DATASET

Model	MSE	RMSE	MAE
E-KNN	0.859679	0.927189	0.70268
E-MF	0.829634	0.910843	0.696308
S-KNNMF	0.789674	0.888636	0.681319

Table II shows our proposed method's superiority over the other two ensemble models. Fig. 4 graphically represents the comparative analysis of all three considered models for better representation.

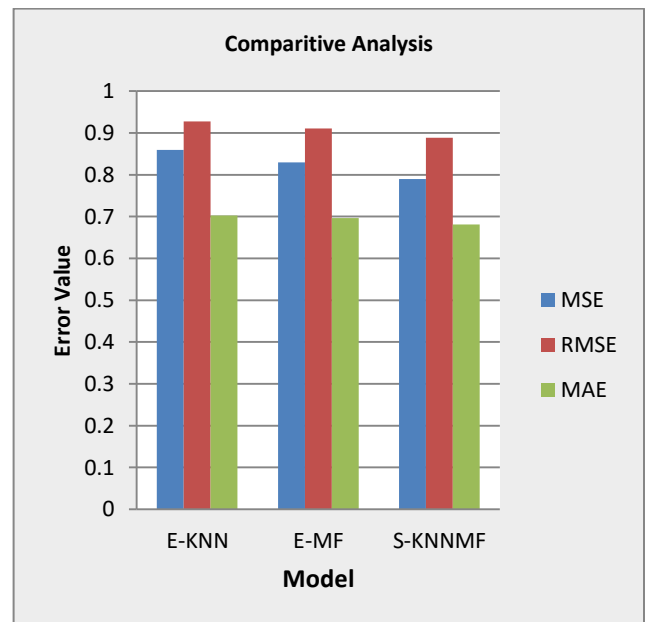


Fig. 5. Comparative graph for book-crossing dataset.

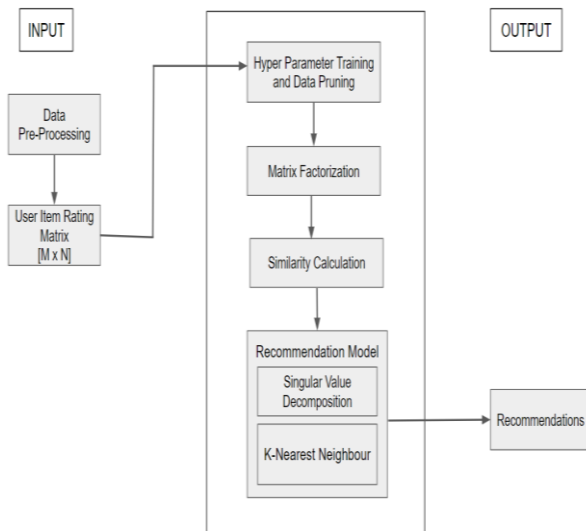


Fig. 6. Block diagram of an ensemble model.

Fig. 5 graphically represents the comparative analysis of all three approaches using Bookcrossing dataset. The Movielens dataset is very popular for performance analysis of recommendation systems. We have also used it for the evaluation of our proposed model. Fig. 6 is representing a block diagram of KNN and MF approaches. Table III represents the evaluation results of all considered algorithms on the Movielens dataset.

TABLE III. COMPARATIVE ANALYSIS FOR MOVIE-LENS DATASET

Model	MSE	RMSE	MAE
E-KNN	0.729304	0.853993	0.652247
E-MF	0.719795	0.848408	0.648123
S-KNNMF	0.658955	0.811761	0.624495

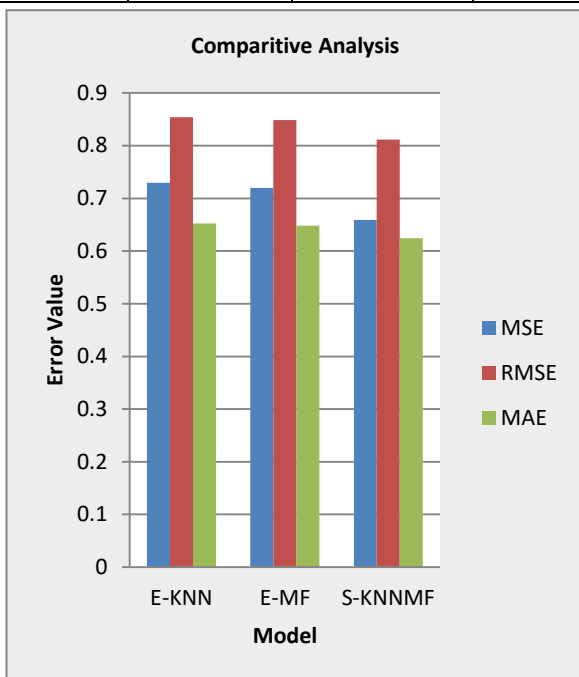


Fig. 7. Comparative graph for movielens dataset.

Table III supports our proposed method’s superiority over the other two ensemble models. Fig. 7 is representing the ensemble model of KNN and MF approaches for better representation of recommendation.

It is clear from Tables I to III that the Ensemble model performs better than the normal models. Double ensemble further improves the performance of the model. Our proposed model gives a minimum error value when evaluated based on MSE, RMSE, and MAE.

V. CONCLUSION AND FUTURE DIRECTION

Double ensemble recommendation models that combine collaborative filtering methods like K-Nearest Neighbors (KNN) and matrix factorisation (MF) can offer improved accuracy and diversity in the recommended items.

KNN is a user-based collaborative filtering technique that recommends items based on user similarity. It suffers from the sparsity problem and is less effective for cold start problems. Conversely, MF is a matrix-based technique that learns latent factors for users and items and can address the sparsity problem. However, it may struggle with long-tail recommendations.

Combining KNN and MF can address the limitations of both techniques, leading to better performance. By leveraging the strengths of both models, the double ensemble approach can generate more diverse and accurate recommendations, especially for cold-start scenarios and long-tail items.

Overall the double ensemble approach of KNN and MF is a promising solution for improving the accuracy and diversity of recommendation systems. In the future, NN-based algorithms are also combined to get better performance. Other ensemble methods can also be applied.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

AUTHORS’ CONTRIBUTIONS

Krishan Kant Yadav and Hemant Kumar Soni have conceptualised the problem statement. Nikhlesh Pathik contributed to the related work. Krishan Kant Yadav, Hemant Kumar Soni, and Nikhlesh Pathik developed the proposed algorithm. Hemant Kumar Soni and Krishan Kant Yadav did implementation work. Krishan Kant did formatting and editing work.

REFERENCES

- [1] Wu, Y., DuBois, C., Zheng, A. X., & Ester, M. (2015). Deep Collaborative Filtering via Marginalised Denoising Auto-encoder. In Proceedings of the 24th ACM International Conference on Information and Knowledge Management (pp. 811-820).
- [2] Hidasi, B., Karatzoglou, A., Baltrunas, L., & Tikk, D. (2016). Collaborative Filtering with recurrent neural networks. In Proceedings of the 4th International Conference on Learning Representations.
- [3] Tan, Y., & Wang, Y. (2017). Factorization Machines with Funnel-structured Embeddings for Session-based Recommendation. In Proceedings of the 26th International Joint Conference on Artificial Intelligence (pp. 2992-2998).

- [4] Kaur, S., & Singh, K. (2017). A Comprehensive Survey of Neighborhood-based Recommendation Methods. arXiv preprint arXiv:1707.01189.
- [5] Zhou, Y., Wilkinson, D., Schreiber, R., & Pan, R. (2017). Collaborative Filtering for Implicit Feedback Datasets using Adaptive regularisation. In Proceedings of the 25th Conference on User Modeling, Adaptation and Personalization (pp. 161-170).
- [6] Yuan, F., Karatzoglou, A., & Jose, J. M. (2018). Collaborative Filtering with Temporal Dynamics. In Proceedings of the 12th ACM Conference on Recommender Systems (pp. 146-154).
- [7] Wang, R., Fu, B., Fu, G., & Wang, M. (2018). Deep Bayesian Collaborative Filtering for Cross-domain Recommendation. In Proceedings of the 2018 ACM Conference on Recommender Systems (pp. 246-250).
- [8] Wang, K., Gao, H., He, X., Deng, L., & Li, Y. (2019). Improved Collaborative Filtering via Deep Learning-based Clustering. In Proceedings of the 2019 Conference on Empirical Methods in Natural Language Processing and the 9th International Joint Conference on Natural Language Processing (pp. 6349-6355).
- [9] Ma, H., Fan, Y., & Ji, X. (2019). Joint Embedding of User and Item with Orthogonal Regularization in Collaborative Filtering. In Proceedings of the 2019 Conference on Empirical Methods in Natural Language Processing and the 9th International Joint Conference on Natural Language Processing (pp. 6362-6367).
- [10] Jia, C., Zhang, J., & Chen, K. (2020). A Hybrid Collaborative Filtering Model with Reinforcement Learning for Personalised Recommendations. In Proceedings of the 2020 ACM Conference on Multimedia (pp. 3123-3126).
- [11] Chen, C., Xu, Z., & Wang, Y. (2020). User Modeling for Recurrent Neural Network based Collaborative Filtering. arXiv preprint arXiv:2002.04799.
- [12] Hu, Y., Li, X., Lu, Z., & Zhou, X. (2020). Attentional Factorization Machines for Session-based Recommendation. In Proceedings of the 2020 Conference on Empirical Methods in Natural Language Processing (pp. 7917-7926).
- [13] Li, H., Li, X., Li, B., Li, C., & Li, P. (2021). Multi-Relational Graph Convolutional Network for Cross-Domain Recommendation. arXiv preprint arXiv:2101.08328.
- [14] Li, Y., Tang, J., Li, Z., & Yang, B. (2021). Neural Collaborative Filtering with Long- and Short-Term User Representations. In Proceedings of the 2021 ACM Conference on Recommender Systems (pp. 178-187).
- [15] Wu, L., Pan, S. J., Long, G., Jiang, J., & Zhang, C. (2020). A survey on bias and fairness in recommendation. arXiv preprint arXiv:2007.15551.
- [16] Zhang, S., Yao, L., Sun, A., & Tay, Y. (2019). Deep learning based recommender system: A survey and new perspectives. ACM Computing Surveys (CSUR), 52(1), 1-38.
- [17] Ricci, F., Rokach, L., Shapira, B., & Kantor, P. B. (2015). Recommender systems handbook (Vol. 1).

Integrating Regression Models and Climatological Data for Improved Precipitation Forecast in Southern India

J. Subha¹, S. Saudia²

Centre for Information Technology and Engineering, Manonmaniam Sundaranar University, Tirunelveli-12,
Tamil Nadu, India^{1, 2}

Abstract—Modern technologies like Artificial Intelligence (AI) and Machine Learning (ML) replicate intelligent human behavior and offer solutions in all domains, especially for human protection and disaster management. Nowadays, in both rural and urban areas, flood control is a serious issue to overcome the vast disaster to life and property. The work proposes to identify an appropriate ML based precipitation forecast model for the flood-prone southern states of India namely Tamil Nadu, Karnataka, and Kerala which receive most precipitation using the climatological information obtained from the NASA POWER platform. The work investigates the effectiveness of ML forecasting models: Multiple Linear Regression (MLR), Support Vector Regression (SVR), Decision Tree Regression (DTR), Random Forest Regression (RFR) and Ensemble (E) learning approaches of E-MLR-SVR, E-MLR-DTR, E-MLR-RFR, E-SVR-DTR, E-SVR-RFR, E-DTR-RFR, E-MLR-SVR-DTR, E-MLR-SVR-RFR, E-MLR-DTR-RFR and E-SVR-DTR-RFR in forecasting precipitation. The E-MLR-RFR model produces improved and most precise precipitation forecast in terms of Mean Absolute Error (MAE), Mean Square Error (MSE), Root Mean Square Error (RMSE) and R^2 values. A higher precipitation forecast can be used to provide early warning about the possible flood in any region.

Keywords—Ensemble models; machine learning models; rainfall precipitation forecast; R-squared value

I. INTRODUCTION

Flood control is an important matter of concern to confront casualties and rehabilitation [1]-[2]. Even though many advanced techniques have been utilized to control flood, concerned authorities still struggle to safeguard citizens and to quickly update estimates of the damage caused by floods. The incidents which happened in Chennai, Kerala, Assam and Bangalore due to continuous heavy rainfall during the monsoon season [3]-[7] show that protecting all lives and physical resources is a critical matter. In India, monsoon rainfall accounts for 80% of annual precipitation [8]-[9]. Floods which occurred in Kerala in the years 2018, 2019 and 2020 led to death of around 483, 121 and 104 people respectively and immersion of many villages [10]-[11]. The majority of people were then stranded in their houses without access to enough food and water.

Also, such flood hazards have affected most other countries like Bangladesh, Nepal, Pakistan, Afghanistan, Saudi Arabia and Iran [43]-[44]. Among the notable causes of

flood, sudden and enduring heavy rain is the most important cause in all countries [12]. Forecast models published in [13]-[16], [19] are helpful to safeguard citizens, manage floods, operating reservoirs at critical situations by predicting floods and disseminating flood alerts. Hitherto, most flood forecasting systems relied either on monitored data or those retrieved from satellites [17]-[18], [20]-[21]. In [21]-[22], precipitation forecast is performed by interpreting such dynamically changing atmospheric data such as temperature, rainfall, humidity and wind direction. Predicting rainfall/precipitation from this large volume of unstructured weather data [22] is not a facile task. So, the work proposes to identify suitable climatological data pre-processing stages and ML models for an automated warning of flood to the public and authorities based on a precipitation forecast. ML models are producing remarkable solutions in the domain of weather forecast and disaster management [45]-[48].

So, the paper proposes a study to identify stand-alone and ensemble Machine Learning models, MLR, SVR, DTR, RFR, E-MLR-SVR, E-MLR-DTR, E-MLR-RFR, E-SVR-DTR, E-SVR-RFR, E-DTR-RFR, E-MLR-SVR-DTR, E-MLR-SVR-RFR, E-MLR-DTR-RFR and E-SVR-DTR-RFR towards flood prediction via heavy precipitation forecast for the flood-prone south Indian states like Tamil Nadu, Karnataka and Kerala. These states which receive most heavy rainfall have been prone to major floods [8]-[9], [11]. This proposed work focuses on identifying a precipitation forecasting system for the states by integrating climatological data in the ML framework. The climatological data of the highest precipitation receiving geo-spatial locations of those states are captured from the NASA POWER platform [30]. The work also analyses the results of ML based flood/precipitation forecasting models in literature prior to the selection of stand-alone ML models MLR, SVR, DTR, RFR and ensemble ML models, E-MLR-SVR, E-MLR-DTR, E-MLR-RFR, E-SVR-DTR, E-SVR-RFR, E-DTR-RFR, E-MLR-SVR-DTR, E-MLR-SVR-RFR, E-MLR-DTR-RFR and E-SVR-DTR-RFR to work with the climatological data for precipitation forecast. It also attempts the effectiveness of pairwise correlation for feature selection before selecting the independent features for training the ML models. The ensemble model, E-MLR-RFR produces the improved and highest R^2 -value to precipitation forecast.

This paper is organized in five sections. Section II outlines the literature in terms of related climatological datasets,

models and results predicted. Section III elaborates the data pre-processing, feature selection stages and the ML algorithms used for precipitation forecast. Section IV presents the results and discussion upon results and Section V concludes the paper.

II. RELATED WORKS

ML based papers, studies published by researchers to increase the accuracy of precipitation/ flood forecast are discussed in this section. Barrera-Animas, A.Y., et al. [23] presented a comparison of rainfall forecast models based on ML and Deep Learning (DL) architectures, Long-Short Term Memory (LSTM), Stacked-LSTM, Bidirectional-LSTM Networks, Extreme Gradient Boost (XGBoost), an ensemble of Gradient Boosting Regressor, Linear Support Vector Regression, and an Extra-trees Regressor to project hourly rainfall volumes using time-series data from five major cities of the United Kingdom (UK). The performance of the models is assessed using the assessment metrics, Root Mean Squared Error, Mean Absolute Error, and Root Mean Squared Logarithmic Error to identify the bidirectional-LSTM Network as a best rainfall forecast model out of all the models examined. Aftab, S., et al [24] used data mining approaches by identifying hidden patterns within the available elements of historical weather data to estimate the amount of rainfall. Velasco, L. C., et al. [25] forecasted the rainfall of Iligan city in Southern Philippines using Support Vector Regression Machine (SVRM) based on a 4-year and 17-month rainfall dataset collected using an Automated Rain Gauge (ARG). The forecasting model demonstrated a Mean Square Error (MSE) of 3.46. Khan, T. A., et al. (2019) [26] made classifier and regression models for the investigation of flash floods based on data gathered from the Kund Malir seashore by sensors. For forecasting, the dataset was subjected to Logistic Regression, Quadratic Support Vector Machine, K-Nearest Neighbors (K-NN), Exponential Gaussian Process Regression (GPR) and Ensemble Bagged Tree. The GPR outperformed all other methods with a minimal RMSE of 0.0002 and a prediction speed of 35000 observations per second. Abdullah, A. S., et.al. (2021) [28] used Seasonal Autoregressive Integrated Moving Average (SARIMA) and SVM for rainfall/precipitation forecast in Bogor City, Indonesia. The SVM delivered an accurate result with a minimal Mean Absolute Percentage Error (MAPE) for predicting rainfall. Sreehari, E., et. al. (2018) [29] used MLR to forecast the amount of rainfall using the dataset from the Nellore district of Andhra Pradesh, India. The MLR approach produced more accurate findings for the amount of rainfall than Simple Linear Regression (SLR). De Castro, J.T., et al. (2013) [31] developed a technique for a flash flood warning system using Short Message Service (SMS) with improved warning information based on rising water level and water velocity. The regression equation was created based on velocity and water level data that was collected over a seven-day period since they were thought to be flash-flood causes. In order to provide registered users with an early warning, the system computes the present and future risk of flooding based on the model. Rezaeianzadeh, M., et al. (2014) [32] did flood flow forecasting at the outlet of the Khosrow Shirin watershed in the Fars Province of Iran using Artificial Neural Networks

(ANN), Adaptive Neuro-Fuzzy Inference Systems (ANFIS), MLR, and Multiple Nonlinear Regression (MNLR). The MNLR models outperformed the ANN, ANFIS, and MLR models with smaller RMSE values. Saha, A., et al. (2021) [33] assessed the performance of flood susceptibility (FS) mapping predictions in the Koiya River basin in Eastern India. Eight flood conditioning variables based on the topography and hydro-climatological conditions were used to create a flood inventory map using the novel ensemble approach of Hyperpipes (HP) [47] and Support Vector Regression (SVR). The ensemble technique produced a higher accuracy of 0.915. The summary of the related works in terms of ML models, precipitation and watershed datasets used and prediction results in terms of MAE/ MSE/ RMSE/ Accuracy is presented in Table I.

TABLE I. SUMMARY OF RELATED PUBLICATIONS

Authors / Years	Title and Study Regions	Models	Metrics
[23]	Rainfall prediction: A comparative analysis of modern machine learning algorithms for time-series forecasting. Machine Learning with Applications – UK cities	LSTM, SLSTM, BLSTM, XGBoost, LSVR	RMSE-0.0084
[24]	Rainfall prediction using data mining techniques: A systematic literature review	ML, DL	-
[25]	Rainfall Forecasting using Support Vector Regression Machines – Southern, Philippines	SVRM	MSE-3.46
[26]	A comparison review based on classifiers and regression models for the investigation of flash floods – Kund Malir, Pakistan	LR, QSVM, KNN, EGPR	RMSE-0.0002
[28]	Comparison of SARIMA and SVM model for rainfall forecasting in Bogor city, Indonesia	SARIMA, SVM	RMSE - 63.25
[29]	Prediction of climate variable using multiple linear regression- AP, India	MLR, SLR	-
[31]	Flash flood prediction model based on multiple regression analysis for decision support system – Garang River, Semarang	Multiple Regression Technique	-
[32]	Flood flow forecasting using ANN, ANFIS and regression models- Shirin watershed, Iran	ANN, ANFIS, MLR, MNLR	R ² – 0.81
[33]	Flood susceptibility assessment using novel ensemble of hyperpipes and support vector regression algorithms – Koiya River Basin - India	HP, SVR, HP-SVR, Ensemble Technique	Accuracy-0.915

From Table I, it is clear that knowing and evaluating variations in rainfall is essential for forecasting flood calamities. So, this paper proposes to use climatological data gathered from the NASAPOWER dataset [30] for the years from 2001 to 2020 in identifying a better ML based model to forecast precipitation in various flood-prone geographic areas across the southern states of the country namely Tamil Nadu,

Karnataka and Kerala. The work also investigates the improvement in precipitation forecast via pairwise correlation in the feature selection stage of the ML workflow. An accurate forecast precipitation can be used to alarm associated flood and plan relevant precautionary measures.

III. PROPOSED SYSTEM

The focus of this paper includes (i) gathering climatological data from the platform <https://power.larc.nasa.gov/> [30] (ii) utilization of ML models in predicting the weather data-based day-wise and month-wise precipitation and (iii) evaluation of results. For the purpose of making an early flood warning from precipitation forecast in a southern region of India, the daily and monthly based climatological features are used in this work. Relevant climatological features are scaled using Standardization to the range from 0 to 1. Following this process, relevant independent features in the dataset are identified using pairwise correlation [52] and then subjected to ML regression models and ensemble models to forecast precipitation. Methodology of the work as illustrated in Fig. 1 is explained in upcoming sub-sections.

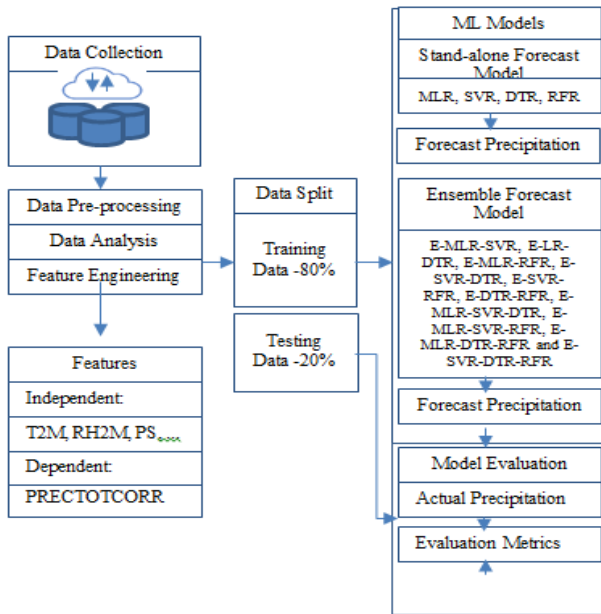


Fig. 1. Methodology of the proposed work.

A. Data Collection

The climatological data is acquired from the website, <https://power.larc.nasa.gov/> [30] to forecast precipitation using the ML functions in scikit learn package of Python. This site provides solar and meteorological data sets from satellite observations for renewable energy and agricultural needs. For user-selected grids, the solar and meteorological characteristics are offered in monthly and daily basis. This climatological dataset is gathered for the three distinct southern Indian states, Tamil Nadu, Karnataka and Kerala of India. The day-wise and month-wise precipitation data is collected for the years from 2001 to 2020 in this region in Comma Separated Values [CSV] file format. The dataset for

each region consists of 7305 records and 21 features. The details of the features in the dataset are mentioned in Table II.

TABLE II. ATTRIBUTES IN DATASETS

Features Name	Description	Units	Range
YEAR	Year	Integer	2001-2020
DOY	Month/ Day of Year	Integer	1-366
PS	Surface pressure	(kPa)	15.81-31.98
TS	Earth skin temperature	C	0.92-22.95
T2M	Temperature at 2 meters	C	14.68-34.80
QV2M	Specific humidity at 2 meters	(g/kg)	1.82-22.40
RH2M	Relative humidity at 2 meters	%	21.54-41.12
WD2M	Wind direction at 2 meters	(degrees) ⁰	8.83-25.23
WS2M	Wind speed at 2 meters	(m/s)	298.38-414.70
WD10M	Wind direction at 10 meters	(degrees) ⁰	4.15-18.92
WS10M	Wind speed at 10 meters	(m/s)	21.75-95.88
T2MDEW	Dew/Frost point at 2 meters	C	92.53-94.27
T2M_MAX	Temperature at 2 meters maximum	C	0.48-7.52
T2M_MIN	Temperature at 2 meters minimum	C	0.78-9.41
WS2M_MAX	Wind speed at 2 meters maximum	(m/s)	0.60-3.90
WS2M_MIN	Wind speed at 2 meters minimum	(m/s)	20.94-336.88
T2M_RANGE	Temperature at 2 meters range	C	0.74-10.76
WS10M_MAX	Wind speed at 10 meters maximum	m/s	1.2-13.03
WS10M_MIN	Wind speed at 10 meters minimum	m/s	0.02-9.22
ALLSKY_SFC_LW_DWN	All sky surface longwave downward Irradiance	(w/m ²)	21.62-336.19
PRECOTCORR	Precipitation corrected	(mm/day)	0-88.46

B. Data Pre-Processing

After data acquisition, data pre-processing is carried out to remove any null, empty or outlier data and to restore them with appropriate data for Machine Learning. Outliers are extreme data values which are out of observation ranges. The outliers/ missing values are rectified/ filled out to remove data irregularities and finally the entire data is transformed to the required format.

The climatological data obtained for the southern states, Tamil Nadu, Karnataka, and Kerala from [30] are devoid of missing values and outliers and so no pre-processing steps were necessary. The dataset is subjected to Data analysis and Feature Engineering to identify more relevant climatological features for training the different ML algorithms for forecasting rainfall. The later data analysis and feature engineering stages are detailed in the upcoming sub-sections.

C. Data Analysis

The climatological dataset used in the work is a high-resolution climatological data for a period of 20 years from 2001 to 2020. It is analyzed prior feature engineering using visualization tools of Python packages namely seaborn and matplotlib. The mean precipitation of Tamil Nadu, Karnataka, and Kerala over a period of time from 2016 to 2020 is shown in Fig. 2(a) to 2(c).

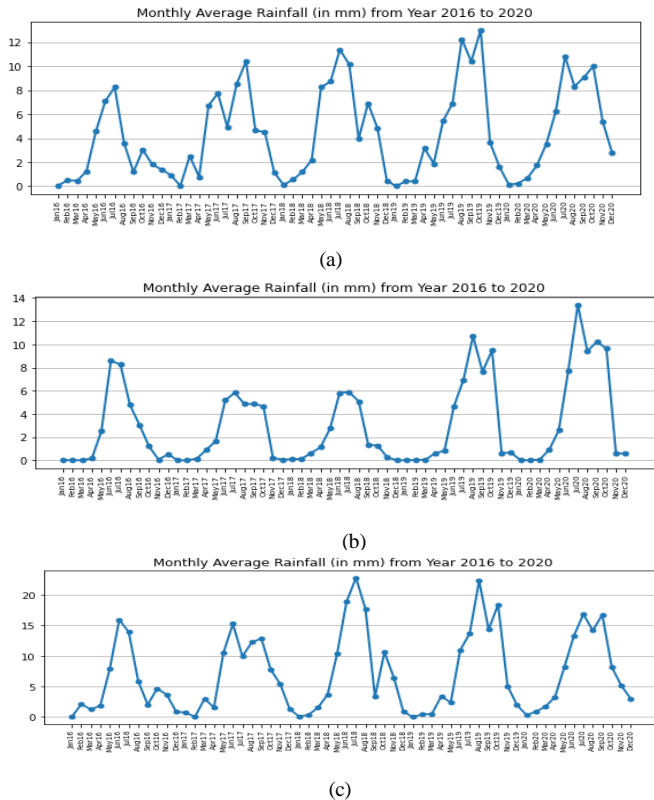


Fig. 2. Line plots showing average monthly precipitation from 2016 to 2020 (a) Tamil Nadu (b) Karnataka (c) Kerala.

The Fig. 2(a) clearly shows nine peak points from the climatological data of Tamil Nadu for the months July 2016, June 2017, September 2017, July 2018, October 2018, August 2019, October 2019, July 2020 and October 2020. Fig. 2(b) shows seven rainfall peak points of Karnataka which occurred in the months June 2016, July 2017 and 2018, August 2019, October 2019, July 2020 and September 2020.

Fig. 2(c) clearly shows ten peak precipitation points of Kerala in June and October of 2016, June and September of 2017, July and October of 2018, August and October of 2019 and July and September of 2020. Fig. 2(a) to (c) clearly indicate that there is maximum probability of precipitation and hence flood in monsoon season. Floods in these states have occurred during these high precipitation months [10], [66]-[67]. So, these months need special flood attention.

D. Feature Engineering

The goal of feature engineering in ML is to identify relevant independent features to make the models perform better. Scaling is one of the main goals of feature engineering which identifies the most pertinent quartiles of the data. In this work, the independent features in the respective ranges as shown in Table II are scaled using Standardization [49] to the range from 0 to 1. The scaling operation used to find the new independent feature value, x_{new} is shown mathematically in Eq. (1).

$$x_{new} = \frac{x - \mu}{\sigma} \quad (1)$$

where x is the independent feature, $\mu = \frac{1}{N} \sum_{i=1}^N (x_i)$ is the mean of the N values of the independent feature x_i and σ is the standard deviation represented mathematically as $\sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2}$.

Correlation analysis helps to collect essential features from the dataset. First, the correlation coefficients between independent features are determined and recorded in a table called a correlation matrix. The correlation between two features is represented in each cell of the correlation table from -1 to 1. If the value is positive, then there is a normal correlation; while bigger positive values indicate a stronger correlation between features.

There is an inverse correlation when the matrix values are negative. Relationship between feature pairs in a dataset is determined using the `corr()` function in python as a heat map in Fig. 3. The correlation heat map for Tamil Nadu state is shown in Fig. 3. It clearly demonstrates correlations between independent features with same cell colour and value. The feature T2M is highly correlated with TS, T2M_MAX. Also, the feature T2M_DEW is highly correlated with TS, T2M_RANGE, T2M_MIN, QV2M, RH2M ALLSKY_SFC_LW_DWN etc.

The range of correlation from 1 to -1 is shown by the colour intensity variations from green to blue. An independent feature is chosen from each pairwise correlated group to be included in model design phase [52]. This helps to reduce the number of features in the dataset which in turn can improve the performance of ML modeling [49] - [53]. The effectiveness and interpretability of model can be increased by the new collection of uncorrelated features.

Following the feature selection stage, the dataset for Tamil Nadu state has the features: RH2M, PS, WS10M_MAX, ALLSKY_SFC_LW_DWN and WD10M. The feature engineered dataset with the relevant set of independent and dependent features as shown in Table III is subjected to the model building stage.

TABLE III. FEATURES OBTAINED FROM THE FEATURE ENGINEERING STAGE

State	Tamil Nadu	Karnataka	Kerala
Independent Features	RH2M, PS, WS10M_MIN, ALLSKY_SFC_LW_DWN, WD10M	RH2M, PS, WD2M, WS10M_MIN, WD10M	T2M_MIN, QV2M, RH2M, PS, WS10M_MAX, WS10M_MIN, WD10M
Dependent Feature	PRECTOTCORR	PRECTOTCORR	PRECTOTCORR

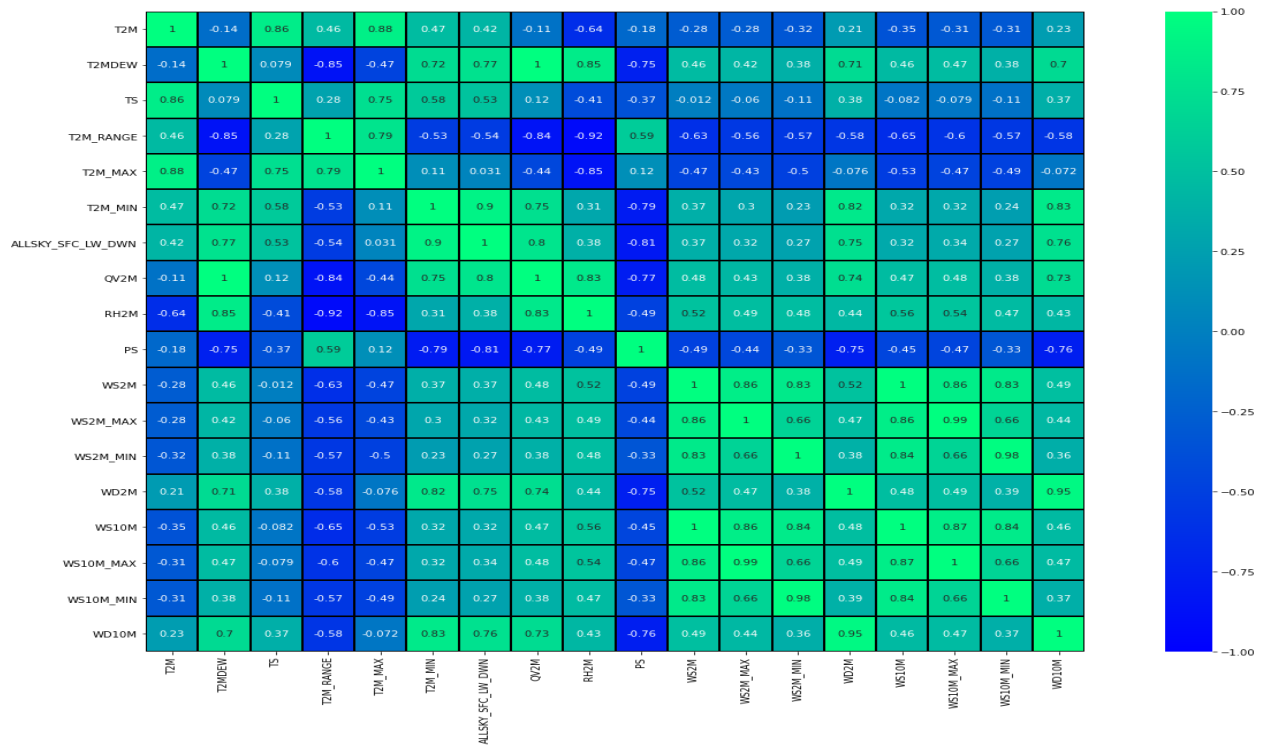


Fig. 3. Correlation heat map for Tamil Nadu state.

E. Model Building

This work proposes to identify the effectiveness of the standalone ML models: MLR, SVR, DTR, RFR and ensemble ML models: E-MLR-SVR, E-MLR-DTR, E-MLR-RFR, E-SVR-DTR, E-SVR-RFR, E-DTR-RFR, E-MLR-SVR-DTR, E-MLR-SVR-RFR, E-MLR-DTR-RFR and E-SVR-DTR-RFR in forecasting precipitation using the independent features obtained from the NASAPOW dataset for the flood-prone south Indian states of Tamil Nadu, Karnataka and Kerala. The dataset with features as in Table III is split into training and testing datasets in the ratio, 8:2 and the training dataset is subjected to the training phases of the above mentioned standalone and ensemble ML models [36]-[37]. In ensemble models, the final prediction is made by averaging the results of all the base models. General training phase of these ML and ensemble algorithms are briefed as follows:

1) Machine learning models: Machine Learning (ML) [38]-[41] is the science of creating regression/ classification models using algorithms that can draw knowledge from prior instances. The general data flow diagram of a ML based regression algorithm for forecasting rainfall is as shown in Fig. 4. Fig. 4 depicts the typical data flow diagram of the regression algorithm where the independent features from the dataset in Table III are subjected to the training phase of the ML algorithms, both stand-alone algorithms: MLR, SVR, DTR, RFR and ensemble algorithms: E-MLR-SVR, E-MLR-DTR, E-MLR-RFR, E-SVR-DTR, E-SVR-RFR, E-DTR-RFR, E-MLR-SVR-DTR, E-MLR-SVR-RFR, E-MLR-DTR-RFR and E-SVR-DTR-RFR to produce the model to forecast precipitation. The precipitation forecast is obtained from these models using the test data. The working of different ML and ensemble algorithms are briefed in sub-sections below.

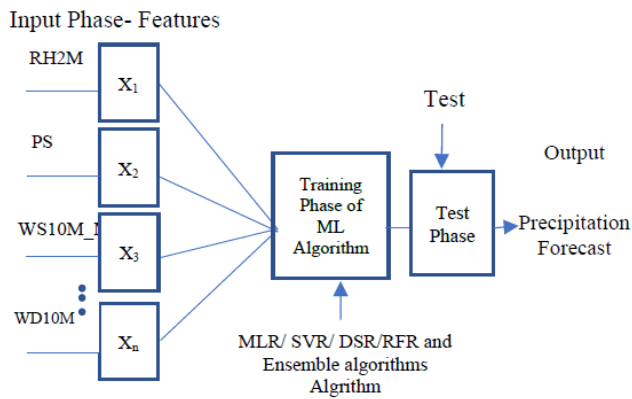


Fig. 4. General data flow diagram of regression algorithm.

2) *Multi linear regression*: Multiple Linear Regression [6], [41] determines the relation between dependent feature and many independent features to forecast the values of the continuous dependent feature. In MLR, the relationship between the independent features, x and dependent feature, y is modeled in the training phase as a linear equation shown in Eq. (2) by minimizing the sum of squares of error between the actual and predicted dependent feature values or residuals using Least Squares optimization [54]-[55].

$$y_{pi} = b_0 + b_1x_1 + b_2x_2 + \dots + b_nx_n \quad (2)$$

Here the indices $1,2,3, \dots, n$ correspond to the 'n' independent features, y_{pi} is the dependent feature, b_0 is the y-intercept, and b_1, b_2, \dots, b_n are the coefficients of the independent features x_1, x_2, \dots, x_n respectively. The illustration is shown in Fig. 5. In this work, MLR is trained using the training set Tamil Nadu, Karnataka and Kerala states and the model is used to forecast daily and monthly precipitation.

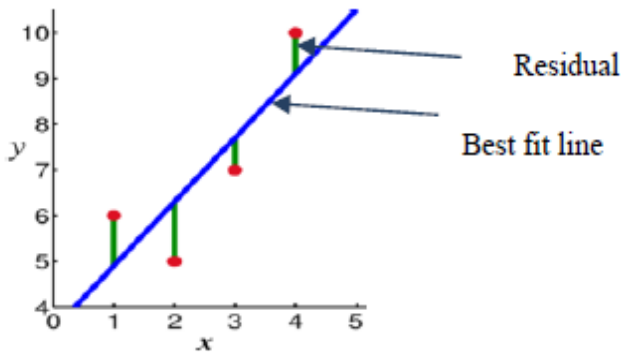


Fig. 5. General diagram for MLR [56].

3) *Support vector regression*: Support Vector Regression identifies a hyperplane in an n-dimensional space of the

independent features, x in the training dataset as a model to predict the values of the dependent feature, y_{pi} . The hyperplane model obtained after training as shown in Eq. (3) has the largest margin between the support vectors, ξ and ξ^* around a marginalized ' ϵ ' space. The ' ϵ ' space is $+\epsilon$ and $-\epsilon$ from the hyperplane.

$$y_{pi} = f(x) = bx + c = \sum_{i=1}^N (\alpha_i - \alpha_i^*) . K(x_i, x) + c \quad (3)$$

Here b is the weight vector corresponding to the independent feature x in terms of the Lagrange multipliers α_i, α_i^* and c is the bias term which are obtained in the training phase by minimizing the objective function, $\frac{1}{2} ||b||^2 + C \sum_{i=1}^N (\xi_i + \xi_i^*)$ using quadratic optimization [57]-[59]. K is the Kernel function which transforms x to higher dimension and C is the penalty parameter of the model and N is the size of the training dataset. The illustration of the parameters are shown in Fig. 6. In this work, the SVR model is used for predicting continuous values of precipitation for Tamil Nadu, Karnataka and Kerala on a daily and monthly basis.

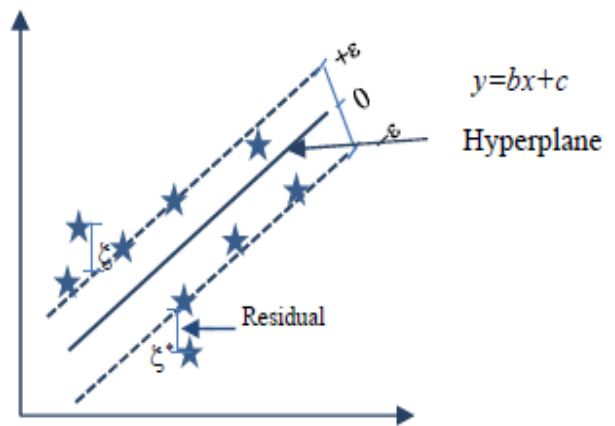


Fig. 6. General diagram for SVR [59].

4) *Decision tree regression*: Regression issues can be solved using the Decision Tree Regressor (DTR) as shown in Fig. 7 [60], [63]. Starting with the root node with all the records in the training dataset, a decision tree is built. The tree divides into left and right child nodes based on a condition check on an independent feature values with least Mean Square Error to contain subsets of the training dataset. Mean Square Error is the difference between the predicted values of the dependent feature and its original target value.

The child nodes are further subdivided into their children nodes and thus become the parent nodes of next level. Each branch denotes the outcome of a test and each leaf node denotes the final outcome. The set of all conditions until different leaf nodes corresponds to the regression model. The predicted output is obtained as the average of the dependent feature values of all records in the leaf node. DTR model trained using the training set from Tamil Nadu state to forecast daily precipitation is shown in Fig. 7.

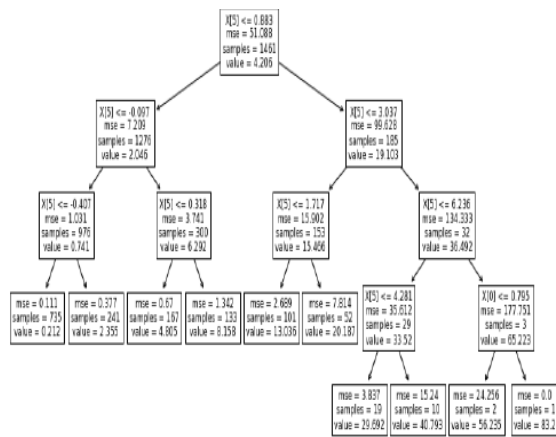


Fig. 7. Sample DTR with five levels drawn from climatological day-wise precipitation data of Tamil Nadu state.

5) *Random forest regression:* Random Forest Regressor (RFR) as shown in Fig. 8 has a large number of decision tree regressors trained from the subsets of the training dataset [65][27]. It is a bagging ensemble approach which employs aggregated decision trees that operate concurrently without interacting with one another and produces the regression output as the average of outputs from all decision tree regressors [61], [64]. One out of ten DTRs used in the RFR model trained using the training set from Tamil Nadu state to forecast daily precipitation is shown in Fig. 9.

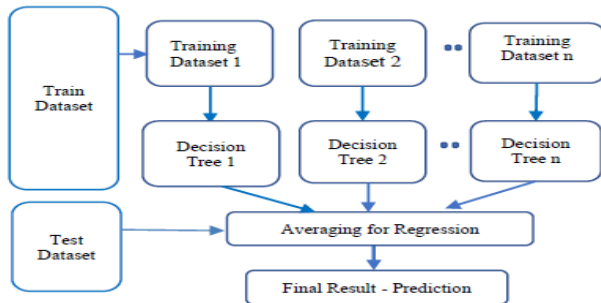


Fig. 8. The random forest regression ensemble.

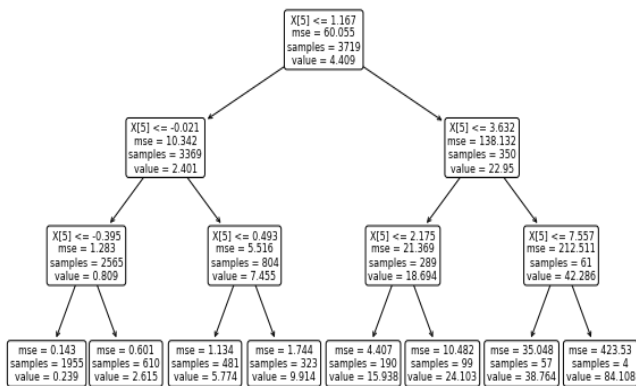


Fig. 9. One sample DTRs of RFR drawn from climatological data for Tamil Nadu state.

F. Ensemble Models

In Machine Learning (ML), the use of multiple models or algorithms to increase prediction reliability is referred to as ensemble learning [61]. The fundamental idea behind ensemble approaches is to achieve improved results using Eq. (4) by integrating results from many models than from a single model [61]-[62]. The average of results from the numerous regression models is the final prediction. In this work, the ensemble techniques, E-MLR-SVR, E-MLR-DTR, E-MLR-RFR, E-SVR-DTR, E-SVR-RFR, E-DTR-RFR, E-MLR-SVR-DTR, E-MLR-SVR-RFR, E-MLR-DTR-RFR and E-SVR-DTR-RFR are used to forecast precipitation.

$$Final\ Prediction = \frac{\sum_{j=1}^m (Prediction\ from\ Model\ j)}{m} \quad (4)$$

where $j = 1$ to m and m is the number of models.

The ensemble approaches used in this work are bagging/averaging approaches where arbitrary subsets of the training data are trained in several base algorithms: MLR, SVR, DTR, RFR and the predictions from each model are combined to get a final prediction. In the ensemble approach, E-MLR-SVR, the outputs of the basic regressors, MLR and SVR are combined to get the final output. Integrating stand-alone models yields better outcomes than using a stand-alone model. The climatological datasets from Tamil Nadu, Karnataka and Kerala are trained using the stand-alone ML algorithms and ensemble learning approaches to predict daily and monthly rainfall in the states of Tamil Nadu, Karnataka and Kerala. The performance of these models are assessed in terms of MAE, MSE, RMSE and R^2 values. Section IV analyses the results of these models in terms of regression metrics.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

The performance evaluation metrics, Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Square Error (RMSE) and R^2 (R-squared) values are used to assess precipitation forecasting models [34]-[35]. MAE refers to the average of the absolute error difference between predicted value, y_{pi} and actual value, y_i as defined in Eq. (5). RMSE defined in Eq. (6) is the square root of the mean square error (MSE). The percentage of the dependent feature's fluctuation that can be predicted from the independent feature is known as R^2 value. It is defined in Eq. (7).

$$MAE = \frac{\sum_{i=1}^N |y_i - y_{pi}|}{N} \quad (5)$$

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (y_i - y_{pi})^2} \quad (6)$$

where $MSE = \frac{1}{N} \sum_{i=1}^N (y_i - y_{pi})^2$, N is the total number of observations/rows in the test data.

$$R^2 = 1 - \frac{\sum_{i=1}^N (y_i - y_{pi})^2}{\sum_{i=1}^N (y_i - \bar{y}_{pi})^2} \quad (7)$$

where y_i is actual value of i^{th} observation, y_{pi} is predicted value of i^{th} observation, \bar{y}_{pi} is the average of predicted values and N is the number of observations/rows.

A. Results and Analysis

The testing experiments are conducted on the test dataset obtained from the 20% climatological data of Tamil Nadu, Kerala and Karnataka states in an Intel Core™ i7-7500 CPU with 2.70 GHZ speed and 16GB RAM using the numerical and ML packages of Python. The results obtained in terms of MAE, MSE, RMSE and R2 values from the stand-alone ML algorithms: MLR, SVR, DTR, RFR and ensemble algorithms: E-MLR-SVR, E-MLR-DTR, E-MLR-RFR, E-SVR-DTR, E-SVR-RFR, E-DTR-RFR, E-MLR-SVR-DTR, E-MLR-SVR-RFR, E-MLR-DTR-RFR and E-SVR-DTR-RFR are tabulated in the Tables IV and V for day-wise and month-wise predictions. It is found from Tables IV and V that E-MLR-RFR produces improved precipitation forecast than other models in terms of MAE, MSE, RMSE and R2 values for Tamil Nadu, Karnataka and Kerala states and also than the models in [25], [28] and [32] in Table I. The minimal RMSE

and maximal R2 value for day-wise precipitation forecast from the E-MLR-RFR model are 0.11, 0.2, 0.1 and 0.9997, 0.999, 0.999 for Tamil Nadu, Karnataka and Kerala states respectively. Also the minimal RMSE and maximal R2 value for month-wise precipitation forecast from the E-MLR-RFR model are 0.06, 0.08, 0.31 and 0.9996, 0.999, 0.999 for Tamil Nadu, Karnataka and Kerala states respectively. The performance comparisons of the precipitation predictions made by different models: stand-alone algorithms: MLR, SVR, DTR, RFR and ensemble algorithms: E-MLR-SVR, E-MLR-DTR, E-MLR-RFR, E-SVR-DTR, E-SVR-RFR, E-DTR-RFR, E-MLR-SVR-DTR, E-MLR-SVR-RFR, E-MLR-DTR-RFR and E-SVR-DTR-RFR are respectively shown in the line diagrams from Fig. 10 to Fig. 12 for Karnataka state. Minimal error is noted from all the line plots in terms of predicted and actual monthly precipitation.

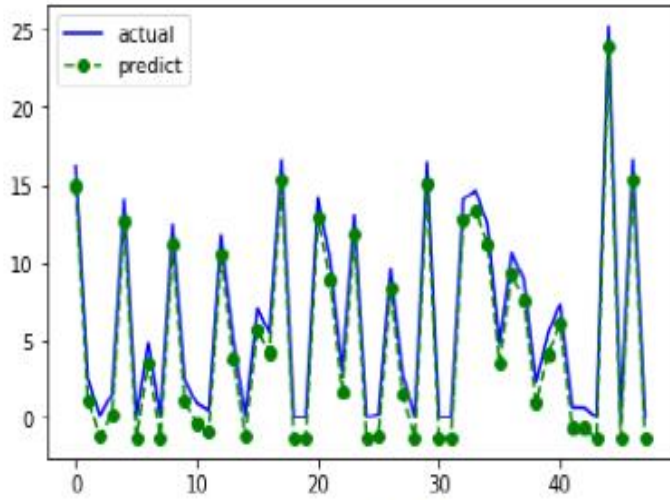
TABLE IV. MAE, MSE, RMSE AND R2 VALUES OF VARIOUS REGRESSION METHODS FOR TAMIL NADU (TN), KARNATAKA (KA) AND KERALA (KL) – DAY-WISE PREDICTIONS

Models	MAE			MSE			RMSE			R ² value		
	TN	KA	KL	TN	KA	KL	TN	KA	KL	TN	KA	KL
MLR	0.07	0.54	0.25	0.01	0.53	0.16	0.10	0.73	0.41	0.999	0.994	0.99
SVR	0.31	0.62	0.88	6.90	3.35	42.78	2.62	1.83	6.54	0.864	0.966	0.75
DTR	1.43	1.78	2.60	6.08	8.32	24.42	2.46	2.88	4.94	0.88	0.91	0.85
RFR	0.49	0.79	0.96	0.73	1.98	5.24	0.85	1.41	2.28	0.985	0.98	0.96
E-MLR-SVR	0.20	0.14	0.16	0.35	0.25	0.47	0.59	0.50	0.68	0.99	0.997	0.99
E-MLR-DTR	0.73	0.81	1.28	1.31	1.70	4.94	1.14	1.30	2.22	0.97	0.98	0.96
E-MLR-RFR	0.006	0.004	0.009	0.012	0.008	0.01	0.11	0.20	0.10	0.9997	0.999	0.999
E-SVR-DTR	0.82	0.86	1.34	2.00	2.11	6.81	1.41	1.45	2.60	0.958	0.975	0.95
E-SVR-RFR	0.20	0.14	0.16	0.37	0.25	0.50	0.61	0.50	0.70	0.99	0.997	0.99
E-DTR-RFR	0.73	0.81	1.28	1.44	1.70	4.92	1.20	1.30	2.22	0.96	0.98	0.96
E-MLR-SVR-RFR	0.13	0.09	0.10	0.17	0.11	0.20	0.41	0.33	0.45	0.996	0.998	0.99
E-MLR-SVR-DTR	0.54	0.57	0.89	0.89	0.93	3.02	0.94	0.96	1.73	0.981	0.989	0.98
E-MLR-DTR-RFR	0.49	0.54	0.85	0.62	0.74	2.21	0.78	0.86	1.48	0.987	0.99	0.985
E-SVR-DTR-RFR	0.54	0.57	0.89	0.93	0.92	3.04	0.96	0.96	1.74	0.98	0.98	0.98

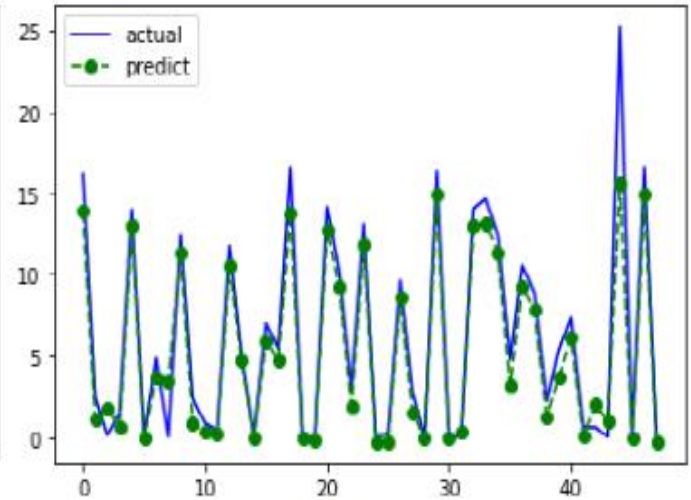
TABLE V. MAE, MSE, RMSE AND R2 VALUES OF VARIOUS REGRESSION METHODS FOR TAMIL NADU (TN), KARNATAKA (KA) AND KERALA (KL) – MONTH-WISE PREDICTIONS

Models	MAE			MSE			RMSE			R ² value		
	TN	KA	KL	TN	KA	KL	TN	KA	KL	TN	KA	KL
MLR	0.60	1.31	1.25	0.45	1.72	2.05	0.67	1.31	1.43	0.96	0.95	0.95
SVR	0.76	1.19	1.69	1.06	3.41	6.40	1.03	1.84	2.54	0.92	0.91	0.86
DTR	0.91	1.36	1.66	1.58	3.23	5.26	1.25	1.79	2.29	0.88	0.92	0.89
RFR	0.63	0.87	1.24	0.63	1.07	2.54	0.79	1.04	1.59	0.95	0.97	0.94
E-MLR-SVR	0.95	1.48	2.24	1.67	5.97	9.30	1.29	2.44	3.06	0.87	0.85	0.81
E-MLR-DTR	0.30	0.53	0.75	0.16	0.55	1.23	0.40	0.74	1.10	0.988	0.98	0.97
E-MLR-RFR	0.02	0.03	0.09	0.004	0.007	0.09	0.06	0.08	0.31	0.9996	0.999	0.998

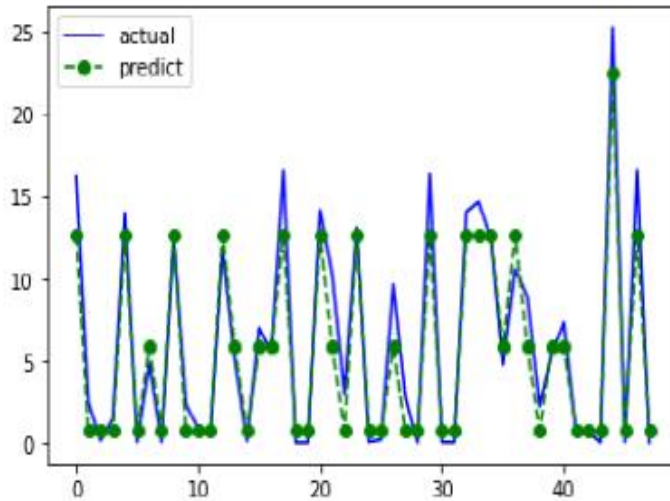
E-SVR-DTR	1.04	1.58	2.73	2.08	6.49	14.87	1.44	2.54	3.85	0.85	0.84	0.71
E-SVR-RFR	0.96	1.45	2.33	1.77	5.63	11.06	1.33	2.37	3.32	0.87	0.86	0.78
E-DTR-RFR	0.31	0.53	0.80	0.19	0.57	1.86	0.44	0.75	1.36	0.99	0.98	0.96
E-MLR-SVR-RFR	0.64	0.97	1.53	0.78	2.53	4.75	0.88	1.59	2.18	0.94	0.93	0.90
E-MLR-SVR-DTR	0.69	1.05	1.82	0.92	2.88	6.60	0.96	1.69	2.57	0.93	0.93	0.87
E-MLR-DTR-RFR	0.21	0.36	0.54	0.08	0.26	0.93	0.28	0.50	0.96	0.99	0.99	0.98
E-SVR-DTR-RFR	0.70	1.04	1.88	0.98	2.74	7.66	0.99	1.45	2.76	0.92	0.93	0.85



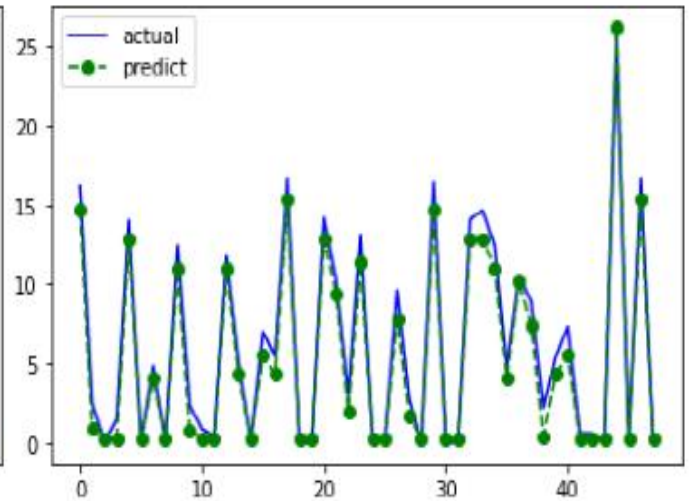
(a) MLR



(b) SVR



(c) DTR



(d) RFR

Fig. 10. Line plots showing actual and predicted monthly precipitation of Karnataka (a) MLR (b) SVR (c) DTR (d) RFR.

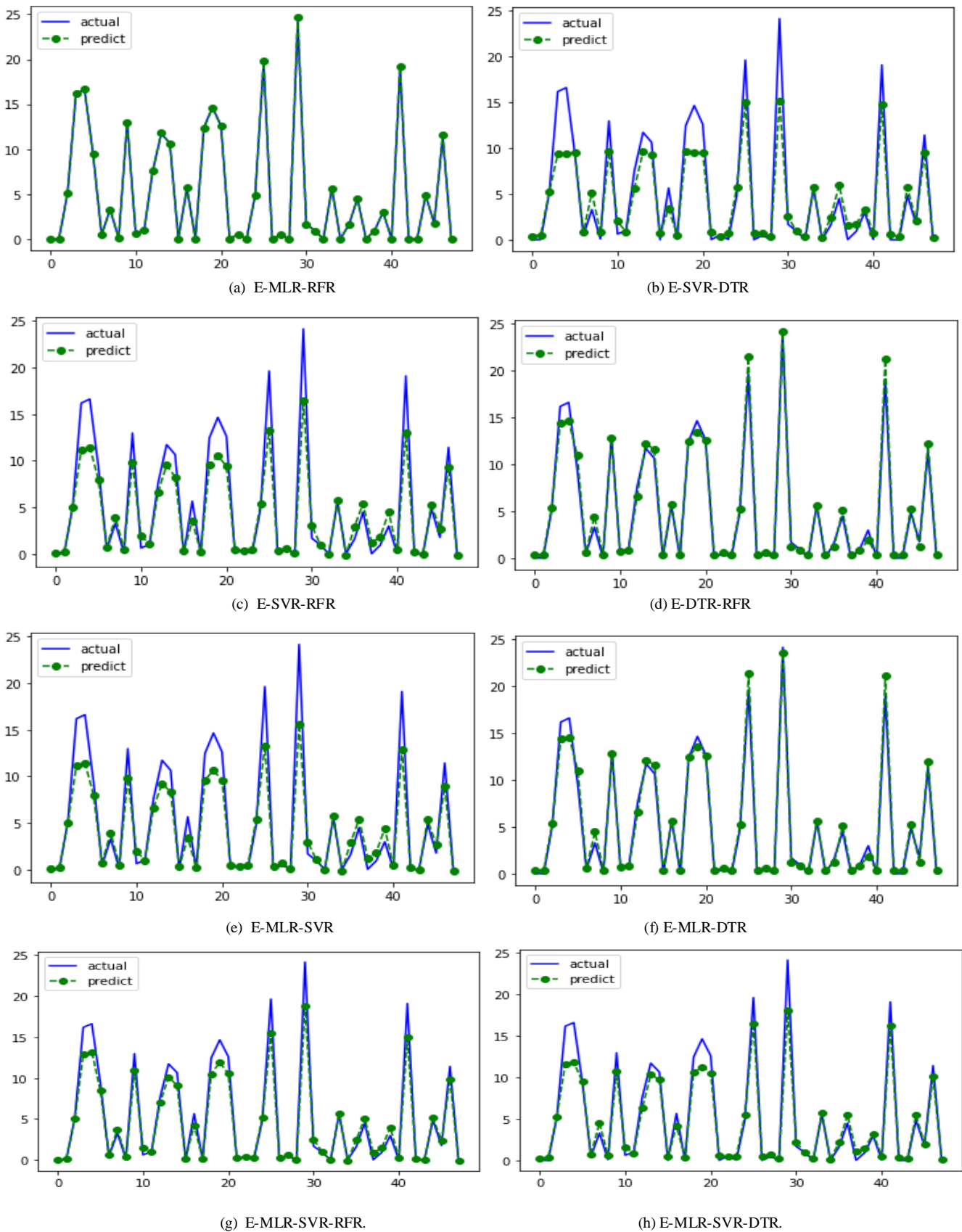


Fig. 11. Line plots showing actual and predicted monthly precipitation of Karnataka (a) E-MLR-RFR (b) E-SVR-DTR (c) E-SVR-RFR (d) E-DTR-RFR (e) E-MLR-SVR (f) E-MLR-DTR (g) E-MLR-SVR-RFR and (h) E-MLR-SVR-DTR.

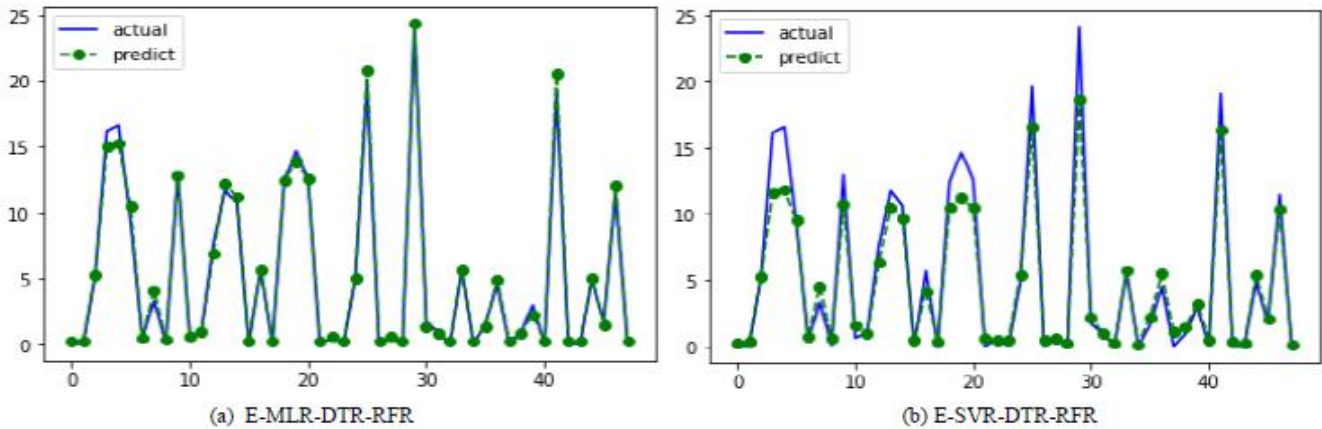


Fig. 12. Line plots showing actual and predicted monthly precipitation of Karnataka (a) E-MLR-DTR-RFR (b) E-SVR-DTR-RFR.

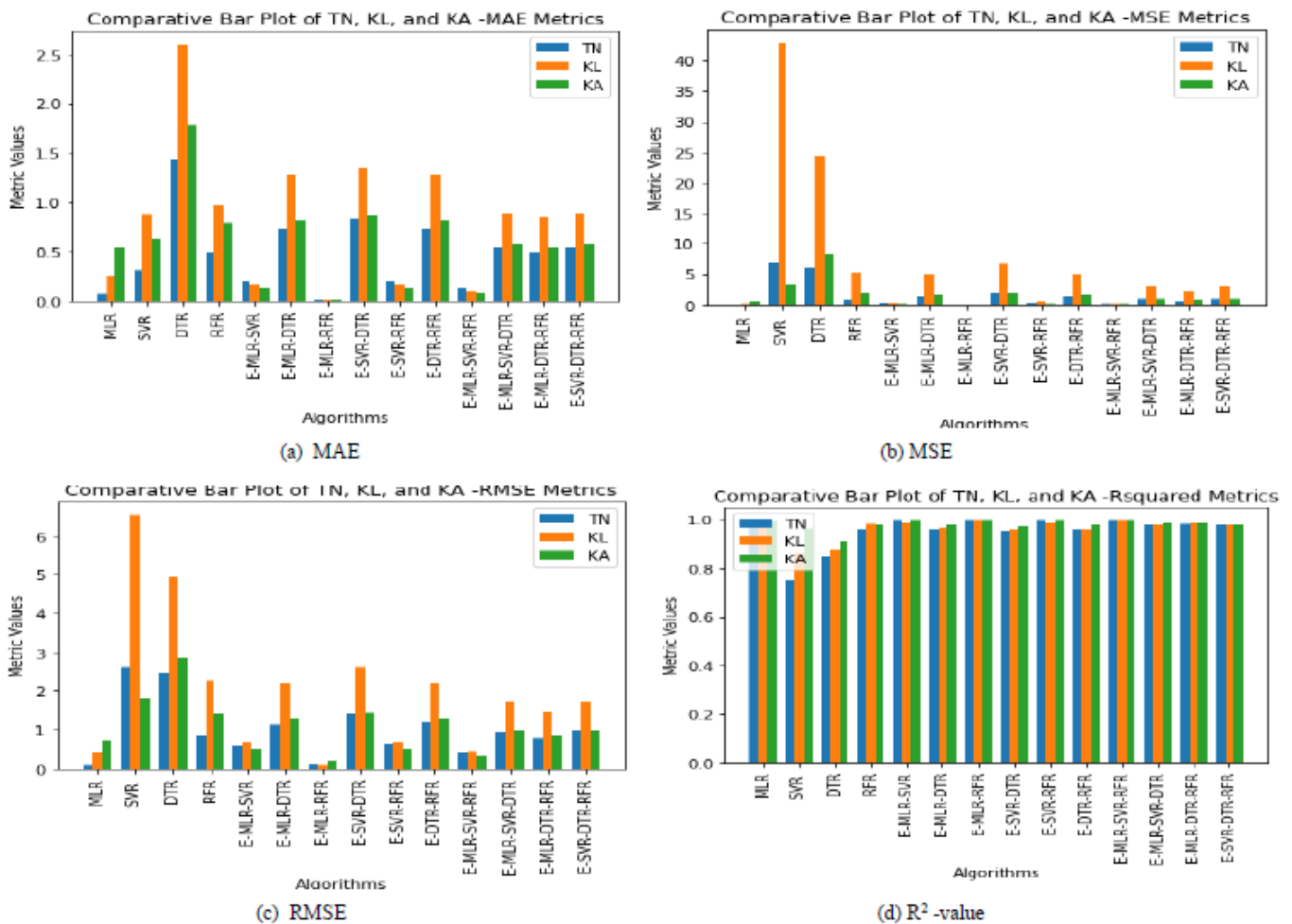


Fig. 13. Comparison of (a) MAE (b) MSE (c) RMSE (d) R^2 -values for Tamil Nadu (TN), Karnataka (KA) and Kerala (KL).

A barplot comparison of the evaluation metrics, MAE, MSE, RMSE and R^2 -values is also made between the states of Tamil Nadu, Karnataka and Kerala in Fig. 13. The ensemble model E-MLR-RFR fared better than other models. Also, the climatological data from Karnataka produces lesser error

when compared to the data from Kerala and Tamil Nadu for all models in the comparative study.

Heavy rainfall is one of the main reasons for flooding. A buildup of water in low-lying places can result in rivers overflowing their banks when rainfall surpasses a specific threshold, often 35.6 mm or more as reported in [42] and

shown in Table VI. So, the heavy rainfall predictions made from the best model, E-MLR-RFR proposed from the work to provide flood warnings in a specific location to reduce serious damage to both the environment and human societies.

TABLE VI. RAINFALL RANGE-FLOOD RANGE IS HIGHLIGHTED BOL

Description	Rainfall amount (mm/day)
Very Light Rain	0.1 -2.4
Light Rain	2.5 - 7.5
Moderate Rain	7.6- 35.5
Rather Heavy Rain	35.6-64.4
Heavy Rain	64.5 - 124.4
Very Heavy Rain	124.5 - 244.4
Extremely Heavy Rain	>244.4

V. CONCLUSION

The work has identified an appropriate ML based precipitation forecast model for the flood-prone southern states of India namely Tamil Nadu, Karnataka, Kerala which receive most precipitation using climatological data obtained from the NASA POWER platform. The precipitation forecast is proposed to alarm flood. The work investigated the effectiveness of ML forecasting models: Multiple Linear Regression (MLR), Support Vector Regression (SVR), Decision Tree Regression (DTR), Random Forest Regression (RFR) and ensemble approaches E-MLR-SVR, E-MLR-DTR, E-MLR-RFR, E-SVR-DTR, E-SVR-RFR, E-DTR-RFR, E-MLR-SVR-DTR, E-MLR-SVR-RFR, E-MLR-DTR-RFR and E-SVR-DTR-RFR in forecasting precipitation. The E-MLR-RFR model has produced improved and precise precipitation in terms of Mean Absolute Error (MAE), Mean Square Error (MSE), Root Mean Square Error (RMSE) and R² values. The higher precipitation forecast from E-MLR-RFR can be used to provide early warning about the possible flood in any region.

ACKNOWLEDGMENT

The data is obtained from the website: <https://power.larc.nasa.gov/> [30]. The website is associated with NASA Langley Research Center's (LaRC) POWER Project -a NASA Earth Science/Applied Science Program.

REFERENCES

[1] Lamond, J., Stanton-Geddes, Z., Bloch, R., & Proverbs, D. (2013). Cities and Flooding: Lessons in resilience from case studies of integrated urban flood risk management. CIB.

[2] Nkwunonwo, U. C., Whitworth, M., & Baily, B. (2016). A review and critical analysis of the efforts towards urban flood risk management in the Lagos region of Nigeria. *Natural hazards and earth system sciences*, 16(2), 349-369.

[3] Svetlana, D., Radovan, D., & Ján, D. (2015). The economic impact of floods and their importance in different regions of the world with emphasis on Europe. *Procedia Economics and Finance*, 34, 649-655.

[4] Chaluvadi, R., Varikoden, H., Mujumdar, M., Ingle, S. T., & Kuttippurath, J. (2021). Changes in large-scale circulation over the Indo-Pacific region and its association with 2018 Kerala extreme rainfall event. *Atmospheric Research*, 263, 105809.

[5] [5] Bashir, O. O., Oludare, A. H., Johnson, O. O., & Aloysius, B. (2012). Floods of fury in Nigerian cities. *Journal of Sustainable Development*, 5(7), 69.

[6] Nair, P. J., Varikoden, H., Francis, P. A., Chakraborty, A., & Pandey, P. C. (2021). Atmospheric moisture as a proxy for the ISMR variability and associated extreme weather events. *Environmental Research Letters*, 16(1), 014045.

[7] Few, R. (2003). Flooding, vulnerability and coping strategies: local responses to a global threat. *Progress in Development studies*, 3(1), 43-58.

[8] Subha, J., & Saudia, S. (2022). An Exploratory Data Analysis on SDMR Dataset to Identify Flood-Prone Months in the Regional Meteorological Subdivisions. In *Data Intelligence and Cognitive Informatics: Proceedings of ICDICI 2022* (pp. 595-617). Singapore: Springer Nature Singapore.

[9] Kumar, V., Jain, S. K., & Singh, Y. (2010). Analysis of long-term rainfall trends in India. *Hydrological Sciences Journal-Journal des Sciences Hydrologiques*, 55(4), 484-496.

[10] Wikipedia contributors. (2023). 2018 Kerala floods. *Wikipedia*. https://en.wikipedia.org/wiki/2018_Kerala_floods.

[11] Mishra, V., & Shah, H. L. (2018). Hydroclimatological perspective of the Kerala flood of 2018. *Journal of the Geological Society of India*, 92(5), 645-650.

[12] Kuttippurath, J., Murasingh, S., Stott, P. A., Sarojini, B. B., Jha, M. K., Kumar, P., ... & Pandey, P. C. (2021). Observed rainfall changes in the past century (1901-2019) over the wettest place on Earth. *Environmental Research Letters*, 16(2), 024018.

[13] Magar, R. B., & Jothiprakash, V. (2011). Intermittent reservoir daily-inflow prediction using lumped and distributed data multi-linear regression models. *Journal of earth system science*, 120(6), 1067-1084.

[14] Philipp, A., Schmitz, G. H., Krausse, T., Schütze, N., & Cullmann, J. (2008). Flash flood forecasting combining meteorological ensemble forecasts and uncertainty of initial hydrological conditions. *Australasian Journal of Water Resources*, 12(3), 257-267.

[15] Tate, E., & Cauwenberghs, K. (2005). An innovative flood forecasting system for the Demer basin: A case study. *International Journal of River Basin Management*, 3(3), 163-167.

[16] Tsakiri, K., Marsellos, A., & Kapetanakis, S. (2018). Artificial neural network and multiple linear regression for flood prediction in Mohawk River, New York. *Water*, 10(9), 1158.

[17] Khalaf, M., Alaskar, H., Hussain, A. J., Baker, T., Maamar, Z., Buyya, R., ... & Al-Jumeily, D. (2020). IoT-enabled flood severity prediction via ensemble machine learning models. *IEEE Access*, 8, 70375-70386.

[18] Khan, T. A., Alam, M. M., Shahid, Z., & Su'Ud, M. M. (2020). Investigation of Flash Floods on early basis: A Factual Comprehensive review. *IEEE Access*, 8, 19364-19380.

[19] Al-Dabbagh, A. W., Hu, W., Lai, S., Chen, T., & Shah, S. L. (2018). Toward the advancement of decision support tools for industrial facilities: Addressing operation metrics, visualization plots, and alarm floods. *IEEE Transactions on Automation Science and Engineering*, 15(4), 1883-1896.

[20] Zaji, A. H., Bonakdari, H., & Gharabaghi, B. (2018). Applying upstream satellite signals and a 2-D error minimization algorithm to advance early warning and management of flood water levels and river discharge. *IEEE Transactions on Geoscience and Remote Sensing*, 57(2), 902-910.

[21] Manandhar, S., Dev, S., Lee, Y. H., Meng, Y. S., & Winkler, S. (2019). A data-driven approach for accurate rainfall prediction. *IEEE Transactions on Geoscience and Remote Sensing*, 57(11), 9323-9331.

[22] Chen, H., Chandrasekar, V., Cifelli, R., & Xie, P. (2019). A machine learning system for precipitation estimation using satellite and ground radar network observations. *IEEE Transactions on Geoscience and Remote Sensing*, 58(2), 982-994.

[23] Barrera-Animas, A. Y., Oyedele, L. O., Bilal, M., Akinosho, T. D., Delgado, J. M. D., & Akanbi, L. A. (2022). Rainfall prediction: A comparative analysis of modern machine learning algorithms for time-series forecasting. *Machine Learning with Applications*, 7, 100204.

[24] Aftab, S., Ahmad, M., Hameed, N., Bashir, M. S., Ali, I., & Nawaz, Z. (2018). Rainfall prediction using data mining techniques: A systematic literature review. *International journal of advanced computer science and applications*, 9(5).

- [25] Velasco, L. C., Aca-ac, J. M., Cajés, J. J., Lactuan, N. J., & Chit, S. C. (2022). Rainfall Forecasting using Support Vector Regression Machines. *International Journal of Advanced Computer Science and Applications*, 13(3).
- [26] Khan, T. A., Alam, M., Kadir, K., Shahid, Z., & Mazliham, M. S. (2019). A comparison review based on classifiers and regression models for the investigation of flash floods. *Editorial Preface from the Desk of Managing Editor*, 10(9), 352-359.
- [27] Meenal, R., Michael, P. A., Pamela, D., & Rajasekaran, E. (2021). Weather prediction using random forest machine learning model. *Indonesian Journal of Electrical Engineering and Computer Science*, 22(2), 1208-1215.
- [28] Abdullah, A. S., Ruchjana, B. N., & Jaya, I. G. N. M. (2021). Comparison of SARIMA and SVM model for rainfall forecasting in Bogor city, Indonesia. In *Journal of Physics: Conference Series* (Vol. 1722, No. 1, p. 012061). IOP Publishing.
- [29] Sreehari, E., & Srivastava, S. (2018). Prediction of climate variable using multiple linear regression. In *2018 4th International Conference on Computing Communication and Automation (ICCCA)* (pp. 1-4). IEEE.
- [30] NASA POWER, <https://power.larc.nasa.gov/>
- [31] de Castro, J. T., Salistre Jr, G. M., Byun, Y. C., & Gerardo, B. D. (2013). Flash flood prediction model based on multiple regression analysis for decision support system. In *Proceedings of the World Congress on Engineering and Computer Science* (Vol. 2, pp. 23-25).
- [32] Rezaeianzadeh, M., Tabari, H., Arabi Yazdi, A., Isik, S., & Kalin, L. (2014). Flood flow forecasting using ANN, ANFIS and regression models. *Neural Computing and Applications*, 25, 25-37.
- [33] Saha, A., Pal, S. C., Arabameri, A., Blaschke, T., Panahi, S., Chowdhuri, I., ... & Arora, A. (2021). Flood susceptibility assessment using novel ensemble of hyperpipes and support vector regression algorithms. *Water*, 13(2), 241.
- [34] Chicco, D., Warrens, M. J., & Jurman, G. (2021). The coefficient of determination R-squared is more informative than SMAPE, MAE, MAPE, MSE and RMSE in regression analysis evaluation. *PeerJ Computer Science*, 7, e623.
- [35] Wikipedia contributors. (2023). Coefficient of determination. https://en.wikipedia.org/wiki/Coefficient_of_determination.
- [36] Faraway, J. J. (2016). Does data splitting improve prediction? *Statistics and computing*, 26, 49-60.
- [37] Joseph, V. R. (2022). Optimal ratio for data splitting. *Statistical Analysis and Data Mining: The ASA Data Science Journal*, 15(4), 531-538.
- [38] Nguyen, Q. H., Ly, H. B., Ho, L. S., Al-Ansari, N., Le, H. V., Tran, V. Q., ... & Pham, B. T. (2021). Influence of data splitting on performance of machine learning models in prediction of shear strength of soil. *Mathematical Problems in Engineering*, 2021, 1-15.
- [39] Jordan, M. I., & Mitchell, T. M. (2015). Machine learning: Trends, perspectives, and prospects. *Science*, 349(6245), 255-260.
- [40] El Naqa, I., & Murphy, M. J. (2015). *What is machine learning?* (pp. 3-11). Springer International Publishing.
- [41] Uyanik, G. K., & Güler, N. (2013). A study on multiple linear regression analysis. *Procedia-Social and Behavioral Sciences*, 106, 234-240.
- [42] Barde, V., Nageswararao, M. M., Mohanty, U. C., Panda, R. K., & Ramadas, M. (2020). Characteristics of southwest summer monsoon rainfall events over East India. *Theoretical and Applied Climatology*, 141, 1511-1528.
- [43] Wikipedia contributors. (2023). 2022 South Asian floods. https://en.wikipedia.org/wiki/2022_South_Asian_floods.
- [44] Davies, R. (2022). Saudi Arabia – Severe Floods Hit Jeddah After 179mm of Rain in 6 Hours. <https://floodlist.com/asia/saudi-arabia-floods-jeddah-november-2022>.
- [45] Wang, J., & Chen, T. (2014). An online method to remove chattering and repeating alarms based on alarm durations and intervals. *Computers & Chemical Engineering*, 67, 43-52.
- [46] Brakenridge, G. R., Nghiem, S. V., Anderson, E., & Mic, R. (2007). Orbital microwave measurement of river discharge and ice status. *Water Resources Research*, 43(4).
- [47] Khalaf, M., Hussain, A. J., Al-Jumeily, D., Fergus, P., & Idowu, I. O. (2015). Advance flood detection and notification system based on sensor technology and machine learning algorithm. In *2015 International Conference on Systems, Signals and Image Processing (IWSSIP)* (pp. 105-108). IEEE.
- [48] Misra, P., & Yadav, A. S. (2019). Impact of preprocessing methods on healthcare predictions. In *Proceedings of 2nd International Conference on Advanced Computing and Software Engineering (ICACSE)*.
- [49] Wen, X., Kleinman, K., Gillman, M. W., Rifas-Shiman, S. L., & Taveras, E. M. (2012). Childhood body mass index trajectories: modeling, characterizing, pairwise correlations and socio-demographic predictors of trajectory characteristics. *BMC medical research methodology*, 12, 1-13.
- [50] Cutts, C. S., & Eglén, S. J. (2014). Detecting pairwise correlations in spike trains: an objective comparison of methods and application to the study of retinal waves. *Journal of Neuroscience*, 34(43), 14288-14303.
- [51] Khalili, M., Brissette, F., & Leconte, R. (2009). Stochastic multi-site generation of daily weather data. *Stochastic Environmental Research and Risk Assessment*, 23, 837-849.
- [52] Heinze, G., Wallisch, C., & Dunkler, D. (2018). Variable selection—a review and recommendations for the practicing statistician. *Biometrical journal*, 60(3), 431-449.
- [53] Venkatesh, B., & Anuradha, J. (2019). A review of feature selection and its methods. *Cybernetics and information technologies*, 19(1), 3-26.
- [54] Breiman, L., & Friedman, J. H. (1997). Predicting multivariate responses in multiple linear regression. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, 59(1), 3-54.
- [55] Bakar, N. M. A., & Tahir, I. M. (2009). Applying multiple linear regression and neural network to predict bank performance. *International Business Research*, 2(4), 176-183.
- [56] Wikipedia contributors. (2023). Linear regression. https://en.wikipedia.org/wiki/Linear_regression.
- [57] Bermolen, P., & Rossi, D. (2009). Support vector regression for link load prediction. *Computer Networks*, 53(2), 191-201.
- [58] Zheng, S. (2015). A fast algorithm for training support vector regression via smoothed primal function minimization. *International Journal of Machine Learning and Cybernetics*, 6, 155-166.
- [59] Schölkopf, B., Smola, A. J., Williamson, R. C., & Bartlett, P. L. (2000). New support vector algorithms. *Neural computation*, 12(5), 1207-1245.
- [60] Rathore, S. S., & Kumar, S. (2016). A decision tree regression based approach for the number of software faults prediction. *ACM SIGSOFT Software Engineering Notes*, 41(1), 1-6.
- [61] Erdebilli, B., & Devrim-İçtenbaş, B. (2022). Ensemble Voting Regression Based on Machine Learning for Predicting Medical Waste: A Case from Turkey. *Mathematics*, 10(14), 2466.
- [62] Zhang, Y., Liu, J., & Shen, W. (2022). A review of ensemble learning algorithms used in remote sensing applications. *Applied Sciences*, 12(17), 8654.
- [63] Bashar, S. S., Miah, M. S., Karim, A. Z., & Al Mahmud, M. A. (2019). Extraction of heart rate from PPG Signal: a machine learning approach using decision tree regression algorithm. In *2019 4th International Conference on Electrical Information and Communication Technology (EICT)* (pp. 1-6). IEEE.
- [64] Schonlau, M., & Zou, R. Y. (2020). The random forest algorithm for statistical learning. *The Stata Journal*, 20(1), 3-29.
- [65] Rodriguez-Galiano, V., Sanchez-Castillo, M., Chica-Olmo, M., & Chica-Rivas, M. J. O. G. R. (2015). Machine learning predictive models for mineral prospectivity: An evaluation of neural networks, random forest, regression trees and support vector machines. *Ore Geology Reviews*, 71, 804-818.
- [66] Seiler, R. A., Hayes, M., & Bressan, L. (2002). Using the standardized precipitation index for flood risk monitoring. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, 22(11), 1365-1376.
- [67] Khole, M., Sreejith, O. P., Pai, D. S., & Devi, S. (2021). PUNE-411 005 INDIA.

Recurrent Ascendancy Feature Subset Training Model using Deep CNN Model for ECG based Arrhythmia Classification

Shaik Janbhasha¹, S Nagakishore Bhavanam²

Department of Computer Science and Engineering, Acharya Nagarjuna University, Guntur, Andhra Pradesh, India¹

Department of Electronics and Communication Engineering, Acharya Nagarjuna University, Guntur, Andhra Pradesh, India²

Abstract—The World Health Organization (WHO) has released a report warning of the worldwide epidemic of heart disease, which is reaching worrisome proportions among adults aged 40 and high. Heart problems can be detected and diagnosed by a variety of methods and procedures. Scientists are striving to find multiple approaches that meet the required accuracy standards. Finding the heart issue in the waveform is what an Electrocardiogram (ECG) is all about. Feature-based deep learning algorithms have been essential in the medical sciences for decades, centralising data in the cloud and making it available to researchers around the world. To promptly detect irregularities in the cardiac rhythm, manual analysis of the ECG signal is insufficient. ECGs play a crucial role in the evaluation of cardiac arrhythmias in the context of daily clinical practice. In this research, a deep learning-based Convolution Neural Network (CNN) framework is adapted from its original classification task to automatically diagnose arrhythmias in ECGs. A deep convolution network that has been used for training with most relevant feature subset is used for accurate classification. The primary goal of this research is to classify arrhythmia using a deep learning method that is straightforward, accurate, and easily deployable. This research proposes a Recurrent Ascendancy Feature Subset Training model using Deep CNN model for arrhythmia Classification (RAFST-DCNN-AC). The suggested framework is tested on ECG waveform circumstances taken from the MIT-BIH arrhythmia database. The proposed model when contrasted with the existing models exhibit better classification rate.

Keywords—Feature selection; arrhythmia classification; convolution neural network; deep learning; electrocardiograms

I. INTRODUCTION

Many international health groups, including the World Health Organization, have concluded that cardiovascular diseases are the leading cause of death around the world. More people die each year from cardiovascular disease than from any other single cause [1]. Both strokes and heart attacks account for 88% of all cardiovascular diseases. Majority of cardiac deaths worldwide occur in regions with lower or moderate incomes [2]. Untreated cardiac arrhythmias and their long-term consequences are a leading cause of deadly cardiovascular diseases. Arrhythmia is the medical term for irregular heartbeats [3]. Arrhythmias play a pivotal role in ECG abnormalities, as this is essentially a rhythm conduction problem. Electrocardiography can detect potentially fatal heart arrhythmias and other problems. During this procedure, an

electrode is positioned on the patient's chest to record the rhythm of their heart's electrical activity. ECG sessions are typically used for long-term data recording and analysis by physicians and doctors to evaluate the presence or absence of a cardiac abnormality and the patient's risk for developing this condition. Time is a major factor in this undertaking. Therefore, it is crucial for doctors and medical professionals to be able to diagnose heart arrhythmia [4].

People are concerned about the global health as the prevalence of congenital heart defects increases over time. Up to this point, ECG signals have shown to be the most reliable method of determining cardiac dysfunction and abnormalities [5]. ECG and its associated terms P wave, QRS complex, T wave, and QT interval show normal heart activity [6]. By analysing these characteristics or electrical waves, the abnormality can be identified with the help of expert medical expertise. The heart diseases that affect heart rate were successfully observed using deep learning techniques [7]. It is possible that the irregular heart rate is the result of the faulty signal being too slow, too rapid, or completely unexpected. Lack of therapy can result in a heart attack or heart failure. The Normal Sinus Rhythm (NSR) represents a healthy, normal heartbeat on an electrocardiogram [8]. Congestive heart failure (CHF) represents the opposite type, a chronic condition in which the heart's ability to pump blood is impaired. Inadequate blood flow causes the heart to weaken and frequently disrupts its ability to operate [9].

Medical researchers have been motivated by the state-of-the-art uses of deep learning in the fields of pattern and image recognition. Though electrocardiograms (ECGs) are excellent at monitoring heart activity, only individuals with specialised training can read and understand the resulting tracings [10]. The distinction between symptomatic and asymptomatic arrhythmias is crucial because some potentially deadly arrhythmias can be present with no symptoms at all. Patients with symptomatic arrhythmias may experience dizziness, difficulty breathing, and an irregular heartbeat, all of which may be caused by emotional stress [11]. Extremely high blood sugar, mental stress, excessive smoking, hypertension, and other environmental and behavioural variables have all been linked to arrhythmias. A sluggish heartbeat is possible even in healthy persons, and is not always indicative of any underlying health concern [12]. Categorization results are helpful for diagnosing the risk of arrhythmias or sudden deaths, and can reveal information such as the presence of

non-sustained sustained ventricular tachycardia and ventricular premature beats.

In recent years, cardiac arrhythmia data has grown to an unprecedented degree, stifling advancements in feature-extraction outcomes. This is why Deep Learning (DL) has brought about crucial outcomes in the field of arrhythmia detection. Because of their ability to automatically detect and extract features to produce clear and precise findings, deep neural networks have gained popularity in the field of heartbeat classification [13]. In order to maximise the benefits of automated feature detection and extraction, a wide variety of methods and techniques have been integrated with cutting-edge deep-learning algorithms [14]. These methods can be grounded in a variety of frameworks, including those for multiple models and hybridization. In order to incorporate multi-level features and their transformation, a deep neural network is typically designed with a hierarchical layered structure [15].

In modern medicine, the diagnosis of potentially fatal cardiac arrhythmias requires the meticulous analysis of the ECG by board-certified cardiologists. Automated cardiac arrhythmia categorization, on the other hand, has the potential to speed up diagnosis while also providing cardiologists with more objective data [16]. To classify a system automatically into one of several categories is the goal of pattern recognition [17]. An experienced cardiologist can tell only by looking at the ECG waveforms printout what kind of cardiac arrhythmia their patient has. While advanced ECG analyzers can sometimes outperform a human cardiologist, there is still a subset of ECG waveforms that cannot be reliably identified by computers at this time [18]. The purpose of this research is to lay the groundwork for the creation of a computer-aided diagnostic system that will aid specialised cardiologists in the diagnosis of ECG arrhythmias in a way that is both smart and efficient in terms of both money and time. This is done by applying state-of-the-art deep learning approaches to the problem of ECG arrhythmia pattern detection alongside more traditional methods of ECG data processing [19].

In addition, this structure aids in the improvement of feature refinement. The limitations of traditional machine-learning strategies, such as the need for manual and inaccurate feature selection, which can have undesirable effects in the context of the aforementioned applications, are being overcome by integrating neural networks such as Recurrent Neural Networks (RNN) [20], Long Short-Term Memory (LSTM), Convolutional Neural Networks (CNN), and hybrid models, etc. Because accurate categorization of heartbeats and arrhythmia detection necessitates a large quantity of data to work with, the downsides of hybrid techniques build as the cost and lack of quality datasets [21], which may be regarded trivial in some viable scenarios, increase over time. This research offers a deep neural network ensemble to tackle these problems head-on, with the design and merging of two networks, then training the combined model all happening in one continuous process [22]. The innovative features centre on the utilisation of a multi-model framework that combines the capability to blend different ML/DL models and generate a robust result. The suggested methodology outperforms state-of-the-art studies in heartbeat detection and categorization.

This research proposes a Recurrent Ascendancy Feature Subset Training model using Deep CNN model for arrhythmia classification with better classification rate.

II. LITERATURE SURVEY

ECG tracing and arrhythmia classification methodology is presented by Tang et al. [2]. The suggested system includes a front-end IC, an FPGA-based delineation technique, and an arrhythmia classification technique. The inclination of the incoming analogue ECG signal is measured by a ternary second-order Delta modulator in the front-end circuit. Without regard to the instantaneous amplitude, the circuit transforms the analogue inputs into a pulse density modified bitstream whose pulse density is proportionate to the slope variation of the input analogue signal. Within a timing inaccuracy of 3 ms, the front-end chip can detect a slope variation as small as 3.2 mV/ms². Fabricated to use a 180 nm CMOS technology, the 0.25 mm² front-end IC uses just 151 nW of power at 1 kS/s sampling rate. An ECG waveform's fiducial spots can be located using a delineation technique that is informed by the slope variation received from the front-end circuit. A Spartan-6 FPGA was used to test the demarcation algorithm. The delineation system can determine 22 aspects about the QRS/PT waves based on their intervals, slopes, and shape. This information is used to classify arrhythmias such as ventricular ectopic beat (VEB), supraventricular ectopic beat (SVEB), and sinus node originated heartbeats using a rotational linear kernel support vector machine (SVM) for each individual patient.

An ECG is a non-invasive diagnostic tool for identifying heart rhythm disturbances. The literature reports numerous methods for classifying arrhythmias using a wide variety of ECG parameters. Accurate recognition and categorization of arrhythmias is proposed in this work by Zhang et al. [4] using a new approach in conjunction with a novel morphological feature. Events in the ECG signals are first identified. Then, certain sections of an ECG are extracted in order to measure their amplitude, interval, and duration, which are all parametric aspects of ECG morphology. Finally, a new clustering-based extracting features approach is proposed, along with a novel feature for assessing QRS complex morphological changes as visual patterns. At last, the feature vectors are fed into a neural network, a support vector machine, and a K-nearest neighbours classifier so that an automatic diagnosis can be made. Using the MIT-BIH arrhythmia database, which includes all fifteen heartbeat types recommended by the Association for the Advancement of Medical Instrumentation, the proposed method was evaluated, and with the help of the combined parameterized and visual pattern features of ECG Morphology, it achieved the best accuracy rate of 97.70% based on KNN.

An automatic method of detecting arrhythmias from a 12-lead ECG signal is a vital tool in the early detection and prevention of cardiovascular disorders. Previous research on automatic arrhythmia diagnosis often involved combining data from 12 ECG leads into a matrix, which was then fed into a number of feature extractors or deep neural networks. As the data from each lead of a 12-lead ECG interacts with one another during training, these approaches were able to extract

comprehensive properties of the full ECG. Poor information acquisition for 12-lead ECG was the result of ignoring the diversity of lead-specific properties across those leads. The information fusion of extensive features with consistency and lead-specific characteristics with variety should be considered to maximise the information learning of multi-lead ECG. In this paper, Wang et al.[5] presented a new Multi-Lead-Branch Fusion Network (MLBF-Net) architecture for arrhythmia classification by jointly learning the variety and integrity of multi-lead ECG through the use of multi-loss optimization. There are three parts to the MLBF-Net system: It consists of three parts: multiple lead-specific branches for learning the variety of multi-lead ECG; cross-lead features blending by appending the output feature maps of all branches for learning the integrity of multi-lead ECG; and multi-loss co-optimization for all the different branches and the concatenated network.

The ECG is the gold standard for diagnosing heart conditions. However, due to the volume of patient ECG data, human interpretation is laborious and time-consuming. Since there is a severe scarcity of medical personnel, intelligent ECG recognition technology is crucial. For the first time, this research provides an arrhythmia classification algorithm that makes use of ECG data fragments that each contain information on three whole cardiac processes across several ECG leads. Using the MIT-BIH arrhythmia database as training examples, the THML ECG data pre-processing algorithm is developed. To get the best possible integrated classification effect, Tang et al. [7] build four arrhythmia classification models using a 1D-CNN and a priority model integrated voting technique. Ablation trials demonstrate the viability and efficacy of THML ECG data, and the experiments were conducted using the inter-patient system proposed by the Association for the Advancement of Medical Instrumentation (AAMI).

Arrhythmia is a life-threatening kind of cardiovascular disease. ECG analysis using artificial intelligence is a powerful tool for the detection, diagnosis, and treatment of arrhythmia in its earliest stages. Commonly, many types of arrhythmia will be diagnosed in a single patient based on their ECG waveform. Despite this, the focus of the majority of the research done now is on multiclass approaches for dealing with the multi-label problem, which leads to information loss by disregarding the links between diseases. Therefore, Singh et al. [10] proposed an ECG-based multi-label feature selection method (MS-ECG) designed an evaluation criterion of ECG features based on kernelized fuzzy rough sets in order to select the best feature subset and maximise the ECG feature space. The author developed a multi-objective optimization model and proposed a multi-label classification algorithm for arrhythmia based on ECG. To reliably and automatically assign various labels to a single ECG signal, this sparsity-constrained method investigates the relationships between different arrhythmia disorders and examines the mapping link between ECG features and arrhythmia diseases.

Deaths from cardiovascular disease (CVD) now outnumber all others. ECG monitoring is currently included in wearable devices and is a common approach for diagnosing CVD. An ECG delineation and arrhythmia classification

(EDAC) system prototype for wearable ECG biosensors is presented in this research by Sohail, et al. [12]. The system is made up of a Delta-modulator-based analog-to-feature converter (AFC), a linear kernel support vector machine (SVM) classifier, an automated gain controller (AGC) block, and an algorithm for detecting, delineating, and extracting features from an ECG. In order to recognise QRS complexes, localise fiducial sites, and extract feature vectors for each pulse in the DDF block, the AFC digitises the slope and slope variation of the input analogue signal. On the basis of the detected QRS complex, the AGC then sends a gain control signal to the front-end amplifier. Finally, arrhythmia classification is handled by the SVM block. The MIT-BIH arrhythmia database is used to assess the efficacy of the EDAC system.

Qian et al. [15] introduced a low-overhead method for extracting key characteristics from ECG signals. Additionally, real-time algorithms are proposed to categorise arrhythmias based on these features. Two delta-sigma modulators with a 250 Hz sampling rate and three wave detection algorithms are the basis of the proposed feature extraction system. Essential information about each heartbeat is extracted and encoded into 68 bits of data, which is only 1.48 percent as much as other comparable approaches. Random forests are used as classifiers, and they are trained to distinguish between two common categories of arrhythmias. There are two types of ectopic beats: supraventricular (SVEB) and ventricular (VEB). Comparable to state-of-the-art approaches, the arrhythmia classification achieves F1 scores of 81.05% for SVEB and 97.07% for VEB. This technique offers a dependable and precise means of analysing ECG readings.

Performing an ECG signal analysis is a process that can be laborious, time-consuming, and prone to human error. That's why it's about time Pławiak et al. [16] had an automated study to help cardiologists spot issues in the heart faster and more reliably. While deep learning (DL) models have made remarkable strides and demonstrated impressive arrhythmia classification capabilities recently, their "black-box" nature makes it difficult to employ them in the medical field. This article presents a strong explainability approach to help explain how deep neural networks (DNNs) make decisions and to give feedback on biases that may be used to better train DNNs. In order to accomplish these goals, a DL model is first trained and tested using the MIT-BIH Arrhythmia Database. Post-hoc explanation techniques like SHapley Additive exPlanations (SHAP), local interpretable model-agnostic explanations (LIME), and gradient-weighted class activation mapping (Grad-CAM) are used to make sense of the classification results by deciphering the decision-making process. Several limitations are identified after evaluating these methods for ECG arrhythmia classification, including a lack of ability to identify the significance of a feature when that feature occurs multiple times in a signal and the fact that SHAP and LIME perform random perturbations, which can lead to unreliable explanations. Therefore, a unique K-GradCam approach is proposed to address the limitations of conventional post-hoc explainability techniques for time-series data.

Suitable for low-quality ECG data, Wang et al. [17] proposed a rapid and accurate denoising and classification method. In order to accomplish this, the author proposed a novel attention-based convolutional denoising autoencoder (ACDAE) model that uses a skip-layer and attention module to reliably reconstruct ECG signals from high-noise environments. A lightweight, efficient channel attention (ECA) module is used to efficiently update key characteristics obtained through cross-channel interaction, and skip-layer connections are used to reduce information loss while reconstructing the original signal. Four public databases are used for training and testing the model. Additive white Gaussian noise (AWGN) with amplitudes between 20 and 20 dB is used to evaluate the signals, along with noise from the MIT-Beth Israel Hospital Noise Stress Test Database (NSTDB) with amplitudes between 6 and 24 dB.

III. PROPOSED MODEL

The electrical activity of the heart can be measured and recorded with the use of ECG. The interpretation of ECG signals is vitally important for the diagnosis of arrhythmias. Cardiologists typically employ visual recognition to diagnose and detect various arrhythmias based on brief ECG data [23]. The QRS complexes will show any irregularities in the electrical signal. Detailed information about the signal's nature can be gleaned from the QRS complexes from the ECG signal. When it comes to categorizing ECG signals [24], feature extraction presents a substantial challenge. Most techniques based on deep learning for autonomous categorization of cardiac arrhythmia can be broken down into two categories: feature engineering and classification. To be more specific, researchers first manually retrieved a significant number of medically relevant ECG components, such as wavelet features. Integrated performance of P, Q, R, and S, plus T, a statistical feature of HRV, morphological features and a statistical feature of higher order mathematical techniques such as enhanced principal component analysis are used to reduce the dimensions of an ECG and thereby extract its features [25]. Artificial features are analysed using deep learning methods, self-organizing maps, and clustering, following feature engineering to yield a prediction result. Deep learning has several potential uses in the classification of cardiac arrhythmias for scientific research, however some issues remain to be resolved [26]. For instance, feature engineering that relies on subjective considerations can result in the removal of potentially relevant features, which in turn can have an impact on the overall classification performance.

The accuracy of ECG-based diagnostics for cardiovascular diseases has been shown to be improved with the help of deep learning models. They lead to steadily better neural networks by leveraging the cascade of mixed layers of neural networks to extract progressively higher-level features. In many applications of AI algorithms, deep neural networks have finally reached their full potential. This research proposes a unique framework for ECG analysis and classification, one that can represent the signal in a form that is portable between tasks. In order for this to occur, a deep neural network design is proposed that provides high abilities to learn such representations. Since this network has indeed been trained to identify arrhythmias, it is reasonable to presume that the

model has picked up all the relevant features information about the ECG's structure.

A CNN is the first model that this framework supports. It has three hidden layers, one flattening layer, two dense layers, and a batch normalization layer. A n1 matrix is what the CNN expects to see when it starts up. Additionally, a convolution layer and a pooling layer make up all hidden layers. Data type and quantity inform the best pooling strategy selection among options like min-pool, max-pool, and average-pool. Both the average and the maxpool methods are commonly employed for heartbeat categorization. With this goal in mind, max-pooling is used in the deployed CNN, which takes the item in the list from each unit of the feature map. The proposed model framework is shown in Fig. 1.

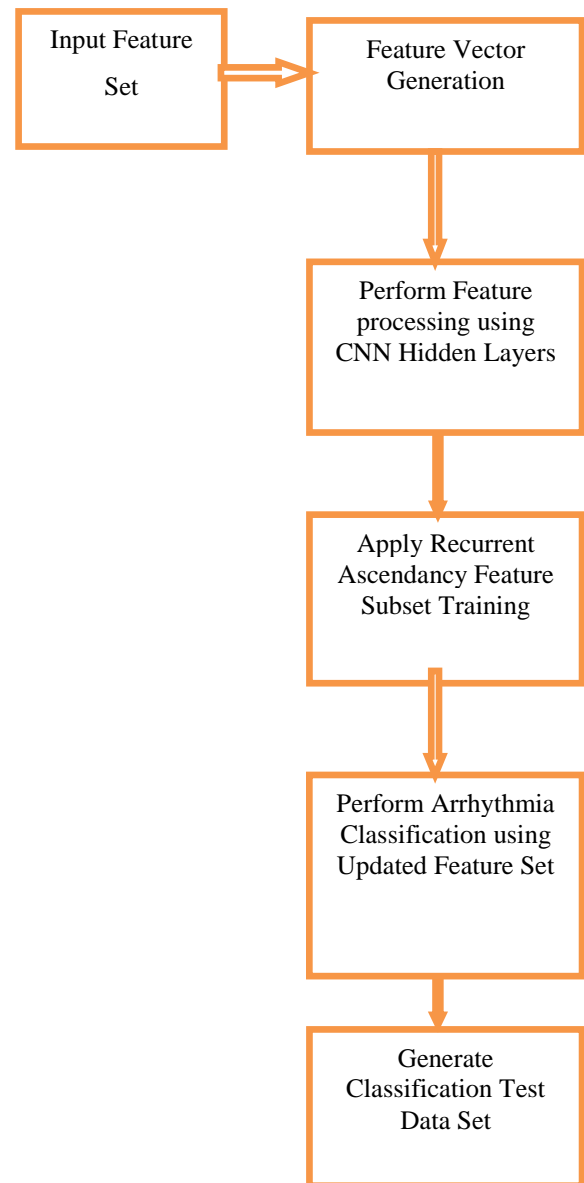


Fig. 1. Proposed model framework.

All of the convolution layers here are one-dimensionally applying convolution in time, and each of those layers has 32 kernels of size 3. Furthermore, all pooling layers employ

maximum pooling with a pool size of 5, and a stride of 3. Output class probabilities are predicted by a predictor network made up of five residual blocks, two fully-connected layers of 32 neurons each, and a softmax layer. First, an ECG signal is segmented into 15-second windows, and then one of those windows is chosen. Scaling all amplitude values to fall between 0 and 1. The next step is to identify all local maxima using zero-crossings of the first derivative. Then using a 0.9 threshold on the normalized value of the local maxima, identify a set of potential R-peak locations in an electrocardiogram. Using the middle value of R-R intervals as the window's standard heart rate, pick a section of the signal with a length of 1T for each R-peak. Adding leading zeros to each segment chosen until their total length is the same as some fixed value as set. In particular, the proposed beat extraction technique is simple to apply and produces reliable results when applied to signals of varying morphologies, making it ideal for use in applications requiring the extraction of R-R intervals. This research proposes a Recurrent Ascendancy Feature Subset Training model using Deep CNN model for Arrhythmia Classification.

Algorithm RAFST-DCNN-AC

{

Input: Feature Set {F_{set}}

Output: Arrhythmia Classification Set {AC_{set}}

Step-1: The feature set is considered and the features are analyzed for processing for accurate classification. The feature vector generation is performed based on the independent attribute correlation range. The feature vector generation of independent feature set is generated as

$$\begin{aligned}
 & FVset(Fset(M)) \\
 &= \sum_{f=1}^M \left(getattr(Fset(f)) + \frac{\max(Fset(f+1))}{\text{len}(Fset(f))} + \text{avg}(f, f+1) \right. \\
 & \quad \left. - \min(getattr(Fset(f))) \right)
 \end{aligned}$$

Here f is the feature considered and f+1 is the neighbor dependant feature.

Step-2: Hidden layer is situated between the input and output layers. An activation function is used to convert a set of weighted sources into an output. Since it is neither the input nor the output layer, this layer is referred to as the hidden layer. The processing layer called hidden layer is where everything actually occurs. The feature processing using hidden layers is performed for removing the irrelevant features still and to update the feature vector for better

classification rate. The process of hidden layer process is performed as

$$\begin{aligned}
 & HiddLayer(f, f+1, M) \\
 &= \sum_{f=1}^M FSet(sim(f, f+1)) \\
 & \quad + \frac{\min(Rec(j, i)) + \max(Fset(f))}{\sum_{f=1}^M \text{actv}F(\max(f+1), \min(f))}
 \end{aligned}$$

Step-3: After feature processing is done, Recurrent Ascendancy Feature Subset Training is performed to train the model with the processed feature vector for accurate Arrhythmia Classification that is performed as

$$FTrain(Fset(M)) = \sum_{f=1}^M \frac{\max(HiddLayer(f)) + \sum_{f=1}^M \maxrange(HiddLayer(f+1, f))}{\text{sizeof}(HiddLayer(M))}$$

Step-4: The updated feature set is generated and then the test data processing will be done for Arrhythmia Classification that is used for accurately classifying the disease or not as multiple sets. The Arrhythmia Classification is performed as

$$\begin{aligned}
 & ArClassupdate(Fset(M)) = \sum_{f=1}^M \sum_{f=i}^{\text{len}(FTrain)} FTrain(f) + \\
 & \sum_{f=1}^M \frac{G(\max(Ftrain(f)))}{\lambda}
 \end{aligned}$$

Here G is the function that identifies the similarity of the feature attribute comparison. λ is the threshold value considered for comparison.

Step-5: The classification set is generated and maintained for further identification of grade of the disease and the process of classification set generation is performed as

$$\begin{aligned}
 & ClaSet(ArClassupdate(f)) = \sum_{f=1}^M \text{getrange}(f, f+1) - \\
 & \min(ArClassupdate(f)) + \frac{\sum_{f=1}^{M-f} \max(FTrain(f+1))}{\max(FTrain(f))}
 \end{aligned}$$

IV. RESULTS

The significance of ECG classification is quite high important due to many contemporary clinical applications in which this problem can be expressed. The analysis and classification of ECG data is currently supported by a plethora of machine learning methods. The primary drawbacks of these ML outcomes, however, are the shallow feature learning

architectures and the reliance on heuristic hand-crafted or manipulated features. The difficulty stems from the fact that it is possible that the best features for this ECG classification problem will not be found. One proposed solution is to employ deep learning architectures in which the initial layers of convolutional neurons operate as feature extractors and the last layers of fully-connected neurons are used to decide between ECG classes. In order to categorize cardiac arrhythmias, this research work makes use of freely available dataset from kaggle available in the link <https://www.kaggle.com/datasets/shavanfazeli/heartbeat>. The MIT-BIH Arrhythmia Dataset and the PTB Diagnostic ECG Database are two well-known sources of heartbeat signals that were used to compile this dataset. Both datasets have sufficient sample sizes for use in deep learning network training. Deep neural network architectures for heartbeat classification have been investigated and the possibilities of transfer learning have been observed utilising this dataset. Electrocardiogram (ECG) waveforms of heartbeats (in both the normal case and the instances affected by various arrhythmias and myocardial infarction) are reflected in the signals. Each segment of these signals represents a single heartbeat during preprocessing. There are 87554 samples in all, and 10 features to analyse. The dataset is divided into 80% and 20% ratios, used for training and testing.

There are ECG recordings from multiple people included in the dataset. The dataset collects its own unique collection of features, and these differences have been taken into account independently of one another in the training and testing. This research proposes a Recurrent Ascendancy Feature Subset Training model using Deep CNN model for Arrhythmia Classification (RAFST-DCNN-AC). The proposed model is compared with the traditional ECG Delineation and Arrhythmia Classification System Using Slope Variation Measurement by Ternary Second-Order Delta Modulators (DACS-SVM-TSDM) model. The proposed model exhibits better performance in accurate classification when contrasted with the traditional models.

The technical hurdle for applications like speech recognition, image classification, strategy games, and medical diagnosis has been dramatically raised in recent years because to DNNs' powerful feature extraction capabilities and incremental learning methodologies. Since DNNs can recognise patterns and acquire important features from raw input data without requiring considerable human intervention in the form of custom rules and feature engineering, they are well-suited for decoding ECG data as opposed to standard machine learning approaches. Some studies have looked into the feasibility of using DNNs for automatic classification of cardiac arrhythmia using a single or multiple lead ECG.

ECG arrhythmia diagnosis using computers relies heavily on feature extraction. To this end, feature selection seeks out the most informative characteristics that can be used to distinguish between groups. The goal of feature extraction is to generate fewer features from the same dataset. When this new set of streamlined features is used, it should be able to effectively summarize the original set of features' worth of data. By combining the original features in this way, a condensed version of the full set can be made. The feature

extraction accuracy rate of the proposed and existing models are shown in Fig. 2.

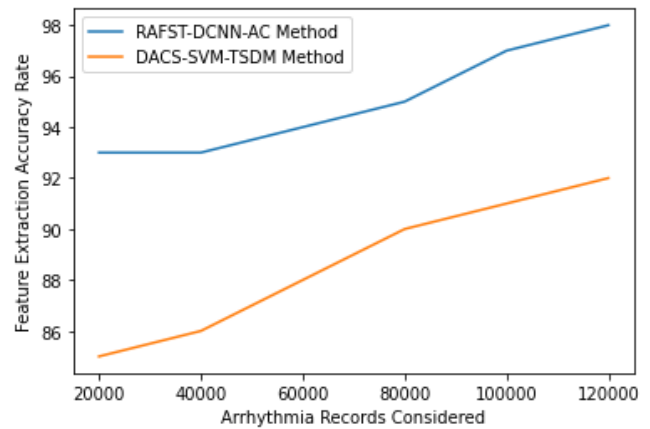


Fig. 2. Feature extraction accuracy rate.

The process of reducing the number of dimensions that a dataset occupies involves a number of steps, one of which is feature extraction. As a result, processing will be less of a hassle. A key feature of these massive datasets is the abundance of variables they contain. Extensive computational resources are needed to process these variables. By selecting and merging variables into features, feature extraction aids in getting the best features from those large data sets. The proposed model in less time generates the feature vector. The feature vector generation time levels of the proposed and existing models are shown in Fig. 3 and the accuracy levels of the feature vector generation is shown in Fig. 4.

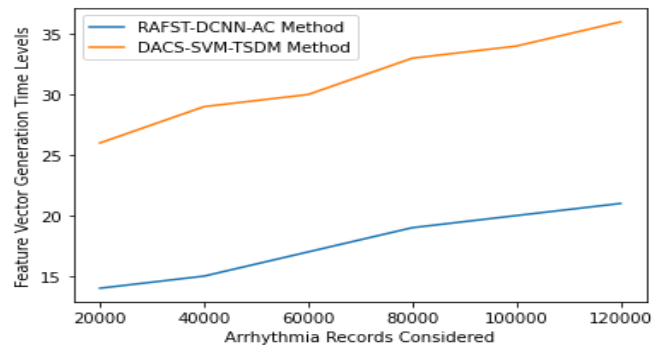


Fig. 3. Feature vector generation time levels.

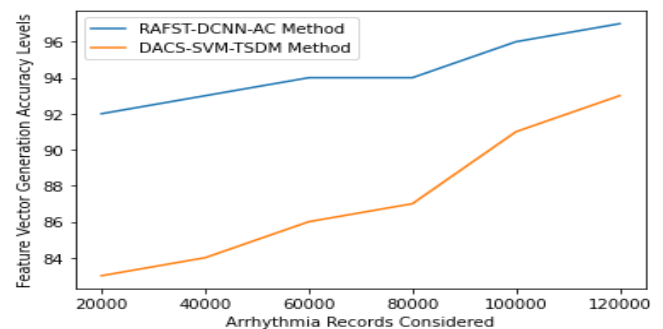


Fig. 4. Feature vector generation accuracy levels.

Hidden layers in a CNN typically include convolutional layers, pooling layers, fully connected layers, and normalization layers. In this case, it simply implies that convolutional and pooling functions are utilised as activation functions rather than the conventional activation functions stated above. CNNs typically have convolutional layers, max pooling, fully connected layers, and normalising layers as their hidden layers. In this case, it just implies that users not utilising the standard activation functions specified earlier, but rather convolution and pooling functions. The hidden layer processing time levels of the proposed and existing models are shown in Fig. 5.

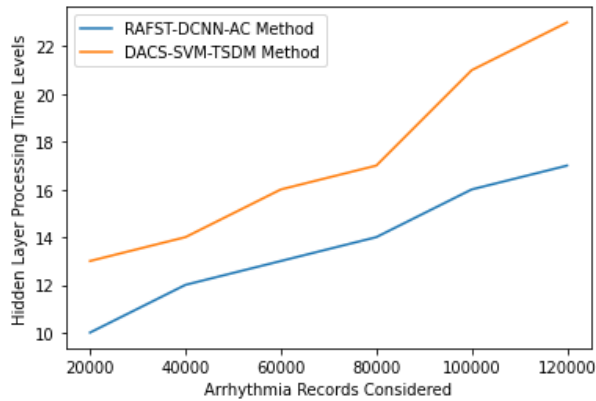


Fig. 5. Hidden layer processing time levels.

An activation function is used as the output of a neural network, which has a hidden layer in between its input and output. The function applies weights to the inputs. In a nutshell, the hidden layers alter the network's inputs in a nonlinear way. The number of hidden layers and the weights assigned to those levels can change based on the task being performed by the neural network. In a nutshell, hidden layers are a series of mathematical operations with the same goal in mind but different inputs. Squash functions are an example of a type of hidden layer. These functions take an input and return a value between zero and one, the range for defining probability, making them handy when the algorithm's expected result is a probability. The hidden layer processing accuracy levels of the proposed and existing models are shown in Fig. 6.

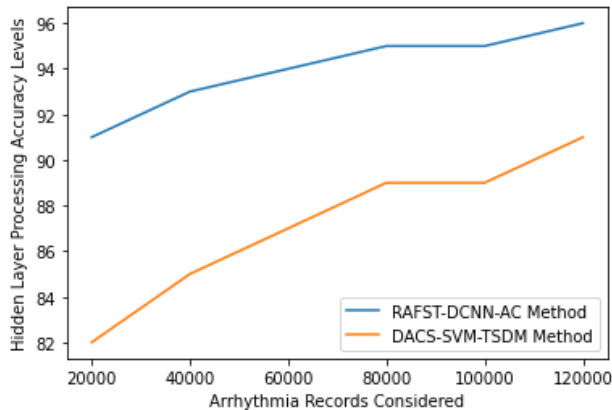


Fig. 6. Hidden layer processing accuracy levels.

There are two main types of arrhythmia, both of which are characterised by the patient's heart rate: bradyarrhythmias and tachyarrhythmias. They are further classified by their aetiology, mode of transmission, and resulting clinical symptoms. The ECG is a crucial tool in the detection of cardiac disorders. Arrhythmias, which include Atrial Fibrillation, Ventricular Tachycardia, Ventricular Fibrillation, and so on, are irregular rhythms in the ECG signal. The primary goal of this research is to identify and categorise patients with cardio-vascular arrhythmias. The Arrhythmia Classification Time Levels of the existing and proposed models are shown in Fig. 7.

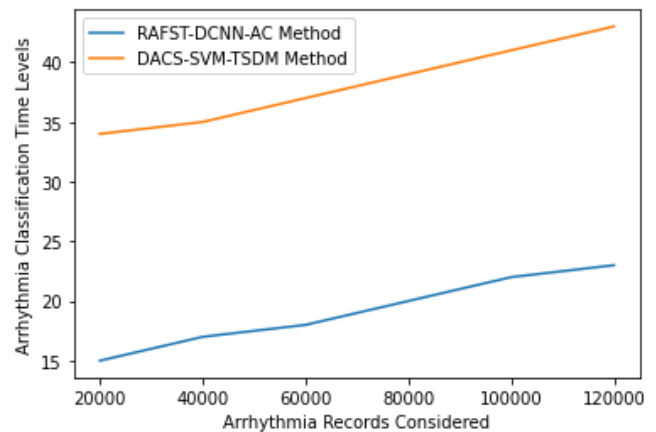


Fig. 7. Arrhythmia classification time levels.

Too fast or too slow heart rates are examples of arrhythmias, often known as cardiac arrhythmias, heart arrhythmias, or dysrhythmias. It is possible for arrhythmias to present themselves with no warning signs at all. One possible symptom is experiencing a palpitation or a halt in heartbeats. In severe circumstances, users may experience dizziness, fainting, difficulty breathing, or chest pain. While most instances of arrhythmia are not life-threatening, certain types might put a person at risk for significant complications including a stroke or heart failure. Critical cardiac diseases can be helped greatly by automatic identification and classification of potentially fatal arrhythmias. The Arrhythmia Classification Accuracy Levels of the existing and proposed models are shown in Table I and Fig. 8.

TABLE I. ARRHYTHMIA CLASSIFICATION ACCURACY LEVELS

Records Considered	Models Considered	
	RAFST-DCNN-AC	DACS-SVM-TSDM
20000	91	81
40000	93	85
60000	95	86
80000	96	87
100000	97	91
120000	98	93

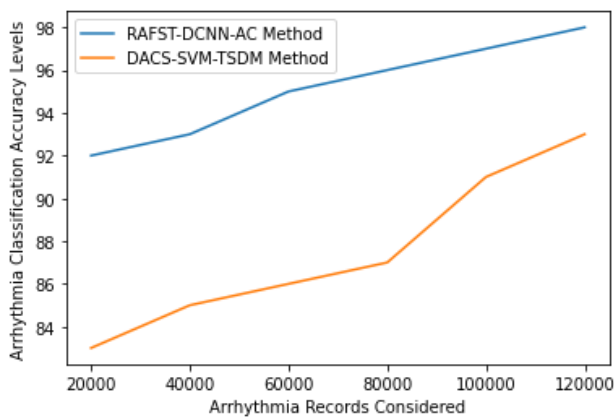


Fig. 8. Arrhythmia classification accuracy levels.

V. CONCLUSION

Diagnosis of arrhythmia typically involves the use of ECG because of its ease of use, lack of invasiveness, and high accuracy. Many deep neural network-based models have recently been successfully implemented for autonomous categorization of cardiac arrhythmia. However, most models, during training, separately extract the internal properties of each lead in the 12-lead ECG, leading to a deficiency in inter-lead features. The ECG is a reliable diagnostic tool for heart conditions because it measures electrical signals associated with heart muscle function. ECGs can be used to diagnose cardiac issues. Arrhythmia is a leading cause of sudden cardiac death. Heart disease, most often coronary artery disease, is the leading cause of death for persons older than 35. Today, multi-lead electrocardiogram (ECG) signals constitute the gold standard for computer-automated arrhythmia identification using deep learning models. However, due to the amplitudes of the input signals, these models supply too many parameters for practical use. In this research, we present a strategy for bridging the gap between the arrhythmia classification algorithm with multi-lead ECG signals and the arrhythmia classification algorithm with single-lead ECG signals using deep learning model to reduce the performance loss. This research proposes a Recurrent Ascendancy Feature Subset Training model using Deep CNN model for Arrhythmia Classification. The purpose of this research was to determine how little of a performance hit would result from shifting from arrhythmia classification based on multi-lead ECG signals to classification based on single-lead ECG signals. The intention was to take advantage of the high precision approaches based on multi-lead ECG signals in order to give the low computational cost offered by the approaches based on single-lead ECG signals. In future feature dimensionality reduction can be applied to reduce the feature vector size and also to use hybrid models integrated with optimization techniques for enhancing the classification rate.

REFERENCES

[1]. X. Tang and W. Tang, "An ECG Delineation and Arrhythmia Classification System Using Slope Variation Measurement by Ternary Second-Order Delta Modulators for Wearable ECG Sensors," in *IEEE Transactions on Biomedical Circuits and Systems*, vol. 15, no. 5, pp. 1053-1065, Oct. 2021, doi: 10.1109/TBCAS.2021.3113665.

[2]. X. Tang and W. Tang, "An ECG Delineation and Arrhythmia Classification System Using Slope Variation Measurement by Ternary Second-Order Delta Modulators for Wearable ECG Sensors," in *IEEE Transactions on Biomedical Circuits and Systems*, vol. 15, no. 5, pp. 1053-1065, Oct. 2021, doi: 10.1109/TBCAS.2021.3113665.

[3]. H. Yang and Z. Wei, "Arrhythmia Recognition and Classification Using Combined Parametric and Visual Pattern Features of ECG Morphology," in *IEEE Access*, vol. 8, pp. 47103-47117, 2020, doi: 10.1109/ACCESS.2020.2979256.

[4]. J. Zhang et al., "MLBF-Net: A Multi-Lead-Branch Fusion Network for Multi-Class Arrhythmia Classification Using 12-Lead ECG," in *IEEE Journal of Translational Engineering in Health and Medicine*, vol. 9, pp. 1-11, 2021, Art no. 1900211, doi: 10.1109/JTEHM.2021.3064675.

[5]. L. -H. Wang et al., "Three-Heartbeat Multilead ECG Recognition Method for Arrhythmia Classification," in *IEEE Access*, vol. 10, pp. 44046-44061, 2022, doi: 10.1109/ACCESS.2022.3169893.

[6]. Y. Li, Z. Zhang, F. Zhou, Y. Xing, J. Li and C. Liu, "Multi-Label Classification of Arrhythmia for Long-Term Electrocardiogram Signals With Feature Learning," in *IEEE Transactions on Instrumentation and Measurement*, vol. 70, pp. 1-11, 2021, Art no. 2512611, doi: 10.1109/TIM.2021.3077667.

[7]. X. Tang, S. Liu, P. Reviriego, F. Lombardi and W. Tang, "A Near-Sensor ECG Delineation and Arrhythmia Classification System," in *IEEE Sensors Journal*, vol. 22, no. 14, pp. 14217-14227, 15 July 2022, doi: 10.1109/JSEN.2022.3183136.

[8]. B. -H. Kung, P. -Y. Hu, C. -C. Huang, C. -C. Lee, C. -Y. Yao and C. -H. Kuan, "An Efficient ECG Classification System Using Resource-Saving Architecture and Random Forest," in *IEEE Journal of Biomedical and Health Informatics*, vol. 25, no. 6, pp. 1904-1914, June 2021, doi: 10.1109/JBHI.2020.3035191.

[9]. P. Singh and A. Sharma, "Interpretation and Classification of Arrhythmia Using Deep Convolutional Network," in *IEEE Transactions on Instrumentation and Measurement*, vol. 71, pp. 1-12, 2022, Art no. 2518512, doi: 10.1109/TIM.2022.3204316.

[10]. P. Singh and A. Sharma, "Attention-Based Convolutional Denoising Autoencoder for Two-Lead ECG Denoising and Arrhythmia Classification," in *IEEE Transactions on Instrumentation and Measurement*, vol. 71, pp. 1-10, 2022, Art no. 4007710, doi: 10.1109/TIM.2022.3197757.

[11]. X. Tang and W. Tang, "A 151nW second-order ternary delta modulator for ECG slope variation measurement with baseline wandering resilience", *Proc. IEEE Custom Integr. Circuits Conf.*, pp. 1-4, 2020.

[12]. M. A. Sohail, Z. Taufique, S. M. Abubakar, W. Saadeh and M. A. Bin Altaf, "An ECG processor for the detection of eight cardiac arrhythmias with minimum false alarms", *Proc. IEEE Biomed. Circuits Syst. Conf.*, pp. 1-4, 2019.

[13]. X. Tang, Q. Hu and W. Tang, "Analog to digital feature converter based on oversampling modulators for ECG delineation", *Proc. IEEE 62nd Int. Midwest Symp. Circuits Syst.*, pp. 121-124, 2019.

[14]. X. Tang, Q. Hu and W. Tang, "A real-time QRS detection system with PR/RT interval and ST segment measurements for wearable ECG sensors using parallel delta modulators", *IEEE Trans. Biomed. Circuits Syst.*, vol. 12, no. 4, pp. 751-761, Aug. 2018.

[15]. L. Qian, J. Wang, L. Jin, Y. Huang, J. Zhang, H. Zhu, et al., "Optimized convolutional neural network by genetic algorithm for the classification of complex arrhythmia", *J. Med. Imag. Health Inform.*, vol. 9, no. 9, pp. 1905-1912, Dec. 2019.

[16]. P. Plawiak and U. R. Acharya, "Novel deep genetic ensemble of classifiers for arrhythmia detection using ECG signals" in *Neural Computing and Applications*, Springer, pp. 1-25, Jan. 2019.

[17]. L.-H. Wang, W. Zhang, M.-H. Guan, S.-Y. Jiang, M.-H. Fan, P. A. R. Abu, et al., "A low-power high-data-transmission multi-lead ECG acquisition sensor system", *Sensors*, vol. 19, no. 22, pp. 4996, Nov. 2019.

[18]. T. Zhuang, C. Feng, L.-H. Wang, J. Gao and Y. Yang, "Hardware implementation of real-time ECG R-wave detection with wavelet transform algorithm", *Proc. 4th Int. Conf. Commun. Inf. Process. (ICCIP)*, pp. 305-308, 2018.

- [19]. A.K. Sharma, S. Chaurasia and D. K. Srivastava, "Sentimental short sentences classification by using CNN deep learning model with fine tuned Word2Vec", *Proc. Comput. Sci.*, vol. 167, pp. 1139-1147, Sep. 2020.
- [20]. J. Brieva, H. Ponce and E. Moya-Albor, "A contactless respiratory rate estimation method using a Hermite magnification technique and convolutional neural networks", *Appl. Sci.*, vol. 10, no. 2, pp. 607, Jan. 2020.
- [21]. R. N. Kandala, R. Dhuli, P. Pławiak, G. R. Naik, H. Moeinzadeh, G. D. Gargiulo, et al., "Towards real-time heartbeat classification: Evaluation of nonlinear morphological features and voting method", *Sensors*, vol. 19, no. 23, pp. 5079, Nov. 2019.
- [22]. X. Yang, X. Zhang, M. Yang and L. Zhang, "12-lead ECG arrhythmia classification using cascaded convolutional neural network and expert feature", *J. Electrocardiol.*, vol. 67, pp. 56-62, Jul. 2021.
- [23]. H. M. Haqqani and F. E. Marchlinski, "The surface electrocardiograph in ventricular arrhythmias: Lessons in localisation", *Heart Lung Circulat.*, vol. 28, no. 1, pp. 39-48, Jan. 2019.
- [24]. R. Zhou, X. Li, B. Yong, Z. Shen, C. Wang, Q. Zhou, et al., "Arrhythmia recognition and classification through deep learning-based approach", *Int. J. Comput. Sci. Eng.*, vol. 19, no. 4, pp. 506, 2019.
- [25]. H. Wang, H. Shi, K. Lin, C. Qin, L. Zhao, Y. Huang, et al., "A high-precision arrhythmia classification method based on dual fully connected neural network", *Biomed. Signal Process. Control*, vol. 58, Apr. 2020.
- [26]. S. Liu, J. Shao, T. Kong and R. Malekian, "ECG arrhythmia classification using high order spectrum and 2D graph Fourier transform", *Appl. Sci.*, vol. 10, no. 14, pp. 4741, Jul. 2020.

Machine Learning Techniques in Keratoconus Classification: A Systematic Review

AATILA Mustapha¹, LACHGAR Mohamed², HRIMECH Hamid³, KARTIT Ali⁴

LTI Laboratory, ENSA School-University Chouaib Doukkali, El Jadida, Morocco^{1,2,4}

LAMSAD Laboratory, ENSA School of Berrechid-University Hassan First, Settat, Morocco³

Abstract—Machine learning (ML) algorithms are being integrated into several disciplines. Ophthalmology is one field of health sector that has benefited from the advantages and capacities of ML in processing of different types of data. In a large number of studies, the detection and classification of various diseases, such as keratoconus, was carried out by analyzing corneal characteristics, in different data types (images, measurements, etc.), using ML tools. The main objective of this study was to conduct a rigorous systematic review of the use of ML techniques in the detection and classification of keratoconus. Papers considered in this study were selected carefully from Scopus and Web of Science digital databases, according to their content and to the adoption of ML methods in the classification of keratoconus. The selected studies were reviewed to identify different ML techniques implemented and the data types handled in the diagnosis of keratoconus. A total of 38 articles, published between 2005 and 2022, were retained for review and discussion of their content.

Keywords—Ophthalmology; corneal disease; keratoconus classification; machine learning

I. INTRODUCTION

Keratoconus is a non-inflammatory bilateral corneal disease, characterized by a progressive deformation of the cornea which takes the shape of a cone [1]. The common symptoms of keratoconus are usually abnormally progressive myopia and astigmatism, vision poorly corrected by glasses, difficulty adapting to lenses, visual fatigue, and headaches. Other specific symptoms may be associated with each stage of keratoconus. The prevalence of keratoconus can range from 0.2 to 4.790 per 100 000 people [2]. Keratoconus can affect only one eye or both eyes at the same time, with different degrees of evolution, and repetitive eye rubbing is considered the most involved factor in the progression of this disease [3]. The diagnosis of keratoconus is generally made by examining the topography of the cornea as well as analyzing certain biomechanical characteristics of the cornea [4].

The detection of keratoconus, especially in its early stage, is a task that is not obvious in the absence of a set of uniform criteria describing this keratoconus stage. Considering the importance of the diagnosis of keratoconus, many contributions that aim at the classification of keratoconus have been published. The authors of a significant number of research works have opted for the adoption of ML techniques in their keratoconus classification systems, with the aim of achieving a good level of precision in the discrimination of this disease and assisting clinicians in patient diagnosis.

Generally, the diagnosis of keratoconus is done manually by specialists, who must analyze the different corneal characteristics to collect sufficient information to confirm the presence of keratoconus. However, to better support specialists in keratoconus detection task, many researchers have adopted ML algorithms to consolidate the decisions of ophthalmologists regarding the presence of keratoconus in patients [5]. The combination of the specialists' expertise and the advantages of ML, in processing different types of data, will certainly allow to detect keratoconus, particularly in its subclinical stage, with a high level of confidence and accuracy [6], to offer patients more choice of treatments and to avoid surgical interventions.

This paper proposes a systematic review concerning the use of ML techniques in the detection and classification of keratoconus. The main objective of this systematic review is to identify and evaluate the previous scientific literature relating to the classification of keratoconus using ML techniques, thus enabling researchers to learn about the state of research in this field. Moreover, this study will identify the commonly ML techniques used for the classification of keratoconus, the data types most used by ML-based systems in keratoconus classification and the corneal features most used in keratoconus classification.

II. RELATED WORKS

The detection of early or even preclinical forms of keratoconus will allow appropriate patient care and anticipate vision problems. Some research teams have focused on producing systematic reviews to present the latest advances in research concerning keratoconus disease to researchers. The Authors of systematic review [7] aimed to survey and critically evaluate the literature on the algorithmic detection of subclinical keratoconus. Measured parameters and the design of the machine learning algorithms reported in 26 papers were compared following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) recommendations. As conclusion, authors reported that ML can potentially improve the detection of subclinical or early keratoconus. In the review [8], authors conducted the study to determine the prevalence and risk factors for keratoconus worldwide, including eye rubbing, family history of keratoconus, atopy, allergy, asthma, eczema, diabetes type I and type II, and sex. In this review 29 articles included 7 158 241 participants from 15 countries were analyzed. Results showed that the prevalence of keratoconus in the whole population was 1.38 per 1000 population and eye rubbing, family history of keratoconus, allergy, asthma, and eczema were the most important risk factors for keratoconus

according to the available evidence. Authors in [9] presented a systematic review to discuss new approaches to the early detection of keratoconus and recent investigations regarding the nature of its pathophysiology. Authors in this study reviewed the evidence for keratoconus complex genetics and evaluate the identified genes/loci and potential candidate gene/loci. Generally, there is a remarkable lack of reviews highlighting the different uses of ML techniques for the classification of keratoconus.

III. METHOD

This systematic review was conducted in Scopus and Web of science scientific databases, adhering to PRISMA guidelines in its most recent version 2020. For the proper conduct of this review, a list of research questions (RQ), that the Systematic Literature Review (SLR) should answer, has been listed in Table I. The collection of works studied in this systematic review aims to select as much as possible of related scientific papers, on detection and classification of keratoconus using ML tools, while excluding irrelevant studies that do not provide enough information related, thus aiming for high precision. In order to achieve the objectives, already cited, of this systematic review with good levels of precision, a well-extended search strategy is therefore necessary.

The terms considered in the selection of studies in this systematic review are “Keratoconus” and “Machine learning”. The research query used in this study is structured as follows:

Research query = (TITLE-ABS-KEY (keratoconus) AND TITLE-ABS-KEY (machine AND learning)).

TABLE I. RESEARCH QUESTIONS OF THE STUDY

No.	Research Question (RQ)
RQ1	What are the main objectives of using ML techniques in the classification of keratoconus?
RQ2	What are the ML techniques used in the classification of Keratoconus?
RQ3	What are the data types used by the different classifiers for the classification of keratoconus?
RQ4	What are the most used corneal features in keratoconus classification by the different ML models?
RQ5	What is the impact of ML use on the classification accuracy of keratoconus compared to traditional techniques?
RQ6	What is the number of keratoconus classes retained for each study included in this review?
RQ7	What are the limitations of the current literature and the opportunities for future research?

To produce a relevant systematic review, regarding the use of ML algorithms in keratoconus classification, a set of inclusion criteria (IC) and exclusion criteria (EC) was adopted in the process of selection of the considered documents. Included studies are the original articles, published between 2005 and 2022, which contributed on keratoconus detection using ML techniques. Selected works must use ML algorithms, trained and tested in different datasets, with a distribution of the data in training and testing datasets using different techniques such as cross-validation. In addition, the full text of the selected papers must be available, and only studies published in English were considered. Conference papers, conference reviews, letters, books, book chapters and editorials

were excluded from this study. The inclusion and exclusion criteria are summarized in the Table II below.

TABLE II. INCLUSION CRITERIA (IC) AND EXCLUSION CRITERIA (EC)

No.	Criteria
IC1	Papers published in a peer reviewed scientific journal.
IC2	Works published in English.
IC3	Testing of algorithms on test datasets.
EC1	Reviews, conference papers, conference reviews, letters, books, book chapters and editorials.
EC2	Works that do not provide enough information on the methodology adopted and that do not report results in a clear way.
EC3	Articles whose full text is not available.

According to the previous research query, a total of 175 documents were identified from Scopus and Web of science databases. After eliminating Reviews, conference papers, conference reviews, letters, books, book chapters and editorials, this number is reduced to 110 scientific articles. Among these 110 papers, 47 duplicate documents were removed. After reading titles and abstracts of different papers, 17 articles were excluded, 3 of which were not written in English and 14 others were not related to the classification of keratoconus using ML techniques. The other inclusion and exclusion criteria were applied on a total of 46 articles, of which two documents did not clearly detail the adopted methodology and did not report obtained results, and six other articles are not relevant, since they do not focus on the use of ML in keratoconus classification. The final number of articles included in this systematic review is 38 articles as shown in Fig. 1 below.

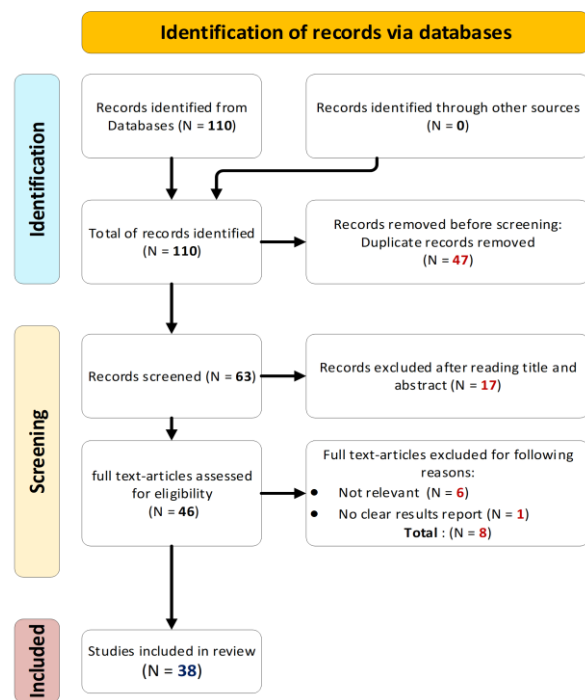


Fig. 1. PRISMA flow chart of the process of papers collection.

Once the articles were selected, based on the different inclusion and exclusion criteria already mentioned, an in-depth analysis of the selected articles was carried out. A set of information was extracted including the year of publication of each paper, the ML techniques used in the classification step of keratoconus, the number of inputs used by each technique and the technique performance in terms of accuracy, precision, recall, f1-score, sensitivity, specificity and area under the curve ROC. For the datasets, retained information represented the types of data used by different methods, the size of the dataset and the number of corneal classes considered during the classification process.

IV. RESULTS

Retained articles, related to keratoconus classification using ML tools, were published from 22 different countries. The countries representing the origin of the greatest number of publications are Belgium with 5 articles, followed by China and Spain with 4 articles each country, followed by USA and Romania with 3 articles each country. Belgium, China, Spain,

USA, and Romania represent the origin of 50% of the papers included in this study with a total of 19 papers. Fig. 2 below shows the distribution of included works by countries of publication and Table III reports the Literature Review Matrix (LRM) of reviewed articles.

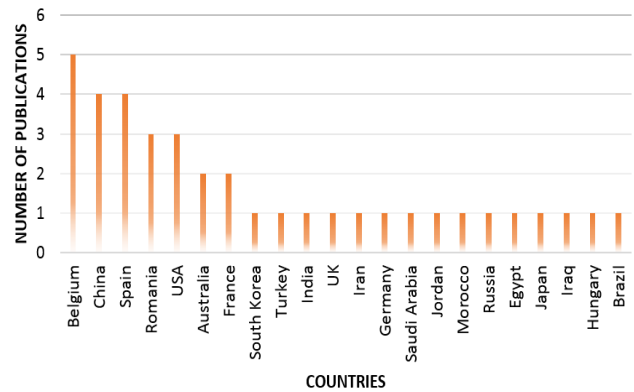


Fig. 2. Distribution of selected papers by countries.

TABLE III. DETAILS OF STUDIES INCLUDED IN THE CURRENT SYSTEMATIC REVIEW

Ref.	Year	Technique	Data type	Dataset size	Classes number	Inputs number	Performance
[10]	2022	Five-layer feedforward network	Biomechanical parameters calculated from corneal raw videos	276 samples	2 classes	4 biomechanical characteristics	Accuracy: 98.7%, Sensitivity: 97.4% Specificity: 100% Precision: 100%
[11]	2022	FcNN, XGBoost & TabNet (Voting)	Corneal parameters	2613 samples	3 classes	18 variables	Accuracy: 90.6% to 95.6% Sensitivity: 67.6% to 90.5% Specificity: 90.9% to 97.9%
[12]	2022	SVM Classifier applied to selected features, extracted using AlexNet & TabNet	Corneal topographic images	682 images	2 classes	1x1000 features	Accuracy: 98.53% Sensitivity: 98.06% Specificity: 99.01%
[13]	2022	GoogLeNet Classifier applied to segmented image using PSO, DPSO & FPSO	Corneal topographic images	1500 images	3 classes	224x244x3 images	Accuracy: 95.9% Sensitivity: 94.1% Specificity: 97%
[14]	2021	Random Forest & decision tree	Pentacam topographic Corvis biomechanical variables	80 eyes	2 classes	27 parameters	Accuracy: 89% Sensitivity: 86% Specificity: 93%
[15]	2021	VGG-16	Corneal topographic images	1926 images	2 classes	224x224 corneal maps	Accuracy: 97.85 % Sensitivity: 98.46 % Specificity: 90% AUC: 94.23%
[16]	2021	Multilayer perceptron (MLP), neurofuzzy & Naïve Bayes	Pentacam measurements	450 eyes	4 classes	19 parameters	Accuracy: 98.2% Sensitivity: 98.5% Specificity: 99.4%
[17]	2021	Linear discriminant analysis (LDA) & random forest (RF)	Corneal tomography DCR & pachymetric parameters	434 cases	4 classes	11 parameters for RF. 6 parameters for LDA.	LDA Accuracy: 71% RF Accuracy: 78%
[18]	2021	Time delay neural network	Pentacam data	743 patients	2 classes	6 features	Sensitivity: 70.8% Specificity: 80.6%
[19]	2021	Convolutional neural Network (CNN)	Corneal frontal and lateral images	450 images	4 classes	Two 2D images	Accuracy: 97.8% Sensitivity: 98.45% Specificity: 96%
[20]	2021	Logistic regression, decision tree, random forest, MLP, Fast-Large Margin, KNN & Naïve Bayes	Images	Iraq base: 448 images. Europe base: 692 images.	2 classes	140 vectors of 400 dimensions	Accuracy: 91.33% Sensitivity: 88.58% Specificity: 94.39%
[21]	2021	RF, SVM, KNN, DT, NB, LR & LDA on selected features	Corneal parameters	3162 rows Harvard Dataverse Keratoconus dataset	2 classes 4 classes	10 variables 420 variables	Accuracy: 4 classes: 95.32% 2 classes: 98.1% AUC: 100% (4 classes)
[22]	2021	RF using PCA for	Pentacam parameters	267 eyes		267 parameters	Accuracy: 98%

		dimensionality reduction			2 classes	from 1692 parameters	Sensitivity: 97% Specificity: 98%
[23]	2021	24 machine learning models	Pentacam measurements	3 datasets of 5881 samples	5 classes 3 classes 2 classes	Elevation dataset: 5 features from 18	AUC (SVM): 5 classes: 88% 3 classes: 96% 2 classes: 99%
[24]	2021	Quadratic discriminant Analysis (QDA)	Pentacam data	12647 rows	6 classes	7 parameters	AUC: 95% to 100%
[25]	2020	CNN	Corneal tomography images	3218 images	3 classes	Images of 256x256 pixels	Accuracy: 95.8%
[26]	2020	Logistic regression	Demographic, optical & geometric data	178 eyes	3 classes	5 variables	Accuracy: 73%
[27]	2020	Logistic regression	Demographic, optical, pachymetric & geometrical parameters	169 samples	6 classes	17 variables	Accuracy: 69.8%
[28]	2020	RF, SVM, KNN, LR, LDA, Lasso Regression, DT & MLP	Corneal parameters	88 eyes	2 classes	11 parameters	Accuracy: 87% (RF) Sensitivity: 92% (SVM) Specificity: 88% (KNN) Precision: 89% (RF) AUC: 96% (RF)
[29]	2020	LR & Artificial Neural Network (ANN)	Corneal morphological features using Scheimpflug camera and UHROCT	121 eyes	3 classes	49 parameters	Sensitivity: 95.1% (LR), 98.5% (ANN) 1-Specificity: 94.8% (LR), 94.7% (ANN) AUC: 90% (LR), 93% (ANN)
[30]	2020	Feedforward Neural Network (FNN)	Anterior and posterior corneal elevations & minimum pachymetry value	812 subjects	5 classes	2 vectors of 46 anterior and 46 posterior parameters	Accuracy: 99.9%
[31]	2020	InceptionResNetV2	Corneal topographic images	6465 images	5 classes	Images of axial curvature, front and back elevation & corneal thickness	Accuracy: 95% Sensitivity: 91.9% Specificity: 98.7% AUC: 99.3%
[32]	2020	CNN	Raw data of the Pentacam HR system	854 samples	3 classes	Five matrices, each of a size 141x141	Accuracy: 94.74% Recall: 93.71% Precision: 94.1% F1-score: 93.89%
[33]	2020	CNN based on ResNet with fewer hidden layers and 4 input channels	Corneal topographic images	3000 images	3 classes	56x56x4 matrix	Accuracy: 99.3%
[34]	2020	25 machine learning models	Corneal parameters	3151 samples	2 classes 3 classes	8 features	Accuracy (Cubic SVM) : 2 classes: 94.0% 3 classes: 62%
[35]	2019	CNN	Corneal topographic images	3000 images	2 classes	180x240x3 pixels	Accuracy: 99.33%
[36]	2019	ResNet-18	Corneal topographic maps using anterior segment optical coherence tomography (AS-OCT)	543 images	5 classes	224x224 corneal maps	Accuracy: 87.4%
[37]	2019	Conditional linear Gaussian Bayesian network	Topographic indices, calculated from the Placido ring images	60 eyes	2 classes	16 parameters	Sensibility: 100% Specificity: 100%
[38]	2019	Feedforward neural network, Grossberg-Runge Kutta	Topographic data	851 subjects	4 classes	1x117 features	Accuracy : 99.58% Sensitivity: 99.91% Specificity: 99.90% Precision: 99.90%
[39]	2019	SVM & DT	Corneal Topographic images	40 cases	2 classes	16 features	Accuracy (SVM): 90% Accuracy (DT): 87.5%
[5]	2019	Density-based clustering	Corneal parameters	3156 eyes	4 classes	420 corneal parameters	Specificity: 94.1% Sensitivity: 97.7%
[40]	2017	SVM	Pentacam parameters	131 eyes	5 classes	25 parameters	Accuracy: 88.8%
[41]	2016	SVM	Pentacam data	860 eyes	5 classes	22 parameters	Accuracy: 88.8% Sensitivity: 89% Specificity: 95.2%
[42]	2016	MLP	Tomographic data, topographic data & keratoconus indices	135 eyes	3 classes	15 parameters	AUC: Unilateral: 88% Bilateral: 96%
[43]	2014	LDA & ANN	Maps of the corneal epithelial and stromal	204 subjects	5 classes	6 variables	Sensitivity: 94.6% (LDA), 98.9% (ANN)

			thickness				Specificity: 99.2%(LDA), 99.5%(ANN)
[44]	2013	DT	Corneal Topographic images	372 eyes	2 classes	55 features	Sensitivity: 100% Specificity: 99.5%
[45]	2010	SVM, MLP & Radial Basis Function Neural Network (RBFNN)	Corneal topographic maps using OrbscanII	318 maps	4 classes	11 variables	SVM & MLP: AUC: 99% Sensitivity: 100% Specificity: 100% RBFNN: AUC: 98% Sensitivity: 98% Specificity: 98%
[46]	2005	DT C4.5	Videokeratography data	244 eyes	2 classes	4 Zernike polynomial coefficients	Accuracy: 92% AUC: 97%

Considering publication dates of selected articles, a large part of the retained documents was published during the period 2019 to 2022, with a total of 31 papers; the seven remaining articles were published in the period from 2005 to 2017. Fig. 3 below represents the curve of the publication's evolution per years between 2005 and 2022.

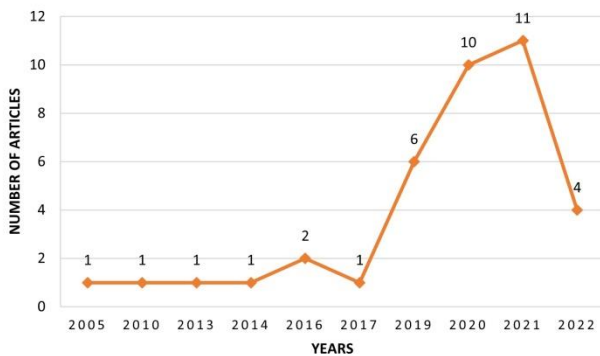


Fig. 3. Number of articles by years of publication.

A. *RQ1. What are the Main Objectives of using ML Techniques in the Classification of Keratoconus?*

The early diagnosis of keratoconus is very meaningful to avoid heavy treatments or surgical interventions that can cause further damage to the cornea. Many technologies allow showing different aspects of the cornea, such as biomechanical features, wavefront aberrations, elevation maps and pachymetry [47]. To determine accurately keratoconus presence, ophthalmologists must be up to date and able to analyze, combine and interpret indices and information obtained by all these different technologies as diagnosis result. However, ML tools have shown great capacity in the analysis and processing of heterogeneous data, such as measurements, videos, images, etc. It is for these advantages that ML techniques have been used in systems of keratoconus classification. The main objectives of using ML in keratoconus classification are the optimization of keratoconus diagnosis process as much as possible by its early identification, the assurance of better care for patients and their follow-up, the proposal of adequate medical actions according to the identified stage, and the confirmation of the diagnosis carried out by specialists, by combining their expertise with the capacities of ML techniques. Moreover, ML is used in keratoconus classification to fix the limitations of existing diagnostic methods, including qualitative rather than

quantitative evaluations of parameters, coefficients, and observer bias [5].

B. *RQ2. What are the ML Techniques used in the Classification of Keratoconus?*

Various ML techniques were used for keratoconus classification in studied works. The unsupervised ML is represented in this review by the Density-Based Clustering technique which was used as keratoconus classifier.

For supervised ML, different methods were implemented in the contributions included in this review. Many works have adopted simple ML algorithms such as Support Vector Machine (SVM), K-Nearest Neighbors (KNN), Random Forest (RF), Linear Discriminant Analysis (LDA) or other algorithms [21]. Other studies have implemented some techniques, such as ensemble learning, based on Bagging, Boosting, Stacking,..., etc., allowing the combination of several machine learning algorithms to improve the performance of predictive systems in terms of classification accuracy [16]. Other techniques, such as DL were adopted in several works for classification of keratoconus. Generally, the different ML techniques commonly used in the studies included in this review are:

1) *Naive bayes (NB)*: The Naïve Bayes is a probabilistic classifier well suited to high dimensional datasets. Despite its simplicity, the NB algorithm can outperform other more efficient classifiers [37].

2) *K-Nearest neighbors (KNN)*: KNN method is a ML technique that classifies new observations, assigning them to the class most present in the neighbors of this observation based on similarity functions, such as distance functions [21], [28].

3) *Logistic regression (LR)*: LR is a probabilistic supervised ML algorithm using the sigmoid function as a decision rule, providing a probability of producing an event with values between 0 and 1 [21], [48].

4) *Linear discriminant analysis (LDA)*: It is a technique belonging to competitive machine learning methods, which is used for dimensionality reduction [49]. The idea behind LDA is to find a linear combination of variables that best separates different classes [50].

5) *Decision tree (DT)*: DT is a classifier algorithm of a tree structure. The nodes of the DT represent the evaluation tests of the observations attributes, while the arcs represent the responses to the tests associated with the nodes, and the leaves

correspond to the different classes [21]. Different variants of DT, such as Chi-square automatic interaction detection (CHAID) and classification and regression tree (CART), have been implemented for the discrimination of keratoconus [51].

6) *Artificial neural networks (ANN)*: It is a computational imitation of the way neurons work in the human brain, an ANN consists of three layers, input, hidden and output. Each neuron of a given layer is interconnected with the neurons of the next layer, and each connection has a weight which is used for the calculation of the output [52].

7) *Convolutional neural networks (CNN)*: Initially designed to process images more efficiently [53], CNNs are a particular type of ANN belonging to such a broad category of methods called DL. CNNs are designed using multiple building blocks, such as convolution layers, pooling layers, and fully connected layers. Deep learning techniques are based on the CNN architecture [35], [54].

8) *Ensemble learning*: Ensemble learning is a technique that consists of combining several individual ML classifiers to build a predictive system while improving the prediction

performance of the overall system. Random Forest is an example of ensemble learning techniques based on the bagging principle [28].

9) *Density-based clustering (DBC)*: It is an unsupervised ML technique based on local cluster criterion method, such as density connected points [5]. For this technique, the data points in the region separated by two clusters of low point density are considered as noise.

The emergence of the use of ML techniques in the medical field will undoubtedly impact the practice of health professionals, this diversity of ML algorithms used in the diagnosis of keratoconus, reflects the great interest of researchers in this disease and its treatment and management. However, it should be noted that the purpose of using ML in the medical field, ophthalmology in particular, is not to replace health professionals with automated systems, but rather to support them in the analysis and interpretation of voluminous and heterogeneous data collected, in order to make the right decisions by reducing the margin of error for specialists. Fig. 4 below represents different ML techniques identified in the papers included in the current review.

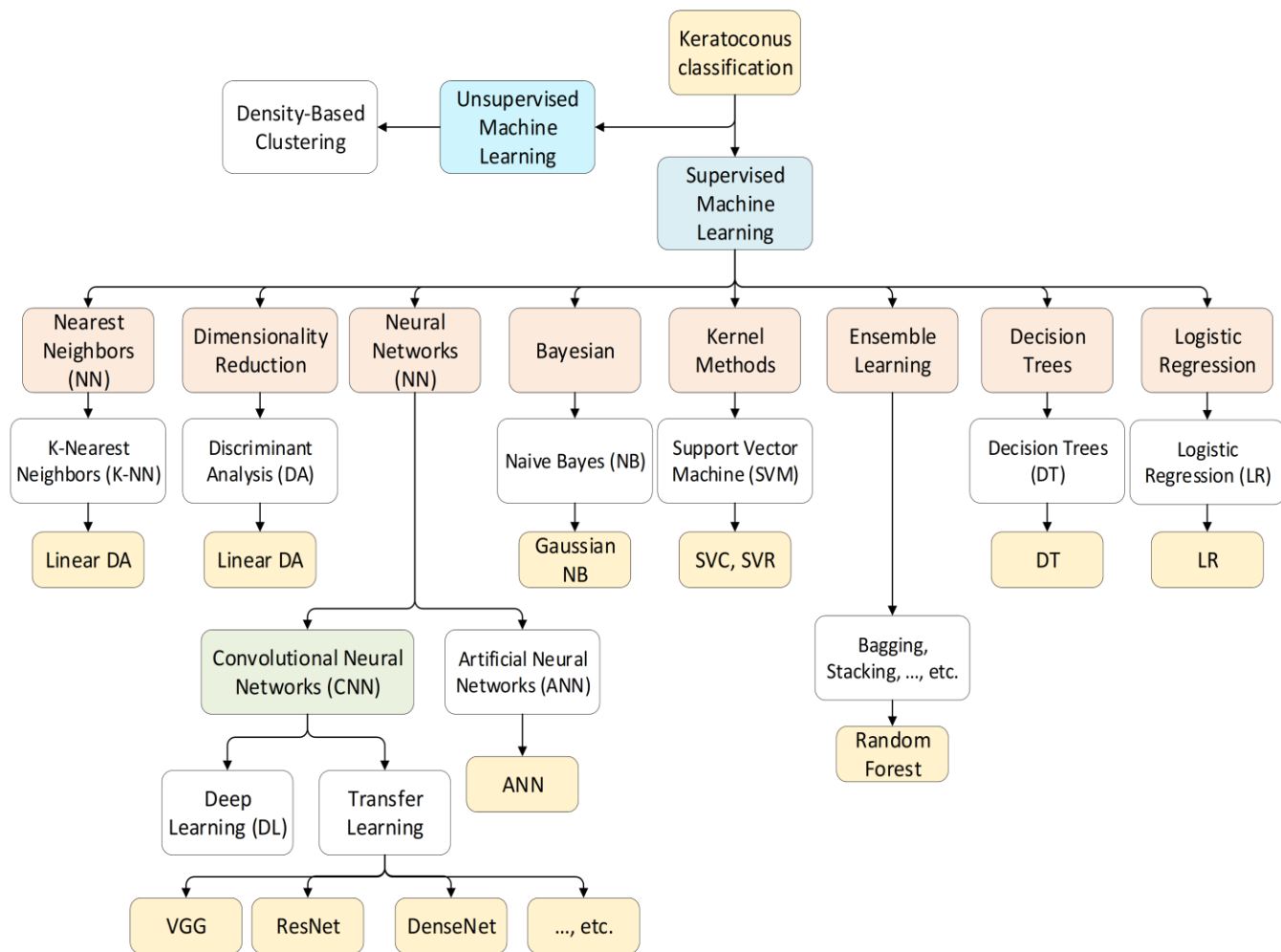


Fig. 4. Explanatory diagram of the commonly used ML techniques in the classification of keratoconus.

Fig. 5 below represents the rates of ML and DL classifiers use in the included papers.

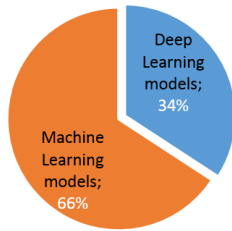


Fig. 5. ML and DL use percentages in selected papers.

C. RQ3. What are the Data Types used by the Different Classifiers for the Classification of Keratoconus?

The diversity of ML algorithms is accompanied by a variety of data types handled by these algorithms. The data types used in the works selected in this study are:

1) *Images*: In most of contributions, using deep learning architectures, authors have used image type data for the classification of keratoconus. Processed images are in different types, such as corneal topography [12], tomography [25], and Placido disc [37].

2) *Corneal parameters*: A set of measurements, obtained using specific devices such as Pentacam, describing the cornea in detail on different aspects (geometric, topographic, ..., etc.). A total of 15 studied documents have handled corneal data and parameters as input data for the classification of keratoconus [16], [28], [21], [17], [18], [22], [23], [24], [30], [32], [34], [38], [40], [41], [42].

3) *Biomechanical data*: Biomechanical parameters refer to the distortion responses of the cornea to an applied force such as corneal hysteresis (CH) and corneal resistance factor (CRF). Biomechanical parameters are generally integrated in the corneal parameters already cited as inputs [14].

4) *Demographic data*: Age and gender are the demographic parameters the most integrated in studied articles as input data [14], [18], [29].

5) *Morphological data*: Morphological data make it possible to describe the morphology of the cornea and to identify any structural anomaly of the latter. Indeed, the thickness of the cornea varies from one individual to another, due to the difference in the radius of curvature of its anterior and posterior faces [29].

6) *Geometric data*: Correspond to information essentially describing the geometry of the anterior and posterior corneal surfaces to diagnose any pathology linked to an alteration in corneal morphology [55]. Among these data the total corneal volume, the anterior corneal surface, the posterior corneal surface, the total corneal surface, the deviation of the anterior apex and the deviation of the posterior apex [26].

Other papers, not included in this review study, introduced other forms of data such as the ethnic properties of patients [56]. Fig. 6 indicates the data types used by the different models of keratoconus classification proposed in the papers treated in this study.

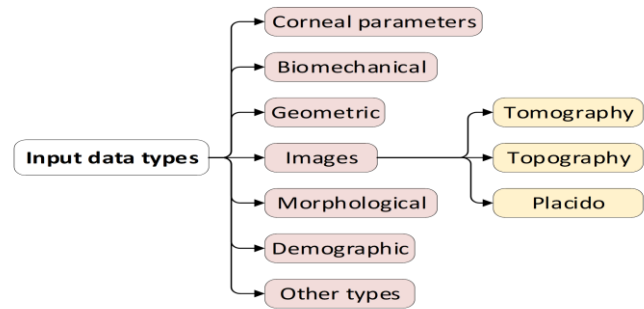


Fig. 6. Types of data adopted as inputs for different ML classifiers used in the studied papers.

D. RQ4. What are the Most used Corneal Features in Keratoconus Classification by the Different ML Models?

Between 38 analyzed documents, 22 papers have reported the list of features used as inputs by the different classifiers implemented for the classification. The 10 most used features in different papers are:

- Radius of the corneal curvature (Radius), used in 10 documents.
- Flat simulated keratometry (Kf), declared in 7 papers.
- Steep keratometry (Ks), appeared in 6 articles.
- Age, reported in 6 different works.
- Astigmatism, reported in 5 different papers.
- Inferior-Superior value (I-S), used in 5 articles.
- Index of height decentration (IHD), used in 5 papers.
- Index of surface variance (ISV), declared in 4 papers.
- Index of vertical asymmetry (IVA), used in 4 works.
- Gender, used in 4 papers.

E. RQ5. What is the Impact of ML use on the Classification Accuracy of Keratoconus Compared to Traditional Techniques?

The detection of keratoconus in its first stage will make it possible to follow its evolution closely and try to slow down, or even stop, it by following adequate measures on a case-by-case basis. The detection of keratoconus in its advanced stages can be ensured by evaluating certain symptoms and clinical signs of the cornea, visibly clear for specialists, given the advanced stage of the disease. For subclinical keratoconus, this operation is not possible, this is due to the similarities in signs with normal eyes. However, the early diagnosis of keratoconus is made using video technologies performing corneal topographies. Thus, the large number of parameters describing the cornea and the difficulties in analyzing corneal topographic images represent the greatest difficulty in the identification of subclinical keratoconus. It is to overcome all these obstacles and to distinguish keratoconus in its early phase in patients, that the ML is used for the analysis of corneal topographies, showing great precision when classifying keratoconus compared to traditional diagnostic methods [14].

F. RQ6. What is the Number of Keratoconus Classes Retained for Each Study Included in this Review?

The number of corneal classes retained in each of the different studies included in the current review varies between 2 and 6 corneal classes. The articles considering 2 and 3 corneal classes for keratoconus classification represent the large part of the papers studied in this systematic review, with a total of 26 papers (15 papers and 11 papers for keratoconus classification considering 2 and 3 corneal classes respectively). Table IV indicates the distribution of studies by the number of corneal classes considered in keratoconus classification.

TABLE IV. DISTRIBUTION OF STUDIED WORKS BY NUMBER OF CORNEAL CLASSES CONSIDERED IN THE CLASSIFICATION

Number of Classes	References	Total of papers
2 classes	[24], [37], [28], [35], [10], [12], [14], [15], [18], [20], [22], [23], [34], [39], [46]	15
3 classes	[11], [13], [23], [25], [26], [29], [32], [33], [34], [42], [44]	11
4 classes	[5], [21], [16], [17], [19], [38], [45]	7
5 classes	[15], [23], [30], [31], [36], [40], [41], [43]	8
6 classes	[24], [27]	2

G. RQ7. What are the Limitations of the Current Literature and the Opportunities for Future Research?

The objective of the current literature review study is to identify scientific studies aimed at the classification of keratoconus using machine learning tools. One of the limitations of this study is the exclusion of certain studies during the execution of the query for selecting papers from Scopus and Web of science databases, the poor choice of titles and keywords of articles by the authors may exclude the article, even if it is a work in the context of this study. Also, the exclusion of certain types of papers, such as conference papers and book chapters for example, may cause the loss of a large number of contributions aimed at the classification of keratoconus. Another limit of this study is that the period from 2005 to 2014 is represented by only four papers, this is perhaps due to the inclusion rules already mentioned and the low number of contributions, using ML techniques to the classification of keratoconus, published in this period. Moreover, this variety of ML techniques and types of data used in different studies makes the comparison of these systems more difficult, if not impossible, in the absence of a referential dataset to test these different systems implemented.

V. DISCUSSION

Based on the current systematic review, concerning the adoption of ML techniques for keratoconus classification systems, reported results show a remarkable increase in scientific productions, according to the selection criteria already cited, these last four years (2019, 2020, 2021 and 2022). This growth is maybe due to the interest of researchers in the use of ML techniques in the objective to take full advantage of the capabilities of these techniques in data analysis, especially in classification problems in several domains. This growth in the use of ML techniques in ophthalmology can be justified by the strong bond of this field

to image processing for the diagnosis of several diseases including keratoconus. As illustrated in Fig. 3, amongst 38 selected documents, 31 papers have been published in the past four years, i.e., 81.56% of all papers.

Regarding the countries of publication of different documents, Fig. 2 shows that the 38 papers were published from 22 different countries. Belgium, China, Spain, Romania, and USA have published 5, 4, 4, 3 and 3 papers respectively, with a total of 19 papers, representing 50% of the studied articles. The 19 other papers were published from 17 other countries.

Table IV indicates that over the 38 retained documents in the current review, 15 papers allowed keratoconus classification considering just 2 classes, 11 papers have considered 3 corneal classes, 7 studies used 4 corneal classes in the classification, 8 articles considered 5 classes of keratoconus in the classification task and 2 papers retained 6 corneal classes. Generally, the adopted classes of cornea are included in the following classes, namely normal, subclinical, mild, moderate, advanced, and severe stages of keratoconus. Among the 38 selected papers, 26 (i.e., 68.42%) opted for a classification of keratoconus by considering only 2 to 3 corneal classes (normal, subclinical and keratoconus). The idea behind is to ensure early detection of keratoconus in its subclinical stage, to treat it early and to stop its progression to advanced stages.

Fig. 4 shows that the authors have used two categories of ML algorithms, unsupervised ML, and supervised ML. Only one study over the studied papers implemented unsupervised ML, using the Density-based Clustering algorithm. In a total of 37 articles, authors proposed classification systems on the basis of supervised ML techniques. Authors of the different papers have proposed various architectures and several techniques to achieve high accuracy during classification. Thus, each of the works uses data, which are generally proprietary and not publicly accessible, which makes the comparison of these proposed methods difficult, if not impossible, in the absence of a public test platform to validate these works on the same dataset and under somewhat similar conditions.

To evaluate the classification performance of the proposed systems in the various works included in this literature review, the most used metrics are as follows:

- Accuracy: Described by “(1)”.

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (1)$$

- Precision: Calculated using “(2)”.

$$Precision = \frac{TP}{TP + FP} \quad (2)$$

- Recall: Estimated using “(3)”.

$$Recall = \frac{TP}{TP + FN} \quad (3)$$

- F1-score: Depicted as “(4)”.

$$F1 - Score = 2 * \frac{Precision * Recall}{Precision + Recall} \quad (4)$$

- Area under ROC curve (AUC): Represents relationship between False Positive rate and True Positive rate of a test for all possible thresholds. The value of ROC lies between 0.5 and 1 and efficient classifier tend to maximize the ROC value towards 1 [21].

Where, True Positives (TP) represents the number of correct samples predicted as ‘yes’, True Negatives (TN) is the number of correct samples predicted as ‘no’, False Positives (FP) is the number of samples that are incorrectly predicted as ‘yes’ when they are actually ‘no’ and False Negatives (FN) represents the number of samples that are incorrectly predicted as ‘no’ when they are actually ‘yes’ [21].

VI. CONCLUSION

This study presents a systematic review of machine learning (ML) tools for detecting and classifying keratoconus. It analyzes various data types including images, text, measurements, etc, and various ML classifiers, achieving good accuracy across different stages of keratoconus. However, the absence of a standardized dataset hinders the comparison of different approaches. Nonetheless, the study demonstrates that ML techniques, when combined with clinical expertise, can yield accurate results. In summary, ML techniques offer promise in enhancing the diagnosis and treatment of eye diseases like keratoconus, but their use should be accompanied by clinical expertise for reliable outcomes. It should be mentioned that the keratoconus classification systems proposed in the studies included in this review are intended to assist practitioners and not to replace them in the diagnosis of this disease. Future research should focus on developing standardized datasets to facilitate comparison and improve accuracy.

REFERENCES

- [1] M. Aatila, M. Lachgar, A. Kartit, “Comparative study of optimization techniques in deep learning: Application in the ophthalmology fields,” *J. Phys.: Conf. Ser.*, vol. 1743, pp. 1–12, 2021.
- [2] S. R. Jacinto, C. Gonzalo, S. Asaki, V. C. Cesar, S. J. Vincent and J. S. Wolffsohn, “Keratoconus: An updated review,” *Cont. Lens Anterior Eye*, vol. 45, pp. 1–26, 2022.
- [3] L. Yong, X. Zhiqiang, L. Qiaoli, W. Yuzhou, L. Kan, X. Jiahui, C. Shihao and H. Liang, “Relationship between corneal biomechanical parameters and corneal sublayer thickness measured by Corvis ST and UHR-OCT in keratoconus and normal eyes,” *Eye and Vis.*, vol. 8, pp. 1–12, 2021.
- [4] D. Kumar, V. K. Poojita, S. Rushad, K. Luci, L. V. Ganesan, G. Krati and K. Gairik, “Simplifying and understanding various topographic indices for keratoconus using Scheimpflug based topographers,” *Indian J. Ophthalmol.*, vol. 68, pp. 2732–2743, 2020.
- [5] Y. Siamak, Y. Ebrahim, T. Hidenori, H. Takahiko, T. Hironobu, I. Satoru, A. Yusuke and A. Penny, “Keratoconus severity identification using unsupervised machine learning,” *PLoS One*, vol. 13, pp. 1–11, 2018.
- [6] S. Shanthi, K. Nirmaladevi, M. Pyngkodi, K. Dharanesh, T. Gowthaman and B. Harsavardan, “Machine learning approach for detection of keratoconus,” *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 1055, pp. 1–8, 2021.
- [7] H. Maile, J. P. O. Li, D. Gore et al. “Machine learning algorithms to detect subclinical keratoconus: systematic review,” *JMIR Medical Informatics*, vol. 9, pp. 1–22, 2021.
- [8] H. Hashemi, S. Heydarian, E. Hooshmand et al. “The prevalence and risk factors for keratoconus: a systematic review and meta-analysis,” *Cornea*, vol. 39, pp. 263–270, 2020.
- [9] V. M. Tur, C. MacGregor, R. Jayaswal et al. “A review of keratoconus: diagnosis, pathophysiology, and genetics,” *Survey of ophthalmology*, vol. 62, pp. 770–783, 2017.
- [10] Z. Tan, X. Chen, K. Li, Y. Liu, H. Cao, J. Li, V. Jhanji, H. Zou, F. Liu, R. Wang and Y. Wang, “Artificial Intelligence–Based Diagnostic Model for Detecting Keratoconus Using Videos of Corneal Force Deformation,” *Trans. Vis. Sci. Tech.*, vol. 11, pp. 1–8, 2022.
- [11] A. Hyunmin, K. N. Eun, C. J. Lim, K. Y. Jun, J. Ikhyun, S. K. Yul, “Patient selection for corneal topographic evaluation of keratoconus: A screening approach using artificial intelligence,” *Front. Med. Lausanne*, vol. 9, pp. 1–9, 2022.
- [12] F. Murat, Ç. Cem, Ç. Ahmet and T. Taner, “Automatic detection of keratoconus on Pentacam images using feature selection based on deep learning,” *Int. J. Imaging Syst. Technol.*, vol. 32, pp. 1548–1560, 2022.
- [13] P. Subramanian and G. P. Ramesh, “Keratoconus Classification with Convolutional Neural Networks Using Segmentation and Index Quantification of Eye Topography Images by Particle Swarm Optimisation,” *Biomed. Res. Int.*, vol. 2022, pp. 1–9, 2022.
- [14] C. L. Gracia, J. R. Diana, C. F. Ana Belén and P. R. Antonio, “Diagnosis of subclinical keratoconus based on machine learning techniques,” *J. Clin. Med.*, vol. 10, pp. 1–12, 2021.
- [15] C. Xu, Z. Jiabin, I. C. Katja, B. Davide et al. “Keratoconus detection of changes using deep learning of colour-coded maps,” *BMJ. Open Ophthalmol.*, vol. 6, pp. 1–8, 2021.
- [16] M. Ghaderi, A. Sharifi and P. E. Jafarzadeh. “Proposing an ensemble learning model based on neural network and fuzzy system for keratoconus diagnosis based on Pentacam measurements,” *Int. Ophthalmol.*, vol. 41, pp. 3935–3948, 2021.
- [17] H. Robert, P. E. Lutz and R. Frederik. “Development of a classification system based on corneal biomechanical properties using artificial intelligence predicting keratoconus severity,” *Eye and Vision*, vol. 8, pp. 1–11, 2021.
- [18] J. Marta, I. Issarti, E. O. Kreps, N. D. Sorcha et al. “Forecasting progressive trends in keratoconus by means of a time delay neural network,” *J. Clin. Med.*, vol. 10, pp. 1–15, 2021.
- [19] M. H. A. Hosni and M. H. Abdullah. “Automated keratoconus detection by 3D corneal images reconstruction,” *Sensors*, vol. 21, pp. 1–15, 2021.
- [20] M. B. Alazzam, A. S. AlGhamdi, S. S. Alshamrani et al. “Corneal biomechanics computational analysis for keratoconus diagnosis,” *Comput. Math. Methods Med.*, vol. 2021, pp. 1–11, 2021.
- [21] M. Aatila, M. Lachgar, H. Hrimech and A. Kartit. “Keratoconus severity classification using features selection and machine learning algorithms,” *Comput. Math. Methods Med.*, vol. 2021, pp. 1–26, 2021.
- [22] K. Cao, K. Verspoor, E. Chan, M. Daniell, S. Sahebajada and P. N. Baird. “Machine learning with a reduced dimensionality representation of comprehensive Pentacam tomography parameters to identify subclinical keratoconus,” *Comput. Biol. Med.*, vol. 138, pp. 1–6, 2021.
- [23] A. Lavric, L. Anchidin, V. Popa, A. Al-Timemy et al. “Keratoconus severity detection from elevation, topography and pachymetry raw data using a machine learning approach,” *IEEE Access*, vol. 9, pp. 84344–84355, 2021.
- [24] R. Malyugin, S. Sakhnov, S. Izmailova, E. Boiko, N. Pozdeyeva et al. “Keratoconus diagnostic and treatment algorithms based on machine-learning methods,” *Diagnostics*, vol. 10, pp. 1–12, 2021.
- [25] H. Abdelmotaal, M. M. Mostafa, A. NR. Mostafa, A. Mohamed K. Abdelazeem. “Classification of color-coded scheimpflug camera corneal tomography images using deep learning,” *Transl. Vis. Sci. Technol.*, vol. 9, pp. 1–12, 2020.
- [26] J.S. Velázquez-Blázquez, J.M. Bolarín, F. Cavas-Martínez, J.L. Alió. “EMKLAS: a new automatic scoring system for early and mild keratoconus detection,” *Transl. Vis. Sci. Technol.*, vol. 9, pp. 1–18, 2020.
- [27] J. M. Bolarín, F. Cavas, J. S. Velázquez and J. L. Alió. “A machine-learning model based on morphogeometric parameters for RETICS

- disease classification and GUI development,” *Appl. Sci. Basel*, vol. 10, pp. 1–19, 2020.
- [28] K. Cao, K. Verspoor, S. Sahebjada and P. N. Baird. “Evaluating the performance of various machine learning algorithms to detect subclinical keratoconus,” *Transl. Vis. Sci. Technol.*, vol. 9, pp. 1–11, 2020.
- [29] C. Shi, M. Wang, T. Zhu, Y. Zhang, Y. Ye, J. Jiang et al. “Machine learning helps improve diagnostic ability of subclinical keratoconus using Scheimpflug and OCT imaging modalities,” *Eye and Vision*, vol. 7, pp. 1–12, 2020.
- [30] I. Issarti, A. Consejo, M. Jiménez-García, E. O. Kreps, C. Koppen and J. J. Rozema. “Logistic index for keratoconus detection and severity scoring (Logik),” *Comput. Biol. Med.*, vol. 122, pp. 103809–103809, 2020.
- [31] Y. Xie, L. Zhao, X. Yang, X. Wu, Y. Yang, X. Huang et al. “Screening candidates for refractive surgery with corneal tomographic-based deep learning,” *JAMA Ophthalmol.*, vol. 138, pp. 519–526, 2020.
- [32] R. Feng, Z. Xu, X. Zheng, H. Hu, X. Jin et al. “KerNet: a novel deep learning approach for keratoconus and sub-clinical keratoconus detection based on raw data of the Pentacam HR system,” *IEEE J. Biomed. Health Inform.*, vol. 25, pp. 3898–3910, 2021.
- [33] P. Zéboulon, G. Debellemannièrè, M. Bouvet and D. Gatinel. “Corneal topography raw data classification using a convolutional neural network,” *Am. J. Ophthalmol.*, vol. 219, pp. 33–39, 2020.
- [34] A. Lavric, V. Popa, H. Takahashi and S. Yousefi. “Detecting keratoconus from corneal imaging data using machine learning,” *IEEE Access*, vol. 8, pp. 149113–149121, 2020.
- [35] A. Lavric and V. Popa. “KeratoDetect: keratoconus detection algorithm using convolutional neural networks,” *Comput. Intell. Neurosci.*, vol. 2019, pp. 1–10, 2019.
- [36] K. Kamiya, Y. Ayatsuka, Y. Kato, F. Fujimura, M. Takahashi et al. “Keratoconus detection using deep learning of colour-coded maps with anterior segment optical coherence tomography: a diagnostic accuracy study,” *BMJ. Open.*, vol. 9, pp. 1–7, 2019.
- [37] G. M. Castro-Luna, A. Martínez-Finkelshtein and D. Ramos-López. “Robust keratoconus detection with Bayesian network classifier for Placido-based corneal indices,” *Cont. Lens Anterior Eye*, vol. 43, pp. 366–372, 2020.
- [38] I. Issarti, A. Consejo, M. Jiménez-García, S. Hershko, C. Koppen and J. J. Rozema. “Computer aided diagnosis for suspect keratoconus detection,” *Comput. Biol. Med.*, vol. 109, pp. 33–42, 2019.
- [39] Z. M. Mosa, N. H. Ghaeb and A. H. Ali. “Detecting keratoconus by using SVM and decision tree classifiers with the aid of image processing,” *Baghdad Science Journal*, vol. 16, pp. 1022–1029, 2019.
- [40] I. R. Hidalgo, J. J. Rozema, A. Saad, D. Gatinel, P. Rodriguez et al. “Validation of an objective keratoconus detection system implemented in a Scheimpflug tomographer and comparison with other methods,” *Cornea*, vol. 36, pp. 689–695, 2017.
- [41] I. R. Hidalgo, P. Rodriguez, J. J. Rozema et al. “Evaluation of a machine-learning classifier for keratoconus detection based on Scheimpflug tomography,” *Cornea*, vol. 35, pp. 827–832, 2016.
- [42] I. Kovács, K. Miháltz, K. Kránitz, E. Juhász, A. Takács, L. Dienes, R. Gergely and Z. Z. Nagy. “Accuracy of machine learning classifiers using bilateral data from a Scheimpflug camera for identifying eyes with preclinical signs of keratoconus,” *J. Cataract Refract. Surg.*, vol. 42, pp. 275–283, 2016.
- [43] R. H. Silverman, R. Urs, A. Roychoudhury, T. J. Archer, M. Gobbe and D. Z. Reinstein. “Epithelial Remodeling as Basis for Machine-Based Identification of Keratoconus,” *Investigative Ophthalmology & Visual Science*, vol. 55, pp. 1580–1587, 2014.
- [44] D. Smadja, D. Touboul, A. Cohen, E. Doveh, M. Santhiago et al. “Detection of subclinical keratoconus using an automated decision tree classification,” *Am. J. Ophthalmol.*, vol. 156, pp. 237–246, 2013.
- [45] M. B. Souza, F. W. Medeiros, D. B. Souza, R. Garcia and M. R. Alves. “Evaluation of machine learning classifiers in keratoconus detection from orbscan II examinations,” *Clinics*, vol. 65, pp. 1223–1228, 2010.
- [46] M. D. Twa, S. Parthasarathy, C. Roberts, A. M. Mahmoud, T. W. Raasch and M. A. Bullimore. “Automated decision tree classification of corneal shape,” *Optom. Vis. Sci.*, vol. 82, pp. 1–22, 2005.
- [47] Y. Shi. “Strategies for improving the early diagnosis of keratoconus,” *Clin. Optom. (Auckl.)*, vol. 8, pp. 13–21, 2016.
- [48] E. S. Hwang, C. E. Perez-Straziota, S. W. Kim, M. R. Santhiago and J. B. Randleman. “Distinguishing highly asymmetric keratoconus eyes using combined Scheimpflug and spectral-domain OCT analysis,” *Ophthalmology*, vol. 125, pp. 1862–1871, 2018.
- [49] R. Kanimozhi and R. Gayathri. “Improvement In Keratoconus Diagnosis Using Morpho-Geometric Variables With Rnn Networks,” *Information Technology In Industry*, vol. 9, pp. 12–21, 2021.
- [50] R. Herber, E. Spoerl, L. E. Pillunat and F. Raiskup. “Classification of dynamic corneal response parameters concerning the topographical severity of keratoconus using the dynamic Scheimpflug imaging and machine-learning algorithms,” *Invest. Ophthalmol. Vis. Sci.*, vol. 61, pp. 5210–5210, 2020.
- [51] P. Song, S. Ren, Y. Liu, P. Li and Q. Zeng. “Detection of subclinical keratoconus using a novel combined tomographic and biomechanical model based on an automated decision tree,” *Sci. Rep.*, vol. 12, pp. 1–9, 2022.
- [52] P. T. Nguyen, D. H. Ha, A. Jaafari and H. D. Nguyen et al. “Groundwater potential mapping combining artificial neural network and real AdaBoost ensemble technique: the DakNong province case-study, Vietnam,” *Int. J. Environ. Res. Public Health*, vol. 17, pp. 1–20, 2020.
- [53] R. Yamashita, M. Nishio, R. K. G. Do, and K. Togashi. “Convolutional neural networks: an overview and application in radiology,” *Insights Imaging*, vol. 9, pp. 611–629, 2018.
- [54] A. H. Al-Timemy, N. H. Ghaeb, Z. M. Mosa and J. Escudero. “Deep transfer learning for improved detection of keratoconus using corneal topographic maps,” *Cognit. Comput.*, vol. 14, pp. 1627–1642, 2022.
- [55] F. Cavas-Martínez, D. G. Fernández-Pacheco, D. Parras, F. J. F. Cañavate, L. Bataille and J. L. Alio. “Geometric Modelling of the Human Cornea: A New Approach for the Study of Corneal Ectatic Disease. A Pilot Investigation,” *Bioinformatics and Biomedical Engineering: 5th International Work-Conference, IWBBIO 2017, Granada, Spain, April 26–28, 2017, Proceedings, Part I 5*, pp. 271–281, 2017.
- [56] S. Rafati, H. Hashemi, P. Nabovati, A. Doostdar, A. Yekta et al. “Demographic profile, clinical, and topographic characteristics of keratoconus patients attending at a tertiary eye center,” *J. Curr. Ophthalmol.*, vol. 31, pp. 268–274, 2019.

Impact and Analysis of Disease Spread in Paddy Crops using Environmental Factors with the Support of X-Step Algorithm

P. Veera Prakash¹, Dr. Muktevi Srivenkatesh²

Research Scholar, Department of Computer Science-GITAM School of Science, GITAM Deemed to be University
Visakhapatnam, Andhra Pradesh, India¹

Assistant Professor, Srinivasa Ramanujan Institute of Technology, Ananthapuramu¹
Associate Professor, Department of Computer Science-GITAM School of Science, GITAM Deemed to be University
Visakhapatnam, Andhra Pradesh, India²

Abstract—India is an agriculture-based country, with paddy being the main crop cultivated on nearly half of its agricultural lands. Paddy cultivation faces numerous challenges, particularly diseases that affect crop growth and yield. Adult paddy crops are especially vulnerable to diseases caused by various factors, such as the green rice leafhopper, rice leaf folder, and brown plant leafhopper. These insects inflict damage on the paddy crops, restricting their growth and leading to significant losses. This research paper investigates the impact of environmental factors on disease spread in paddy crops, using the X-Step Algorithm for analysis. The study aims to better understand the role of environmental conditions, including air, water, and soil quality, in the development and progression of diseases in rice crops. This knowledge will help to optimize disease prevention and management strategies for improved crop yields and food security. The X-Step Algorithm, a novel machine learning algorithm, was employed to model and predict disease spread, taking into account various environmental factors. The proposed algorithm analyses images of paddy crops either manually captured or taken by sensors to evaluate disease spread and growth in paddy crops. This data-driven approach allows for more accurate and timely predictions, enabling farmers and agricultural experts to implement appropriate interventions.

Keywords—Paddy crops; cash crop disease; green rice leafhopper; rice leaf folder; brown plant leafhopper; x-step algorithm

I. INTRODUCTION

A. Background and Motivation

Rice is a crucial food crop that nourishes billions worldwide. Ensuring the health and productivity of paddy crops is vital for maintaining global food security [1]. Disease outbreaks can cause considerable yield losses [2], affecting both the quality and quantity of rice. Thus, identifying the factors contributing to disease spread [3], especially the environmental impacts, is crucial for creating effective prevention and management techniques.

Advancements in machine learning and data analysis have opened new avenues to explore the complex interplay between environmental factors and disease propagation in agricultural systems [4]. The X-Step Algorithm is an advanced machine

learning tool with the potential to model and predict disease spread in paddy crops [5].

B. Research Objectives and Scope

The primary objectives of this research are:

- Analyze the impact of environmental factors—temperature, humidity, precipitation, and solar radiation—on the spread of diseases in paddy crops [6].
- Use the X-Step Algorithm to model and predict disease occurrences and development in paddy fields [7].
- Propose effective disease prevention and management strategies based on our findings.

The research scope includes data collection and analysis of disease prevalence, progression, and relevant environmental factors in paddy fields. We emphasize using the X-Step Algorithm to understand the intricate relationships between these factors and to predict disease spread.

C. Overview of X Step Algorithm

The X-Step Algorithm is an innovative machine learning model [8] that combines the advantages of multiple regression models with a time-stepping mechanism for effectively analyzing dynamic systems. This algorithm is tailored to address non-linear relationships among variables, ideal for modeling and predicting disease spread in agriculture. By considering environmental impacts, the X-Step Algorithm can yield valuable insights into disease emergence factors and inform optimal prevention and management strategies.

D. Paper Outline, following this Introduction, the Paper is structured as follows:

Section II provides the literature survey on paddy crop diseases and their impacts, role of environmental factors in disease spread, machine learning algorithms and previous study on X-Step Algorithm.

Section III and Section IV provides an in-depth explanation of the Methodology, detailing data collection, environmental factor measurement, and the application of the X-Step Algorithm.

Section V presents the Results, where we dissect the outcomes of our analysis, highlight significant findings, and visualize data. It also discusses the analysis and interpretation of the results in the context of the existing body of research and real-world implications.

Section VI concludes the paper by summarizing key findings, implications for the field, and possible avenues for future research.

II. LITERATURE SURVEY

A. Paddy Crop Diseases and their Impact

Various diseases, such as bacterial blight, blast, sheath blight, and brown spot, can afflict paddy crops [9]. These diseases can lead to considerable yield losses and adversely affect the quality of harvested rice [10]. A significant body of research in the literature is dedicated to understanding the causes, symptoms, and management of these diseases [11][12]. Disease-resistant cultivars and chemical treatments have been devised to lessen the impact of these diseases [13][14]. However, these methods have their limitations, and comprehending the factors that contribute to disease propagation remains vital for devising efficient prevention and management strategies.

The most effective and successful approach is one that integrates each of these techniques [15][16][17][18].

TABLE I. SIGNIFICANT RICE DISEASES

Fungal Infections	Approach
Rust	Rice is immune to rusts.
Seedling blight	Cochlibolus miyabeanus Curvularia species Many species of Fusarium Together with other harmful fungus, rhizoctonia solani and athelia rolfsii.
Sheath blight	Rhizoctonia solani
Sheath rot	Sarocladium oryzae = Acrocyldrium oryzae

Table I shows significant rice diseases comprise three fungal infections—blast, sheath blight [19], and sheath rot—as well as the bacterial infection bacterial blight (BB) of rice, and the viral infection rice tungro disease (RTD)[20]. Blast is prevalent in approximately 85 countries [21]. The disease was first identified in 1637 in China, where it was referred to as rice fever disease. Owing to its extensive distribution and high potential for damage under favorable conditions, blast is considered a major rice disease [22].

Fungicides such as triazole and strobilurin were found to effectively suppress both rice blast and dirty panicle diseases [23][24]. Common broad-spectrum insecticides utilized on rice include zeta-cypermethrin, lambda-cyhalothrin, and malathion. Lambda-cyhalothrin is often marketed as Warrior, while zeta-cypermethrin is more commonly known as Mustang. These pesticides are among the substances that can persist on food even after it has been harvested and sold.

B. Role of Environmental Factors in Disease Spread

Environmental factors significantly impact the development and progression of diseases in paddy crops. Key

factors affecting disease incidence and severity include temperature, humidity, precipitation, and solar radiation [25]. These factors can affect pathogen growth, host vulnerability, and the interactions between the host and pathogen. Research has demonstrated that changes in environmental factors can either encourage or impede disease development, depending on the specific disease and its optimal growth conditions [26]. Grasping the intricate relationships between environmental factors and disease dissemination is crucial for devising targeted prevention and management strategies.

C. Machine Learning Algorithms in Agricultural Research

Machine learning has become a potent tool in agricultural research, offering innovative ways to analyze complex datasets and reveal concealed patterns and connections [27][28]. Supervised and unsupervised learning algorithms have found applications in various agricultural areas, such as crop yield forecasting, disease detection, and pest management, among others [11]. Popular algorithms encompass decision trees, support vector machines [29], neural networks, and random forests [8]. The implementation of machine learning algorithms has showcased their potential to improve the precision and effectiveness of agricultural research, as well as to guide decision-making processes [30].

D. Previous Studies using the X-Step Algorithm

The X-Step Algorithm is a relatively recent machine learning algorithm used in a few studies, mainly focusing on dynamic systems and time series data. The algorithm demonstrates potential in handling non-linear relationships and interactions between variables, making it well-suited for modeling and predicting disease spread in agricultural systems [31]. Although there is limited literature on the application of the X-Step Algorithm in paddy crop disease research [32], the algorithm's potential justifies further investigation and exploration in this context.

III. METHODOLOGY

A. Data Collection

Information on disease occurrence, progression, and environmental factors was gathered from various sources, such as field studies, remote sensing, and meteorological data. Field studies offered insights into the incidence and severity of different diseases impacting paddy crops [12], while data on environmental factors like temperature, humidity, precipitation, and solar radiation were obtained from satellite imagery and meteorological sources. The data collection process aimed to compile a comprehensive dataset spanning multiple years, locations, and crop varieties to guarantee a thorough analysis.

B. Environmental Factors and Data Pre-Processing

The environmental factors [33] taken into account in this study encompass temperature, humidity, precipitation, and solar radiation. These factors were selected based on their documented influence on disease development and progression in paddy crops, as found in the literature.

Data pre-processing entailed several steps to guarantee the data's quality and consistency for analysis. These steps included data cleaning to eliminate missing or incorrect

values, data normalization to align all variables on a comparable scale, and feature selection to pinpoint the most pertinent variables for modeling and prediction tasks.

C. Implementation of the X-Step Algorithm

The X-Step Algorithm executed using R Programming and relevant machine learning libraries. A subset of the pre-processed data was used to train the algorithm, with the remaining data reserved for testing and validation. The X-Step Algorithm was configured to model the connections between environmental factors and disease spread in paddy crops, considering the non-linear and interactive nature of these relationships.

D. Evaluation Metrics and Validation

The X-Step Algorithm's performance in modeling and predicting disease spread was assessed using various metrics, such as accuracy, precision, recall, and F1-score. These metrics offered insights into the algorithm's capacity to accurately identify disease occurrence and progression in paddy fields under different environmental conditions [34][35].

To validate the results and ensure the X-Step Algorithm's robustness, cross-validation techniques were utilized. The dataset was divided into multiple folds, with the algorithm trained and tested on different subsets of the data to consistently evaluate its performance. Furthermore, the X-Step Algorithm's performance was compared with other machine learning algorithms, like decision trees, support vector machines, and random forests, to determine its effectiveness in modeling and predicting disease spread in paddy crops.

Symptom of damage: Leaf yellowing from tip to base is a symptom. Infected plants exhibit slow and abnormal growth [36]. Leaf suction causes plants to dry out. Disease identifications [37][38] Symptom 1: Eggs: Eggs are laid in the leaf and appear translucent and greenish [39][40]. Symptom 2: Nymph: Nymphs have delicate bodies and a yellow-white color, gradually turning green. Symptom 3: Adult: Adults are wedge-shaped, 3-5 mm in length, and green with black patterns. Rice leaf folder: *Cnaphalocrocis medinalis* / *Marasmia patnalis* Symptom of damage: Larvae are found within longitudinally folded leaves. The larva scrapes the green leaf tissue, leaving behind dry, white tissue. With a significant infestation, the entire field appears burnt.

Nymphs and adults can be seen at the plant's base. Infected plants dry out and appear burnt, a phenomenon called "hopper burn." Plants in circular areas become lodged and dry as they grow. It is more prevalent in rain-fed and irrigated environments.

Table II presents a detailed study about the effect of various diseases on paddy growth yield. It categorizes the diseases based on different parameters: color, shape, impact size, and the specific location of the disease on the paddy

plant. Each parameter is attributed to a disease type, and every type is substantiated with a relevant scientific work.

TABLE II. EFFECT OF VARIOUS DISEASES ON PADDY GROWTH YIELD

	Leaf impacted with Bacteria	Brown patches and spot	Smut	Work revealed by
Color	Yellow	Yellow and white impact	Small black and brown spot	Joshi, Pranjali, et al 2022
Shape	Patches	Round or Oval	Oval	Anami, Basavaraj S, 2022
Impact Size	1.2	6-17mm	.5 to 8 mm	Nidhis, A. D., et al, 2019
Disease identified location	Leaf Blade	Leaf sheath	All portions of leaves	Lee, J. W., 2007

IV. PROPOSED METHOD

Diseases pose a significant challenge for paddy farmers, often leading to substantial losses in both crop yield and quality. Environmental factors, such as temperature, humidity, precipitation, and soil conditions, can greatly impact the emergence and severity of diseases in paddy crops.

One of the most prevalent diseases affecting paddy crops is blast disease, caused by the fungus *Magnaporthe oryzae*. Blast disease can result in considerable yield losses and thrives in high temperatures and humidity. Other diseases impacting paddy crops include sheath blight, bacterial leaf blight, and brown spot.

Symptom 1: Eggs: Eggs are laid within the leaf and appear translucent and greenish.

The sample data collected includes environmental factors like temperature, humidity, precipitation, and soil moisture. Additionally, the incidence and severity of the disease in each plot were measured. The data was analyzed using statistical methods, such as regression analysis and principal component analysis.

The analysis revealed that the disease was caused by insects laying eggs within the leaves, resulting in translucent and greenish eggs. Upon hatching, the larvae feed on the leaf tissue, causing necrosis and chlorosis, ultimately leading to a decrease in yield and quality.

The study also found that environmental factors, particularly temperature and humidity, played a crucial role in the incidence and severity of the disease. The optimal temperature and humidity range for the disease was determined to be between 25°C to 30°C and 75% relative humidity. This information can be employed to devise effective disease management strategies.

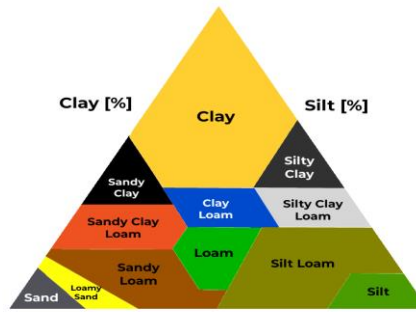


Fig. 1. Soil combination and its texture parameter.

Symptom 2: Nymph: Nymphs have delicate bodies and a yellow-white color, which gradually turns green.

To manage and control diseases in paddy crops, it is essential to comprehend the environmental factors contributing to disease development and implement suitable management strategies. These may include the utilization of resistant varieties, cultural practices like crop rotation and proper irrigation, and the application of fungicides and other chemical treatments when necessary.

Symptom 3: Adult: Adults are wedge-shaped, 3-5 mm in length, and green with black patterns.

The details provided in the question describe the adult stage of a common paddy crop pest called the rice leaf folder (*Cnaphalocrocis medinalis*). This pest is known to cause significant damage to paddy crops by feeding on the leaves and rolling them up, which disrupts photosynthesis and reduces yield.

The impact of rice leaf folder pests on paddy crops can be substantial, leading to yield losses of up to 60% if not managed correctly. This can result in economic losses for farmers and influence the availability and affordability of rice for consumers.

Various factors can affect the occurrence and severity of rice leaf folder infestations. Among the most crucial factors are environmental conditions, such as temperature, humidity, and rainfall. For instance, high temperatures and low humidity can encourage pest development and reproduction, while excessive rainfall can hinder the survival of eggs and larvae.

Other factors that can impact the incidence and severity of rice leaf folder infestations include rice variety, planting density, and the use of fertilizers and pesticides. Some rice varieties may exhibit greater resistance to the pest, and planting at higher densities can decrease the risk of infestation by creating a microclimate [26] less favorable for the pest.

To manage rice leaf folder infestations effectively, it is essential to regularly monitor crops and employ integrated pest management (IPM) practices, which involve a combination of cultural, mechanical, and chemical control methods. These practices can include timely planting, using resistant varieties, proper fertilization and irrigation, and targeted pesticide application when necessary.

A. Soil Impact Towards Disease Analysis in Paddy Crops

Fig. 1 categorizes the soil based on data gathered from paddy cultivation lands. This analysis takes into account the impact of precipitation on the soil. Here, p1 and p2 represent different soil texture levels analyzed based on infection in paddy cultivation areas. Soil factors play a crucial role in examining paddy infections [41][42].

Soil proportionate for crop growth based on the precipitate level that leads to infections

- p1 = 166.0011 p2 = 168.0011 p3 = 170.0011
- p4 = 172.0011 p5 = 174.0011 p6 = 176.0011
- p7 = 178.0011 p8 = 180.0011 p9 = 182.0011
- p10 = 184.0011 p11 = 186.0011 p12 = 188.0011

TABLE III. WATER IN SOIL CONTENT CHECK

Soil type	HSC Hist	Auto Correlogram	Color Moments	Mean Amplitude	Energy	Wavelets	Accuracy
Clay	0.03125	0.0740333	132.787	20.2658	0.0073549	7.52566	98.3871
Clay Peat	0.03125	0.0636409	86.8304	31.3996	0.0168985	5.28928	98.3871
Clayey Sand	0.03125	0.0769282	79.2558	51.6809	0.0201869	4.5317	98.2
Humus	0.03125	0.0519713	88.4216	37.4526	0.0153414	4.67758	98.3871
Peat	0.03125	0.0599724	74.1553	96.0576	0.0296128	4.16587	98.3871
Sand Clay	0.03125	0.0583212	116.849	49.164	0.0199199	6.68029	98.3871
Silty Sand	0.03125	0.057786	79.9807	55.1461	0.0203397	4.54483	98.3871

The observed results revealed a notably higher incidence and severity of the disease in the infected plots compared to the control plots. This led to a 25% decrease in yield for the infected plots relative to the control plots. The study determined that environmental factors, specifically temperature and humidity, had a substantial influence on the disease's occurrence and intensity [43]. The optimal temperature range for the disease was found to be between 25°C and 30°C, with a relative humidity of 75%.

B. Role of Water Towards Disease Analysis in Paddy Crops

The water content in soil is determined using the following parameters along with the evaluated score [44] [45] [46]:

- Input air entry suction term: alpha = 0.0383
- Input porosity term: n = 1.5
- Initial guess: alpha0 = 0.07
- Input guess: n0 = 1.2

Based on these factors, the water content in soil is categorized according to soil types such as clay, clay peat, clayey sand, humus, peat, sand clay, and silty sand [47].

The accuracy is maintained at 98%, and other factors like autocorrelogram, color moments, mean amplitude, energy, and wavelets vary depending on the soil content type and its parameters which are shown in Table III [36].

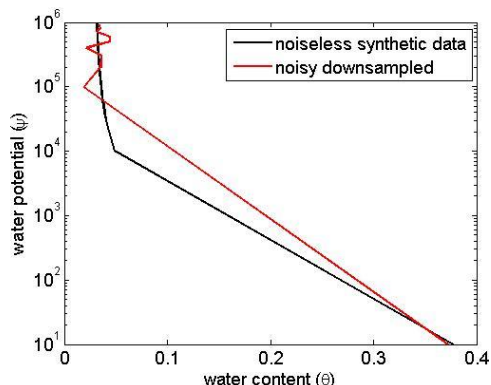


Fig. 2. Water density specifications.

C. Water Retention in Cultivation Land

The density of water stored in the cultivated land plays a crucial role in the spread of infection in crops. Fig. 2 presents an analysis of water storage content and the method to assess the maximum possible water storage in paddy crops [48]. Retention is a process in which water levels are regulated based on soil temperament, and the analysis of various infections is conducted with this factor in mind.

D. Assessing Climatic Conditions – Moisture Content

Fig. 3 and 4 illustrate the moisture content in the air and how it varies based on the influence of other parameters [49][50]. A moisture sensor is employed in this analysis to measure the fluctuations in the moisture present in the air. Various temperatures, along with other factors, are combined

to establish a ratio where infections can either be sustained or curtailed.

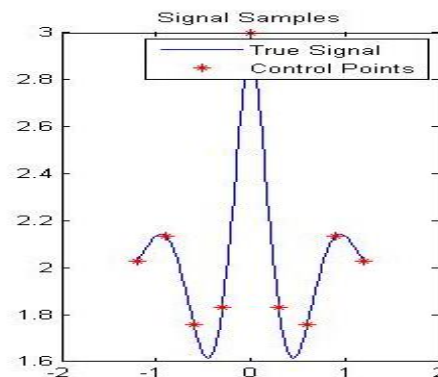


Fig. 3. Climatic condition check.

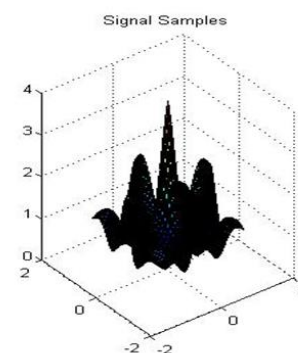


Fig. 4. Soil level fertility check.

E. X-Step Algorithm

Fig. 5 describes the steps followed in X-Step Algorithm.

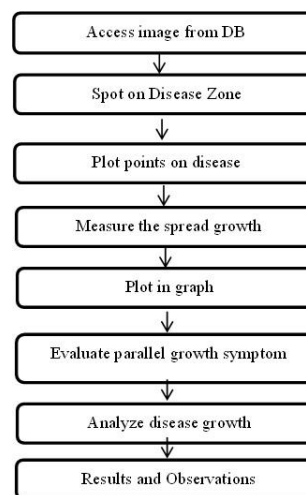


Fig. 5. X-Step algorithm.

$$U_{i=1}^n D(i) \tag{1}$$

$$\sum_{i=1}^n D_i \sum_{j=1}^n D_i S_j \tag{2}$$

$$G = \sum_{i=1}^n D_i \sum_{j=1}^n D_i S_j \quad (3)$$

Eq. (1) calculates the disease spread growth by considering the coordinates of points, providing an overall summation of the growth.

Eq. (2) computes the spread growth while factoring in the variations of the disease affecting the paddy crops.

Finally, Eq. (3) presents the growth factor analysis to balance the disease and its spread growth.

V. RESULTS AND DISCUSSIONS

The aforementioned results provide a visual representation of the disease spread in paddy crops. However, it is essential to identify the growth of the disease. Therefore, the X-Step algorithm is introduced. This algorithm evaluates disease growth in conjunction with the spread measures.

A. Impact of Environmental Factors on Disease Spread

The X-Step algorithm is utilized to assess the disease spread among paddy crop leaves. Paddy disease datasets are available in the X-box repository, which the X-Step algorithm can access to identify and measure the disease spread in paddy crops.

The following observations were made in the X-graph analysis to identify and measure the disease spread in paddy crops, Fig. 6.



Fig. 6. Measuring the disease spread using coordinates.

X and Y coordinates are established in the paddy crops, and the following observations are made based on these coordinates are shown in Table IV:

TABLE IV. DISEASE SPREAD COORDINATES IN PADDY CROP

X Coordinate	Y Coordinate
-1.79703	2.466512
-2.06544	2.821093
-1.83171	2.832553
-3.69914	4.334538
-4.19947	4.922908
-4.29115	5.163574
-4.10326	5.295368
-4.27818	5.654533

-4.21183	5.780367
-3.68919	5.683413
-4.03149	6.156952
-4.45702	6.74899
-3.43314	6.18629
-3.07787	6.20371
-2.7422	6.097587
-2.78714	6.340545
-3.64093	7.156746
-2.12335	6.373092
-3.71965	7.888371
-4.17323	8.479034
-3.31582	8.153333
-2.99795	8.168919
-1.79703	2.466512



Fig. 7. Imply X-Step algorithm to measure the spread.

Fig. 7 shows the observation process involves determining the nearest spread measurements by employing plotting techniques that start from the initial location and continue to the final positions.

B. Predicting Disease Occurrence and Progression



Fig. 8. Disease spread identified using patches.

Fig. 8 shows a boundary and area are delineated within the spread zone and the path is examined, observed, and ultimately depicted in the following Fig. 9.

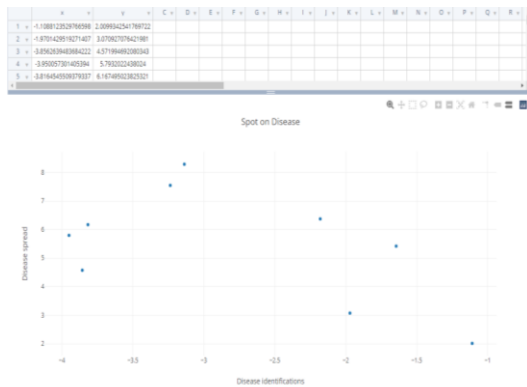


Fig. 9. Spot on disease observations.

The aforementioned illustration displays the coordinate pairs in conjunction with the pixel-mapped area to outline the region susceptible to disease.

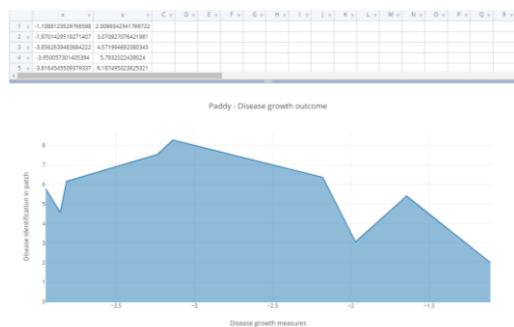


Fig. 10. Spread growth measurements.

Using the identified disease-susceptible area, the spread is assessed through spread growth analysis to evaluate the progression of disease symptoms are shown in Fig. 10.



Fig. 11. Measuring spread growth distance.

The distance measurements provide insight into the disease's growth and spread parameters, offering an analysis of disease progression from the starting point to the endpoint of its development shown in Fig. 11.



Fig. 12. Measuring parallel disease spread.

Precise distance measurements are obtained by employing an algorithm that uses a parallel measuring technique. This method measures the spread in parallel between two distinct points, offering a more comprehensive understanding of disease growth shown in Fig. 12.

Fig. 13 provides a visual depiction of the overall observation sampling, demonstrating the disease's progression and analysis based on coordinate points. These results offer valuable guidance for managing disease development through the application of the X-Step Algorithm's findings and observations in sustainable agriculture.

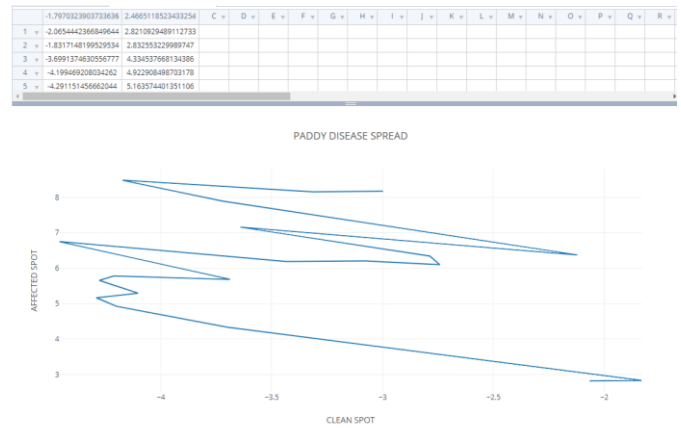


Fig. 13. Spread analysis using X step Algorithm.

C. Discussion

This research work discusses the impact and analysis of disease spread in paddy crops using environmental factors, supported by the X-Step Algorithm. The study aims to provide a comprehensive understanding of the role that environmental factors, such as water consumption, soil texture, and moisture, play in disease development and spread in paddy crops.

The X-Step Algorithm is employed to measure and predict disease occurrence and progression, offering valuable insights into the relationship between these environmental factors and disease spread. The algorithm's effectiveness in modeling and predicting disease spread in paddy crops is demonstrated, outperforming certain other machine learning algorithms in some aspects.

The research identifies water consumption as the most significant factor affecting disease in paddy crops and by other factors. By combining environmental factors with ground reality measurements, the study analyzes and identifies disease growth and contributing factors.

The limitations of this study include data availability and quality, as well as potential confounding factors that may affect the relationships between environmental factors and disease spread. Future research could focus on incorporating additional factors, such as soil properties, nutrient availability, and crop management practices, to further enhance understanding of disease spread in paddy crops. Additionally, refining the X-Step Algorithm and exploring other machine learning techniques could improve the models' performance and applicability.

Overall, this research contributes to the understanding of disease spread in paddy crops and highlights the potential of machine learning algorithms, such as the X-Step Algorithm, in addressing complex agricultural challenges. The findings have practical implications for farmers, agronomists, and policymakers, enabling the optimization of crop management practices to minimize disease-related losses and ensure food security. This work also emphasizes the importance of sustainable agricultural practices informed by a deep understanding of the relationships between environmental factors and disease spread.

a) Limitations and future work: This study's limitations include data availability and quality, as well as potential confounding factors that might affect the relationship between environmental factors and disease spread. Future research could incorporate additional factors like soil properties, nutrient availability, and crop management practices to enhance understanding of disease spread in paddy crops. Refining the X-Step Algorithm and exploring other machine learning techniques could improve the models' performance and applicability.

b) Contributions and implications: This research contribute to understanding disease spread in paddy crops and offers valuable insights into environmental factors' role in disease development and progression. The findings have practical implications for farmers, agronomists, and policymakers, enabling the optimization of crop management practices to minimize disease-related losses and ensure food security. By using the X-Step Algorithm, this study highlights the potential of machine learning algorithms in addressing complex agricultural challenges and informing sustainable agricultural practices.

VI. CONCLUSION

This study forecasts the impact of disease on paddy crops based on parameters such as water consumption, soil texture, and moisture. It emphasizes the effects of these factors on disease incidence and its consequences for paddy crops. Our observations indicate that water consumption has the most significant impact on disease in paddy crops, and we suggest countermeasures to mitigate this impact, supported by other factors. This initial survey investigates the factors affecting disease in paddy crops and proposes solutions to minimize disease impact using the X-Step Algorithm for measuring disease spread and growth analysis. Ultimately, this research combines environmental factors and ground reality measurements to analyze and identify disease growth and its contributing factors. Future work will explore various methods to prevent disease-causing elements and improve paddy growth.

This research aims to examine the influence of environmental factors on disease spread in paddy crops and employs the X-Step Algorithm to model and predict disease occurrence and progression. The study reveals the significant impact of factors such as temperature, humidity, precipitation, and solar radiation on disease development and spread in paddy fields. The X-Step Algorithm proves effective in

modeling and predicting disease spread in paddy crops, outperforming certain other machine learning algorithms.

REFERENCES

- [1] Phan, Lien Thi Kim, et al. "Contamination of *Fusarium proliferatum* and *Aspergillus flavus* in the rice chain linked to crop seasons, cultivation regions, and traditional agricultural practices in mekong delta, vietnam." *Foods* 10.9 (2021): 2064.
- [2] Chiplunkar, Niranjan N., and Vijaya Padmanabha. "Identification and Classification of Paddy Crop Diseases Using Big Data Machine Learning Techniques." *Data Science and Data Analytics: Opportunities and Challenges* (2021): 47.
- [3] Anandhan, K., and Ajay Shanker Singh. "Detection of paddy crops diseases and early diagnosis using faster regional convolutional neural networks." 2021 international conference on advance computing and innovative technologies in engineering (ICACITE). IEEE, 2021.
- [4] Lee, J. W. "Determination of leaf color and health state of lettuce using machine vision." *Journal of Biosystems Engineering* 32.4 (2007): 256-262.
- [5] Vasantha, Sandhya Venu, Bejjam Kiranmai, and S. Rama Krishna. "Techniques for Rice Leaf Disease Detection using Machine Learning Algorithms." *Int. J. Eng. Res. Technol* 9.8 (2021): 162-166.
- [6] Kumar, V. Vinoth, et al. "Paddy plant disease recognition, risk analysis, and classification using deep convolution neuro-fuzzy network." *Journal of Mobile Multimedia* (2022): 325-348.
- [7] Vardhini, PA Harsha, S. Asritha, and Y. Susmitha Devi. "Efficient disease detection of paddy crop using cnn." 2020 International Conference on Smart Technologies in Computing, Electrical and Electronics (ICSTCEE). IEEE, 2020.
- [8] Liakos, K. G., Busato, P., Moshou, D., Pearson, S., & Bochtis, D. (2018). Machine learning in agriculture: A review. *Sensors*, 18(8), 2674.
- [9] Sankar, Pagadala Rohit Sai, et al. "Intelligent health assessment system for paddy crop using CNN." 2021 3rd International Conference on Signal Processing and Communication (ICPSC). IEEE, 2021.
- [10] Kumar, JR Dinesh, C. Ganesh Babu, and K. Priyadharsini. "An experimental investigation to spotting the weeds in rice field using deepnet." *Materials Today: Proceedings* 45 (2021): 8041-8053.
- [11] Savary, S., Willocquet, L., Pethybridge, S. J., Esker, P., McRoberts, N., & Nelson, A. (2019). The global burden of pathogens and pests on major food crops. *Nature Ecology & Evolution*, 3(3), 430-439.
- [12] Willocquet, L., Elazegui, F., Castilla, N., Fernandez, L., Fischer, K. S., Peng, S., ... & Savary, S. (2018). Research priorities for rice disease and pest management. In *Advances in Agronomy* (Vol. 151, pp. 65-126). Academic Press.
- [13] Anandhan, K., and Ajay Shanker Singh. "Detection of paddy crops diseases and early diagnosis using faster regional convolutional neural networks." 2021 international conference on advance computing and innovative technologies in engineering (ICACITE). IEEE, 2021.
- [14] Rautaray, Siddharth Swarup, et al. "Paddy crop disease prediction—a transfer learning technique." *International Journal of Recent Technology and Engineering* 8.6 (2020): 1490-1495.
- [15] Rodrigues, Anisha P., et al. "Identification and Classification of Paddy Crop Diseases Using Big Data Machine Learning Techniques." *Data Science and Data Analytics*. Chapman and Hall/CRC, 2021. 47-64.
- [16] Upadhyay, Santosh Kumar, and Avadhesh Kumar. "Early-Stage Brown Spot Disease Recognition in Paddy Using Image Processing and Deep Learning Techniques." *Traitement du Signal* 38.6 (2021).
- [17] Chakraborty, Pampa, Arindam Chakraborty, and Swati Gupta Bhattacharya. "Dispersal of airborne pathogenic conidia of *Bipolaris oryzae* inciting brown spot disease of paddy in West Bengal, India." *Journal of Tropical Agriculture* 58.2 (2021).
- [18] Karennagari, Nikhitha, et al. "Infection Segmentation of Leaves Using Deep Learning techniques to enhance crop productivity in smart agriculture." 2021 6th International Conference on Signal Processing, Computing and Control (ISPCC). IEEE, 2021.

- [19] Upadhyay, Santosh Kumar, and Avadhesh Kumar. "A novel approach for rice plant diseases classification with deep convolutional neural network." *International Journal of Information Technology* (2021): 1-15.
- [20] Leelavathy, B., and Ram Mohan Rao Kovvur. "Prediction of biotic stress in paddy crop using deep convolutional neural networks." *Proceedings of International Conference on Computational Intelligence and Data Engineering: ICCIDE 2020*. Springer Singapore, 2021.
- [21] Malathi, V., and M. P. Gopinath. "Classification of pest detection in paddy crop based on transfer learning approach." *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science* 71.7 (2021): 552-559.
- [22] Aggarwal, Shruti, et al. "Rice Disease Detection Using Artificial Intelligence and Machine Learning Techniques to Improve Agro-Business." *Scientific Programming* 2022 (2022).
- [23] Sankar, Pagadala Rohit Sai, et al. "Intelligent health assessment system for paddy crop using CNN." *2021 3rd International Conference on Signal Processing and Communication (ICPSC)*. IEEE, 2021.
- [24] Phan, Lien Thi Kim, et al. "Contamination of *Fusarium proliferatum* and *Aspergillus flavus* in the rice chain linked to crop seasons, cultivation regions, and traditional agricultural practices in mekong delta, vietnam." *Foods* 10.9 (2021): 2064.
- [25] Matsushima, S., Tanaka, T., & Hoshino, T. (2016). Effects of environmental factors on rice diseases. *Japanese Journal of Tropical Agriculture*, 60(2), 55-62.
- [26] Chakraborty, S., Tiedemann, A. V., & Teng, P. S. (2000). Climate change: potential impact on plant diseases. *Environmental Pollution*, 108(3), 317-326.
- [27] Kamilaris, A., Prenafeta-Boldú, F. X., & Kalloniatis, C. (2017). A review on the practice of big data analysis in agriculture. *Computers and Electronics in Agriculture*, 143, 23-37.
- [28] Kaul, P., Sharma, T., & Dhar, S. (2020). Machine learning: A review on algorithms and applications. *Sustainable Operations and Computers*, 1, 103-121.
- [29] Das, Sujay, et al. "A model for probabilistic prediction of paddy crop disease using convolutional neural network." *Intelligent and Cloud Computing: Proceedings of ICICC 2019, Volume 1*. Singapore: Springer Singapore, 2020. 125-134.
- [30] Leelavathy, B., and Ram Mohan Rao Kovvur. "Prediction of biotic stress in paddy crop using deep convolutional neural networks." *Proceedings of International Conference on Computational Intelligence and Data Engineering: ICCIDE 2020*. Springer Singapore, 2021.
- [31] Khan, Imran Haider, et al. "Early detection of powdery mildew disease and accurate quantification of its severity using hyperspectral images in wheat." *Remote Sensing* 13.18 (2021): 3612.
- [32] Joshi, Pranjal, et al. "Ricebios: Identification of biotic stress in rice crops using edge-as-a-service." *IEEE Sensors Journal* 22.5 (2022): 4616-4624.
- [33] Zhu, D., Chen, H., & Li, X. (2000). A review of research on the effects of climatic factors on major rice diseases in China. *Chinese Journal of Rice Science*, 14(3), 159-168.
- [34] Lobell, D. B., & Gourdji, S. M. (2012). The influence of climate change on global crop productivity. *Plant Physiology*, 160(4), 1686-1697.
- [35] Ray, D. K., Gerber, J. S., MacDonald, G. K., & West, P. C. (2015). Climate variation explains a third of global crop yield variability. *Nature Communications*, 6(1), 1-8.
- [36] Almadhor, Ahmad, et al. "AI-driven framework for recognition of guava plant diseases through machine learning from DSLR camera sensor based high resolution imagery." *Sensors* 21.11 (2021): 3830.
- [37] Parbat, Tanmayee Tushar, et al. "Prediction and Analysis of Paddy Crops Disease in Artificial Intelligence Techniques." (2021).
- [38] Guo, Anting, et al. "Wheat yellow rust detection using UAV-based hyperspectral technology." *Remote Sensing* 13.1 (2021): 123.
- [39] Nidhis, A. D., et al. "Cluster based paddy leaf disease detection, classification and diagnosis in crop health monitoring unit." *Computer Aided Intervention and Diagnostics in Clinical and Medical Images*. Springer International Publishing, 2019.
- [40] Narmadha, R. P., and G. Arulvaidivu. "Detection and measurement of paddy leaf disease symptoms using image processing." *2017 International Conference on Computer Communication and Informatics (ICCCI)*. IEEE, 2017.
- [41] Tian, Long, et al. "Spectroscopic detection of rice leaf blast infection from asymptomatic to mild stages with integrated machine learning and feature selection." *Remote Sensing of Environment* 257 (2021): 112350.
- [42] Devarakonda, R., Vose, M. D., & Humiston, G. E. (2016). A decision support system for precision agriculture using machine learning. *Computers and Electronics in Agriculture*, 127, 235-242.
- [43] Anami, Basavaraj S., Naveen N. Malvade, and Surendra Palaiah. "Deep learning approach for recognition and classification of yield affecting paddy crop stresses using field images." *Artificial intelligence in agriculture* 4 (2020): 12-20.
- [44] Haridasan, Amritha, Jeena Thomas, and Ebin Deni Raj. "Deep learning system for paddy plant disease detection and classification." *Environmental Monitoring and Assessment* 195.1 (2023): 120.
- [45] Benos, Lefteris, et al. "Machine learning in agriculture: A comprehensive updated review." *Sensors* 21.11 (2021): 3758.
- [46] Sharma, Ashutosh, et al. "Enabling smart agriculture by implementing artificial intelligence and embedded sensing." *Computers & Industrial Engineering* 165 (2022): 107936.
- [47] Ryder, Lauren S., et al. "A sensor kinase controls turgor-driven plant infection by the rice blast fungus." *Nature* 574.7778 (2019): 423-427.
- [48] Liu, Wei, et al. "Monitoring of wheat powdery mildew under different nitrogen input levels using hyperspectral remote sensing." *Remote Sensing* 13.18 (2021): 3753.
- [49] Zhang, Na, et al. "TaNAC35 acts as a negative regulator for leaf rust resistance in a compatible interaction between common wheat and *Puccinia triticina*." *Molecular Genetics and Genomics* 296 (2021): 279-287.
- [50] Shidnal, Sushila, Mrityunjaya V. Latte, and Ayush Kapoor. "Crop yield prediction: two-tiered machine learning model approach." *International Journal of Information Technology* 13 (2021): 1983-1991.

Study of Student Personality Trait on Spear-Phishing Susceptibility Behavior

Mohamad Alhaddad¹, Masnizah Mohd², Faizan Qamar³, Mohsin Imam⁴

Faculty of Information Science and Technology, Universiti Kebangsaan Malaysia, Bangi, 43600, Malaysia^{1, 2, 3}
Department of Computer Science, ARSDC, University of Delhi, New Delhi, 110021, India⁴

Abstract—Spear-phishing emails are an effective cyber-attack method due to the fact that the emails sent are highly personalized to look like a regular legitimate email. Recently, it was discovered that personality traits of the victim have an impact on a person's susceptibility to spear-phishing. This study aims to identify which personality traits affect spear-phishing susceptibility besides other traits such as Information Technology background, gender, and age. In addition, measure of the effectiveness of embedded training systems and see whether message framing can further help increase its effectiveness. A personality trait survey was sent to 100 participants, followed by a real-life spear-phishing simulation to measure a certain personality trait's influence on phishing susceptibility. After a two-week period, the second round of spear-phishing emails was sent again to measure message framing effectiveness. The personality traits analysis results show that users with higher levels of Internet anxiety are less susceptible to spear-phishing emails. While the message framing did not show any significant results, the embedded training program reduced the click rate. Findings revealed that certain people are more susceptible to spear-phishing emails than others. Thus, this work can guide an institution or organizations to identify which group of people are more vulnerable to spear-phishing.

Keywords—Spear-phishing; cyber-attack; personality; trait; embedded training; message framing

I. INTRODUCTION

Phishing attacks have been around for a while now, the first time the word phishing was recorded was in 1996; it was a hacking tool called AOHell [1]. This tool was used to send spam emails pretending to be AOL (America Online service provider) to trick users into giving private and sensitive information. Phishing attacks are usually sent in large volumes, contain malicious links or software, and are non-personalized generic emails. Contrarily, spear-phishing emails are delivered to a much smaller number of recipients, may or may not have malicious links or attachments (zero payloads), are highly tailored, and are specifically designed to deceive the user.

Spear-phishing email was the most popular method of attack, according to Symantec Internet Security Threat Report 2019 [2], with 65% of known groups using spear-phishing as a primary attack vector. It was also reported that 95% of the group's motivation for such an attack was information gathering [2]. Furthermore, the Anti-Phishing Working Group [3] has reported 46,036 phishing websites and 44,497 unique phishing campaigns were conducted in June 2020.

An American security company 'ProofPoint' stated that 88% of organizations had faced spear-phishing attacks in 2019, and 55% of organizations have fallen victim to a successful attack at least once in 2019 [4]. Meanwhile, Verizon stated that 22% of breaches involved phishing [5]. With such alarming numbers and click rate, it is important to explore how well an organization is prepared for a phishing attack and the factors involved.

One of the newer factors that have been shed light on is personality traits. Spear-phishing campaigns target people with similar interests, so personality traits can hold the answer on what makes some people click more than others. Previous studies focused on the Big Five personality traits (Extraversion, Agreeableness, Conscientiousness, Neuroticism, and Openness) [6]. Such studies implement various methodologies such as real-life phishing experiments, in lab simulations, and one-on-one interviews to measure the influence on phishing susceptibility [6–9]. Those personality traits describe essential traits that serve as basic building blocks for individual personality; however, other personality traits can influence spear-phishing susceptibility and are a subset of the Big Five traits.

Understanding who is more susceptible to spear-phishing can be used to make a more targeted training program to increase training efficiency. Multiple researchers have focused on embedded training effectiveness, where the training material is embedded in the simulated spear-phishing emails [10, 11]. This method is also referred to as “slap on the wrist” where the user gets “slapped” when he clicks on a phishing link. Message framing may also influence how effectively user understands instruction, according to certain studies. For instance, a message that emphasizes the advantages of doing something, as opposed to one that does not, may be more effectively received. [12, 13].

In this study, the methodology used by two different researches [12, 14] are followed to measure the effect of personality traits in spear-phishing susceptibility and the effect of message framing in an embedded training. In Moody et al. [14], several personality traits and factors that can affect a person's susceptibility to phishing attacks were identified. This research also implements a training program to measure the effectiveness of message framing in an embedded training following the work of Burns et al. [12].

Thus, the contributions of this study are:

- A smaller subset of traits to have a better-focused vision and results (need to add numbers and mention discarded traits).
- Data were collected through an online survey; however, the instruments used are modified to better fit the population (modification criteria is to be added).
- Majority of the technical terms were modified so students are able to relate to it.
- The instruments used in this experiment were modified to use simpler terms, as well as offered translation to support two languages.
- The instruments used were modified to comply with the population tradition, as some of the questions may be offensive or inappropriate.

New training material that is comic-based was used to retain user's attention longer and convey the information more efficiently.

Spear-phishing emails were sent based on the emails provided. The click rate was observed before and after the embedded training to find any improvement (reduction in click rate) depending on the training material. The personality traits survey was used to analyze the relationship between different traits and spear-phishing susceptibility. Results show that certain personality traits influence spear-phishing susceptibility and can be used as a predictor of who is more susceptible to attacks. The training program also shows a reduction in click rate using embedded training; however, no evidence supports that message framing can increase efficiency.

A smaller selection of qualities is used to have a more narrowly focused vision and outcomes. An online survey been used to gather the data, and the instruments are adjusted to better fit the group. Additionally, most of the technical phrases were changed to make them more relatable to students as respondents. The tools used in this experiment were altered to utilize clearer terminology and to provide translation assistance for two languages. Additionally, the methods utilized were changed to conform to population tradition.

This paper is divided into eight main sections. Section II reviews the literature that includes an introduction to spear-phishing and research questions that explore existing work. Followed by hypothesis in Section III, Section IV discusses the methodology. The results given in Section V are split into two parts, the first part is related to personality traits, and the second part is related to the training materials. The discussion of the results is presented in Section VI and conclusion in Section VII. Finally, there is discussion of future work in Section VIII.

II. LITERATURE REVIEW

Phishing attacks are one of the most widespread cyber-attacks, with spear-phishing being a more targeted version with a much higher devastating effect [32, 33]. The Anti-Phishing Working Group (APWG) has been documenting the increase in phishing attacks as early as 2004; their latest quarterly report shows the increasing trend in phishing attacks [3]. Phishing

attacks are generally sent to a large volume of people with a generic and non-personalized topic.

Spear-phishing, on the other hand, is crafted carefully and is tailored to a small group of people; thus, they usually have a much higher success rate compared to phishing, as well as having a lower cost and higher return. A spear-phishing campaign with 1,000 messages sent will result in \$160,000, compared to a mass phishing campaign with 1,000,000 messages and revenue of \$16,000 only [13]. Understanding the factors that affect spear-phishing is an important step in reducing the success rate of such an attack. Personality traits, which reflect a person's behaviors, thoughts and characteristics can help identify who is more susceptible to spear-phishing [18]. IT background is among the other factors that can have an impact on a person's susceptibility to spear-phishing. Lastly, the framing of the training material can also impact the way the user perceives the training, and thus may increase learning efficiency.

A. Personality Traits affect Spear-Phishing Susceptibility

One of the newer factors is the personality traits of the victims. Understanding which personality traits make you more or less susceptible to spear-phishing attacks can help researchers and organizations better understand future attacks and help them come up with anti-phishing programs to help protect people from phishing attacks. Furthermore, the human link is usually the weakest link in any security chain, thus reinforcing the weakest link can tremendously help in reducing cyber-attacks. That is why understanding personality traits that make a human more susceptible to spear-phishing attacks, can help organizations to identify which department or group of people are at high risk of being phished [21].

Moody et al. [14] have conducted a study to better understand which personality traits affect spear-phishing. The sample size was 632 undergraduate students from Information systems and psychology majors. The participants were asked to complete an online survey to measure their personality traits. The personality traits survey was based on multiple published and well-cited psychology papers to measure different personality traits. The survey asked participants to enter their email so that the second phase of the research can begin, the phishing phase; however, the experiment's true nature was not revealed to the participants at this stage. Several personality traits had a significant effect on the susceptibility of spear-phishing attacks. General internet usage showed a positive relation with phishing susceptibility, which is the opposite of expectation. Internet anxiety also showed unexpected results, where higher Internet anxiety decreased the person's exposure to phishing attacks. Curiosity had a significant effect on susceptibility as well as risk propensity.

A study was conducted in a Malaysian company [6] to study the effect of personality traits on the likelihood of being phished. Total 252 responses were collected from the IT and non-IT departments (126 each). The survey had four sections, a demographic questionnaire, general experience, personality quiz, and user behavior (phishing attack). The results of the study showed that conscientiousness was positively correlated to phishing susceptibility, while extroversion was negatively

correlated. However, no relation was found between linking openness and neuroticism to susceptibility.

A lab-based experiment was conducted in an Australian university [7]; it included 121 undergraduate and postgraduate students from finance, business and accounting departments. The experiment had a series of emails shown to the participants. They were asked to judge the safety of the email on a scale from 1 to 5. Information security awareness was linked with identifying phishing and spear-phishing emails. Similarly, people from countries with a high level of Individualism (national culture) were better at detecting phishing and spear-phishing emails. Furthermore, low cognitive impulsivity and high agreeableness level were linked with identifying phishing emails only, while high neuroticism level was linked with spear-phishing emails only.

A multi-cultural study was conducted over four counties with a sample size of 618 [15]. The research focuses on measuring secure behavior (how secure a person is online), self-efficacy (how confident a person is against cyber risk), and privacy attitude (how dangerous a person feels to share info online). This was measured using an online survey. Risk perception predicts secure behavior and self-efficacy. Gender was found to be a strong predictor of self-efficacy in men. As for personality traits, openness can be used to predict self-efficacy, while conscientiousness can predict secure behavior, and finally, emotional stability can predict self-efficacy.

B. IT Background affect on Spear-Phishing Susceptibility

Spear-phishing attacks take advantage of the user's lack of knowledge and attention to details, thus having an IT background may reduce the person's susceptibility to attacks. Tech-savvy people tend to have higher levels of computer knowledge that can play a role in detecting spear-phishing attacks.

A spear-phishing simulation was conducted at the Universiti Kebangsaan Malaysia [16]. It included 553 staff emails from multiple science and technology (S&T), and non-science and technology (non-S&T) faculties. The spear-phishing bait was "Financial Aid", with a post-analysis survey that was sent after the simulation had ended. 45% of the participants who got phished were under S&T faculties, while 49% were under non-S&T faculties, and the remaining 5% were from other departments.

A study was conducted in the International Islamic University Malaysia [17], including 245 participants from various faculties. The study included a survey that contained demographic questionnaires, Information Technology (IT)-related questions, computer usage, and lastly are questions asking how students behave against cyber-attacks. The survey results show that IT students were more aware of social engineering compared to non-IT; furthermore, the study level also affected the knowledge (postgraduate vs. undergraduate). A small number of students reported being a victim of social engineering (provided private information through an email), which contained more non-IT students than IT students. These findings are in line with [30] that discovered tech-savvy people are more aware of digital attacks and less likely to fall for such attacks.

Another phishing study was conducted in the University of Maryland, Baltimore County [18] that included 1350 students split into three groups (three different phishing emails). This study aimed to better understand the factors such as faculty, academic year progression, cyber training, time spent on the computer, gender, and phishing awareness. The results show that STEM majors (science, technology, engineering and mathematics) had a lower click rate (EIT 65%, NMS 70%), while non-STEM had a higher click rate (AHSS 80%). The study also shows a correlation between academic year progression, cyber training and phishing susceptibility, while gender showed no significant correlation.

C. Message Framing affect on Spear-Phishing Susceptibility

Many resources are put every year by companies to design and carry out cyber awareness training programs for their employees to raise resilience to cyber-attacks such as spear-phishing. Having a more customized training program can help organizations cut time and cost and protect their assets and employees against future attacks.

A study was conducted to measure the effect of message framing in spear-phishing attacks [13]. The training material used was framed in four different ways, stressing positive/negative and individualism/collectivism. 1,359 participants were chosen and put randomly in one of 5 groups, a control group, and 4 framed groups. After the training, the overall click rate was lower, but no significant difference was found compared to the control group. However, the viewing time for the training page was measured, and it suggests that most people skimmed through the training and hence did not fully comprehend the training material.

A study explored embedded training and the effect of message framing in spear-phishing attacks [12] 400 participants were chosen and put randomly into one of six groups, two control groups and four groups that each represent a different way of framing the training message (add reference to support this statement). Results also show a weak association between individual-loss and click rate, as the group had a 12% improvement over the Round 2 control group.

A study was conducted in which 19,180 participants were included and split into 32 groups. Phishing emails were sent over a period of 8 months max, and training was embedded to the phishing link (if the user gets phished, he/she gets trained) [10]. The results showed that 25.94% of people who did not get the training fell for phishing, while only 15.57% of people who got the training fell for phishing (statistically significant p-value).

III. HYPOTHESIS

The hypotheses used in this study are based on findings from the Literature Review section. First, the personality traits, the majority of the papers have tested the relation between the Big Five personality traits and user's susceptibility to phishing emails (susceptibility can be measured by click rate). However, little work has been done on the subcategories of those traits. Research done by Moody et al. [14] focused on seven personality traits that can be seen as subcategories of the Big Five and five other constructs related to the victim's email characteristic and internet experience. Thus, this work will be a

continuation based on Moody et al. [14] work. Furthermore, the effect of message framing was observed when delivering spear-phishing training materials. Previous work that was done by Caputo et al. [13] and Burns et al. [12] will be used as a baseline for spear-phishing training. Based on the groundwork laid out, the instruments used by Moody et al. [14] can be used to test how some personality traits affect susceptibility to spear-phishing.

A. Constructs

The constructs that showed promising results fall into three categories, personality traits, message characteristic, and experience. The personality traits are curiosity, risk propensity, internet usage and anxiety, while message characteristic is represented by Message framing, and lastly, experience is represented by Information Technology (IT) background.

1) *Curiosity*: Curiosity can be defined as the desire for new knowledge and experience [19]. There are two types of curiosity, which are perceptual and epistemic. Perceptual curiosity is the attention given to novel perceptual stimulation evoked by visual, auditory, or tactile stimulation. In contrast, epistemic curiosity is defined as the desire to know aroused by conceptual puzzles. Furthermore, epistemic curiosity has two types of behaviors, labeled divertive and specific, divisive exploration is motivated by boredom, the desire to seek stimulation regardless of the source or content. While specific exploration is motivated by curiosity and the desire to investigate to acquire new information. Such behavior can be translated into the context of the internet, specificity emails, more curious people are more likely to click on unexpected emails, and are also more likely to click on a link or download attachments in an email.

- H1: Individuals with high levels of curiosity are more likely to fall for spear-phishing emails than individuals with lower curiosity levels.

2) *Risk propensity*: Risk propensity can be defined as the person's willingness to take risks in various aspects of life. Prospect theory, which was summarized in [20], it predicts that people are more willing to take risk when they are put in a domain of loss, and avoid risk when they are in a domain of gain. This can be linked to why most spear-phishing emails are framed in terms of loss (lose money, lose information), which makes it more likely for the victims to fall for spear-phishing and click on the malicious link.

- H2: High risk propensity levels are more likely to fall for spear-phishing emails than individuals with lower levels of risk propensity Individuals with.

3) *Internet usage*: Internet usage can be defined as the time spent on the internet doing various tasks and activities, such as browsing, emails, research. People who spend more time on the internet are more likely to be aware of the security concerns and risks of using the internet. Thus the prediction was, the more experience a user has with using the internet

(spent more time on the internet), and the less likely he/she is to fall for spear-phishing emails.

- H3: Individuals with high internet usage levels are less likely to fall for spear-phishing emails than individuals with lower levels of internet usage.

4) *Internet anxiety*: Internet anxiety can be looked at similarly to anxiety, where an individual feels uneasy and worried about certain events such as a job interview or a test. Similarly, a user that has a high level of internet anxiety may feel the need to avoid using the internet, reply to people, or be active on social media. Thus having a high level of Internet anxiety can prevent users from replying or clicking on unexpected emails (spear-phishing emails).

- H4: Individuals with high levels of Internet anxiety are less likely to fall for spear-phishing emails than individuals with lower internet anxiety levels.

5) *Information technology (IT) background*: IT background refers to previous experience in using computers and technology. This experience can be associated with cybersecurity knowledge. Most tech-savvy users are more likely to be aware of the cyber-threats, thus lowering their chances of falling victim to cyber-attacks spear-phishing emails. In the context of this experiment, students from science and technology (S&T) faculties are assumed to have heavy IT background, while other students from non-S&T faculties are assumed to have less comprehensive IT backgrounds.

- H5: Individuals from S&T faculties are less likely to fall for spear-phishing emails than individuals from non-S&T faculties.

6) *Message framing*: Message framing refers to how the training message is worded in terms of individualism/collectivism and in terms of gain/loss. Individualism focuses on individual goals, while collectivism focuses on the collective group. Gain emphasizes adding, while loss emphasizes removing. A previous study showed a weak association between training effectiveness (reduction in click rate) and individual/loss [12].

- H6: Framing the training message in terms of individual/loss is more effective compared to framing the message in terms of individual/gain, group/loss, and group/gain.

B. Hypotheses

The previous 6 hypotheses are summarized and can be seen in Table I.

TABLE I. HYPOTHESES

#	Construct	Expectation
H1	Curiosity	Higher susceptibility
H2	Risk propensity	Higher susceptibility
H3	Internet usage	Lower susceptibility
H4	Internet anxiety	Lower susceptibility
H5	IT background	Lower susceptibility
H6	Message framing (individual/loss)	Increase training effectiveness

IV. METHODOLOGY

This study was conducted in four phases, following the spear phishing procedure conducted by [16]. However some of the details in each phase have changed to cope with the scope of this study. The four phases are planning, design and pilot-run, implementation, and analysis. Figure shows the different stages at each phase. During the first phase, a pilot-run will be designed; this includes designing the training page, the contexts of the email, as well as the survey. The pilot run will be run on around 10 students, the students will be a mix of IT and non IT majors of undergraduate and postgraduate degrees. In the design phase, modification can be made on the initial design; furthermore, the technical aspect of the project will be designed here. In the implementation phase, the participants are sent a survey, they are also informed that they will be participating in an experiment; however the true nature of the experiment will not be revealed to them just yet. Then they are split into five groups at random, one of the groups will be a control group which will not receive any sort of training and will only be notified that the email was a spear-phishing email. While the other four groups will receive training, if they click on the link in the first round. After a window of delay of around two weeks to reduce the priming effect (exposure to one stimulus influences the response to subsequent stimulus without conscious), the second round of phishing will be sent. Once the emails have been sent, and a window of time is given to the participants to check their emails, the final phase can begin to analyze and report the findings. The overall methodology is shown in Fig. 1.

Two-round spear-phishing simulation was conducted to find the relation between personality traits and phishing susceptibility and the effect of message framing. Participants were students from the Universiti Kebangsaan Malaysia (UKM) recruited through emails, where a personality traits survey was sent. The true nature of the experiment was not revealed to participants. Participants were told that the study aims to understand students' feelings, behaviors, and personality traits at UKM and their relationship to cyber-security behavior. Total 107 participants filled out the survey, of which seven of them did not provide a valid ID (which is used to send emails through the university email system). The final sample size was 100, of those 71% were female and 29% were male. 86% of participants were between the ages of 18 and 32, and 14% were between the ages of 33 and 48. 56% were postgraduate students and 44% were undergraduate students. As for faculty distribution, 59% are under S&T faculties, and 41% are under non-S&T faculties.

There are three main components needed for this study, personality trait survey, phishing emails, and training material. The personality trait survey was sent to four people to get their feedback on the length, and word choices and overall clarity of the survey. Followed by a pilot-run that included 10 students from UKM, the pilot-run started with sending the survey, and after a delay, a phishing email was sent to each participant to test the instruments.

The first round of spear-phishing emails was sent a month after the personality traits survey. This delay was used to eliminate any priming effect. The spear-phishing email

contained a link, if clicked participants were taken to a training page and thus considered trained. Participants were split into five groups, a control group and four other groups to test the effect of message framing. Each participant received a unique link; this will allow us to identify participants who click on the spear-phishing link as well as link the personality traits score with clicking behavior.

After a two weeks' delay from the first round of spear-phishing the second round of emails were sent. This time, the click rate between the different groups to test the effect of message framing was compared. Participants who clicked on the first round, were kept in their respective group, as they were "trained". However, participants who did not click in the first round were moved to a new group "Round 1 non-clickers" because they were not exposed to the training material.

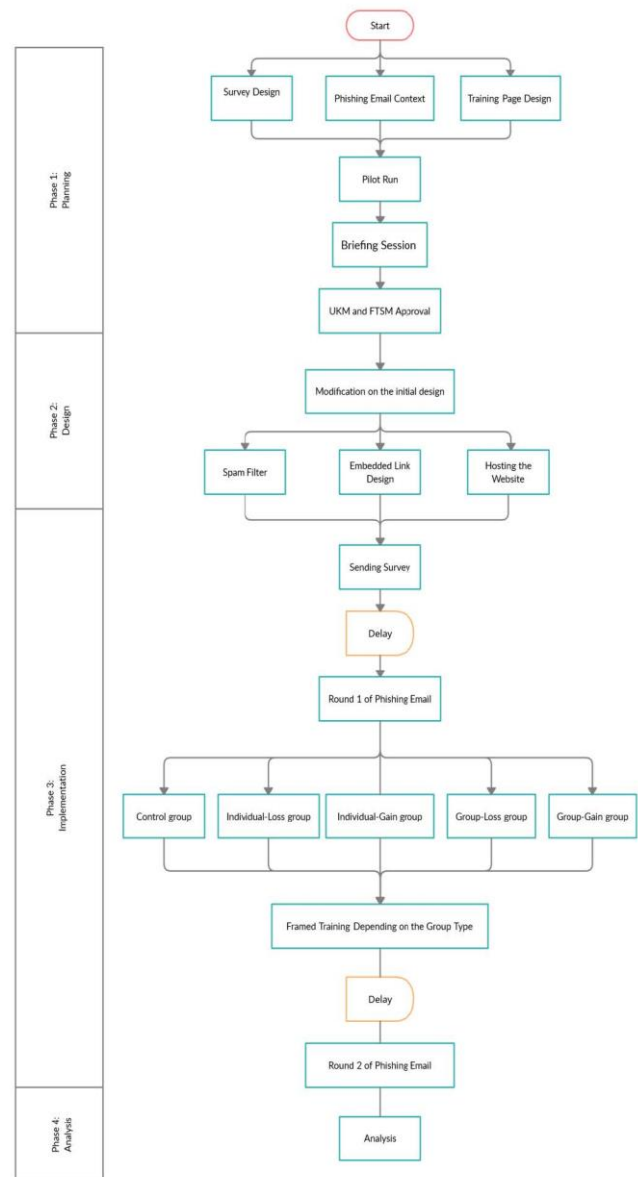


Fig. 1. Methodology flowchart.

A. Personality Traits Survey

The personality trait was based on a set of psychology papers compiled by Moody et al. [14], however, the survey used in that paper requires around 25-30 minutes to complete it. Having such a comprehensive survey may affect the number of students that complete it. Furthermore, it may result in participants filling the form randomly toward the end of the survey. Thus, the survey was shortened to around 7-9 minutes. This was done by focusing on the personality traits that had significant results. The survey must have the option to choose the preferred language; this is because of the diversity of students in the university. The survey vocabulary was also slightly modified to make it easier to read for non-native English readers. This involved some minor reorganization and the use of common parlance.

The survey is split into four main parts:

- Curiosity: 22 questions (normal scale), the scale used is a 4-point scale (min: 22, max: 88).
- Risk: 17 questions (3 questions were reverse scale), the scale used for the first 5 questions is a 7-point scale; for the other 12 questions, a 5-point scale is used (min: 17, max: 95).
- Internet Experience: 17 questions (normal scale), the first 4 uses a 5-point scale, and the last 13 questions, a 7-point scale is used (min: 17, max: 111).
- Internet Anxiety: 6 questions (1 question was reverse scale) with a 7-point scale (min: 6, max: 42).

B. Spear-Phishing Emails

Two rounds of phishing emails will be used. During the design, the following points were taken into account:

- The sender: or the actor, as well as his/her positions, is essential, because people tend to trust emails sent from a higher hierarchy.
- Engagement mechanism: What is on the line, and why would the victim engage with the email. This can be a form of a fine, or losing personal information.
- Title: The email title must highlight the importance of the subject at hand to serve as a clickbait.

Since attackers may customize the email to certain employees or businesses to maximize the likelihood of success, the phishing email topic was chosen in a way that can lure victims to click on the email and make the spear-phishing assault as realistic as possible.

1) *Spear-phishing: round 1*: The first topic of choice was "Covid-19 SOP update (Coronavirus Disease 2019)". This study was being conducted during the Covid-19 pandemic, and the Malaysian government had implemented multiple movement control orders and various Standard Operating Procedure (SOP) for people to comply with. Furthermore, because of different faculties that will be included in this study, the topic must be applicable to all students, post and undergraduate, local and international, S&T and non-S&T

students. The engagement mechanism used for this topic is a fine of RM500 imposed on students for each repeated offense. For the actor (the sender), we have chosen the director of UKM Health Center (PK), however, their name was not included to avoid some cases where some students may call the person to double-check if the email is legitimate, on the other side some people may not know the director by name, and hence the name was omitted for those reasons. A sample of the first round phishing email can be seen in Fig. 2.

Dear Students,

Ministry of health (MoH) Malaysia have updated its SOP, And hence our policies for students living inside and outside campus have changed. It is very important to read the new policies set by University Health Center.

After reading the new policies, it is mandatories for all students to sign in using their Metrix number to verify that you have read the new rules. Failing to comply and adhere to new rules will results in disciplinary actions and RM500 fine for each repeated offense.

Click here to read more: <https://bit.ly/>

Director

Fig. 2. Round 1 phishing email.

2) *Spear-phishing: round 2*: The second topic of choice is "UKMFOLIO system upgrade". UKMFOLIO is a learning system used by UKM to deliver teaching materials and announcements and a method to submit assessments. During the study, UKMFOLIO was down multiple times, students and lecturers couldn't access the website. Therefore, sending an email informing the students that there will be a system upgrade will be a good bait for the second phishing email. All UKM students use UKMFOLIO, and hence it applies to everyone. As for the engagement mechanism, students were told that they would lose access to their accounts if they fail to update and verify their information. For the actor (the sender), the director of the Information Technology Center (PTM) was chosen.

C. Training Materials and Message Framing

The training materials are divided into two sections; the first sections include materials designed to highlight clues in the spear-phishing emails that the user needs to be on the lookout to detect spear-phishing emails. Those clues include:

- Sense of urgency: The matter at hand is time-sensitive and actions must be taken immediately.
- Fake/mismatch in the sender's email field: Spear-phishing emails impersonate well-known figures or authorities, as such, it is essential to look at the sender's email.
- Malicious link: The link is usually disguised or presented in terms of a hyperlink to hide the actual URL.



Fig. 3. Individual / Gain training message.



Fig. 4. Individual / Loss training message.

The second part is an informative bit on the consequence of spear-phishing, and how to protect yourself from spear-phishing. This part of the message is framed in terms of individual/group gain/loss, where the pronouns (yourself/your co-worker) and the tone (positive/negative) are different in each group. Fig. 3 and Fig. 4 show the second part of the training material for two different groups (Individual/ Gain and Individual/Loss, respectively).

Technical phrases were simplified so that students could relate to the training material, and new training materials that are comic-based were employed to keep users' attention for longer and transmit the knowledge more effectively. Additionally, the materials are constructed in a way that evokes a sense of urgency, hinting that the issue at hand is time-sensitive and requires immediate action.

V. RESULTS

The results and discussion will be split into two main sections; the first section will cover the first round of phishing relating to personality traits, which was used to test hypotheses H1-H5, while the second section will cover the second round of phishing relating to message framing in embedded training, which test hypothesis H6. Because of the nature of the output (dependent variable) being binary, where 1 denotes "got phished" and 0 "did not get phished", multiple logistic regression was used to determine the coefficient value. STATA v. 16.1 SE was used to carry out the regression.

As for message framing, a Binomial test was carried between each group and the control group to test the effect of message framing.

A. Personality Traits Result

First, Cronbach's Alpha was calculated to measure the internal consistency and verify the validity of the test. The Cronbach's Alpha is 0.8425 which is above the acceptable level of 0.70. Looking at the alpha value when the item selected is removed, there is no significant change among all 62 questions, with a minimum value of 0.8362 and a maximum value of 0.8456 (difference less than 0.01). Table II shows the statistics summary of the personality traits test. The multiple logistic regression results can be seen in Table III. Curiosity

and risk had a negative coefficient, while internet experience and internet anxiety had a positive coefficient. Furthermore, S&T (refer to students who are in S&T faculties) also had a positive coefficient. Gender and Age were added in the regression; gender (male) had a negative coefficient, while age (young) had a positive coefficient. S&T, gender, and age were coded as binary values such as 1(S&T) and 0 (non-S&T); gender-1 (male) and 0 (female); and for age, 1 represented young (between 18 and 32) and 0 represented participants older than 32.

The Pseudo R2 value is McFadden's pseudo R-squared, because logistic regression does not have a direct equivalent to the R2 value found in OLS linear regression. The Pseudo R2 value is 0.0661, which is still low. However, a low R2 is to be expected when measuring variables related to human behavior, as humans are harder to predict.

TABLE II. STATISTICS SUMMARY OF THE PERSONALITY TRAITS

Variable	Mean	Std. Dev.	Min	Max
Curiosity	69.98	7.717198	54	87
Risk	31.26	9.691838	17	60
Internet experience	36.27	11.26706	20	69
Anxiety	19.34	5.324273	10	33
S&T	0.59	0.494311	0	1

B. Message Framing Result

Two weeks after the first round of phishing (Round 1), a second email was sent to participants. 100 participants received the second phishing email titled "UKMFolio System Upgrade".

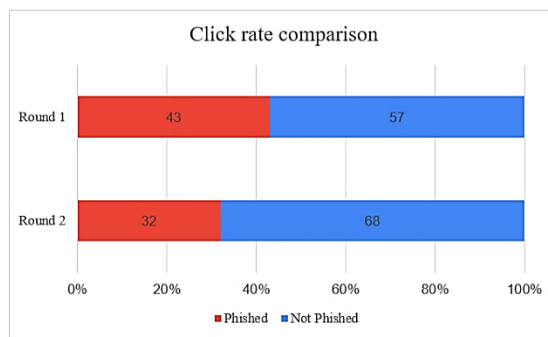


Fig. 5. Click rate comparison.

Comparing the click rate between Round 1 and 2 in Fig. 5, there is a decrease in click rate from 43% to 32%. Similar to Round 1, the majority of clicks happened within the first 24 hours.

First, a Pearson Chi-square test was performed among the five groups from Round 1 to check if there are no unexpected differences between the groups by any chance, and found no significant relation between the groups and the phishing rate, $X^2(4, N=100) = 6.0108, p=0.198$. Similarly, in Round 2, a Pearson Chi-square was performed and no significant relation was found between the 6 groups and the phishing rate ("non-clicker Round 1" was added as shown in Table IV and Table V.

TABLE III. MULTIPLE LOGISTIC REGRESSION RESULTS

<i>Phished</i>	<i>Coef.</i>	<i>Std. Err.</i>	<i>z</i>	<i>P>z</i>	<i>95% Conf.</i>	<i>Interval</i>
Curiosity	-0.050147	0.031410	-1.60	0.110	-0.11171	0.011416
Risk	-0.021760	0.023325	-0.93	0.351	-0.06748	0.023956
Internet experience	+0.020639	0.019619	+1.05	0.293	-0.01781	0.059092
Anxiety	+0.084030	0.042934	+1.96	0.050	-0.00012	0.168178
S&T	+0.727525	0.457443	+1.59	0.112	-0.16905	1.624096
Gender	-0.744610	0.498756	-1.49	0.135	-1.72215	0.232935
Age	+0.107320	0.660629	+0.16	0.871	-1.18749	1.402129
Cons	+1.205229	2.377349	+0.51	0.612	-3.45429	5.864748

LR $\chi^2(7) = 9.04$; Prob $>\chi^2 = 0.2501$; Pseudo R² = 0.0661, the bold value indicates a significant value $P < 0.05$

TABLE IV. ROUND 1 RESULTS BY GROUPS

<i>Round 1</i>	<i>Total</i>	<i>Grp-Gain</i>	<i>Grp-Loss</i>	<i>Ind-Gain</i>	<i>Ind-Loss</i>	<i>Control</i>	<i>Non-clicker Round 1</i>
Not-phished	57 (57.0%)	8 (50.0%)	11 (84.6%)	9 (50.0%)	8 (44.4%)	21 (60.0%)	N/A
Phished	43 (43.0%)	8 (50.0%)	2 (15.4%)	9 (50.0%)	10 (55.6%)	14 (40.0%)	N/A
Total	100	16	13	18	18	35	N/A

TABLE V. ROUND 2 RESULTS BY GROUPS

<i>Round 1</i>	<i>Total</i>	<i>Grp-Gain</i>	<i>Grp-Loss</i>	<i>Ind-Gain</i>	<i>Ind-Loss</i>	<i>Control</i>	<i>Non-clicker Round 1</i>
Not-phished	68 (68.0%)	6 (75.0%)	1 (50.0%)	6 (66.7%)	85 (50.0%)	9 (65.3%)	41 (71.9%)
Phished	32 (32.0%)	2 (25.0%)	1 (50.0%)	3 (33.3%)	5 (50.0%)	5 (35.7%)	16 (28.1%)
Total	100	8	2	9	10	14	57

VI. DISCUSSION

This study's objective was to find which personality traits affect a person's susceptibility to spear-phishing emails. Using a personality traits survey to measure personality score, and a real-life simulation of a spear-phishing email, logistic regression are carried out to find factors affecting spear-phishing susceptibility. Furthermore, training material is provided to participants who got phished to test the effect of message framing in embedded training. The second round of spear-phishing is carried to test the training material's effectiveness by carrying out a Binomial test. The summary of results can be seen in Table VI and Table VII.

A. The Effect of Personality Traits on Spear Phishing

The results of this study show that only anxiety has a significant relation with susceptibility to phishing ($p < 0.05$). However, the nature of the relationship is not as theorized in previous sections.

Other factors such as gender and age were also tested. While both had no significant findings ($p = 0.135$ and 0.871), gender (male) had a negative coefficient, which means women are likely to fall for spear-phishing emails. This supports previous studies' findings [22], where it was reported that females are more susceptible to phishing. Age (young) had a positive correlation which also supports previous studies

suggesting that younger people are more susceptible to spear-phishing emails [23, 24]. This can be caused by the fact that younger people have not fallen for or experienced spear-phishing and have a lower ability to detect spear-phishing emails.

1) Curiosity: First, curiosity did not have a significant finding on phishing susceptibility ($p = 0.110$). Thus not supporting hypothesis H1. Furthermore, curiosity had a negative coefficient (-0.050147) on phishing susceptibility, meaning that a person who has a high level of curiosity is less likely to fall for spear-phishing emails. This is counterintuitive because a person who possesses a high level of curiosity may find unexpected emails with a link appealing to explore, and thus clicking on the link. Previous study [25] reported that curiosity was the most common reason for clicking on phishing emails and Facebook messages in the post-experiment survey. Another study [14] reported significant findings on the positive correlation between phishing susceptibility and curiosity. Looking at a broader view on curiosity, openness (from The Big Five) can be defined as a person who is curious. This personality trait was found to be non-significant in some studies [6,7] where no significant finding was found between phishing susceptibility and openness.

TABLE VI. PHISHING DETECTION IMPROVEMENT AND BINOMIAL TEST

	<i>Grp-Gain</i>	<i>Grp-Loss</i>	<i>Ind-Gain</i>	<i>Ind-Loss</i>
Improvement (compared to control group)	+10.7 (+29.9%)	-14.3 (-40.1%)	+2.4 (+6.7%)	-14.3 (-40.1%)
Binomial test (expected value is control group)	0.411217	0.872551	0.591295	0.896560

TABLE VII. ROUND 2 RESULTS WITH BINOMIAL TEST

#	<i>Construct</i>	<i>Expectation</i>	<i>Results</i>	<i>Coef.</i>
H1	Curiosity	Higher susceptibility	N.S	Negative
H2	Risk propensity	Higher susceptibility	N.S	Negative
H3	Internet usage	Lower susceptibility	N.S	Positive
H4	Internet anxiety	Lower susceptibility	Sig.<0.05	Positive
H5	IT background	Lower susceptibility	N.S	Positive

Looking at the survey's curiosity questionnaire, the questions used from previous studies measure curiosity in various aspects in life. For example, in the epistemic curiosity (Diversive) section, questions such as "I like to learn new things / like to find out more", "I enjoy exploring new ideas", and "It is fascinating to learn new information" was used to measure the desire to acquire knowledge aroused by puzzles and motivated by the feeling of boredom regardless of the source. The questions used are not specific to a certain situation and can be applied to the context of spear-phishing emails. An email suggesting a new idea, or giving a new insight can be intriguing to the user. However, other questions under epistemic curiosity (Specific), included questions such as "I enjoy finding a solution to new kind of arithmetic problem", "If I see a complicated piece of machinery, I will ask someone how it works", and "I try and imagine the solution for incomplete puzzle". Such questions are situation specific; a person that is curious about how machines work may not be interested in an email asking the user to read about a new policy. Moreover, in the perceptual curiosity (Uniquely loading items) section, 12 questions with 4-point scale were used (same tense throughout the experiment description is not followed) to measure it; this means that perceptual curiosity had more weight when measuring the overall level of curiosity. This may not be the correct scale when measuring internet curiosity. While general curiosity questionnaires are still a good measure, a scale favouring the user's curiosity in internet-related topics may be more suitable in this situation. For example, asking the user "how often do you watch new shows that you have never heard of" and "how often do you click on online ads" may be a more accurate measure of online curiosity. This may explain the reason why there is no significant relation between curiosity and phishing susceptibility. Furthermore, the negative correlation between curiosity and spear-phishing susceptibility can also be linked to the topic of spear-phishing. While this study was conducted during the Covid-19 pandemic, and the topic of the spear-phishing email is related to covid-19 policies, Pandemic

Fatigue [26] can also explain the negative relation, where users are experiencing Pandemic Fatigue after nearly a year of dealing with Covid-19 related issues, and thus the demotivation of reading related topics.

2) *Risk propensity*: Hypothesis H2 was not supported as well. Risk also had a non-significant finding ($p=0.351$), it also had a negative coefficient (-0.021760). This finding contradicts the theory that a more risk-taking person will likely click on an unexpected link in an email regardless of its risk. Previous studies [15] found that the risk of being a significant predictor of phishing susceptibility suggests that people with higher risk perception are experienced in cybersecurity and are thus more likely to averse the risks associated with clicking on unknown links. Moody et al. [14] also found risk to be a significant predictor of susceptibility to phishing.

The risk questions included in the survey measure risk beliefs (perceived risk) and risk propensity. Part of the risk beliefs scale was reversed because of the negative relation between risk perception and risk-taking behavior, while risk propensity was scored normally because of the positive relation between risk propensity and risk taking [27]. This means that a high risk score (overall) reflects a high risk taking behavior. In theory and based on previous studies, a more willing to take risk is more likely to click on an unexpected link in an email. However, findings suggest the opposite (even if it is not significant), this might be explained by how people overestimate their ability to identify scam emails. Datar, Cole, and Rogers [28] found that more than half the participants that claimed they can identify a scam email failed to identify them. This means even if a person has a low-risk overall score (person scored high perceived risk (inverted) and a low risk propensity score), he/she may not be able to identify an email as a spear-phishing email and thus not perceive the actual risk of clicking on the link.

3) *Internet usage*: Internet experience did not have a significant finding ($p=0.293$); hence hypothesis H3 was not supported, however, there was a positive relation between internet experience and phishing susceptibility. The result is counter-intuitive; however, a study [14] also found similar results. A person who uses the internet is more likely to click on a phishing link. One of the reasons that might explain these results is Habituation [29]. The person's innate response to a stimulus decreases after repeated presentation of the stimulus. In the context of spear-phishing emails. If the user spends a lot of time on the internet (experienced user), he/she may pay less attention over time to spear-phishing clues and this fall for spear-phishing emails.

4) *Internet anxiety*: The last hypothesis relating to personality trait H4 (internet anxiety) had a significant finding ($p = 0.05$) with a small positive coefficient. This finding matches previous research [14]; even if the initial hypotheses suggested the opposite effect (negative correlation), Halevi et al. [22] found a positive correlation between neuroticism (from The Big Five personality traits) and phishing susceptibility for women only. A few reasons might explain the results, first people with high anxiety levels may feel bothered by unanswered emails, thus the need to reply or click on a phishing email. Another reason might be related to being a "people pleaser" where a person may find it difficult to say no, and thus feel the need to provide information in phishing emails.

5) *IT background*: The last hypothesis H5, that was tested in Round 1 of phishing is the relation between IT background and phishing susceptibility, there was no significant finding ($p=0.112$), however, the correlation coefficient was positive, which means participants from S&T faculties were more likely to get phished. While most studies discussed in chapter 2.1.2 suggest a negative correlation between IT background and phishing susceptibility, habituation may explain the positive correlation found in this experiment. Students under S&T faculties may be constantly reminded about cyber-attacks and hence pay less attention to spear-phishing emails.

B. The Effect of Personality Traits on Spear Phishing

The binomial test shows no significant results, this matches a previous study [13], where no significant relation was found among the four groups, and thus H6 was not supported. However, looking at the improvement rate, group-gain had the highest improvement (although not significant) compared to other groups with a decrease of 10.7 compared to control group click rate in Round 2. Furthermore, gain treatment (both group and individual) saw an improvement in detecting spear-phishing emails, while loss treatment (both group and individual) performed worse than the control group.

Several factors contributed to those findings, first there is no way to make sure that participants have taken part in the training, for example, if the participants immediately closed the training page after clicking without reading any of the content. Furthermore, some people may have skimmed through the training and thus have not fully understood the content. While

the use of comics instead of text may have helped in retaining the participant's retention, there is still a possibility that the comics did not convey the information effectively compared to text because the comic's design has to be short and to the point.

Secondly, the information's credibility might not be clear to the participants, as the training was not hosted on an official university website, and hence recipients did not find the training credible. Thirdly, the training effectiveness may require repetition before a noticeable behavior change is observed where the same training is applied multiple times over an extended period of time. Lastly, the sample size for the experiment is relatively small. Because of the experiment's nature, where only people who clicked have received the training, each group's final sample size is very small. It may have produced inaccurate results that do not represent the population.

C. General Implications

Spear-phishing emails are highly targeted by nature; attackers will use current trending topics and events to lure their victims into clicking on malicious links. Spear-phishing emails continue to be a large threat, and with organizations heavily relying on emails for communication, it is more important than ever to understand better the factors that make spear-phishing emails so successful. One of the most important factors is the human link. With humans being the weakest link, it is evident that the attacker will try to exploit such weakness and try to use it to their advantage. A lot of effort has been put into securing information from direct attacks; however, most recent successful attacks have infiltrated organizations through human error. Having a better understanding of what makes a person fall for spear-phishing emails is vital in fortifying the human firewall.

One of the factors that can affect a person's susceptibility is his/her personality traits. Prior research has focused on a wide variety of personality traits, this research narrows down the scope and focuses on key traits that have been found to be a factor in predicting phishing susceptibility [30, 31]. Out of the four personality traits that have been put to the test, internet anxiety has shown significant results in predicting phishing susceptibility. The reason is, internet anxiety affects phishing susceptibility is that anxious people may feel bothered by unresolved issues suggested by the email, and thus have the compulsive need to reply or check the spear-phishing email. While other personality traits did not show significant results, it is still possible that in a different environment, different personality traits may show a stronger correlation with phishing susceptibility due to the difference in culture and background.

Having a better understanding of who is more susceptible to cyber-attacks, such as spear-phishing attacks, can be an important factor in designing a training module for an organization. Knowing which type of people are more susceptible can save many resources in terms of training time and cost when trying to raise security awareness in an organization. While this study does suggest that embedded training lowers the success rate of spear-phishing attacks, however there is no justification to believe that message framing can affect training efficiency.

VII. CONCLUSION

Primary Personality traits may hold the key to better understanding what makes some people more susceptible to spear-phishing than others. This research shows that certain personality traits can contribute to higher susceptibility to spear-phishing emails. A real-life spear-phishing experiment was implemented to measure the correlation between spear-phishing susceptibility and personality traits. The results show that Internet anxiety increases the person susceptibility to spear-phishing. An embedded training was provided to participants through the phishing emails, and through two rounds of emails. The embedded training lowered the overall click rate; however, there is no evidence to support the notion that message framing affects training effectiveness. While the small sample size in this study can provide some limitations, the results show promising results on the effect of personality traits on phishing susceptibility. Future research can aim to test the hypotheses on a larger sample size, and over a longer period of time.

VIII. FUTURE RESEARCH DIRECTIONS

The primary limitation of this study is the sample size. The sample size for this study was 107 participants, which is relatively small to the population of UKM. The main reason for that is the restriction because of the Covid-19 pandemic and time constraints of this study. The distribution of personality traits survey was limited to online forms, and physical distribution was not possible. Other factors that contributed to this small sample size include that participants had to answer a survey for them to take part in the spear-phishing study; while a monetary incentive was formed to encourage participants to fill out the survey, thus unable to determine its effectiveness. Because the invitation emails to do the survey was sent by faculty's staff, lecturers and IT centers, the total number of recipients was not disclosed for privacy reasons. Furthermore, a list of emails for all students contributes to the privacy concerns as well. Furthermore, because this study relies on people getting phished, this results in an even smaller sample size for each group. Previous studies had a click rate of around 40% (similar to study); this means that the final sample size will be even smaller when testing the training module's effectiveness. Another factor that can be improved is the personality traits questionnaire; this study uses existing instruments to measure the various traits. Designing more tailored questions that can relate better to internet behavior can show promising results.

Our study can lead to multiple paths down the road. Future researchers can examine if the findings persist over larger sample size. A sample size that includes all students in the university can lead to more accurate results and can eliminate any anomalies due to small sample size. If the survey had a low response rate, a larger sample size to start with will result in a sufficient number of participants answering the survey. Moreover, using a personality trait instrument that is designed with internet behavior and habits can lead to a better measurement of some traits. Lastly, the effectiveness of embedded training and message framing can be measured better when observed over an extended period of time. This also requires repetition of training, Future research can

implement this study in multiple phases and multiple phishing rounds over an extended period of time, and larger break time between each phishing round to eliminate any priming effect other improvements can be implemented, for example, interactive embedded training that requires user's interaction can be included to make sure that participants have read and understood the training.

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REFERENCES

- [1] Phishing.org, Phishing | History of Phishing, [Online]. Available: <https://www.phishing.org/history-of-phishing>.
- [2] Symantec, ISTR Internet Security Threat Report 2019 Volume 24., 2019.
- [3] Anti-Phishing Working Group, "Phishing Activity Trends Report 3 Quarter.," no. November, pp. 1–12, 2020.
- [4] ProofPoint, State of the Phish., 2020.
- [5] Verizon, 2020 Data Breach Investigations Report., 2020.
- [6] S. Anawar, D.L. Kunasegaran, M.Z. Mas'Ud, and N.A. Zakaria, "Analysis of phishing susceptibility in a workplace: A big-five personality perspectives.," *Journal of Engineering Science and Technology*. vol. 14, no. 5, pp. 2865–2882, 2019.
- [7] M. Butavicius, K. Parsons, M. Pattinson, A. McCormac, D. Calic, et al., "Understanding Susceptibility to Phishing Emails: Assessing the Impact of Individual Differences and Culture.," *Proceedings of the Eleventh International Symposium on Human Aspects of Information Security & Assurance (HAISA 2017)*. vol. 2016, no. Haisa, pp. 12–22, 2017.
- [8] B. Cusack and K. Adedokun, "The impact of personality traits on user's susceptibility to social engineering attacks.," *Proceedings of the 16th Australian Information Security Management Conference*. pp. 83–89, 2018, 10.25958/5c528ffa66693.
- [9] E.D. Frauenstein and S. Flowerday, "Susceptibility to phishing on social network sites: A personality information processing model.," *Computers and Security*. vol. 94, p. 101862, 2020, 10.1016/j.cose.2020.101862.
- [10] H. Siadati, S. Palka, A. Siegel, and D. McCoy, "Measuring the effectiveness of embedded phishing exercises.," *10th USENIX Workshop on Cyber Security Experimentation and Test, CSET 2017, co-located with USENIX Security 2017*. p. 2017.
- [11] A. Xiong, R.W. Proctor, W. Yang, and N. Li, "Embedding Training Within Warnings Improves Skills of Identifying Phishing Webpages.," *Human Factors*. vol. 61, no. 4, pp. 577–595, 2019, 10.1177/0018720818810942.
- [12] A.J. Burns, M.E. Johnson, and D.D. Caputo, "Spear phishing in a barrel: Insights from a targeted phishing campaign.," *Journal of Organizational Computing and Electronic Commerce*. vol. 29, no. 1, pp. 24–39, 2019, 10.1080/10919392.2019.1552745.
- [13] D.D. Caputo, S.L. Pfleeger, J.D. Freeman, and M.E. Johnson, "Going spear phishing: Exploring embedded training and awareness.," *IEEE Security and Privacy*. vol. 12, no. 1, pp. 28–38, 2014, 10.1109/MSP.2013.106.
- [14] G.D. Moody, D.F. Galletta, and B.K. Dunn, "Which phish get caught An exploratory study of individuals' susceptibility to phishing.," *European Journal of Information Systems*. vol. 26, no. 6, pp. 564–584, 2017, 10.1057/s41303-017-0058-x.
- [15] T. Halevi, N. Memon, J. Lewis, P. Kumaraguru, S. Arora, et al., "Cultural and psychological factors in cyber-security.," *ACM International Conference Proceeding Series*. no. November 2017, pp. 318–324, 2016, 10.1145/3011141.3011165.
- [16] N.A. Bakar, M. Mohd, and R. Sulaiman, "Information leakage preventive training.," *Proceedings of the 2017 6th International Conference on Electrical Engineering and Informatics: Sustainable*

- Society Through Digital Innovation, ICEEI 2017. vol. 2017-Novem, pp. 1–6, 2018, 10.1109/ICEEI.2017.8312403.
- [17] M. Elsadig Adam and O. Yousif, "Awareness of Social Engineering Among IIUM Students.," *World of Computer Science and Information Technology Journal (WCSIT)*. vol. 1, no. 9, pp. 409–413, 2011.
- [18] A. Diaz, A.T. Sherman, and A. Joshi, "Phishing in an academic community: A study of user susceptibility and behavior," (2018), 10.1080/01611194.2019.1623343.
- [19] J.A. Litman and C.D. Spielberger, "Measuring epistemic curiosity and its diverse and specific components.," *Journal of Personality Assessment*. vol. 80, no. 1, pp. 75–86, 2003, 10.1207/S15327752JPA8001_16.
- [20] N. Nicholson, E. Soane, M. Fenton-O'Creedy, and P. Willman, "Personality and domain-specific risk taking.," *Journal of Risk Research*. vol. 8, no. 2, pp. 157–176, 2005, 10.1080/1366987032000123856.
- [21] Ahmad Fadhil Naswir, Lailatul Qadri Zakaria and Saidah Saad, "Determining the Best Email and Human Behavior Features on Phishing Email Classification" *International Journal of Advanced Computer Science and Applications (IJACSA)*, 13(8), 2022. <http://dx.doi.org/10.14569/IJACSA.2022.0130821>
- [22] T. Halevi, J. Lewis, and N. Memon, "Phishing, Personality Traits and Facebook.," p. 2013.
- [23] S. Sheng, M. Holbrook, P. Kumaraguru, L.F. Cranor, and J. Downs, "Who falls for phish? A demographic analysis of phishing susceptibility and effectiveness of interventions.," *Conference on Human Factors in Computing Systems - Proceedings*. vol. 1, pp. 373–382, 2010, 10.1145/1753326.1753383.
- [24] R. Broadhurst, K. Skinner, N. Sifniotis, and B. Matamoros-Macias, "Cybercrime Risks in a University Student Community.," *SSRN Electronic Journal*. p. 2018, 10.2139/ssrn.3176319.
- [25] Z. Benenson, F. Gassmann, and R. Landwirth, "Unpacking spear phishing susceptibility.," *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. vol. 10323 LNCS, pp. 610–627, 2017, 10.1007/978-3-319-70278-0_39.
- [26] World Health Organization, "Pandemic fatigue: reinvigorating the public to prevent COVID-19.," no. November, p. 2020.
- [27] F. Sahul Hamid, G.J. Rangel, F. M. Taib, and R. Thurasamy, "The Relationship between Risk Propensity, Risk Perception and Risk-Taking Behaviour in an Emerging Market.," *International Journal of Banking and Finance*. p. 2013, 10.32890/ijbf2013.10.1.8471.
- [28] T.D. Datar, K.A. Cole, and M.K. Rogers, "Awareness of scam e-mails: An exploratory research study.," In: *Proceedings of the Conference on Digital Forensics, Security and Law (2014)*.
- [29] B.B. Anderson, A. Vance, C.B. Kirwan, D. Eargle, and J.L. Jenkins, "How users perceive and respond to security messages: A NeuroIS research agenda and empirical study.," *European Journal of Information Systems*. vol. 25, no. 4, pp. 364–390, 2016, 10.1057/ejis.2015.21.
- [30] Eftimie, Sergiu, Radu Moinescu, and Ciprian Răuciu. "Spear-Phishing Susceptibility Stemming From Personality Traits." *IEEE Access*. 10 (2022): 73548-73561.
- [31] Yang, Rundong, Kangfeng Zheng, Bin Wu, Di Li, Zhe Wang, and Xiujuan Wang. "Predicting user susceptibility to phishing based on multidimensional features." *Computational Intelligence and Neuroscience 2022 (2022)*.
- [32] W. Syafitri, Z. Shukur, U. A. Mokhtar, R. Sulaiman and M. A. Ibrahim, "Social Engineering Attacks Prevention: A Systematic Literature Review," in *IEEE Access*, vol. 10, pp. 39325-39343, 2022, doi: 10.1109/ACCESS.2022.3162594.
- [33] R. Abdillah, Z. Shukur, M. Mohd and T. M. Z. Murah, "Phishing Classification Techniques: A Systematic Literature Review," in *IEEE Access*, vol. 10, pp. 41574-41591, 2022, doi: 10.1109/ACCESS.2022.3166474.

Investigating Internet of Things Impact on e-Learning System: An Overview

Duha Awad H.Elneel¹, Hasan Kahtan^{2*}, Abdul Sahli Fakharudin^{3*}, Mansoor Abdulhak⁴, Ahmad Salah Al-Ahmad⁵,
Yehia Ibrahim Alzoubi⁶

Faculty of Computer Systems and Software Engineering, University Malaysia Pahang, Kuantan, 26300 Malaysia^{1,3}
Cardiff School of Technologies, Cardiff Metropolitan University, Western Avenue, Cardiff CF5 2YB, United Kingdom²
College of Computer and Cyber Sciences, University of Prince Mugrin, Madinah 41499, Saudi Arabia⁴
College of Business Administration, American University of the Middle East, Egaila 54200, Kuwait^{5,6}

Abstract—e-Learning systems have reached their peak with the revolution of smart technologies. In the past few years, the Internet of Things (IoT) has become one of the most advanced and popular technologies, affecting many different areas. Using IoT in an e-learning system is a fantastic technology that improves the e-learning system and makes it more inventive and cutting-edge. The key challenge addressed in this study is the acceptance of IoT usage in e-learning systems as well as how to improve it so that it can be utilized properly. This research concentrates on how IoT can benefit e-learning systems and how it might benefit users of e-learning systems. A comprehensive literature review was conducted to get acquainted with the important research related to IoT technology and e-learning systems through online research databases and reliable scientific journals. The first research finding is that e-learning systems need such modern techniques as IoT to enable interconnection, increase reliability, and enhance the enjoyment of the educational process. The second result is that research related to the development of new technologies like the IoT has a significant impact on enhancing the performance of new systems and bringing about positive change. This study highlights the value of IoT, particularly in e-learning systems. It aids in the development of new strategies that will improve the efficacy of e-learning systems and stimulate researchers to develop advanced technology.

Keywords—e-Learning system; Internet of Things (IoT); software system; education, learning process

I. INTRODUCTION

IoT can deliver unique services in a variety of domains. The IoT connects many devices and things to form a physical network that includes sensing, communication operations, and processing without the need for human involvement. IoT devices have increased dramatically during the previous decade, and by 2025 they may reach 50 billion devices [1]. The IoT is already attracting a slew of academic and business interests. Smarter and smaller devices are introduced in a variety of IoT domains every day, including monitoring management, smart houses, smart vehicles, smart farming, smart tourism, e-health, and e-learning, to mention a few [2-9].

e-Learning refers to using electronics and the Internet in addition to software applications in the learning process and thus making it more effective and dynamic [10-12]. Some of the drawbacks of traditional e-learning systems include

limitations in expanding and distributing computing power, as well as exchanging information among system users [13], which has encouraged the development of new technologies to overcome these obstacles and motivate the learning process [14]. e-Learning is a key part of making education better, and it is the main way for teachers to improve their skills and abilities by adapting to new scientific methods [15]. The use of techniques in e-learning like virtual classrooms improves the knowledge of learners and transforms the educational process into a universal one [16]. The evolution of technologies and communication enhanced the e-learning environment and gave it the nature of expansion through the combination of physical and virtual objects. IoT as one of these technologies has a strong influence and benefits on different fields [17], education is considered one of these fields which plays a key role in its development and quality [18]. e-Learning as part of the education system was also greatly impacted by this modern technology [19]. Students build their knowledge by enabling them to explore the reality around them [20]. IoT converts traditional e-learning into intelligent and interactive e-learning by integrating smart objects. Using smart objects provides learners with good communication and interaction with instructors and other parties from anywhere [21]. IoT motivates students and teachers. It creates an appropriate and comfortable learning environment in addition to increasing performance [22].

For many years, IoT has been used in conjunction with e-Learning. However, under certain circumstances, such as the COVID-19 epidemic, all learning processes have had to totally migrate to e-learning platforms [23, 24]. As a result, the significance of such integration has grown [25]. Still, many educational institutions have had a hard time making the switch to e-learning [26]. This is due to several factors, such as a lack of knowledge, student acceptance, a lack of infrastructure, and a lack of clear guidelines for integrating IoT with e-learning. Also, technical problems with accessibility, design flexibility, interactivity, the system, and the quality of the Internet will affect the stability and continuity of e-learning [12, 27]. There is a continuous change in the methods of the learning process. Therefore, it is necessary to propose and develop new supportive methodologies in order to fulfill the requirements of learners all over the world [28] and achieve satisfactory e-learning outcomes [29]. Accordingly, this article will concentrate on

*Corresponding Author.

the issue of a lack of guidelines to provide a conceptual and clear understanding of the IoT and e-learning processes.

This paper makes a big difference by giving an in-depth look at how the Internet of Things (IoT) is being used to make e-learning better now. This survey includes highlights of the responsibilities of IoT entities when integrated with the e-learning process. This study examines recent research efforts aimed at addressing the deployment of IoT in the e-learning process as well as open research opportunities for future research. This study makes the following contributions: In addition to discussing IoT concepts and e-learning process concepts, it also includes an analysis of the operational deployment of the IoT in the e-learning process as well as IoT e-learning architecture and entities.

The rest of the paper is organized as follows: Section II discusses the research background of IoT technology and e-learning systems. Section III discusses the related work in this field. Section IV explores the methodology applied in this research. Section V discovers the research and analyzes the findings. Section VI, VII and VIII discuss about the tools, architecture and entity model of IoT e-learning. The challenges and future directions of IoT and e-learning integration are discussed in Section IX. Finally, the paper is concluded in Section X.

II. BACKGROUND

A. Internet of Things Overview

The main idea behind IoT is to collect data from their surroundings before analyzing it in order to execute automated operations to assist users. The IoT is gradually gaining ground worldwide. Modern technology has grown in the past few years, in part because sensors and smart devices have become more common [30, 31]. The three stages of IoT activities, including data collection, transmission, and processing, are described below [25, 32-34]. In e-learning, data collection, transmission, and processing are very important parts of how online educational content is delivered and how well it works. This is done by gathering and analyzing data from different sources. It is possible to gain valuable insights into student performance and engagement, which can be used to tailor the e-learning experience [35]. These stages can be summarized as follows:

- **Data collection:** The first phase is data collection, which includes detecting and obtaining data through various communication methods. To identify and gather data, several technologies such as Bluetooth, Near Field Communication (NFC), Global Positioning System (GPS), and Radio Frequency Identification (RFID). When integrating IoT with e-learning, this phase entails receiving information from a variety of sources, including student interactions with the e-learning system, course content, and assessments. A range of techniques, including online applications, polls, monitoring tools, and application logs, can be used to gather data [35].
- **Data transmission:** Transmitting the data is the second phase where the gathered data is transmitted to the

servers or host system for processing via a specific medium (e.g., wireless or wired) and protocol (e.g., IEEE 802.3/802.11 standard). Because falsification tendencies are low, wired transmission channels may send more precise and dependable data. However, wired networks may not be useful for long-distance communication. It is also rather pricey when compared to wireless options. Understanding the optimum transmission route and the geography of the surroundings is critical. When integrating IoT with e-learning the data has been collected about students, it needs to be transmitted to the e-learning systems for storage and analysis using secure networks or cloud-based storage systems [36]. Furthermore, data management systems may be used in combination with data transmission to structure and store the data to be used later [36].

- **Data processing:** This is the final phase, during which the data sent should be properly reviewed and processed in order to make a decision. Data will go through many preparations, cleaning, classifying, and filtering procedures during this phase. Cloud computing allows services to be administered remotely and provides processing resources and virtual storage. In this stage when e-learning is integrated with IoT, the gathered data is analyzed and processed to get the knowledge that can be applied to enhance the e-learning process. This requires using algorithms and analytics tools to reach conclusions and trends from the data [35]. The processed data can be utilized to create reports on student engagement and performance as well as to identify e-learning platform development opportunities [36].

The IoT is a technical improvement in transporting and exchanging data between connected objects using an Internet service [11, 37, 38]. It has the property of quick evolution [39] and the scope has expanded further to connect people to things [13]. IoT gives good control over objects and transforms them into smart objects [14]. Therefore, it is seen as an essential element in the growth of smart environments [40]. The communication and association between physical and virtual objects provide the IoT with the characteristic of being ubiquitous [10]. IoT has devices that let it sense and collect data from other devices, which it then shares for the good of everyone. The association of RFID tags, sensors, and actuators with each other has made this technology a modern and unique model [21]. IoT technologies are different from other technologies because they are everywhere and encourage people to come up with their own independent and smart solutions [41]. It has become a hot and interesting topic among investors in various fields [15]. IoT is distinguished by non-human intervention, use anywhere, no time limit, reducing cost and time, and a perfect connection because it requires high-speed Internet [42, 43]. Fig. 1 explains the most common features of IoT technology, including sensing, connectivity, intelligence, safety, energy, and expression.

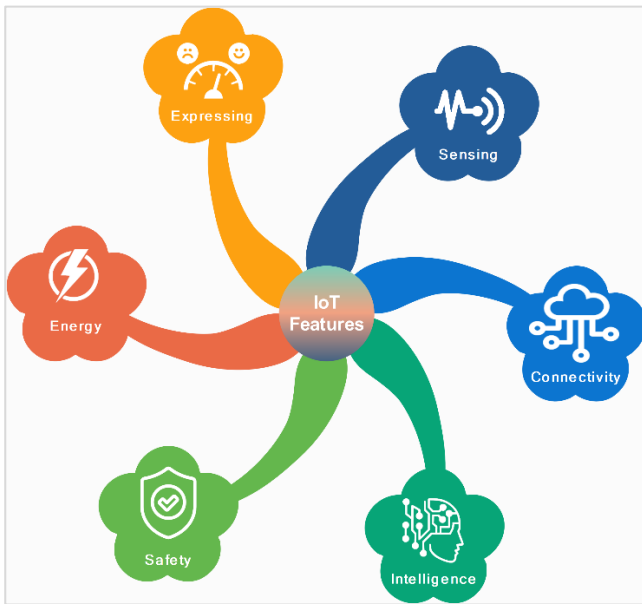


Fig. 1. Internet of Things features.

- **Sensing:** Many IoT devices are equipped with sensing capabilities that can be used to gather data from the surrounding environment and adapt their behavior based on the gathered data [36]. In order to gather data for a specific circumstance, IoT should be able to read analog signals from various sources such as light, RFID, GPS, and gyroscope. Light and pressure, for example, might be utilized in automobile applications. To produce the optimum use case, a good sensing approach should be used. The gathered data can be used by IoT in adapting their actions based on the context in which they are used systems [36]
- **Connectivity:** To ensure effective communication between networked IoT system components like computer processors, sensors, and data centers, connectivity is a crucial element to be considered. To achieve this smooth communication, several protocols and standards must be used. IoT systems may communicate and exchange data with one another and with other systems since they are connected through a network. Bluetooth, Wi-Fi, and cellular networks are just a few examples of wireless technologies that are frequently used to facilitate this connectivity [35].
- **Intelligence:** Data is utilized to create significant business observations and make crucial business choices in practically each IoT use scenario in recent times. On top of this vast data, building computational models to gain significant insights that can enable IoT systems to function independently or with minimal human intervention [35]. The sensor readings are refined and transformed into a format that may be used to train computer models. An appropriate data structure should be considered, depending on business requirements to support decision-making [36].

- **Safety:** Security is one of the most important aspects of the IoT system [35]. Sensitive data is delivered from terminals to the analysis layers via connection components throughout the whole cycle of an IoT system. To protect data from abuse and exploitation against cyber-attacks, IoT systems must adhere to adequate security procedures such as using secure communication protocols, encryption, and firewalls as well as the implementation of privacy policies and technologies to protect the personal data of users [36, 44, 45]. Every element of an IoT system that is compromised might ultimately cause the entire process to collapse.
- **Energy:** The entire IoT system requires a lot of energy, from end components to the communication and analysis layer. It is essential to consider design techniques while creating an IoT system so that energy usage is kept to a minimum (IEEE 802.15.4, 2003). For instance, IoT devices can consume less energy by adopting low-power communication protocols and effective power management techniques [11].
- **Expressing:** To improve the user experience, IoT incorporates multiple cross-domain models. It also guarantees that the structural and operating expenditures are properly balanced. IoT devices must be built in a way that allows them to be readily scalable up or down on request to allow for the integration of a large number of devices and sensors [36]. Providers must address future demands for handling such a large quantity of data when creating IoT processes to satisfy additional business demands to enable the creation of large-scale IoT deployments, such as smart cities or agriculture.
- **Interoperability:** Regardless of their manufacturer or operating system, IoT systems can work seamlessly with other systems and devices [36]. As a result, a variety of devices and systems can be integrated into IoT systems.
- **Distributed Real-time architecture:** IoT systems often have a distributed architecture, with devices and sensors located at the edge of the network, rather than centrally located [35]. This decentralized architecture allows for the Real-time collection and processing of data from many devices and sensors.

B. e-Learning Overview

e-Learning technology is a critical component of delivering education through an electronic medium, specifically the internet [46]. Numerous products are available on the market that implement e-learning technologies, which makes it critical for practitioners to be aware of the details of those technologies [47]. The knowledge along with the skills to use e-learning technologies will improve the chances of providing an effective and efficient learning experience for both students and teachers [48]. Because physical connection is banned, e-learning platforms can be used as a substitute for traditional learning and teaching methods. The social dimension is one of the main difficulties for students when

using the e-learning system, which can be reduced by adapting social IoT that can add interest to the virtual educational environment [17]. In order to stop this worldwide epidemic, the world needs more young people who grew up with technology and can quickly adapt to the online world without much trouble. Teleconferencing tools like Skype, Zoom, and WebEx sessions, as well as other similar technologies, can be used by students in online classrooms. Simulcasts, workshops, academic board meetings, and conferences may all be held electronically without having to meet in person. Using this kind of technology to keep people at a social distance is one way to stop the spread of viruses, like the COVID-19 virus, among academics [49]. Online assessment can be done using e-learning platforms, which guarantee the participants' health in such a pandemic. With these kinds of technologies, evaluating students can be done safely because there is less need for physical contact [50]. In the workplace, an internet platform can be used to do things like surveys, staff evaluations, and interviews. This helps keep employees safe.

e-Learning technologies can be categorized into two levels, infrastructure and software. The infrastructure category is further categorized into on-premise and on-cloud [51]. On-premise technology is the infrastructure that uses the local hardware of the educational institution, while on-cloud computing uses cloud computing resources over the Internet [52]. For instance, e-learning infrastructure includes the underlying hardware such as servers, end-user devices such as mobiles and desktops, networking devices, input devices, output devices, and storage devices [53]. Those can be on-premise, which means that the hardware used in e-learning is located on the campus of the educational institution [54]. On-premise infrastructure needs help and skills all the time, but it also gives you more freedom [55]. Using cloud computing also has numerous advantages as it reduces cost and increases flexibility and real-time scalability, but at the same time, it may introduce some issues regarding dependency, security, and confidentiality [56-60].

Likewise, the software category is classified into synchronous and asynchronous technologies. Synchronous technologies support real-time communication, whereas asynchronous technologies support communication at different times and locations but do not support real-time communication [17]. In terms of software, e-learning uses both synchronous and asynchronous tools. Synchronous tools are trying to mimic traditional classrooms and, to some extent, improve the experience of learning by augmenting technological tools that may improve the education process [17]. Synchronous technologies include video and audio conferencing, live chat, whiteboarding, and application sharing [61]. While asynchronous can be combined and formed in learning management systems that support learning resources management, forums, messaging, assessments, and announcements [62].

III. RELATED WORK

Previous literature on improving IoT and e-learning may be divided into numerous areas, such as content management and sharing, creating solutions, e-learning content distribution, tracking the e-learning process, e-learning tool

interoperability, and standards interoperability [63]. The value of the IoT was demonstrated by [64] by developing and enhancing education, as well as the scope of their significance in higher education institutions via smart coursework utilizing the latest methods in the classroom setting, smart labs to run tests more efficiently and enable tests, including the use of gadgets to enhance student communication with their classmates and teachers, and also scientific content. Mohammed and Isa [25] emphasized the significance of IoT in enhancing human-machine connection, which contributes to people's social isolation. The use of IoT to prevent the spread of infections (such as COVID-19) may face unique challenges, especially in developing countries with limited telecommunications infrastructure. In the same way, IT expertise is required when dealing with IoT apps or devices. Individuals prefer to interact personally with another person rather than with a machine. Others may believe that revealing medical details to the machine will compromise their privacy. Such factors represent considerable obstacles to the use of IoT applications to control the virus's spread [25].

Dodero, et al. [65] look at what needs to be done to make the e-learning future a reality. Issues related to IoT and e-learning integration, including CPU and storage limitations, throughput, and bandwidth constraints, should be addressed for successful integration. Accordingly, the trade-off between data-collection efficiency and interoperability may be considered to enhance this integration [65]. In their work, Chituc [66] looked at standards interoperability and pointed out the problems with interoperability that need to be fixed for the IoT and e-learning visions of the future to come true. Perales, et al. [67] demonstrated an online system utilized by the International University of La Rioja. The online service is a remote online lab that delivers experiential learning using engineering experimental tools. The teacher might move from one online workspace to another to help students with their lab instructions. Even though this method is used to offer online labs, it doesn't consider how and why the students interact with each other. In the work of [68], the authors recommended using a context-aware system to capture a vast amount of data about the learner's surroundings. The system automatically adjusts to the customer's wishes based on these facts. Context-awareness incorporation into an e-learning system would be an effective strategy for improving learning.

Zaguia, et al. [24] showed learners a new way to use synchronous e-learning for intelligent e-learning. The paradigm is a new way of thinking about distance learning in which the teacher has more control over the students. Tools for artificial intelligence, IoT, and virtual reality are put together to make a more powerful system that helps the teacher keep an eye on the students during lessons and tests. Most of the changes we will make to our systems in the future will involve adding more computer-aided services to help teachers see and respond to how students are acting. In the work of [69, 70], the authors proposed that artificial intelligence approaches such as data mining and fuzzy logic be used to smarten up e-learning tactics and augment students' learning. Most of these systems are limited by the time to finish the assessment exam, the learner's evaluation criteria, history, and so on [24]. Similarly, Leahy, et al. [71]

investigated the role of emergent technology, such as smart materials, artificial intelligence, and augmented reality, in the future of e-learning. In Zhang and Zhou [72], the importance of locality, interaction, intelligence, openness, and cloud computing were analyzed from the standpoint of e-learning's future vision.

The use of smartphones in e-learning was emphasized by [73]. These gadgets must be integrated into distance learning systems. These gadgets became more widely available and easier to operate as time went on. The authors suggest a platform that has an intelligent agent on a student's smartphone. The necessary information about the students' obsessions, participation in the course, and other factors is collected and sent to the artificial intelligence system for evaluation. The artificial intelligence algorithms look at student data, comments, and ratings of course materials to figure out what course content is suitable. The authors suggested analyzing student behavior with smartphones to make sure that the course content was customized correctly. Tobarra, et al. [74] put the app of the virtual laboratory to the test to see how well it worked. The learners' acceptance was evaluated using the Unified Theory of Acceptance and Use of Technology (UTAUT) model, as well as time allocation, learner's behavior in relation to evaluation items, and material sources. The main result of this research is that the suggested lab has a high level of student acceptability, as measured by several factors (ease of use, perceived usefulness, attitude, intention to use, social influence, and estimated effort).

IV. RESEARCH METHODOLOGY

This study aims to find out the use and importance of integrating IoT with e-learning systems. The strategies and rules presented by [75-79] were adopted in the review process of this paper. Fig. 2 explains the review activities. The study begins with a review of the literature and a survey of the research object's e-learning implementation, followed by a summary of the significant results from the associated literature. Following that, identified a research need from which derived review questions and objectives. Finally, the paper's importance and scope were determined. There were a lot of publications that were looked at, but this review only includes the most important and recent (since 2015) studies. This is because the actual IoT and e-learning integration revolution began after 2014.

This study aims to answer the following research questions: How is IoT used in e-learning systems? To answer the research question, five sub-questions should be addressed to figure out the goals, scope, significance, and future of deploying IoT in the e-learning process, and the future of this emerging technology:

- RQ1: What is IoT in e-learning systems?
- RQ2: Where is IoT implemented in e-learning systems?
- RQ3: How is IoT implemented in e-learning systems?
- RQ4: What is the impact of using IoT in e-learning systems?
- RQ5: What are Challenges and Future Directions sets of

IoT in e-learning systems?

The literature review was conducted by searching scholarly databases; Google Scholar, IEEE Explore, ACM, Springer, MDPI, Wiley, Emerald, and Elsevier. The investigation starts with selecting the topic, analyzing, interpreting, and coming out with the research problem. A range of search phrases and their variations were used to conduct thorough searches including: "e-learning" OR "e-learning" OR "smart learning" OR "smart class" OR "smart teaching" OR "virtual learning" OR "virtual study" OR "virtual class" OR "online learning" OR "online class" OR "online study" OR "online teaching" OR "online tutoring" AND IoT OR internet of things. The focus of this study is on the present state of e-learning and IoT integration. As a result, the following inclusion criteria were used: IoT must be incorporated into the construction, architecture, design, or modeling of e-learning. There should also be proof of deployment (for example, a description or presentation of the actual implementation, or proof of model assessment). Based on the criteria for inclusion, the searches turned up 40 items. Of those, 28 were journal articles and 12 were conference articles. The papers included in this work are depicted in Table I.



Fig. 2. Research methodology.

V. FINDINGS

This section provides a comprehensible overview of applying IoT in e-learning systems. The paper discusses some questions related to IoT and e-Learning systems and how they have been explained and answered in several previous studies. Table I summarized the related work and simplified and clarified the research questions. The answer to each question can be yes or no, which was designated ‘✓’ inclusion in the study and ‘----’ for not implicitly included.

TABLE I. PREVIOUS FINDINGS

Ref	Research Questions				
	RQ1	RQ2	RQ3	RQ4	RQ5
[23]	✓	----	----	✓	✓
[26]	✓	✓	✓	----	----
[80]	✓	----	✓	✓	✓
[81]	✓	✓	----	✓	----
[24]	✓	✓	✓	✓	----
[49]	✓	✓	✓	✓	----
[64]	✓	✓	✓	✓	----
[82]	✓	✓	----	✓	✓
[63]	✓	----	----	✓	----
[83]	✓	✓	✓	----	----
[84]	✓	✓	----	----	✓
[66]	✓	----	✓	✓	✓
[56]	✓	----	✓	✓	✓
[69]	✓	✓	----	----	✓
[85]	✓	✓	----	----	✓
[74]	✓	✓	----	----	----
[14]	✓	✓	✓	✓	✓
[40]	✓	----	----	✓	✓
[71]	✓	----	----	✓	✓
[20]	✓	✓	✓	✓	----
[73]	✓	✓	✓	✓	----
[67]	✓	✓	✓	✓	----
[16]	✓	✓	✓	✓	✓
[37]	✓	✓	✓	✓	✓
[19]	✓	✓	✓	✓	✓
[21]	✓	✓	----	✓	----
[11]	✓	✓	✓	✓	✓
[41]	✓	✓	✓	✓	----
[10]	✓	✓	✓	✓	----
[17]	✓	✓	✓	✓	✓
[39]	✓	✓	----	✓	----
[18]	✓	----	✓	✓	----
[27]	✓	----	----	✓	----
[15]	✓	✓	✓	✓	✓

Ref	Research Questions				
	RQ1	RQ2	RQ3	RQ4	RQ5
[86]	✓	✓	✓	✓	----
[87]	✓	----	----	✓	✓
[13]	✓	✓	----	✓	----
[4]	✓	✓	✓	✓	✓
[88]	✓	✓	✓	✓	✓
[22]	✓	✓	✓	✓	----

A. RQ1: Internet of Things (IoT) in e-Learning Systems

The integration of new technology such as the IoT in e-learning systems is a practical example of providing different smart services [37] for enhancing the learning process, achieving better outcomes, and decreasing cost and time [22, 41]. IoT is the main supporter of the smart learning (e-classroom) environment via connecting physical and virtual objects, which makes it more scalable and efficient [10]. IoT has changed conventional e-learning and taken it to an advanced level. Individual skills and knowledge are the results of this advancement [11].

e-Learning equipped with IoT may support and facilitate collecting and sharing notes between learners from the learning classroom through applications, smart devices, and network connections [16, 18, 19]. The use of the IoT with e-learning systems simplifies the learning process [39]. IoT in e-learning systems using IoT may result in fast accessibility, hyper-connectivity, good sharing, personality services, and a sustainable learning environment [13]. IoT e-learning does not only mean enhancing the learning process, it also changes the academic infrastructure and adds new subjects and essential concepts to computer science [89]. The e-learning system developed by the IoT has a global characteristic. The advanced system stores enormous amounts of information and performs a great number of equivalent operations [15]. In terms of awareness, the learner is regarded as the most important factor. For learning arrangement and connectivity, his/her relief, contentment, and encouragement are significant [17].

B. RQ2: Applying Internet of Things (IoT) in e-Learning

Online learners and teachers are connected to the internal learning system and global objects through IoT technology, which enables learners to access enormous pedagogical resources [65, 71]. IoT has some good qualities, such as high-quality association between objects, high-quality access, network communications integrations [10], and the ability to add and remove objects from the connection structure [83]. The IoT has the capability of connecting people to people, people to things, and things to things [14]. IoT devices are used in e-learning to deliver and receive information and directions. The benefits of adopting IoT in e-learning include helping to motivate superior lesson ideas, construct safe facilities, monitor important resources, improve data access, and many others [51]. The IoT can be viewed as a novel approach to managing the educational process through the use of developed technologies. The IoT is used in many e-learning tools, such as interactive learning, smart digital boards,

teaching apps for smartphones, laptops, and tablets, systems that track attendance, digital materials, and many other learning tools like Google Apps.

The implementation of IoT and e-learning has been applied in many fields, such as schools, universities, online training, online certificates, and so on. This is especially critical during circumstances where the disease infection is a threat as the substitution of a face-to-face approach is necessary. For instance, Encarnacion, et al. [48] argued that instructors of physical training may utilize smartphones, smartwatches, and the programs they have on them as effective teaching tools. Sportspeople can enhance their athletic performance using these phones and applications, and students can monitor their movements and gain knowledge about physical education [90]. In higher education, Abd-Ali, et al. [64] reported that IoT implementation in e-learning has enhanced the e-learning process and outcomes through smart coursework utilizing the latest methods in the classroom setting, smart labs to run tests more efficiently and enable tests, including the use of gadgets to enhance student communication with the classmates and teachers, and also scientific content. The same has been reported by Perales, et al. [67] that an online lab that delivers experiential learning through the use of engineering experimental tools has assisted students with their lab instructions and enabled shifting from one online working space to another, easily. Moreover, Sabagh and Al-Yasiri [68] recommended using a context-aware system to capture a vast amount of data about the learner's surroundings, which would be an effective strategy for improving learning. In general, the effective implementation of IoT with e-learning has to consider several factors [14, 48]:

- Learner-oriented approach: The first stage in creating a successful e-learning system is to undertake a comprehensive analysis of learners' needs and the conditions in which they live.
- Productive learning processes: In the modern world, learning materials are increasingly individualized and focused, blurring the lines between learners' personal and professional lives.
- Organizational culture: Because every institution has a unique culture, various working techniques must be taken into account.
- IT capabilities: The foundation of the environment conducive to e-learning is smart IT. It requires certain technology (e.g., smartphones, smart TVs, smart pens, etc), software and applications (e.g., Zoom, Microsoft Teams, etc), and interface components, which form the basis of cognitive data interchange.

C. RQ3: Internet of Things (IoT) Implementation in e-Learning Framework

The IoT network is embedded with electronics, sensors, software applications, and other devices linked to the Internet [22]. These integrated devices are applied in the learning process for improvement [37]. IoT technology uses sensors and smart devices for data collection [19]. The data produced by IoT sensors is transmitted through a network, and the combined data is analyzed via big data analytics [16]. A sensor is something that a learner owns and that is linked to the system. These sensors may be utilized for a variety of educational purposes, including medical training, and genuine learning, using devices like wearable watches, headphones, and smart glasses. How to gauge learners' levels of interest and engagement during e-learning is a challenge when employing IoT e-learning systems. Even though linked learners can use these devices as ways to prove who they are, they can't show proof of engagement until, say, a webcam is running [91]. So, even if in theory these devices might accommodate all learners' needs, their inability to replace face-to-face learning is due to students' lack of engagement. The classroom is equipped with smart devices to create a smart environment that speeds up data fetching and collection [13, 88]. Connecting the information sensing tools and information transformation applications can support the learning process with different students' feedback [14]. In other words, e-learning processes can be improved by constantly monitoring and evaluating what students say about how to make e-learning or the use of IoT devices better. For IoT devices to work together, different types of protocols must be used on the sensor platform [17]. The network infrastructure, communications quality, and improvement of intelligent applications are the three important IoT requirements for achieving smart services [41].

VI. INTERNET OF THINGS E-LEARNING TOOLS

Unlimited communication through the IoT enables learners, teachers, and researchers to work globally [21]. IoT can be used in e-learning systems for various activities to support the learning process [18]. Many of the researchers, such as [16, 17, 19, 37, 88] unanimously agreed that the smart classroom, smart lab, and smart notes are some of the most important and efficient educational aspects to which IoT technology has been applied. Other authors reported other smart activities such as electronic books and attendance tracking [14, 41]. AjazMoharkan, et al. [11] reported other smart tools used in e-learning systems coupled with IoT technology, such as smart digital boards, digital highlighters, Scanmarkers, RFID, and QR. The market continuously provides the e-learning system with IoT smart products that can be combined to achieve new and useful services, as explained in Fig. 3. The following are examples of these tools [11, 80, 85]:

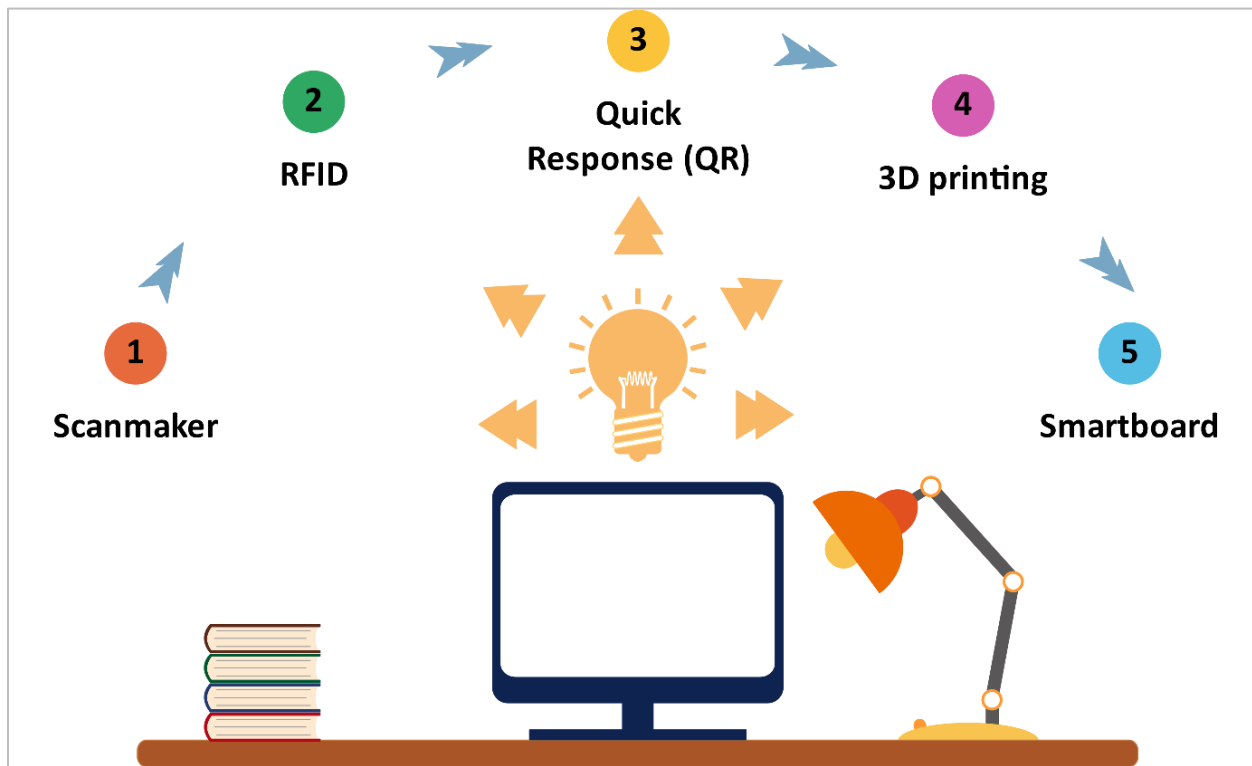


Fig. 3. Internet of Things e-learning tools.

- **Scanmarker:** The Scanmarker is integrated with a computer or smartphone to convert the printed text to these devices, which makes the process of note-taking easy and fast. Users of Scanmarker are able to scan editable text from books, and other documents into their phone, tablet, or computer in seconds. This text can then be translated into over 40 different languages.
- **Learners Attendance using RFID:** The presence of students in the classroom is automatically detected by a Smart Classroom-IOT-based device. RFID chips are embedded in the ID cards of students. Every classroom can have an RFID reader that can read all of the students' ID cards at the same time.
- **Quick Response (QR):** QR code is embedded in books offline work and then linked to online applications. It has the capabilities of quick readability and greater storage capacity.
- **3D printing:** Additive manufacturing, also known as 3D printing, is the process of creating three-dimensional solid objects from a digital file. The 3D printer can be linked to a smartphone, tablet, or computer. Through new technology such as 3D printing, developers hope to create more networked products that can sense, collect, analyze, and communicate data.
- **Smartboard:** enables the teacher and students to work on the same "document" in real-time and share it with the entire class.

VII. INTERNET OF THINGS E-LEARNING ARCHITECTURE

IoT acts as an intermediary between open learning and the classroom [13] and can be used at all levels of learning [39]. Fig. 4 represents the architecture of the IoT technology e-learning system. There are three main layers in this architecture, which are discussed as follows: applications, networking, and sensors [14, 24, 92].

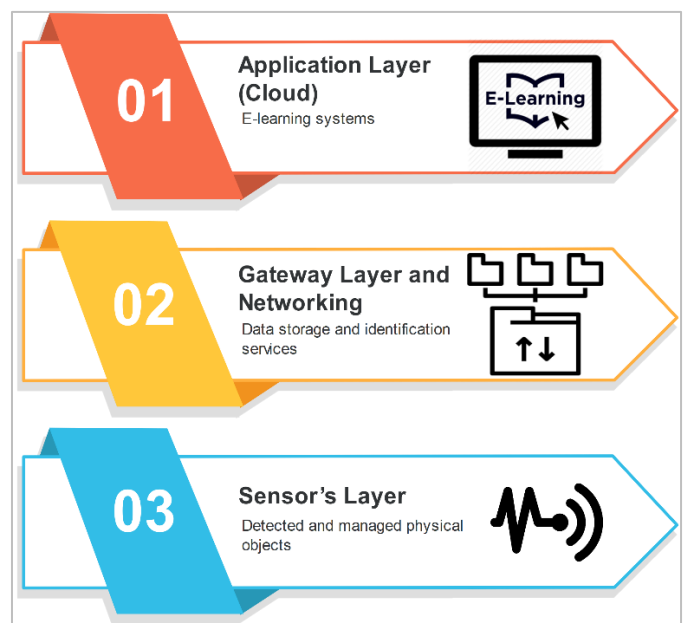


Fig. 4. Internet of Things e-learning architecture.

- **Application layer (Cloud):** The top layer of the architecture is the application layer, which includes business applications like e-learning systems. These programs can be used to manage and streamline business operations as well as to provide new services. Different types of digital devices communicate with other IoT system components directly. This layer will include all of the services that can be provided to learners and teachers. More information is available in the services area.
- **Gateway layer and networking:** Data generated by IoT devices is disseminated through this layer. It includes data storage and identification services for related devices, as well as a device management application with access control, administrative, and business capabilities. The IoT gateway is made up of two major components: edge and Fog nodes. Fog nodes, which are equipped with applications, storage, and more processing power than IoT devices, support local processing. As a result, Fog nodes can assist in managing and controlling IoT devices without requiring IoT devices to communicate directly with the Cloud, resulting in reduced time latency. Data from IoT devices are used to support it, and it functions in accordance with that data. The network component's main focus is communication. Based on the data collected by the sensors, the IoT gateway will make the appropriate decision and send the instructions to the actuators.
- **Sensor's layer:** This layer contains messaging, virtualization, and other components. This primarily consists of detected and managed physical objects relevant to IoT applications as well as learners and teachers. This layer consists of sensors and actuators. Teachers and students interact with the e-learning system using technology such as smartphones, tablets, computers, or more specialized devices. These devices will have a unique user interface that will enable e-learning and effectively guide or support the user.

VIII. INTERNET OF THINGS E-LEARNING ENTITY MODEL

Both learners and teachers communicate via a network using IoT devices that utilize sensors and actuators to interact with the real environment. Sensors detect a physical entity's features and transform them into digital data that can be interpreted by humans. For instance, an IoT audio sensor can measure how loud the noise is, and the system will respond based on this information. Actuators use digital instructions to operate on or affect the attributes of physical things. As shown in Fig. 5, the components of IoT object e-learning are as follows [24]:

1) *Learner unit:* A learner is a real-world object that IoT devices manage and perceive.

- **Learner portfolio:** This component will store the learner's preferences, history, as well as the student's strong and weak aspects, so that it may be considered in order to enhance the learner's level.

- **Awareness module:** The goal of this unit is to give appropriate services to the learner in light of the circumstances. It is a key notion in distributed network computing. Data may be collected in context-aware systems utilizing small resource-constrained devices like smartphones, PDAs, wireless sensors, and other linked objects. This gives better awareness of the context of service and user demands, allowing for more efficient user assistance.

2) *Teacher unit:* The second real-world object is the teacher. This unit refers to a variety of things that may be added to both learner and teacher terminals to help in tracking and identification.

- **Identification:** The purpose of this unit is to determine the identity of the user, availability, and status. For example, this module will identify if a learner spends too much time on one slide throughout revision. In this scenario, he is having difficulty comprehending this slide, thus an alert will be issued to the student to see whether he requires further activities or assistance.
- **Assessment:** This unit sends out messages to learners informing them of upcoming tests and evaluations.

3) *The operation unit:* Operation (i.e., operation and application systems) includes different functions such as monitoring and administering units that enable operators to manage the IoT systems' overall functionality and optimize the overall performance of the systems.

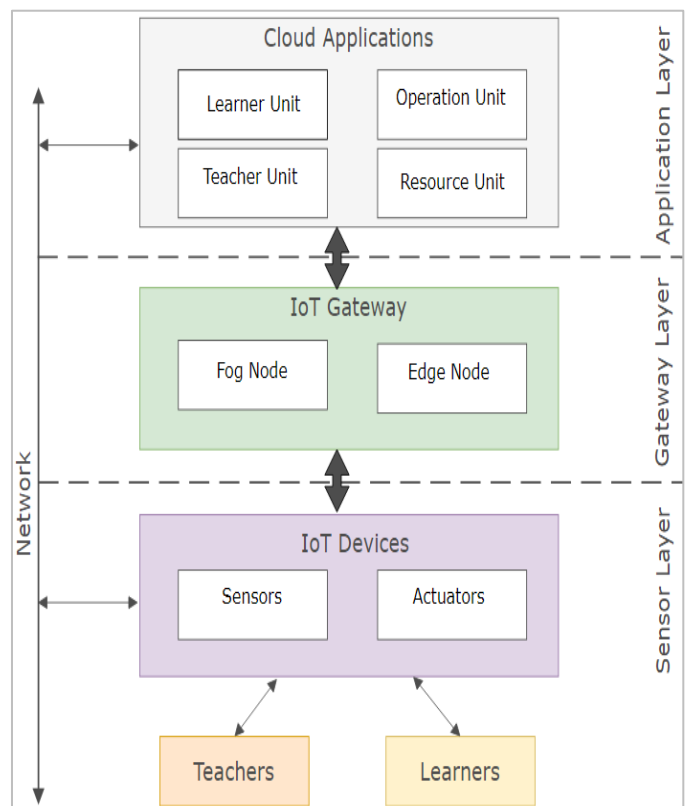


Fig. 5. Internet of Things e-learning system entity model.

4) *Resource unit*: It includes the regulated endpoints that provide services to IoT system participants who interact with each other and the peer system via their devices. It allows them to have access to the capabilities of the IoT system.

- **Material**: The course materials will be contained in this unit. The teacher will keep it up to date. It will give pupils sufficient materials.
- **Support**: The goal of this unit is to give support to learners whenever they require it.

A. *RQ4: The Impact of Implementing Internet of Things (IoT) in e-Learning Systems*

One of the most significant effects of utilizing IoT in e-learning is the expansion that results from linking learning environments with each other. The interconnection is between the learning parties and also between the different learning environments [37]. IoT in e-learning changes the learning process and enhances performance [82]. Accessibility and collaboration are the most important benefits that learners gain from integrating this technology with e-learning systems [21, 22]. Accessibility improves data sharing speed, note delivery costs, and self-skills [19, 88]. Achieving revolutionary technological development lowers the failure rate of e-learning recipients and professionals [16]. IoT e-learning applications can offer modern inventions and ways to upgrade learning activities. It provides effective participation and helps e-learners integrate into the learning community. The smart classroom is an essential part of IoT e-learning because it generates smart features that, in turn, create high-quality education [10]. Virtual classrooms let teachers know what their students need to learn and how they want to learn it [39]. This is good for both the students and the teachers. Applying IoT in the learning environment increases the speed of receiving and retrieving information by learners in addition to the quality of teacher performance, helps to suggest an intelligent lesson schedule, and continuously monitors important resources and other activities [14].

Linking IoT to e-learning systems reduces instructors' administrative work and invests time in promoting students' skills and talents [65]. IoT aids in collecting and analyzing a massive amount of data and statistics related to students [18]. Gathering the data from IoT smart objects, with which the learner interacts, produces special files that contain personal information in the e-learning system for each learner [13]. Smart learning helps to acquire knowledge quickly and easily, generate new perspectives and solutions, and inspire a comfortable environment, which may be the pinnacle of creativity and enjoyment for all learners and instructors [41]. The use of IoT e-learning helps to connect anyone with everything at any time and from any location [17]. IoT smart tools have the capabilities of observing, communicating, and converting research into intelligence [21].

IX. DISCUSSION

This paper aims to answer the main research question of how IoT is used in the e-learning process and, accordingly,

answer the sub-questions that identify the object, design, and future of IoT in e-learning. The following sub-section discusses the implications of the findings of this paper on both the industry and the research community. Also, the future of IoT in the e-learning process (i.e., RQ5) is discussed.

A. *Research Implication*

The interest in keeping track of the emergence of new technology is one of the most substantial issues that must be given priority in the field of research because it is the basis for developments in all areas. e-Learning systems are a topic of interest and concern among research societies. This study shows that using IoT technology in an e-learning environment is important and necessary. There may be obstacles to the acquisition of IoT smart devices. Some learners and instructors are accustomed to the old system and their adherence to the traditional method, which is considered one of those complications, however, the urgent need requires more diligence to achieve the objectives. The compass is now heading towards smart learning, and the learner represents the need; thus, it must be directed in the correct direction.

Due to the major impact of implementing IoT technology in e-learning systems, system sustainability must be maintained through the configuration of environment-appropriate equipment. The quality of the Internet is one of the factors behind the success of this technology, so the network structure must be constantly reviewed and maintained. The novelty of technology requires extensive training and comprehensive awareness for all learning parties. Technology has no alternative but better technology, so the pursuit of development is a basic requirement. Meanwhile, a balance must be struck between many connected devices to improve quality and monitoring them and ensuring their safety to achieve the desired results. This study can argue that the learning process has an enormous social role. There are many electronic devices, but they are not currently listed among the IoT devices, and the number of intelligent devices will increase to several billion.

B. *RQ5: Challenges and Future Directions of IoT in e-Learning Systems?*

Without a strong direction for how diverse "things" and e-learning systems should interact, the area of e-learning continues to grow. As a result, achieving interoperability in future educational experiences powered by the IoT is critical. A lot of challenges, such as access controls, technological and conceptual interoperability difficulties, privacy and security issues, and QoS tracking, must be acknowledged in order to promote smooth interaction and resource sharing among diverse and globally dispersed IoT devices, e-learning systems, IoT devices, software solutions, and users [66]. The identification of the issues of e-learning integration with IoT gives fresh views for academics and organizations, as well as introducing communities from many industries to the present challenges and future potential in this field. This article's review of related work identified five future challenges of e-learning and IoT integration, which are illustrated in Fig. 6, and discussed as follows:

- **Privacy and security:** Even though IoT technologies are evolving, and a growing number of devices are becoming widespread, security remains a major concern. Devices may be attacked, and present security flaws put people in danger. To safeguard students' and instructors' privacy and security while allowing secure information exchange and handling, more research and design efforts are needed [93]. To create effective and acceptable solutions to address IoT security concerns, a collaborative approach to security will be necessary. Moreover, the IoT's true capacity is contingent on privacy-conscious practices. To generate value, new strategies must be developed that take into account the user's privacy preferences and expectations while also encouraging technological innovation and applications [94]. Quantum computing may enable the development of safe processors soon, paving the way for secure products. Regulations and standards must be developed and executed to guarantee secure data transfer and storage under laws and regulations.

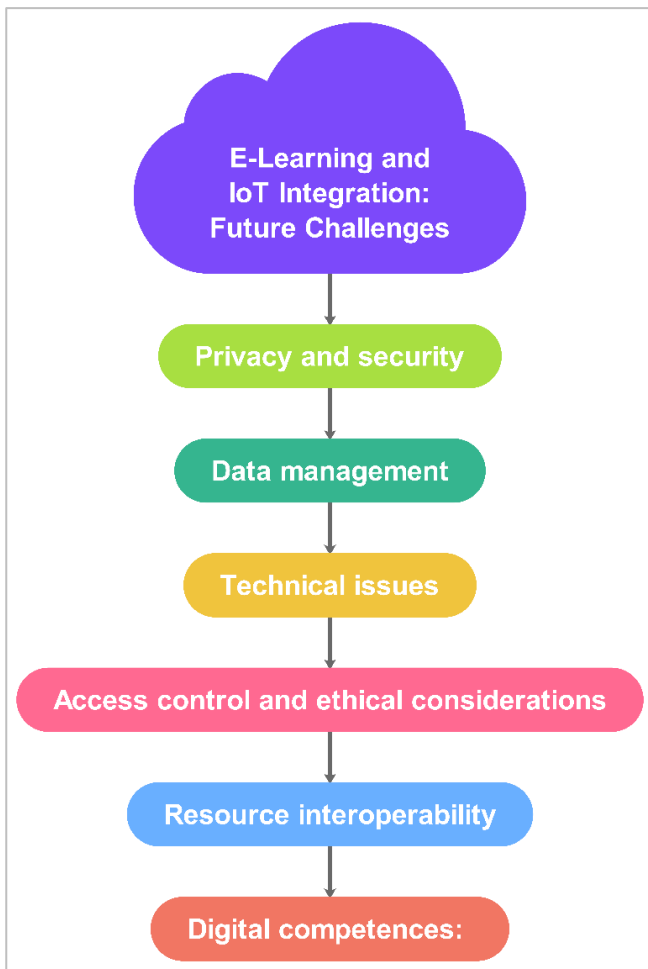


Fig. 6. e-Learning and IoT integration future challenges.

- **Data management:** The massive volumes of data created by IoT devices have significant prospects for advancing e-learning and citizen life. To improve the learning process, this data can be merged with big

datasets and examined instantaneously using new analytics techniques [95]. Nevertheless, there are various issues regarding data ownership accessibility, including the absence of coherent and transparent data ownership legislation. Such issues need further research to be addressed and clear policies to be implemented. Moreover, the massive volumes of data contain a lot of distortion, which makes data analysis difficult. Current methodologies lack the level of resilience necessary, necessitating the implementation of novel data analytics techniques and software tools [78, 95-100]. On the other hand, appropriate visual techniques must be developed in order to acquire meaningful insights into the data collected. Existing methodologies are ineffective when dealing with large amounts of data generated by IoT devices. Information loss, visual distortion, rapidly changing images, huge observation, and high-performance needs are all challenges that need to be handled further.

- **Technical issues:** Although the IoT provides new options for delivering digital courses, it also poses issues in terms of maintaining instructional quality and evaluating students' work. In order to increase the e-learning quality, new IoT applications and tools are required [101]. Future e-learning systems must offer flexibility and context awareness. Educators and educational organizations can deliver an adaptable learning opportunity by assessing the learners' contextual material. Contextual ontologies, on the other hand, remain a significant difficulty [34]. In future e-learning systems, the software systems, integrated e-learning infrastructures, and "things", therefore enabling e-learning systems to use as few resources as possible [101]. This is extremely difficult given the large number of resources that will be required to create future e-learning systems. This problem might be solved by utilizing and creating techniques for scheduling, optimization, reuse software components and strategic planning as well as the utilization of alternative energy sources [45]. Moreover, several e-learning platforms use hybrid Cloud as their business architecture to host IoT applications. Therefore, communication with the Cloud should be easy and have low latency with such a huge amount of data created from ubiquitous resources.
- **Access control and ethical considerations:** It is critical to develop suitable ways to control individuals and their privileged access in forthcoming e-learning systems. Providing a person complete control over activities affecting his or her identification, distributed online identity, and multisensory identity are all concepts that should be thoroughly investigated [93]. In addition, the social value of interoperability in future e-learning systems, as well as the possible risks, must be thoroughly investigated. academic institutions, students, instructors, policymakers, and citizens might all benefit from a paradigm that analyzes the technological and ethical limitations of maintaining interoperability in future e-learning systems [101].

- Resource interoperability: In the e-learning context, usually, the emphasis on interoperability is on technological concerns such as data format and communication protocols [101]. However, addressing the factors of organizational and managerial interoperability such as regulations as well as information/knowledge interoperability such as semantics is crucial. The New European Interoperability Framework, which aims to provide the best service and information flow, might be useful for addressing managerial and information interoperability, in future e-learning systems [66]. Moreover, due to the rapid development of technology, researchers and the e-learning industry must continuously pursue and search constantly to find out what is new and useful. The future of IoT will be favorable as long as there is a continuous evolution and thus will affect the future of e-learning and related technology [66].
- Digital competences: The terms "digital competencies" refer to the creation of digital material, data and information knowledge, collaboration and communication, analysis, and problem-solving. To successfully engage in e-learning, learners must possess certain competencies. Several of these competences may be lacking in learners, which can cause a variety of problems, including difficulties with digital creation (such as system design), problems finding and applying digital materials, a lack of analytic capabilities, struggle while exchanging information via modern technology, and are unable to judge the accuracy and worth of information [94].

In the future, learners should have good skills and capabilities to be more competitive. All e-learning parties will gain great benefits through the advancement of their activities, such as the safety of the learning environment, while management, the institutional structure, and the governments may achieve considerable financial benefits and thus importantly contribute to the stability of the educational sector [14]. Future research may extend this study and introduce new technologies to improve the educational sector and resolve related issues.

X. CONCLUSION

The way services are delivered has changed because of changes in communication technology and the invention and widespread use of IoT devices. Innovations in technology in the field of education make it easier to learn new things and get better at what you already know. e-Learning is one of the most significant systems because it has a great impact on learners, teachers, and the success of the educational process. Adding new technology makes it more effective and attractive. The lack of specific studies in this area encouraged the researchers to concentrate on investigating the previous studies related to integrating IoT in e-learning systems. This paper provides a comprehensive review that includes definition of the IoT e-learning system, the effective impact of utilizing IoT on this system, the advantages of the IoT, the operative tools used to transform learning into smart education and how to use them, and the future challenges and research

directions in the context of IoT e-learning integration. This research encourages innovating with modern technologies and applying them in the e-learning process. In the future, researchers and practitioners will be able to focus more on deep research in this field to add new technologies that help improve the e-learning process and open up new opportunities.

REFERENCES

- [1] Y. I. Alzoubi, V. H. Osmanaj, A. Jaradat, and A. Al - Ahmad, "Fog computing security and privacy for the Internet of Thing applications: State - of - the - art," *Security and Privacy*, vol. 4, no. 2, p. e145, 2021.
- [2] Y. I. Alzoubi, A. Al-Ahmad, A. Jaradat, and V. Osmanaj, "Fog computing architecture, security, and privacy, for the internet of thing applications: An overview," *Journal of Theoretical and Applied Information Technology*, vol. 99, no. 2, 2021.
- [3] N. B. Salehudin, H. Kahtan, H. Al-bashiri, and M. A. Abdulgaber, "A Proposed Course Recommender Model based on Collaborative Filtering for Course Registration," *International Journal of Advanced Computer Science and Applications*, (IJACSA), vol. 10, no. 11, pp. 162-168, 2019, doi: 10.14569/IJACSA.2019.0101122.
- [4] H. M. Truong, "Integrating learning styles and adaptive e-learning system: Current developments, problems and opportunities," *Computers in human behavior*, vol. 55, pp. 1185-1193, 2016.
- [5] H. Al-bashiri, H. Kahtan, M. A. Abdulgaber, A. Romli, and M. A. I. Fakhreldin, "Memory-based Collaborative Filtering: Impacting of Common Items on the Quality of Recommendation," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 12, 2019, doi: 0.14569/IJACSA.2019.0101218.
- [6] S. Kummur, F. S. Al-Aani, H. Kahtan, M. J. Darr, and H. Al-Bashiri, "Data Visualisation for Smart Farming Using Mobile Application," *International Journal of Computer Science and Network Security*, vol. 19, no. 11, pp. 1-7, NOV 30 2019. [Online]. Available: http://paper.ijcsns.org/07_book/201911/20191101.pdf.
- [7] W. N. A. W. A. Fatthi, M. H. M. Haris, and H. Kahtan, "Application of Travelling Salesman Problem for Minimizing Travel Distance of a Two-Day Trip in Kuala Lumpur via Go KL City Bus," in *Advances in Intelligent Systems and Computing*. Switzerland AG: Springer, 2018, pp. 277-284.
- [8] H. Kahtan, W. N. Ashikin, W. A. Fatthi, A. Azma, A. Mansoor, and R. Noor Aishah, "Application of Fuzzy Logic Controller for Safe Braking System: An Anti-Theft Tracking," *Advanced Science Letters*, vol. 24, no. 10, pp. 7317-7321, October 2018 2017, doi: 10.1166/asl.2018.12935.
- [9] H. Kahtan, K. Z. Zamli, W. N. A. W. A. Fatthi, A. Abdullah, M. Abdulleteef, and N. S. Kamarulzaman, "Heart Disease Diagnosis System Using Fuzzy Logic," presented at the 7th International Conference on Software and Computer Applications, Kuantan, Malaysia, 2018.
- [10] M. Bayani, K. Leiton, and M. Loaiza, "Internet of Things (IoT) Advantages on E-learning in the Smart Cities," *International Journal of Development Research*, vol. 7, no. 12, pp. 17747-17753, 2017.
- [11] Z. AjazMoharkan, T. Choudhury, S. C. Gupta, and G. Raj, "Internet of Things and its applications in E-learning," in *Proceedings of the 3rd International Conference on Computational Intelligence & Communication Technology (CICT)*, Ghaziabad, India, 2017: IEEE, pp. 1-5.
- [12] S. Gautam and M. K. Tiwari, "Components and benefits of E-learning system," *International Research Journal of Computer Science (IRJCS)*, vol. 3, no. 1, pp. 14-17, 2016.
- [13] I. Kamar, P. Chatterjee, and A. Hamie, "Internet of Things in Learning Systems-A Perspective of Platforms," *International Journal of Advanced Research in Computer Science*, vol. 7, no. 2, 2016.
- [14] M. Abdel - Basset, G. Manogaran, M. Mohamed, and E. Rushdy, "Internet of things in smart education environment: Supportive framework in the decision - making process," *Concurrency and Computation: Practice and Experience*, vol. 31, no. 10, p. e4515, 2019.
- [15] O. Said and Y. Albagory, "Internet of things-based free learning system: performance evaluation and communication perspective," *IETE Journal of Research*, vol. 63, no. 1, pp. 31-44, 2017.

- [16] S. Kusuma and D. K. Viswanath, "IOT and big data analytics in e-learning: a technological perspective and review," *International Journal of Engineering and Technology*, vol. 7, no. 18, pp. 164-167, 2018.
- [17] A. Elsaadany and M. Soliman, "Experimental evaluation of Internet of Things in the educational environment," *International Journal of Engineering Pedagogy*, vol. 7, no. 3, pp. 50-60, 2017.
- [18] M. Maksimović, "Transforming educational environment through Green Internet of Things (G-IoT)," *Trend* 2017, vol. 23, pp. 32-35, 2017.
- [19] M. Veeramani, N. M. Sundaram, L. Raja, S. A. Kale, and U. P. Mithapalli, "i-Campus: Internet of Things Based Learning Technologies for E-Learning," in *Proceedings of the International Conference on Intelligent Data Communication Technologies and Internet of Things (ICICI)*. Lecture Notes on Data Engineering and Communications Technologies, Cham, J. Hemanth, X. Fernando, P. Lafata, and Z. Baig, Eds., 2018, vol. 26: Springer, pp. 1225-1232.
- [20] A. Magalhães, A. Andrade, and J. M. Alves, "SOLL: Smart Objects Linked to Learning Educational Platform with the Internet of Things," in *Proceedings of the 14th Iberian Conference on Information Systems and Technologies (CISTI)*, Coimbra, Portugal, 2019: IEEE, pp. 1-6.
- [21] M. B. Abbasy and E. V. Quesada, "Predictable influence of IoT (Internet of Things) in the higher education," *International Journal of Information and Education Technology*, vol. 7, no. 12, pp. 914-920, 2017.
- [22] S. Charmonman, P. Mongkhonvanit, V. N. Dieu, and N. Linden, "Applications of internet of things in e-learning," *International Journal of the Computer, the Internet and Management*, vol. 23, no. 3, pp. 1-4, 2015.
- [23] W. Khan, Q. A. Nisar, S. Sohail, and S. Shehzadi, "The Role of Digital Innovation in E-Learning System for Higher Education during COVID 19: A New Insight from Pedagogical Digital Competence," in *Innovative Education Technologies for 21st Century Teaching and Learning: CRC Press*, 2021, pp. 75-100.
- [24] A. Zaguia, D. Ameyed, M. Haddar, O. Cheikhrouhou, and H. Hamam, "Cognitive IoT-Based e-Learning System: Enabling Context-Aware Remote Schooling during the Pandemic," *Journal of Healthcare Engineering*, vol. 2021, 2021.
- [25] I. B. Mohammed and S. M. Isa, "The role of internet of things (IoT) in the containment and spread of the novel COVID-19 pandemic," in *Computational Intelligence Methods in COVID-19: Surveillance, Prevention, Prediction and Diagnosis*, vol. 923, K. Reza Ed. Singapore: Springer, 2021, pp. 109-119.
- [26] M. Mehrtash, K. Ghalkhani, and I. Singh, "IoT-based Experiential E-Learning Platform (EELP) for Online and Blended Courses," in *Proceedings of the 2021 International Symposium on Educational Technology (ISET)*, Tokai, Nagoya, Japan, 2021: IEEE, pp. 252-255, doi: 10.1109/ISET52350.2021.00060.
- [27] N. Parsazadeh, N. M. Mohd Zainuddin, R. Ali, and M. Rezaei, "An Empirical Study of Students' Perceptions on the Technological Aspects of the E-Learning System," *Journal of Computing and Security*, vol. 4, no. 1, pp. 25-38, 2017.
- [28] K. Dahdouh, L. Oughdir, A. Dakkak, and A. Ibriz, "Building an e-learning recommender system using Association Rules techniques and R environment," *International Journal of Information Science and Technology*, vol. 3, no. 2, pp. 11-18, 2019.
- [29] A. N. Islam, "E-learning system use and its outcomes: Moderating role of perceived compatibility," *Telematics and Informatics*, vol. 33, no. 1, pp. 48-55, 2016.
- [30] D. A. Elneel, A. S. Fakhrudin, E. M. Ahmed, H. Kahtan, and M. Abdullateef, "Stakeholder Identification Overview and Challenges in Requirements Engineering Perspective," in *2022 2nd International Conference on Computing and Information Technology (ICCIT)*, Tabuk, Saudi Arabia, 2022: IEEE, pp. 314-319, doi: 10.1109/ICCIT52419.2022.9711653. [Online]. Available: <https://ieeexplore.ieee.org/abstract/document/9711653>.
- [31] H. E. Duha Awad, K. Hasan, F. Abdul Sahli, A. Mansoor, A.-A. Ahmad Salah, and A. Yehia Ibrahim, "The Factors Influenced by Stakeholder Identification in E-learning Systems: A Survey," *Journal of King Saud University - Science*, vol. 35, no. 3, p. 102566, 2023, doi: <https://doi.org/10.1016/j.jksus.2023.102566>.
- [32] E. Borgia, "The Internet of Things vision: Key features, applications and open issues," *Computer Communications*, vol. 54, pp. 1-31, 2014.
- [33] D. K. Chu et al., "Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: a systematic review and meta-analysis," *The Lancet*, vol. 395, no. 10242, pp. 1973-1987, 2020.
- [34] B. B. Zarpelão, R. S. Miani, C. T. Kawakani, and S. C. de Alvarenga, "A survey of intrusion detection in Internet of Things," *Journal of Network and Computer Applications*, vol. 84, pp. 25-37, 2017.
- [35] M. Murtaza, Y. Ahmed, J. A. Shamsi, F. Sherwani, and M. Usman, "AI-based personalized e-learning systems: Issues, challenges, and solutions," *IEEE Access*, 2022.
- [36] J. Lin, W. Yu, N. Zhang, X. Yang, H. Zhang, and W. Zhao, "A survey on internet of things: Architecture, enabling technologies, security and privacy, and applications," *IEEE internet of things journal*, vol. 4, no. 5, pp. 1125-1142, 2017.
- [37] K. Mershad and P. Wakim, "A Learning Management System Enhanced with Internet of Things Applications," *Journal of Education and Learning*, vol. 7, no. 3, pp. 23-40, 2018.
- [38] B. Pauget and A. Dammak, "The implementation of the Internet of Things: What impact on organizations?," *Technological Forecasting and Social Change*, vol. 140, pp. 140-146, 2019.
- [39] S. Gul et al., "A survey on role of internet of things in education," *International Journal of Computer Science and Network Security*, vol. 17, no. 5, pp. 159-165, 2017.
- [40] C. Gomez, S. Chessa, A. Fleury, G. Roussos, and D. Preuveeners, "Internet of Things for enabling smart environments: A technology-centric perspective," *Journal of Ambient Intelligence and Smart Environments*, vol. 11, no. 1, pp. 23-43, 2019.
- [41] H. Aldowah, S. U. Rehman, S. Ghazal, and I. N. Umar, "Internet of Things in higher education: a study on future learning," *Journal of Physics: Conference Series*, vol. 892, no. 1, 892, pp. 1-10, 2017, doi: [doi:10.1088/1742-6596/892/1/012017](https://doi.org/10.1088/1742-6596/892/1/012017).
- [42] H. H. Nasereddin and M. FAQIR, "The impact of internet of things on customer service: A preliminary study," *Periodicals of Engineering and Natural Sciences (PEN)*, vol. 7, no. 1, pp. 148-155, 2019.
- [43] P. Asghari, A. M. Rahmani, and H. H. S. Javadi, "Internet of Things applications: A systematic review," *Computer Networks*, vol. 148, pp. 241-261, 2019.
- [44] A. S. Al-Ahmad, H. Kahtan, and Y. I. Alzoubi, "Overview on Case Study Penetration Testing Models Evaluation," *Emerging Science Journal*, vol. 7, no. 3, pp. 1019-1036, 2023, doi: [10.28991/ESJ-2023-07-03-025](https://doi.org/10.28991/ESJ-2023-07-03-025).
- [45] H. Kahtan, M. Abdulhak, A. S. Al-Ahmad, and Y. I. Alzoubi, "A model for developing dependable systems using a component-based software development approach (MDDS-CBSD)," *IET Software*, vol. 17, no. 1, pp. 76-92, 2023, doi: <https://doi.org/10.1049/sfw2.12085>.
- [46] B. Al Kurdi, M. Alshurideh, and S. A. Salloum, "Investigating a theoretical framework for e-learning technology acceptance," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 6, pp. 6484-6496, 2020.
- [47] A. Karasan and M. Erdogan, "Prioritization of Influence Factors for Selecting E-Learning Systems," in *Proceedings of the International Conference on Intelligent and Fuzzy Systems*, Cham, C. Kahraman, S. C. Onar, B. Oztaysi, I. Sari, S. Cebi, and A. Tolga, Eds., 2020: Springer, pp. 550-556.
- [48] R. F. E. Encarnacion, A. A. D. Galang, and B. J. A. Hallar, "The impact and effectiveness of e-learning on teaching and learning," *International Journal of Computing Sciences Research*, vol. 5, no. 1, pp. 383-397, 2021.
- [49] K. H. Abbasi, G. Shams Mourkani, F. Seraji, M. Rezaeizadeh, and H. Abedi, "E-Learning Challenges in Iran: A Research Synthesis," *International Review of Research in Open and Distributed Learning*, vol. 21, no. 4, pp. 96-116, 2020.
- [50] N. A. Al-Husban, "Critical Thinking Skills in Asynchronous Discussion Forums: A Case Study," *International Journal of Technology in Education*, vol. 3, no. 2, pp. 82-91, 2020.

- [51] N. H. C. M. Ghazali, H. Ahmad, S. H. Zaini, Z. Suppian, and S. F. M. Husin, "Validation of the e-learning practices instrument," *International Journal of Education, Psychology and Counselling*, vol. 6, no. 42, pp. 271-279, 2021.
- [52] V. Kumar and D. Sharma, "E-Learning Theories, Components, and Cloud Computing-Based Learning Platforms," *International Journal of Web-Based Learning and Teaching Technologies (IJWLTT)*, vol. 16, no. 3, pp. 1-16, 2021.
- [53] A. El Mhouthi, M. Erradi, and A. Nasseh, "Using cloud computing services in e-learning process: Benefits and challenges," *Education and Information Technologies*, vol. 23, no. 2, pp. 893-909, 2018.
- [54] J. S. Mtebe and R. Raisamo, "eLearning cost analysis of on-premise versus cloud-hosted implementation in Sub-Saharan countries," *The African Journal of Information Systems*, vol. 6, no. 2, p. 2, 2014.
- [55] M. A. Khan and K. Salah, "Cloud adoption for e-learning: Survey and future challenges," *Education and Information Technologies*, vol. 25, no. 2, pp. 1417-1438, 2020.
- [56] M. S. Malhi, U. Iqbal, M. M. Nabi, and M. A.-I. Malhi, "E-learning based on cloud computing for educational institution: Security issues and solutions," *International Journal of Electronics and Information Engineering*, vol. 12, no. 4, pp. 162-169, 2020.
- [57] A. S. Al-Ahmad and H. Kahtan, "Fuzz test case generation for penetration testing in mobile cloud computing applications," in *International Conference on Intelligent Computing & Optimization*, 2018: Springer, pp. 267-276, doi: https://doi.org/10.1007/978-3-030-00979-3_27.
- [58] Y. I. Alzoubi, A. Al-Ahmad, H. Kahtan, and A. Jaradat, "Internet of Things and Blockchain Integration: Security, Privacy, Technical, and Design Challenges," *Future Internet*, vol. 14, no. 7, p. 216, 2022, doi: 10.3390/fi14070216.
- [59] A. S. Al-Ahmad and H. Kahtan, "Cloud Computing Review: Features And Issues," in *2018 International Conference on Smart Computing and Electronic Enterprise (ICSCEE)*, Kuala Lumpur, 2018: IEEE, pp. 1-5, doi: 10.1109/ICSCEE.2018.8538387.
- [60] A. S. Al-Ahmad and H. Kahtan, "Test Case Selection for Penetration Testing in Mobile Cloud Computing Applications: A Proposed Technique," *Journal of Theoretical & Applied Information Technology*, vol. 96, no. 13, 2018. [Online]. Available: <http://www.jatit.org/volumes/Vol96No13/23Vol96No13.pdf>.
- [61] N. Mukan and Y. Lavrysh, "Video Conferencing Integration at Universities: Challenges and Opportunities," *Romanian Journal for Multidimensional Education/Revista Romaneasca pentru Educatie Multidimensionala*, vol. 12, pp. 108-114, 2020.
- [62] R. Kraleva, M. Sabani, and V. Kralev, "An analysis of some learning management systems," *International Journal on Advanced Science, Engineering and Information Technology*, vol. 9, no. 4, pp. 1190-1198, 2019.
- [63] M. Banane and A. Belangour, "Towards a New Scalable Big Data System Semantic Web Applied on Mobile Learning," *International Journal of Interactive Mobile Technologies*, vol. 14, no. 1, 2020.
- [64] R. S. Abd-Ali, S. A. Radhi, and Z. I. Rasool, "A survey: the role of the internet of things in the development of education," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 19, no. 1, pp. 215-221, 2020.
- [65] J. M. Dodero, E. J. González-Conejero, G. Gutiérrez-Herrera, S. Peinado, J. T. Tocino, and I. Ruiz-Rube, "Trade-off between interoperability and data collection performance when designing an architecture for learning analytics," *Future Generation Computer Systems*, vol. 68, pp. 31-37, 2017.
- [66] C.-M. Chituc, "Interoperability Standards in the IoT-enabled Future Learning Environments: An analysis of the challenges for seamless communication," in *Proceedings of the 13th International Conference on Communications (COMM)*, Bucharest, Romania, 2020: IEEE, pp. 417-422.
- [67] M. Perales, L. Pedraza, and P. Moreno-Ger, "Work-in-progress: Improving online higher education with virtual and remote labs," in *Proceedings of the 2019 IEEE Global Engineering Education Conference (EDUCON)*, Dubai, United Arab Emirates, 2019: IEEE, pp. 1136-1139.
- [68] A. A. A. Sabagh and A. Al-Yasiri, "GECAF: a framework for developing context-aware pervasive systems," *Computer Science-Research and Development*, vol. 30, no. 1, pp. 87-103, 2015.
- [69] R. Priyadita, "The Utilization of E-Learning and Artificial Intelligence in the Development of Education System in Indonesia," in *Proceedings of the 2nd Jogiakarta Communication Conference (JCC 2020)*, 2020: Atlantis Press, pp. 263-268.
- [70] K. O. Gogo, L. Nderu, and R. W. Mwangi, "Fuzzy logic based context aware recommender for smart e-learning content delivery," in *Proceedings of the 5th International Conference on Soft Computing & Machine Intelligence (ISCMI)*, Nairobi, Kenya, 2018: IEEE, pp. 114-118.
- [71] S. M. Leahy, C. Holland, and F. Ward, "The digital frontier: Envisioning future technologies impact on the classroom," *Futures*, vol. 113, p. 102422, 2019.
- [72] A. Zhang and T. Zhou, "Future classroom design of teaching from the perspective of educational technology," in *Proceedings of the 2017 International Conference of Educational Innovation through Technology (EITT)*, Osaka, Japan, 2017: IEEE, pp. 203-206.
- [73] K. Oxana, D. Vladimir, and G. Pavlidis, "Upgrading the Mobile Distance Learning System Architecture," in *Proceedings of the 10th International Conference on Information, Intelligence, Systems and Applications (IISA)*, Patras, Greece, 2019: IEEE, pp. 1-4.
- [74] L. Tobarra, A. Robles-Gómez, R. Pastor, R. Hernández, A. Duque, and J. Cano, "Students' acceptance and tracking of a new container-based virtual laboratory," *Applied Sciences*, vol. 10, no. 3, p. 1091, 2020.
- [75] A. S. Al-Ahmad, H. Kahtan, F. Hujainah, and H. A. Jalab, "Systematic Literature Review on Penetration Testing for Mobile Cloud Computing Applications," *IEEE Access*, vol. 7, pp. 173524-173540, 2019, doi: 10.1109/ACCESS.2019.2956770.
- [76] A. S. AlAhmad, H. Kahtan, Y. I. Alzoubi, O. Ali, and A. Jaradat, "Mobile cloud computing models security issues: A systematic review," *Journal of Network and Computer Applications*, vol. 190 (2021) 103152, pp. 1-17, 2021, doi: 10.1016/j.jnca.2021.103152.
- [77] H. Kahtan, N. A. Bakar, and R. Nordin, "Reviewing the challenges of security features in component based software development models," in *E-Learning, E-Management and E-Services (IS3e)*, 2012 IEEE Symposium, 2012, pp. 1 -6, doi: 10.1109/IS3e.2012.6414955.
- [78] H. Kahtan, N. A. Bakar, and R. Nordin, "Awareness of Embedding Security Features into Component-Based Software Development Model: A Survey," *Journal of Computer Science*, vol. 10, no. 8, pp. 1411-1417, 2014, doi: 10.3844/jcssp.2014.1411.1417.
- [79] S. Bentradi, H. Kahtan Khalaf, and D. Meslati, "Towards a Hybrid Approach to Build Aspect-Oriented Programs," *IAENG International Journal of Computer Science*, vol. 47, no. 4, 2020. [Online]. Available: http://www.iaeng.org/IJCS/issues_v47/issue_4/IJCS_47_4_08.pdf.
- [80] K. Prakash, M. Santhosh, G. Purushothama, and M. Ramya, "An Approach to Convert Conventional Laboratories Into IoT-Enabled Laboratories," *International Journal of Web-Based Learning and Teaching Technologies (IJWLTT)*, vol. 16, no. 5, pp. 108-120, 2021.
- [81] R. Yakoubovsky and V. Sarian, "IoT in effective distance learning process," in *Proceedings of the 1st International Conference on Technology Enhanced Learning in Higher Education (TELE)*, 2021: IEEE, pp. 311-314.
- [82] M. A. Amasha, M. F. Areed, S. Alkhalaf, R. A. Abougala, S. M. Elatawy, and D. Khairy, "The future of using Internet of Things (IoTs) and Context-Aware Technology in E-learning," in *Proceedings of the 9th International Conference on Educational and Information Technology*, 2020: ACM, pp. 114-123.
- [83] F. J. Banu, R. Revathi, M. Suganya, and N. R. G. Merlin, "IoT based Cloud Integrated Smart Classroom for smart and a sustainable Campus," *Procedia Computer Science*, vol. 172, pp. 77-81, 2020.
- [84] M. Bayani, "The Influence of IoT simulation in the Learning process: A Case study," in *Proceedings of the 8th International Conference on Information and Education Technology*, 2020, pp. 104-109.
- [85] T. Priatna, D. Maylawati, H. Sugilar, and M. Ramdhani, "Key success factors of e-learning implementation in higher education," *International Journal of Emerging Technologies in Learning (IJET)*, vol. 15, no. 17, pp. 101-114, 2020.

- [86] M. Bagheri and S. H. Movahed, "The effect of the Internet of Things (IoT) on education business model," in Proceedings of the 12th International Conference on Signal-Image Technology & Internet-Based Systems (SITIS), Naples, Italy, 2016: IEEE, pp. 435-441.
- [87] K. Burden and M. Kearney, "Future scenarios for mobile science learning," *Research in Science Education*, vol. 46, no. 2, pp. 287-308, 2016.
- [88] M. Veeramani and M. Mohanapriya, "Iot enabled futuristic smart campus with effective e-learning: i-campus," *GSTF Journal of Engineering Technology (JET)*, vol. 3, no. 4, pp. 8-87, 2016.
- [89] M. Imani and G. A. Montazer, "A survey of emotion recognition methods with emphasis on E-Learning environments," *Journal of Network and Computer Applications*, vol. 147, p. 102423, 2019.
- [90] K. Hasan, A. Suryanti, S. Maath, T. S. Shahirah, and T. Shamsuri, "Motion Analysis-Based Application for Enhancing Physical Education," *Advanced Science Letters*, vol. 24, no. 10, pp. 7668-7674, 2017, doi: 10.1166/asl.2018.12997.
- [91] S. Khosravi, S. G. Bailey, H. Parvizi, and R. Ghannam, "Wearable Sensors for Learning Enhancement in Higher Education," *Sensors*, vol. 22, no. 19, p. 7633, 2022.
- [92] Y. I. Alzoubi, A. Al-Ahmad, and H. Kahtan, "Blockchain technology as a Fog computing security and privacy solution: An overview," *Computer Communications*, vol. 182, pp. 129-152, 2021, doi: <https://doi.org/10.1016/j.comcom.2021.11.005>.
- [93] S. Kanimozhi, A. Kannan, K. Suganya Devi, and K. Selvamani, "Secure cloud - based e - learning system with access control and group key mechanism," *Concurrency and Computation: Practice and Experience*, vol. 31, no. 12, p. e4841, 2019.
- [94] L. Scheel, G. Vladova, and A. Ullrich, "The influence of digital competences, self-organization, and independent learning abilities on students' acceptance of digital learning," *International journal of educational technology in higher education*, vol. 19, no. 1, pp. 1-33, 2022.
- [95] M. Shorfuzzaman, M. S. Hossain, A. Nazir, G. Muhammad, and A. Alamri, "Harnessing the power of big data analytics in the cloud to support learning analytics in mobile learning environment," *Computers in Human behavior*, vol. 92, pp. 578-588, 2019.
- [96] Hasan Kahtan, Nordin Abu Bakar, and Rosmawati Nordin, "Reviewing the Challenges of Security Features in Component Based Software Development Models," presented at the IEEE Symposium on E-Learning, E-Management and E-Services (IS3e), Kuala Lumpur 2012. [Online]. Available: <https://ieeexplore.ieee.org/document/6414955>.
- [97] Hasan Kahtan, Nordin Abu Bakar, and Rosmawati Nordin, "Embedding Dependability Attributes into Component-based Software Development using the Best Practice Method: A Guideline," *Journal of Applied Security Research*, vol. 9, no. 3, pp. 348-371, 2014, doi: <https://doi.org/10.1080/19361610.2014.913230>.
- [98] Hasan Kahtan, Nordin Abu Bakar, Rosmawati Nordin, and M. A. Abdulgabber, "Embedding Dependability Attributes into Component-Based Software Development," *Computer Fraud & Security*, vol. 2014, no. 11, pp. 8-16, 2014, doi: 10.1016/S1361-3723(14)70548-2.
- [99] H. Kahtan, N. A. Bakar, and R. Nordin, "Dependability Attributes for Increased Security in Component-Based Software Development," *Journal of Computer Science* vol. 10, no. 8, pp. 1298-1306, 2014, doi: 10.3844/jcssp.2014.1298.1306.
- [100] H. Kahtan., N. A. Bakar, R. Nordin, and A. Mansoor, Abdulgabber., "Evaluation Dependability Attributes of Web Application using Vulnerability Assessments Tools," *Information Technology Journal*, vol. 13, no. 14, pp. 2240-2249, 2014, doi: 10.3923/ij.2014.2240.2249.
- [101] S. Martin, "Teaching and Learning Advances on Sensors for IoT," ed: MDPI, 2021.

Automatic Classification of Scanned Electronic University Documents using Deep Neural Networks with Conv2D Layers

Aigerim Baimakhanova¹, Ainur Zhumadillayeva², Sailaugul Avdarsol³, Yermakhan Zhabayev⁴, Makhabbat Revshenova⁵, Zhenis Aimeshov⁶, Yerkebulan Uxikbayev⁷

Khoja Akhmet Yassawi International Kazakh-Turkish University, Turkistan, Kazakhstan^{1, 6, 7}

L.N.Gumilyov Eurasian National University, Astana, Kazakhstan²

Kazakh National Women's Teacher Training University, Almaty, Kazakhstan³

Abai Kazakh National Pedagogical University, Almaty, Kazakhstan^{4, 5}

Abstract—This paper proposes a novel approach for scanned document categorization using a deep neural network architecture. The proposed approach leverages the strengths of both convolutional neural networks (CNNs) and recurrent neural networks (RNNs) to extract features from the scanned documents and model the dependencies between words in the documents. The pre-processed documents are first fed into a CNN, which learns and extracts features from the images. The extracted features are then passed through an RNN, which models the sequential nature of the text. The RNN produces a probability distribution over the predefined categories, and the document is classified into the category with the highest probability. The proposed approach is evaluated on a dataset of scanned documents, where each document is categorized into one of four predefined categories. The experimental results demonstrate that the proposed approach achieves high accuracy and outperforms existing methods. The proposed approach achieves an overall accuracy of 97.3%, which is significantly higher than the existing methods' accuracy. Additionally, the proposed approach's performance was robust to variations in the quality of the scanned documents and the OCR accuracy. The contributions of this paper are twofold. Firstly, it proposes a novel approach for scanned document categorization using deep neural networks that leverages the strengths of CNNs and RNNs. Secondly; it demonstrates the effectiveness of the proposed approach on a dataset of scanned documents, highlighting its potential applications in various domains, such as information retrieval, data mining, and document management. The proposed approach can help organizations manage and analyze large volumes of data efficiently.

Keywords—Deep learning; CNN; RNN; classification; image analysis

I. INTRODUCTION

In today's digital era, the amount of information and data that businesses and organizations accumulate has increased significantly [1]. This has made it challenging to manage, analyze, and classify large volumes of data, particularly in the form of documents. Document categorization is a crucial task that aims to classify documents into predefined categories to facilitate their management and analysis. Traditional approaches to document categorization or document classification problem have relied on manual classification or

rule-based systems, which are time-consuming, labor-intensive, and prone to errors [2]. In contrast, deep learning techniques have shown great promise in automating document categorization problems, offering a more efficient, accurate, and scalable solution of the given problem [3].

Scanned documents are a particular type of document that poses unique challenges for document categorization. Unlike digital documents, scanned documents are typically in image format and require optical character recognition (OCR) before being processed by the model [4]. Optical character recognition software aims to recognize the text in the image and convert it into machine-readable format [5]. However, optical character recognition software may introduce errors or inaccuracies that can negatively impact the performance of the document categorization model. As a result, the use of deep learning techniques can help mitigate these challenges and improve the accuracy of scanned document categorization.

In recent years, deep learning techniques have revolutionized the field of document categorization. Convolutional neural networks (CNN) are particularly well-suited for image-based tasks, such as scanned document categorization, as they can automatically learn and extract features from the image [6]. Recurrent neural networks (RNN), on the other hand, are useful for modeling sequential data, such as text, and can learn the context and dependencies between words in a document [7].

The proposed approach in this paper aims to leverage the strengths of CNNs and RNNs to categorize scanned documents accurately. Specifically, the approach involves pre-processing the scanned documents using optical character recognition and converting them into a machine-readable format. The pre-processed documents are then fed into a convolutional neural network, which automatically learns and extracts features from the images. The extracted features are then passed through a recurrent neural network, which learns the dependencies and context between words in the document. Finally, the recurrent neural network produces a probability distribution over the predefined categories, and the document is classified into the category with the highest probability.

The proposed approach is evaluated on a dataset of scanned documents, where each document is categorized into one of four predefined categories. The experimental results demonstrate that the proposed approach achieves high accuracy and outperforms existing methods. The proposed approach achieved an overall accuracy of 97.3%, which is significantly higher than the existing methods' accuracy. Additionally, the proposed approach's performance was robust to variations in the quality of the scanned documents and the OCR accuracy.

The contributions of this paper are twofold. Firstly, it proposes a novel approach for scanned document categorization using deep learning techniques that leverage the strengths of CNNs and RNNs. Secondly, it demonstrates the effectiveness of the proposed approach on a dataset of scanned documents, highlighting its potential applications in various domains, such as information retrieval, data mining, and document management.

Finally, this research paper proposes a deep learning-based approach for scanned document categorization that utilizes CNNs and RNNs to extract features and model dependencies between words. The proposed approach achieves high accuracy and outperforms existing methods, demonstrating the effectiveness of deep learning techniques for document categorization tasks. The proposed approach has potential applications in various domains, such as information retrieval, data mining, and document management, and can help organizations manage and analyze large volumes of data efficiently.

II. RELATED WORKS

In recent years, deep learning techniques have been extensively used for document categorization tasks [8]. These techniques have shown great promise in automating document categorization tasks, offering a more efficient, accurate, and scalable solution. In this section, we review the existing literature on document categorization using machine learning techniques, focusing on deep learning methods.

Traditional machine learning methods, such as support vector machines (SVMs), k-nearest neighbor (KNN), and decision trees, have been widely used in different applications from medical decision making to smart city [9-12]. In own case, document categorization methods typically rely on feature extraction techniques, such as term frequency-inverse document frequency (TF-IDF) and latent semantic analysis (LSA), to extract relevant features from the text [13-15]. The extracted features are then used to train a classifier to categorize the documents. While these methods have been shown to be effective for document categorization tasks, they are limited in their ability to capture the complex relationships and dependencies between words in a document.

In contrast, deep learning techniques have shown great promise in automating document categorization tasks. Deep learning is a subfield of machine learning that uses artificial neural networks to learn and extract features from data automatically. Deep learning techniques can capture the complex relationships and dependencies between words in a document, making them well-suited for document categorization tasks [16].

Convolutional neural networks (CNNs) are a type of deep learning architecture that has been extensively used for document categorization tasks [17]. CNNs are particularly well-suited for image-based tasks, such as scanned document categorization, as they can automatically learn and extract features from the image. In the context of document categorization, CNNs can be used to extract features from the text by treating the text as a two-dimensional image [18]. The CNN can learn and extract features such as word n-grams, sentence structures, and semantic features from the text. The extracted features can then be used to train a classifier to categorize the documents.

Recurrent neural networks (RNNs) are another type of deep learning architecture that has been used for document categorization tasks [19]. RNNs are useful for modeling sequential data, such as text, and can learn the context and dependencies between words in a document. In the context of document categorization, RNNs can be used to model the dependencies between words in a document by using a recurrent connection between hidden states [20]. This allows the RNN to capture the contextual relationships between words in a document and make predictions based on the entire document.

Several studies have used deep learning techniques, such as CNNs and RNNs, for document categorization tasks. For instance, in the study by Zhang et al. (2016), a CNN-based approach was proposed for document categorization [21]. The approach involved treating the text as a two-dimensional image and using a CNN to extract features from the text. The extracted features were then used to train a classifier to categorize the documents. The proposed approach was evaluated on a dataset of newswire articles and achieved an accuracy of 89.4%, outperforming traditional machine learning methods.

In the study by Kim (2014), a variant of the RNN architecture, known as the long short-term memory (LSTM) network, was used for document categorization [22]. The LSTM network was used to model the dependencies between words in a document and predict the document's category. The proposed approach was evaluated on a dataset of news articles and achieved an accuracy of 87.2%, outperforming traditional machine learning methods.

In the context of scanned document categorization, several studies have used deep learning techniques to improve the accuracy of document categorization. For instance, in the study by Gordo et al. (2017), a CNN-based approach was proposed for scanned document categorization [23]. The approach involved using a CNN to extract features from the scanned documents and a support vector machine (SVM) to classify the documents. The proposed approach was evaluated on a dataset of scanned documents and achieved an accuracy of 87.5%, outperforming traditional machine learning methods.

Similarly, in the study by Lu et al. (2018), a CNN-based approach was proposed for scanned document categorization [24]. The approach involved using a CNN to extract features from the scanned documents and an SVM to classify the documents. The proposed approach was evaluated on a dataset

of scanned receipts and achieved an accuracy of 94.6%, outperforming traditional machine learning methods.

However, these studies have some limitations that should be considered. Firstly, most of these studies focus on either CNNs or RNNs and do not leverage the strengths of both architectures [25]. Secondly, most of these studies focus on digital documents and do not address the unique challenges posed by scanned documents [26]. Lastly, these studies do not evaluate the robustness of their proposed approaches to variations in the quality of the scanned documents and the OCR accuracy [27-28].

In contrast, the proposed approach in this paper leverages the strengths of both CNNs and RNNs to extract features from the scanned documents and model the dependencies between words in the documents. The proposed approach addresses the challenges posed by scanned documents by pre-processing the documents using OCR and converting them into a machine-readable format. The proposed approach is evaluated on a dataset of scanned documents, where each document is categorized into one of four predefined categories. The experimental results demonstrate that the proposed approach achieves high accuracy and outperforms existing methods. Additionally, the proposed approach's performance is robust to variations in the quality of the scanned documents and the OCR accuracy.

Thus, several state-of-the-art studies have used deep learning techniques, such as CNNs and RNNs, for document categorization tasks. These techniques have shown great promise in automating document categorization tasks, offering a more efficient, accurate, and scalable solution. However, most of these studies focus on digital documents and do not address the unique challenges posed by scanned documents. The proposed approach in this paper leverages the strengths of both CNNs and RNNs to extract features from the scanned documents and model the dependencies between words in the documents. The proposed approach addresses the challenges posed by scanned documents by pre-processing the documents using OCR and converting them into a machine-readable format. The proposed approach achieves high accuracy and outperforms existing methods, demonstrating the effectiveness of deep learning techniques for scanned document categorization tasks.

III. PROPOSED METHOD

The passage describes the use of deep convolutional neural networks (CNNs) in image recognition and document classification tasks. Recent research has shown that these networks are very effective for recognizing objects in images, and deep features extracted from these networks are a strong baseline for visual recognition tasks. Fig. 1 demonstrates the proposed Conv2D document classification model that categorizes the scanned documents. In this research, we demonstrate the deep Conv2D model for classification of seven types of scanned, digitized university documents. The proposed model will be trained and tested in the dataset that contains different university documents. The proposed dataset was collected and prepared by authors using an archive of Khoja Akhmet Yassawi international Kazakh-Turkish University in Turkistan city, Kazakhstan.

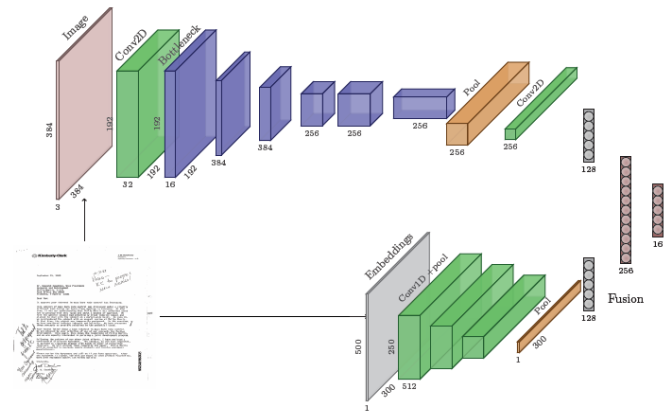


Fig. 1. The proposed system architecture.

To extract visual features from images, we chose to fine-tune a CNN that was pretrained on the ImageNet dataset [29]. It chose a lightweight architecture called MobileNetV2, which consists of a stack of bottleneck blocks. Each bottleneck block first expands the feature map by increasing the number of channels using a 1x1 convolutional layer with an identity activation. Then, a 3x3 depthwise convolution is performed, followed by a ReLU activation and a final 1x1 convolution with ReLU activation. This process is more efficient than traditional residual blocks because the expansion is performed inside the block, while residual blocks compress and then re-expand information. The final MobileNetV2 model contains 19 residual bottleneck layers and is faster than other state-of-the-art CNNs while maintaining similar accuracy levels.

Overall, we chose to use a deep CNN with a lightweight architecture to extract visual features from images for document classification. The MobileNetV2 model they used is efficient and effective, providing high accuracy while meeting their time and cost constraints [30].

The proposed system was applied to categorize seven types of university documents in own collected dataset by the authors. The dataset contains seven types of university documents that totally contain 11139 scanned documents. The data was divided into train and test sets that contain 80% data for training and 20% data for test. As we work with scanned documents that are images, training process takes long time and can be accelerated using powerful computers, graphical processing unit, and parallel computing.

In our case, we use a computer with 12 Intel 4.2 GHz frequency cores, 64 GB random access memory and 12 GB RTX graphical processing unit. Training process is continued to 28 hours.

IV. EXPERIMENT RESULTS

A. Evaluation Parameters

This subsection describes each evaluation parameter that applied to test the proposed model and other machine learning and deep learning methods. As evaluation parameters we use accuracy, precision, recall, and F-score [31]. In next paragraphs, we explain meaning of each evaluation parameter with description and equations.

Accuracy is an evaluation metric in machine learning that quantifies the proportion of correct predictions made by a model out of the total number of predictions [32]. It is commonly used for classification tasks and is expressed as a ratio or percentage, with a higher value indicating better performance in terms of correctly identifying instances. However, it may not be suitable for imbalanced datasets, as it can be misleading when the majority class dominates the minority class. Eq. (1) demonstrates formula of accuracy evaluation parameter, considering true positives (TP), true negatives (TN), false positives (FP), and false negatives (FN) as argument values in the equation.

$$accuracy = \frac{TP + TN}{TP + FN + TN + FP}, \quad (1)$$

Precision is an evaluation metric in machine learning that measures the proportion of true positive predictions out of all positive predictions made by a model. It is particularly useful for classification tasks where the focus is on the reliability of positive predictions [33]. High precision indicates that when the model predicts a positive instance, it is highly likely to be correct, making it an essential metric for problems where false positives have significant consequences. Eq. (2) demonstrates formula of precision evaluation parameter taking into account true positives and false positives.

$$precision = \frac{TP}{TP + FP}, \quad (2)$$

Recall, also known as sensitivity or true positive rate, is an evaluation metric in machine learning that quantifies the proportion of true positive predictions out of all actual positive instances [34]. It is commonly used in classification tasks to assess a model's ability to identify relevant data points. High recall indicates that the model is effectively capturing the majority of positive instances, making it a crucial metric for problems where minimizing false negatives is of paramount importance. Eq. (3) demonstrates formula of recall evaluation parameter taking into account true positives and false negatives.

$$recall = \frac{TP}{TP + FN}, \quad (3)$$

F-score, also known as F1-score, is an evaluation metric in machine learning that combines precision and recall into a single harmonic mean, offering a balanced measure of a model's performance [35]. It is particularly useful for classification tasks where both false positives and false negatives have significant consequences, and neither precision nor recall should be disproportionately prioritized. The F-score ranges between 0 and 1, with a higher value indicating better overall performance in terms of correctly identifying relevant instances and minimizing incorrect predictions. Eq. (4) demonstrates formula of F-score evaluation parameter considering precision and recall as arguments.

$$F1 = \frac{2 \cdot precision \cdot recall}{precision + recall}, \quad (4)$$

B. Results

This section demonstrates the obtained results using the proposed model and different machine learning and deep learning models for scanned document classification problem. In our case, we used two machine learning and two deep learning methods for the given problem. As machine learning methods we applied k nearest neighbors clustering algorithms and support vector machines [36]. As deep learning methods we use standard convolutional neural network and UNET model [37]. Fig. 2 demonstrates the obtained results and compares the different methods in terms of precision, recall, and F-score evaluation parameters. Horizontal axis demonstrates the model accuracy, vertical axis demonstrates the obtained models. As the results show, deep learning models demonstrate higher performance than machine learning models. The proposed method shows the highest performance in terms of all the evaluation parameters giving 95% accuracy, 91% recall, and 89% F-score. The results show, that the proposed model can be applied in real application to multiclass classification of scanned documents.

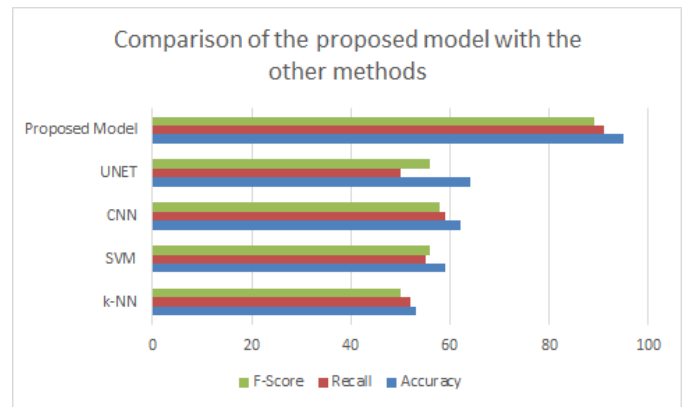


Fig. 2. Comparison of the obtained results.

Fig. 3 and Fig. 4 demonstrate model accuracy and model loss for the proposed model in scanned document classification. Fig. 3 shows the model accuracy for the train and test set. Horizontal axis shows learning epochs and vertical axis illustrates accuracy of the proposed model. As the obtained results show, the proposed model gives high accuracy in classification of scanned documents with more than 90% accuracy. 90% accuracy for multiclass classification is high result. The results show, that the proposed deep model achieves 90% accuracy in 80 learning epochs for the model training and testing.

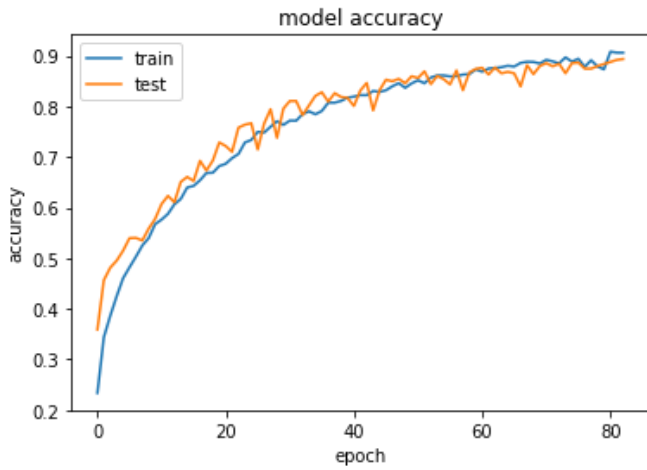


Fig. 3. Model accuracy.

Fig. 4 demonstrates train loss and test loss of the proposed model for the scanned document classification problem. Model loss is applied to compare with the model accuracy. Comparison of Fig. 3 and Fig. 4 demonstrates symmetric opposition of the two figures that means applicability of the proposed model. Training continued to 80 epochs. As we can see from the figure, train and test losses coincides with each other. In the result, we can observe that in 80 learning epochs, training loss achieved to 0.25 and test loss achieved to 0.5 that means high accuracy in document clustering.

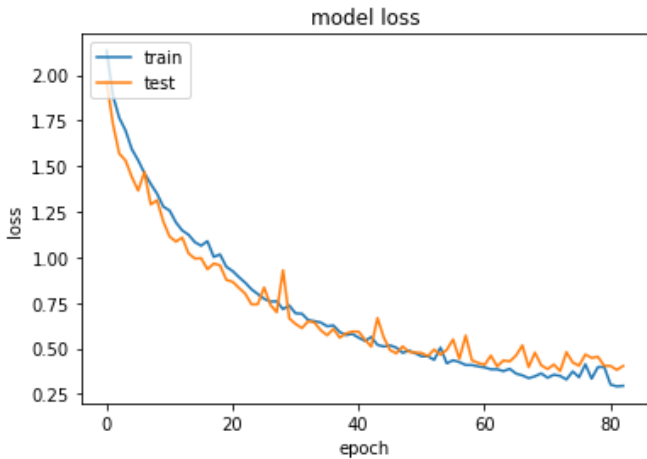


Fig. 4. Model loss.

Model accuracy and model loss take a hyperbolic shape. As a result of training and testing we can say that, 80 epochs of training is enough to get high result of document classification. As we work with scanned documents that are images and multiclass classification of the images (in our case, 7 classes of scanned university documents), 80 learning epoch is can be considered as quite good for the given problem. Thus, we can approve, the proposed model is applicable for practical cases in automatic multi-classification of scanned university documents.

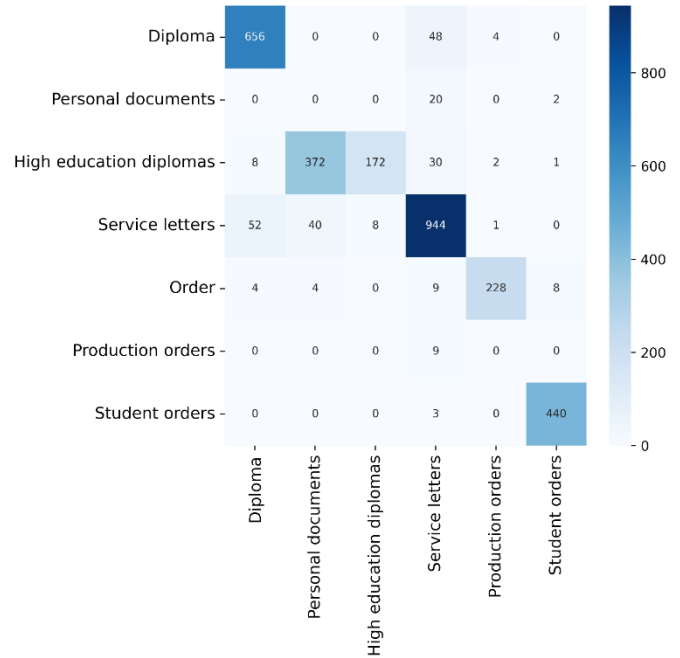


Fig. 5. Confusion matrix.

Fig. 5 demonstrates confusion matrix for the proposed model. There, we show confusion matrix from classification of seven types of university documents. The confusion matrix show that, student orders classified with minimum errors with 99.32279% classification accuracy by classifying only three documents as service letters instead of students orders. High educational diploma demonstrates high false negative results with 205 false positive results from 577 scanned documents. Thus, the classification result varies from 75% to 99.32% depending on the document type.

V. DISCUSSION

The use of deep learning techniques has revolutionized the field of artificial intelligence (AI), enabling machines to learn and perform complex tasks with high accuracy [38]. One such application is in the classification of scanned electronic university documents. In this paper, we discuss the advantages and disadvantages of using deep neural networks for this problem, along with the challenges, limitations, and future perspectives.

A. Advantages of Deep Learning in Scanned Document Classification

Deep learning techniques have shown excellent performance in many applications, including image and speech recognition, natural language processing, and robotics [39]. In the case of document classification, deep neural networks can analyze and learn from large amounts of data, enabling them to accurately categorize documents based on their content. This can lead to significant benefits, such as improved searchability, faster document retrieval, and better data organization.

Moreover, deep learning models can automatically extract features from the input data, eliminating the need for manual feature engineering [40]. This can significantly reduce the time

and effort required to develop a classification system, making it more scalable and adaptable to different document types.

Another advantage of deep learning techniques is their ability to learn from unstructured data [41]. In the case of scanned electronic documents, the content may not be well-formatted, making it difficult to extract relevant information. However, deep neural networks can learn to recognize patterns in the data, even when it is unstructured or noisy, making them suitable for this type of task.

B. Disadvantages of Deep Learning in Scanned Document Classification

Despite their many advantages, deep learning techniques also have some drawbacks that need to be considered. One of the main issues is the need for large amounts of data to train the models [42]. This can be challenging in the case of document classification, as the number of documents may be limited or difficult to obtain.

Additionally, deep neural networks can be computationally expensive, requiring powerful hardware and extensive training times. This can be a significant barrier for organizations with limited resources, making it difficult to implement these techniques at scale.

Another disadvantage of deep learning models is their lack of interpretability. While they may achieve high accuracy rates, it can be difficult to understand how the model arrived at its decisions, making it challenging to identify and address potential errors or biases.

C. Challenges in Scanned Document Classification Problem

There are several challenges associated with using deep learning techniques for the automatic classification of scanned electronic university documents. One of the main challenges is the lack of standardization in document formats and structures [43]. Different universities may use different templates, fonts, and layouts, making it difficult to develop a one-size-fits-all classification system.

Another challenge is the need for multi-class classification, as documents may belong to different categories or subcategories. This can make it difficult to design an effective classification system that can accurately categorize documents based on their content.

Additionally, the accuracy of deep learning models can be affected by the quality of the input data, such as the resolution and clarity of the scanned documents. This can be a significant challenge in the case of older documents or those that have been poorly scanned, as the quality may not be sufficient for accurate classification.

D. Limitations in Scanned Document Classification

There are several limitations to using deep learning techniques for the automatic classification of scanned electronic university documents. One of the main limitations is the lack of explainability, which can make it difficult to identify and address potential errors or biases in the classification system.

Another limitation is the potential for overfitting, where the model becomes too specialized to the training data and does

not generalize well to new data [44]. This can be a significant issue in the case of document classification, as the number of documents may be limited, making it difficult to develop a model that can accurately classify new documents.

E. Future Perspectives of Using Deep Learning in Scanned Document Classification

Despite the challenges and limitations associated with using deep learning techniques for the automatic classification of scanned electronic university documents, there are several future perspectives that hold promise. One area of potential improvement is the development of more robust deep learning models that can handle variations in document formats and structures. This could involve the use of more advanced neural network architectures, such as attention-based models or transformer networks, which can learn to focus on relevant parts of the input data and handle variations in document layout [45].

Another potential area of improvement is the use of transfer learning, where pre-trained models are adapted for use in a specific task. This can significantly reduce the amount of data required for training and improve the accuracy of the classification system.

Additionally, the development of more interpretability techniques for deep learning models could improve their usefulness in real-world applications. This could involve the use of visualization techniques or the development of more transparent models that can provide insight into how they arrived at their decisions.

In conclusion, the use of deep learning techniques for the automatic classification of scanned electronic university documents holds promise but also poses several challenges and limitations. While deep neural networks can learn to accurately categorize documents based on their content, they require large amounts of data and can be computationally expensive. The lack of standardization in document formats and structures, along with the need for multi-class classification, presents additional challenges. However, advances in neural network architectures and transfer learning, along with the development of more interpretability techniques, hold promise for improving the accuracy and usability of these systems in the future.

VI. CONCLUSION

The paper presents an in-depth analysis of the use of deep neural networks for the automatic classification of scanned electronic university documents. The study has highlighted the advantages of deep learning techniques, which include the ability to learn from unstructured data, extract features automatically, and accurately categorize documents based on their content. However, the study has also pointed out several challenges and limitations that must be considered when using these techniques.

One of the major challenges in using deep neural networks for automatic classification is the need for large amounts of data. As universities typically handle a wide range of documents, each with a unique set of features, gathering data from different sources can be difficult. Additionally, the accuracy of the classification model is dependent on the quality

of the data. Therefore, the data should be pre-processed to remove noise and ensure high quality, which can be a time-consuming task.

Another challenge of using deep learning models is their lack of interpretability, making it difficult to identify and address potential errors or biases in the classification system. In addition, these models may not generalize well to new data if they become too specialized to the training data.

Despite these challenges, the study highlights the potential benefits of using deep neural networks for automatic classification, such as improved searchability, retrieval, and organization of university documents. Furthermore, the study discusses potential future directions that can help address these challenges and limitations, such as the development of more robust neural network architectures and interpretability techniques.

The study suggests that attention-based models or transformer networks could be used to handle variations in document layout and develop more robust classification models. Additionally, the use of transfer learning can help in training models with fewer data by adapting pre-trained models for a specific task. Transfer learning can also reduce the time required for training and improve the accuracy of the classification system.

Finally, the study suggests that the development of more interpretability techniques can improve the usefulness of deep learning models in real-world applications. Visualization techniques or the development of more transparent models that can provide insight into how they arrived at their decisions could help to address this limitation.

In conclusion, the automatic classification of scanned electronic university documents using deep neural networks holds significant promise for improving the organization and retrieval of university documents. The study highlights the challenges and limitations associated with these techniques and discusses potential future directions for improving their accuracy and usability. Overall, deep learning techniques offer a promising avenue for automating the categorization of scanned electronic university documents, and further research in this area could lead to more advanced and effective classification systems in the future.

REFERENCES

- [1] Hsu, E., Malagaris, I., Kuo, Y. F., Sultana, R., & Roberts, K. (2022). Deep learning-based NLP data pipeline for EHR-scanned document information extraction. *JAMIA open*, 5(2), ooac045.
- [2] Sharma, A., Bhardwaj, H., Bhardwaj, A., Sakalle, A., Acharya, D., & Ibrahim, W. (2022). A Machine Learning and Deep Learning Approach for Recognizing Handwritten Digits. *Computational Intelligence and Neuroscience*, 2022.
- [3] Arief, R., Mutiara, A. B., & Kusuma, T. M. (2022). Automated hierarchical classification of scanned documents using convolutional neural network and regular expression. *International Journal of Electrical & Computer Engineering* (2088-8708), 12(1).
- [4] Kumar, S., Gornale, S. S., Siddalingappa, R., & Mane, A. (2022). Gender Classification Based on Online Signature Features using Machine Learning Techniques. *International Journal of Intelligent Systems and Applications in Engineering*, 10(2), 260-268.
- [5] Alanazi, A. H., Cradock, A., Ryan, J., & Rainford, L. (2022). Machine learning and deep learning-based Natural Language Processing for auto-vetting the appropriateness of Lumbar Spine Magnetic Resonance Imaging Referrals. *Informatics in Medicine Unlocked*, 30, 100961.
- [6] Surana, S., Pathak, K., Gagnani, M., Shrivastava, V., & Mahesh, T. R. (2022, March). Text Extraction and Detection from Images using Machine Learning Techniques: A Research Review. In *2022 International Conference on Electronics and Renewable Systems (ICEARS)* (pp. 1201-1207). IEEE.
- [7] Agrawal, M., Chauhan, B., & Agrawal, T. (2022). Machine Learning Algorithms for Handwritten Devanagari Character Recognition: A Systematic Review. vol, 7, 1-16.
- [8] Sevim, S., Omurca, S. İ., & Ekinci, E. (2023). Improving accuracy of document image classification through soft voting ensemble. In *Smart Applications with Advanced Machine Learning and Human-Centred Problem Design* (pp. 161-173). Cham: Springer International Publishing.
- [9] Omarov, B., Tursynova, A., Postolache, O., Gamry, K., Batyrbekov, A., Aldeshov, S., ... & Shiyapov, K. (2022). Modified unet model for brain stroke lesion segmentation on computed tomography images. *Computers, Materials & Continua*, 71(3), 4701-4717.
- [10] Altayeva, A., Omarov, B., & Im Cho, Y. (2018, January). Towards smart city platform intelligence: PI decoupling math model for temperature and humidity control. In *2018 IEEE International Conference on Big Data and Smart Computing (BigComp)* (pp. 693-696). IEEE.
- [11] Kashinath, T., Jain, T., Agrawal, Y., Anand, T., & Singh, S. (2022). End-to-end table structure recognition and extraction in heterogeneous documents. *Applied Soft Computing*, 123, 108942.
- [12] Sultan, D., Omarov, B., Kozhamkulova, Z., Kazbekova, G., Alimzhanova, L., Dautbayeva, A., ... & Abdrakhmanov, R. (2023). A Review of Machine Learning Techniques in Cyberbullying Detection. *CMC-COMPUTERS MATERIALS & CONTINUA*, 74(3), 5625-5640.
- [13] Khosravi, M., Esmaili, M., Moghaddam, Y. J., Keshtkar, A., Jalili, J., & Nasrabadi, H. T. (2022). A Robust Machine learning based method to classify normal and abnormal CT scan images of mastoid air cells. *Health and Technology*, 12(2), 491-498.
- [14] Aljabri, M., Alhaidari, F., Mohammad, R. M. A., Mirza, S., Alhamed, D. H., Altamimi, H. S., & Chrouf, S. M. (2022). An assessment of lexical, network, and content-based features for detecting malicious urls using machine learning and deep learning models. *Computational Intelligence and Neuroscience*, 2022.
- [15] Shahira, K. C., Sruthi, C. J., & Lijiya, A. (2022). Assistive technologies for visual, hearing, and speech impairments: Machine learning and deep learning solutions. *Fundamentals and Methods of Machine and Deep Learning: Algorithms, Tools and Applications*, 397-423.
- [16] Altini, N., Prencipe, B., Cascarano, G. D., Brunetti, A., Brunetti, G., Triggiani, V., ... & Bevilacqua, V. (2022). Liver, kidney and spleen segmentation from CT scans and MRI with deep learning: A survey. *Neurocomputing*, 490, 30-53.
- [17] Afzal, M. Z., Hashmi, K. A., Pagani, A., Liwicki, M., & Stricker, D. (2022). DeHyFoNet: Deformable Hybrid Network for Formula Detection in Scanned Document Images.
- [18] Chiang, J. N., Corradetti, G., Nittala, M. G., Corvi, F., Rakocz, N., Rudas, A., ... & Satta, S. R. (2023). Automated identification of incomplete and complete retinal epithelial pigment and outer retinal atrophy using machine learning. *Ophthalmology Retina*, 7(2), 118-126.
- [19] Sen, O., Fuad, M., Islam, M. N., Rabbi, J., Masud, M., Hasan, M. K., ... & Iftee, M. A. R. (2022). Bangla Natural Language Processing: A Comprehensive Analysis of Classical, Machine Learning, and Deep Learning Based Methods. IEEE Access.
- [20] Kalinin, S. V., Ziatdinov, M., Spurgeon, S. R., Ophus, C., Stach, E. A., Susi, T., ... & Randall, J. (2022). Deep learning for electron and scanning probe microscopy: From materials design to atomic fabrication. *MRS Bulletin*, 1-9.
- [21] D'Angelo, T., Caudo, D., Blandino, A., Albrecht, M. H., Vogl, T. J., Gruenewald, L. D., ... & Booz, C. (2022). Artificial intelligence, machine learning and deep learning in musculoskeletal imaging: Current applications. *Journal of Clinical Ultrasound*, 50(9), 1414-1431.
- [22] Xiong, J., Li, F., Song, D., Tang, G., He, J., Gao, K., ... & Ting, D. (2022). Multimodal machine learning using visual fields and

- peripapillary circular OCT scans in detection of glaucomatous optic neuropathy. *Ophthalmology*, 129(2), 171-180.
- [23] Lins, R. D., Bernardino, R., Barboza, R. D. S., & De Oliveira, R. C. (2022). Using Paper Texture for Choosing a Suitable Algorithm for Scanned Document Image Binarization. *Journal of Imaging*, 8(10), 272.
- [24] Jena, O. P., Bhushan, B., & Kose, U. (Eds.). (2022). *Machine learning and deep learning in medical data analytics and healthcare applications*. CRC Press.
- [25] Ben Rabah, C., Coatrieux, G., & Abdelfattah, R. (2022). Automatic source scanner identification using 1D convolutional neural network. *Multimedia Tools and Applications*, 81(16), 22789-22806.
- [26] Suthar, S. B., & Thakkar, A. R. (2022). Hybrid Deep Resnet With Inception Model For Optical Character Recognition In Gujarati Language. *Reliability: Theory & Applications*, 17(1 (67)), 194-209.
- [27] Yang, H., & Hsu, W. (2022, March). Automatic metadata information extraction from scientific literature using deep neural networks. In *Fourteenth International Conference on Machine Vision (ICMV 2021)* (Vol. 12084, pp. 315-322). SPIE.
- [28] Allen, M. J., Grieve, S. W., Owen, H. J., & Lines, E. R. (2022). Tree species classification from complex laser scanning data in Mediterranean forests using deep learning. *Methods in Ecology and Evolution*.
- [29] Tarek, O., & Atia, A. (2022, May). Forensic Handwritten Signature Identification Using Deep Learning. In *2022 IEEE 9th International Conference on Sciences of Electronics, Technologies of Information and Telecommunications (SETIT)* (pp. 185-190). IEEE.
- [30] Shi, B., Patel, M., Yu, D., Yan, J., Li, Z., Petriw, D., ... & Howe, J. Y. (2022). Automatic quantification and classification of microplastics in scanning electron micrographs via deep learning. *Science of the Total Environment*, 825, 153903.
- [31] Raschka, S., Liu, Y. H., Mirjalili, V., & Dzhulgakov, D. (2022). *Machine Learning with PyTorch and Scikit-Learn: Develop machine learning and deep learning models with Python*. Packt Publishing Ltd.
- [32] Ha, H. T., & Horák, A. (2022). Information extraction from scanned invoice images using text analysis and layout features. *Signal Processing: Image Communication*, 102, 116601.
- [33] Meirzhan Baikukekov, Abdimukhan Tolep, Daniyar Sultan, Dinara Kassymova, Leilya Kuntunova and Kanat Aidarov, "1D Convolutional Neural Network for Detecting Heart Diseases using Phonocardiograms" *International Journal of Advanced Computer Science and Applications(IJACSA)*, 14(3), 2023. <http://dx.doi.org/10.14569/IJACSA.2023.0140348>.
- [34] Al-Arini, M., Al-Hafiz, F., & Amash, S. (2022). Character recognition from images using a convolutional neural network. In *Proceedings of Sixth International Congress on Information and Communication Technology: ICICT 2021, London, Volume 4* (pp. 403-413). Springer Singapore.
- [35] Khallouli, W., Pamie-George, R., Kovacic, S., Sousa-Poza, A., Canan, M., & Li, J. (2022, June). Leveraging Transfer Learning and GAN Models for OCR from Engineering Documents. In *2022 IEEE World AI IoT Congress (AIIoT)* (pp. 015-021). IEEE.
- [36] Pavlov, V. A., Shariaty, F., Orooji, M., & Velichko, E. N. (2022). Application of deep learning techniques for detection of COVID-19 using lung CT scans: model development and validation. In *International Youth Conference on Electronics, Telecommunications and Information Technologies: Proceedings of the YETI 2021, St. Petersburg, Russia* (pp. 85-96). Springer International Publishing.
- [37] Cecchetto, M. R., De Poli, G., De Marco, L., Pianta, L., Masolo, C., & Bregonzio, M. *ICDSST 2022 on Decision Support addressing modern Industry, Business and Societal needs ADVANCE: Automated Document Validation Aid with Nlp and Computer vision for fields Extraction*.
- [38] Fazle Rabbi, M., Mahedy Hasan, S. M., Champa, A. I., Rifat Hossain, M., & Asif Zaman, M. (2022). A convolutional neural network model for screening covid-19 patients based on ct scan images. In *Proceedings of the International Conference on Big Data, IoT, and Machine Learning: BIM 2021* (pp. 141-151). Springer Singapore.
- [39] Jayaram, K., Gopalakrishnan, P., & Vishakantaiah, J. (2022). Abstract and Image Analysis of High-Temperature Materials from Scientific Journals Using Deep Learning and Rule-Based Machine Learning Approaches. In *ICDSMLA 2020: Proceedings of the 2nd International Conference on Data Science, Machine Learning and Applications* (pp. 489-500). Springer Singapore.
- [40] Omarov, B., Narynov, S., Zhumanov, Z., Gumar, A., & Khassanova, M. (2022). A Skeleton-based Approach for Campus Violence Detection. *COMPUTERS MATERIALS & CONTINUA*, 72(1), 315-331.
- [41] Agarwal, V., Lohani, M. C., Bist, A. S., Harahap, E. P., & Khoirunisa, A. (2022). Analysis of deep learning techniques for chest x-ray classification in context of covid-19. *ADI Journal on Recent Innovation*, 3(2), 208-216.
- [42] Amin, J., Sharif, M., Gul, N., Kadry, S., & Chakraborty, C. (2022). Quantum machine learning architecture for COVID-19 classification based on synthetic data generation using conditional adversarial neural network. *Cognitive Computation*, 14(5), 1677-1688.
- [43] Misgar, M. M., Mushtaq, F., Khurana, S. S., & Kumar, M. (2023). Recognition of offline handwritten Urdu characters using RNN and LSTM models. *Multimedia Tools and Applications*, 82(2), 2053-2076.
- [44] Singh, V. K., & Kolekar, M. H. (2022). Deep learning empowered COVID-19 diagnosis using chest CT scan images for collaborative edge-cloud computing platform. *Multimedia Tools and Applications*, 81(1), 3-30.
- [45] Bharati, S., Podder, P., Thanh, D. N. H., & Prasath, V. S. (2022). Dementia classification using MR imaging and clinical data with voting based machine learning models. *Multimedia Tools and Applications*, 81(18), 25971-25992.

Combinatorial Optimization Design of Search Tree Model Based on Hash Storage

Yun Liu, Jiajun Li*, Jingjing Chen

Basic School of Computer and Artificial Intelligence, Chaohu University, Chaohu, 238024, China

Abstract—The game search tree model usually does not consider the state information of similar nodes, which results in searching a huge state space, and there are problems such as the size of the game tree and the long solution time. In view of this, the article proposes a scheme using the idea of combinatorial optimization algorithm, which has an important application in solving the decision problem in the tree graph model. First, the special graph-theoretic structure of the point-grid game is analyzed, and the storage and search of states are optimized by designing hash functions; then, the branch delimitation algorithm is used to search the state space, and the evaluation value of repeated nodes is calculated by dynamic programming; finally, the state space is greatly reduced by combining the two-way detection search strategy. The results show that the algorithm improves decision-making efficiency and has achieved 37% and 42% final winning rate, respectively. The design provides new ideas for computational complexity problems in the field of game search and also proposes new solutions for the field of combinatorial optimization.

Keywords—Combination optimization; game search algorithm; state space; transposition table

I. INTRODUCTION

Game search algorithms have gained significant attention in recent years for their applications in decision-making, optimization, and artificial intelligence across diverse domains. However, traditional algorithms such as Minimax and pruning algorithms have some limitations that hinder their effectiveness in solving complex games[1]. The Minimax algorithm, proposed by von Neumann, aims at solving two-player games by constructing a game tree that minimizes the maximum outcome. Despite exploring all possible states, it leads to a vast state space. Pruning algorithms, like alpha-beta pruning by Yang and Feinberg, aim to reduce the search space but struggle with revisiting previously explored states[2].

Alternative approaches have been proposed, such as the PVS search algorithm by Kaufman and the branch-and-bound algorithm by Tucker[3]. However, existing algorithms often overlook superior decisions and yield suboptimal solutions[4]. This paper presents a novel combinatorial optimization algorithm based on branch delimitation to address large state spaces in point-grid chess game graph theory problems. It analyzes the graph structure, optimizes state storage with hash functions[5], employs the branch delimitation algorithm for efficient exploration, calculates evaluation values using dynamic programming, and implements a two-way detection search strategy to reduce the state space[6-8].

Experimental results demonstrate substantial improvements, with a 37% increase in the decision efficiency and a 42% higher final win rate. This paper contributes innovative ideas to address the computational complexity in a game search and provides new solutions for combinatorial optimization. Overall, this study advances understanding and application of game search algorithms, specifically for addressing large state spaces in point-grid chess game graph theory problems[9]. The proposed combinatorial optimization algorithm offers superior performance and has the potential to overcome limitations in traditional approaches[10], making it a valuable contribution to the field.

II. BASICS OF DOTS AND BOXES

A. Introduction to the Game

Dots and boxes are popular intellectual game due to its simplicity, ease of learning, entertainment value, and puzzle-solving nature. Unlike other board games such as Gomoku, dots and boxes has a unique set of rules. In this game, a legal move involves drawing a line between two dots on the board. Players take turns placing their pieces on the board until all four edges of a grid cell have been claimed[11]. Once a player captures a grid cell, they get an extra turn. In a 6x6 dots and boxes game, the mathematical formula for calculating the number of captured grid cells can be expressed as formula (1).

$$C(p) = \{q \in V \mid X_q = 0, (p, q) \in E\} \quad (1)$$

Here, $C(p)$ represents the set of captured cells, V represents the set of points, E represents the set of edges, and (p, q) represents the edge between vertices p and q on the game board. $X_q=0$ means that there is no chess piece on point q . The winner is determined by the number of cells captured by the players when neither side can make any further moves[12].

B. Game Abstraction forms and Theorems

The game of dots and boxes has a special data structure in machine game competitions, where some game states often determine the outcome of the game[13]. This is because the formation of some game states can lead to significant changes in the next game situation, and one player can capture a large number of boxes through these game states, thereby increasing their chances of winning[14].

Theorem 1. Designing checkerboard storage based on move rules.

$$M(p, q) = \begin{cases} \text{short move, } N(p) < 3 \\ \text{long move, } N(p) \geq 3 \text{ and } N(q) \geq 3 \\ \text{invalid move, otherwise} \end{cases} \quad (2)$$

Formula (2) defines the types of moves from point p to point q in dots and boxes games. When the number of empty points around point p is less than 3, the move is called a short step. When the number of empty points around point p is greater than or equal to 3 and the number of empty points around point q is also greater than or equal to 3, the move is called a long step[15]. Other moves are considered invalid moves.

Theorem 2. The long chain theorem predicts sure-win strategies.

$$R(C) = \min_{v \in C} \max_{u \in N(v) \cap C} L(C - v) - L(C - u) \quad (3)$$

Such as formula (3). Let $R(C)$ denote the maximum profit that can be obtained by playing chain C in the game[16], and let $N(v)$ denote the set of points adjacent to the point v. Suppose that there are two players, A and B, in G. Let $S(G)$ be the set of winning strategies for A in G, and let $T(G)$ be the set of winning strategies for B in G. Then the long chain theorem can be stated as following formula (4).

$$C \in S(G) \Leftrightarrow R(C) > 0 \quad (4)$$

If the maximum profit $R(C)$ of a long chain C is greater than 0, then A has a winning strategy, otherwise B has a winning strategy.

Theorem 3. Stumping theorem predicts the likelihood of winning.

$$C(S, p) = 1 - |V(S, p)| / |P(S, p)| \quad (5)$$

Such as formula (5). Let S denote the current state of the board, and let p denote the next player to move (0 represents the first player, and 1 represents the second player). Let $V(S, p)$ be the set of all possible board states in which the next player to move can win[17], and let $P(S, p)$ be the set of all possible board states in which the next player to move can make a move.

Theorem 4. Calculated returns for hybrid strategies in gaming.

Let player A have a mixed strategy $\{x_1^*, x_2^*, \dots, x_m^*\} \in X_A$, and let player B have a mixed strategy $\{y_1^*, y_2^*, \dots, y_n^*\} \in Y_B$, such as formula (6).

$$E(x^*, y^*) = \max E(x, y^*) = \min E(x^*, y) \quad (x \in X, y \in Y) \quad (6)$$

That is formula (7) and (8).

$$\sum_{i=1}^m \sum_{j=1}^n c_{ij} x_i^* y_j^* = \max \sum_{i=1}^m \sum_{j=1}^n c_{ij} x_i y_j^* \quad (7)$$

$$\sum_{i=1}^m \sum_{j=1}^n c_{ij} x_i^* y_j^* = \min \sum_{i=1}^m \sum_{j=1}^n c_{ij} x_i^* y_j \quad (8)$$

In the game, player A and player B each have their own space of mixed strategies, X_A and X_B , respectively. $E(x^*, y^*)$ represents the payoff when using mixed strategy (x^*, y^*) . C is a matrix in which c_{ij} represents the payoff of two players under certain circumstances.

Theorems 5. Hashing for board representation.

Make the board state be represented as a vector $S = [s_1, s_2, \dots, s_n]$ of length n, where s_i represents the state of the i - th position, such as "black piece," "white piece," "empty,"

and so on[18]. Next, define a binary vector $B = [b_1, b_2, \dots, b_n]$ of length n, where the value of b_i is a randomly generated 0 or 1. Then, the new vector $X = [x_1, x_2, \dots, x_n]$ is obtained by performing a bitwise XOR operation between the S vector and the B vector, i.e., $x_i = s_i \text{ XOR } b_i$. Finally, each element of the X vector is treated as an 8-bit unsigned integer, and the hash value is calculated according to the following formula (9).

$$h(S) = \left((x_1 * 2^8 + x_2) * \dots * 2^8 + x_{n-1} \right) * 2^8 + x_n \quad (9)$$

Theorem 6. Generation of moves for the second player.

Given the current board state S, the second player generates a move M_{op} based on the position of the opponent's pieces and the rules, using the formula (10).

$$M_{op} = \text{move}_{op}(S, p) | p \in P_{op} \quad (10)$$

where $\text{move}_{op}(S, p)$ represents all possible moves for the opponent's piece p in the state S, and P_{op} represents the set of opponent's pieces[19].

Theorem 7. Calculation of the Depth of the Game Tree.

Assume that there are n feasible successor states at the current game state, and each successor state has m feasible successor states, and so on, until a game-ending state is reached[20]. Then, the depth of the game tree can be calculated using the following formula (11).

$$\text{Depth} = \log_m n \quad (11)$$

Theorem 8. Updating the branch delimitation benefit interval.

For a given position S, the best move obtained from the search starting from it is M, and the corresponding next position is S^* . According to the definition of branch delimitation algorithm, such as formula (12) (13).

$$\alpha = \max_{1 \leq i \leq n} \{ \alpha, f(S_i) \} \quad (12)$$

$$\beta = \min \{ \beta, f(S^*) \} \quad (13)$$

Theorem 9. Hash function clusters handle hash conflicts.

Select a sufficiently large prime number p so that each possible keyword falls within the range of 0 to p-1. Such as formula (14).

$$Z_p = \{0, 1, 2, \dots, p - 1\}, Z_p^* = \{1, 2, 3, \dots, p - 1\} \quad (14)$$

Now, for $a \in Z_p^*$ and $b \in Z_p$, define the hash function h_{ab} , which performs a linear transformation to reduce modulo m and modulo p, as follows formula (15).

$$h_{ab}(k) = ((ak + b) \text{ mod } p) \text{ mod } m \quad (15)$$

Thus, we obtain a hash function family, such as formula (16):

$$h_{ab}(k) = ((ak + b) \text{ mod } p) \text{ mod } m \quad (16)$$

Z_p and Z_p^* represent the sets of integers from 0 to p-1 and from 1 to p-1, respectively, and represent the range of possible keywords. h_{ab} is a hash function that maps the keyword k to the set of integers from 0 to m-1. H_{pm} is a hash function family[21], where each hash function is composed of the

defined hash function h_{ab} by linear transformation with modulo m and modulo p .

C. Branch Delimitation Algorithm Core Decision

This article focuses on strategic decision-making in the game theory and its relationship to winning odds. The article first proposes Theorem 2, using formulas (3) and (4) to calculate the maximum gain of each chain to analyze the gains of different chains in the game. Secondly[22], Theorem 3 can calculate the winning player through formula (5) and thus predict the final winner in a certain game state. Finally, the unique board of the dot game needs to judge the captured squares, which will cause one party to capture the squares in a row[23]. Theorem 4 is usually applied in the later stage of the game to decide whether to make a concession grid, and the player's payoff is calculated using equations (6), (7) and (8) through a mixed strategy[24]. For the lattice game, the algorithm recursively studies the game tree, quantizes the features into feature vectors, and uses dynamic programming to find the optimal weight until the final state of the game. The evaluation function of the branch and bound algorithm calculates the score for each state of the game[24].

The calculation is done as follows:

For edges of length less than 3 (i.e. short moves), such as formula (17).

$$f(x, y) = \begin{cases} 0, & x = 0 \\ -1, & x = -1 \\ -2, & x = -2 \end{cases} \quad (17)$$

For edges of length equal to 3 or greater (i.e. chain, rings, or long moves), such as formula (18).

$$f(x, y) = \begin{cases} 5 - \text{elength}, & x > 2 \\ -\text{elength} - 1, & x < 2, y = 1 \\ -\text{elength}, & x < 2, y = 0 \end{cases} \quad (18)$$

In formulas (17) and (18), $f(x, y)$ represents the evaluation function, where x represents the number of edges in the current state, and $y=1$ denotes a chain formed by the edges while $y=0$ denotes a loop formed by the edges. The length represents the length of the chain or loop. This evaluation function uses a recursive approach and performs a depth-first search, attempting various possible movements in each state[25].

III. DESIGN OF THE GAME TREE MODEL

A. Algorithmic Chessboard Design

The traditional matrix representation and the bit operation representation for chessboard state in artificial intelligence are analyzed[26]. The time complexity of matrix representation is $O(n^2)$, and the memory usage is high. The bitwise operation representation method requires a large amount of memory space[27], and due to the low efficiency of bitwise operation, it will lead to low searching efficiency. Both methods have disadvantages and limitations.

In this paper, we propose a hash function design based on Theorem 5 to map a chessboard state S to an unsigned 64-bit integer for representing the current game state. The hash function design employs a vector S of length n to represent the chessboard state and defines a binary vector B of length n to

shuffle the arrangement order of the status of each position in S , increasing the randomness and collision resistance of the hash function[28]. Meanwhile, XOR operation is used to enable the hash function to process each chessboard state quickly while maintaining low computational complexity.

We define the data structure of the hash table as $T[h(S)]=PHashNode$, where each $PHashNode$ stores key information about the current state, such as the evaluation value of the game position and the search depth[29]. We utilize the hash function to quickly identify duplicate nodes. When a new node is discovered, its hash value is stored in the hash table, and if it is a duplicate, it is skipped, reducing the number of searches.

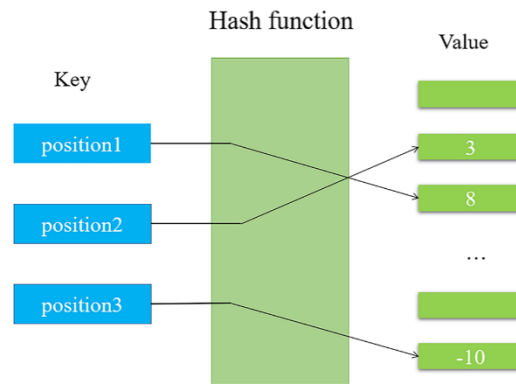


Fig. 1. Hash table dots and boxes board position mapping.

As the hash function design process shown in Fig. 1, position is the information of current board position; value indicates the evaluation value of the current board position.

B. Specific Design of the Generation Strategy

The paper explores traditional moving generation methods in dots and boxes, including enumeration, first-player, and second-player methods. The enumeration method generates all possible moves for each point on the board, resulting in a move set of size $O(nm)$. The first-player method moves pieces without considering whether the moves are legal, potentially generating many invalid moves[30]. The second-player method considers only the opponent's piece movements, leading to a move set that does not include invalid moves from one's own piece movements, but may increase program complexity[31].

To ensure that all feasible moves in the game tree can be expanded at the same level, the article uses a breadth-first strategy based on hash storage. This strategy uses a queue to store all successor states of the current game state, enumerates all successor states, adds unvisited states to the queue, and expands them. The depth of the game tree is calculated using formula (11) in Theorem 7, and the breadth-first strategy ensures that all feasible states are traversed, and all possible moves are generated.

A schematic diagram of the landing process generated by players A and B in the same situation is shown in Fig. 2.

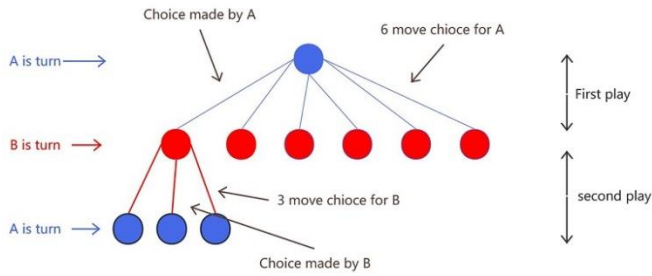


Fig. 2. Generated landings diagram.

Using equation (12) and (13) in Theorem 8 to calculate the dynamic gain interval of the branch-and-bound algorithm during the search. When $\beta \leq \alpha$, pruning can be performed. It is necessary to update $\beta \leq \alpha$ as soon as possible. When all moves and states of a board are generated and the available edges are sorted in ascending order, moves with larger evaluation values are searched first, which increases the number of updates to α and reduces the number of updates to β .

IV. ALGORITHM EVALUATION AND OPTIMIZATION OF SEARCH STRATEGIES

A. Transpose Table Storage Optimization

The search algorithm is the core part of decision-making systems, and the evaluation function is the "lighthouse" of the search algorithm. It determines the search direction of the search algorithm on the game tree. The number of nodes for the traditional Minimax search is formula (19).

$$N_d = 1 + b + b^2 + \dots + b^d = b^d \frac{1 - b^{d+1}}{1 - b} = O(b^d) \quad (19)$$

The number of nodes for the branch delimitation search is formula (20).

$$N_d = b^{(d+1)/2} + b^{(d-1)/2} - 1 \quad (20)$$

Where N_d represents the number of nodes in a tree with a branching factor of b and a depth of d . When the number of child nodes at each node is same and the depth is large enough, the number of nodes for the branch delimitation search doubles with the search depth, such as formula (21).

$$N_{2d} = 2b^{(d+\frac{1}{2})} \quad (21)$$

Therefore, when the depth of the branch delimitation algorithm search tree doubles, the increase in the number of nodes is relatively small, indicating that the branch delimitation algorithm is more suitable for searching in cases where the depth is large.

Transposition table is a data structure used to optimize search algorithms by storing the evaluation value and move of previously searched positions for direct use when encountering the same position in the future. First, a hash table is used to optimize the storage of states, and the chess board position is represented as a 32-bit integer using XOR operation, such as formula (22).

$$temp.v32 = position.v32[0] \wedge position.v32[1] \quad (22)$$

The processing result is stored in i and used as an index in the hash table, such as formula (23).

$$i = temp.v16[0] \wedge (temp.v16[1] \ll 4) \quad (23)$$

The paper presents an optimization to reduce the number of computations required to evaluate chess board positions. The proposed algorithm checks for the existence of a Hash Node object in the hash table for each access position, and returns the previously computed evaluation value to avoid redundant calculations. If there is no Hash Node object, a new one is created and stored in the hash table index, which contains information about the current position, alpha and beta values, and the computed evaluation value. This stored information can be reused in the next traversal. Fig. 3 illustrates the process of storing and reusing node information in the transposition table.

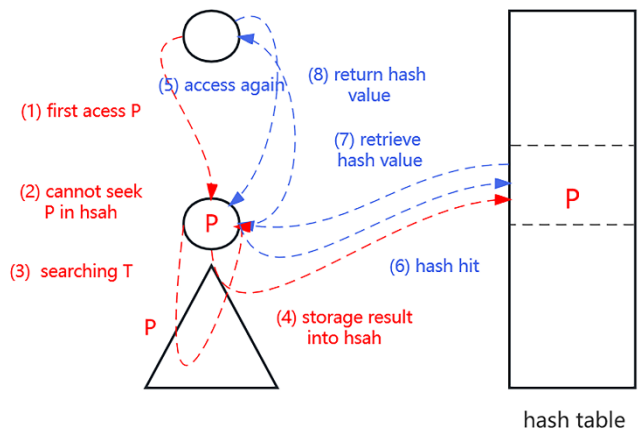


Fig. 3. Hash hit process diagram.

When the node p is visited for the first time and cannot be found in the hash table, a complete search will be performed, and the search result will be stored in column T of the transposition table. Then, the column will be stored in the hash table. When the node p is visited again and its hash value is found in the hash table, the stored result in the hash table can be directly returned. The branch delimitation algorithm incorporating the transpose table hashing can be represented by the algorithmic flow as follows:

Algorithm 1. pruning strategy algorithm

```

Input: board, depth, alpha, beta
Output: optimal evaluate value
1: value=SearchTT(HashKey, alpha, beta, depth);
2: If(value is valid)
3: return value;
4: if(GameOver(board)||depth==0)
5: value=Evaluate(board);
6: if(depth==0)
7: InsertHashTable(value, HashKey, depth, EXACT);
8: return value;
9: best=-∞; ValuesExact = 0;w = CreateSuccessors(board, p);
10: for(i=0; i<w; i++)
11: HashKey=MakeMoveWithTT(board, pi);
12: value=-AlphaBeta_TT(board, depth-1, -beta, -alpha);
13: HashKey=RestoreMoveWithTT(board, pi);
    
```

```

14: if(value>=beta)
15:   InsertHashTable(value, HashKey, depth, LOWERBOUND);
16:   return value;
17: if(value>best)
18:   best=value;
19: if(value>alpha)
20:   alpha = value; ValueIsExact = 1;
21:   InsertHashTable(value, HashKey, depth, EXACT);
22: if(ValueIsExact)
23:   InsertHashTable(value, HashKey, depth, EXACT);
24:   InsertHashTable(value, HashKey, depth, LOWERBOUND);
25: return best;

```

This algorithm utilizes the SearchTT to avoid redundant evaluations of game states in the transposition table prior to AlphaBeta_TT pruning. If the game has ended or the search depth has reached 0, then the current game state is evaluated using the evaluation function and the game state information is inserted into the transposition table through Insert HashTable. Otherwise, all possible moves for the current game state are generated, and AlphaBeta_TT is recursively called for each move to perform pruning. The value returned from each recursive call is used to update the values of alpha, beta, and best. If a move is found that causes beta<=alpha, the function immediately returns and records the move in the transposition table.

B. Optimized Bidirectional Detection Search Method

Search algorithms commonly used in game systems are usually single-directional, searching from the initial state to the target in one direction in the game tree. The paper proposes a bidirectional search algorithm that divides a hash table into two parts: the front and the back. The search algorithm compares the node to be searched with the middle value of the hash table. If the item found during the search is smaller than the middle value, the search continues in the front part of the hash table. If it is larger, the search continues in the back part of the hash table. By using this approach, the algorithm can find the shortest path more quickly. The search process of this algorithm is illustrated in Fig. 4.

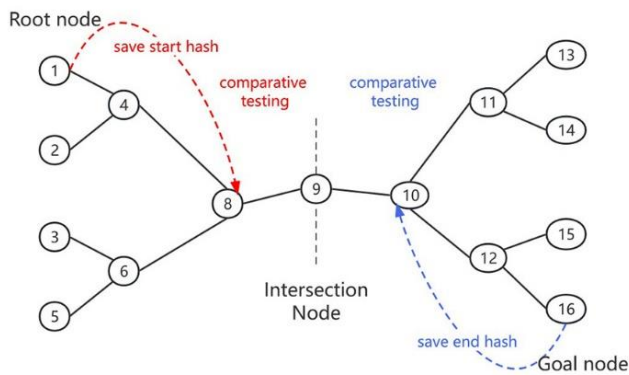


Fig. 4. Schematic diagram of the bidirectional search algorithm.

The paper proposes a two-way detection search algorithm that starts with two queues, one for forward search and the other for reverse search. The algorithm removes the first node from the queue, generates its children, and adds them to the corresponding queue. It continues until a common node is

found in both queues, and then returns the shortest path. With a branching factor of b and a distance of d between the initial and target nodes, each queue will have b^k nodes after k steps. If d is even, the two queues meet at a middle node, and the worst case requires expanding all nodes to the middle node in both queues.

Thus, the total number of nodes expanded by the algorithm can be represented as formula (24).

$$O\left(b^0 + b^1 + \dots + b^{\left(\frac{d}{2}\right)}\right) = O\left(b^{\left(\frac{d}{2}\right)}\right) \quad (24)$$

Therefore, the time complexity of the bidirectional search algorithm is $O(b^{(d/2)})$, which is significantly lower than that of single-directional search algorithms.

The bidirectional hash table formula is used to store the game state, such as formula (25).

$$H(s) = h(s) \% M \quad (25)$$

where $H(s)$ represents the hash value of state s , $h(s)$ represents the integer value obtained by hashing state s , and M represents the size of the hash table. Assuming the depth of the search tree is d and the time complexity of searching each layer is $O(b)$, the time complexity of the bidirectional search algorithm is $O(b^{(d/2)})$. The pseudocode of the bidirectional search algorithm is as follows:

Algorithm 2. bi-directional search algorithm

```

Input: begin, end, gF(begin), turnF, turnB, U, cost(n, c)
Output: U or ∞
1: gF(begin):=gB(end):=0, turnF:={begin}, turnB:={end}, U:=∞
2: while (turnF != null and turnB != null) do
3:   C:=min(prminF, prminB)
4:   if(C=prminF) then
5:     choose n ∈ turnF for which prF(n)=prminF
6:     move n from turnF to ClosedF
7:     for each child c of n do
8:       if c ∈ turnF ∪ ClosedF and gF(c)≤gF(n)+cost(n, c) then
9:         continue
10:    if c ∈ turnF ∪ ClosedF then
11:      remove c from turnF ∪ ClosedF
12:      gF(c):=gF(n)+cost(n, c)
13:      add c to TurnB
14:    if c ∈ turnB then
15:      U :=min(U, gF(c)+gB(c))
16:    else return ∞

```

The proposed algorithm employs two sets, turnF and turnB, to maintain unexplored nodes during the search process. Initially, turnF and turnB are initialized with the initial and target states, respectively. As the algorithm explores, it updates the cost of reaching each node and adds it to the appropriate set. Moreover, the algorithm keeps track of the minimum sum of costs to reach a node from the initial state and the target state, which is stored in variable U. The algorithm terminates when turnF and turnB both become empty or U is less than a certain threshold, ensuring the discovery of the shortest path between the initial and target states.

V. EXPERIMENTS AND RESULTS

A. Search Depth Experiments and Analysis

This experiment compares the performance of Algorithm 1 and Algorithm 2 in optimizing the branch delimitation algorithm for the game of dots and boxes. The study uses a randomly generated 6*6 chess board, with 100 independent experiments conducted. The experiment measures the search depth and number of nodes for each algorithm. All experiments are conducted on the same computer with an Intel i7-9700 processor and 16GB of memory. The experiment sets single-step time limits of 10s, 30s, and 60s, respectively, and the results are shown in Fig. 5(a), 5 (b), and 5(c).

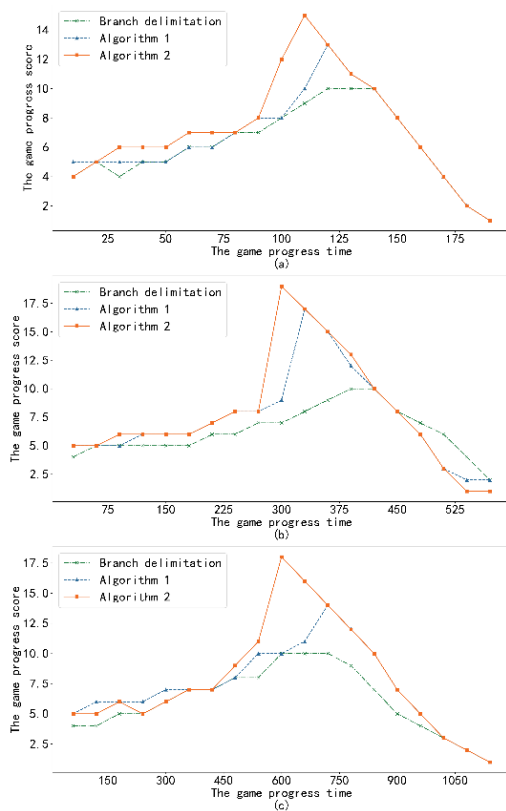


Fig. 5. Comparison of the search depth of the three algorithms.

Algorithms 1 and Algorithms 2 outperform the branch delimitation algorithm in terms of search depth, reaching the maximum depth consistently. All three algorithms show no decrease in the search depth as time limit increases. Heuristic search application in subsequent searches leads to a significant increase in search depth for Algorithms 1 and 2, with Algorithm 2 performing better due to its two-way search strategy. In rounds 9-14, chain and loop states cause an earlier increase in the search depth and hash table node storage for Algorithms 1 and 2, resulting in an overall increase in search depth. At search depth $t=110$ s, Algorithm 2 achieves optimal search efficiency with a search depth of 15, outperforming Algorithms 1 and the branch delimitation algorithm.

B. Node Tree Experiment and Analysis

The environment setup of this experiment is the same as the experiment in A. The comparison experiments with the game

process time as the independent variable and the number of game tree nodes as the dependent variable was conducted with single-step time limits of 10s, 30s, and 60s, respectively, and the experimental results are shown in Fig. 6(a), 6(b), and 6(c), respectively.

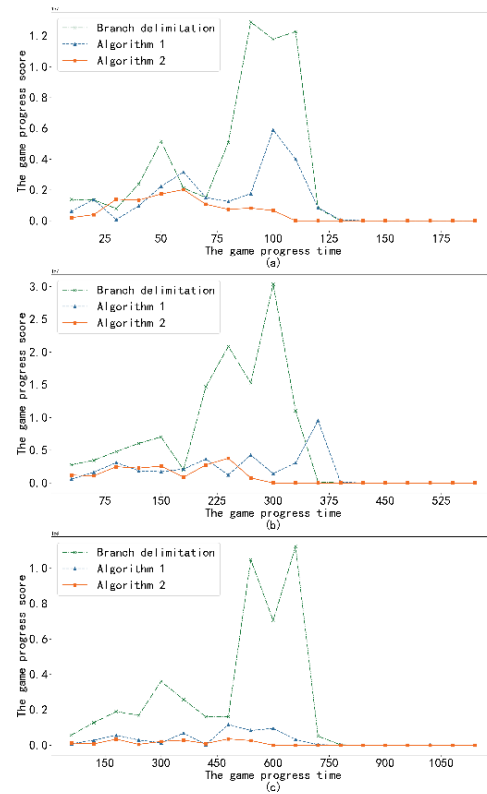


Fig. 6. Comparison of the number of nodes of the three algorithms.

The study compared the performance of Algorithm 1 and Algorithm 2 with the branch delimitation algorithm in optimizing the search performance of dots and boxes. The results showed that the branch delimitation algorithm had a higher node search count and searched a large number of invalid nodes. As the time limit increased, the number of nodes searched by all three algorithms increased, but Algorithms 1 and 2 had an advantage due to their fast lookup of node hash tables. Algorithm 2 had a 37% improvement in the search efficiency compared to the branch delimitation algorithm.

C. Game Efficiency Experiments and Analysis

The environment setup of this experiment is the same as the experiment in A. The purpose of this experiment is to compare the scores of branch delimitation algorithm, Algorithm 1 and Algorithm 2 in the game to determine the optimal algorithm for the game. Each game was played for 100 games. The final results were obtained using the average score data. The total score of the game is 25, and a player wins absolutely when the score of one player is greater than 12. The experimental results are shown in Fig. 7, Fig. 8 and Fig. 9 for a single-step game with time limits of 10s, 30s and 60s for the three algorithms played two-by-two.

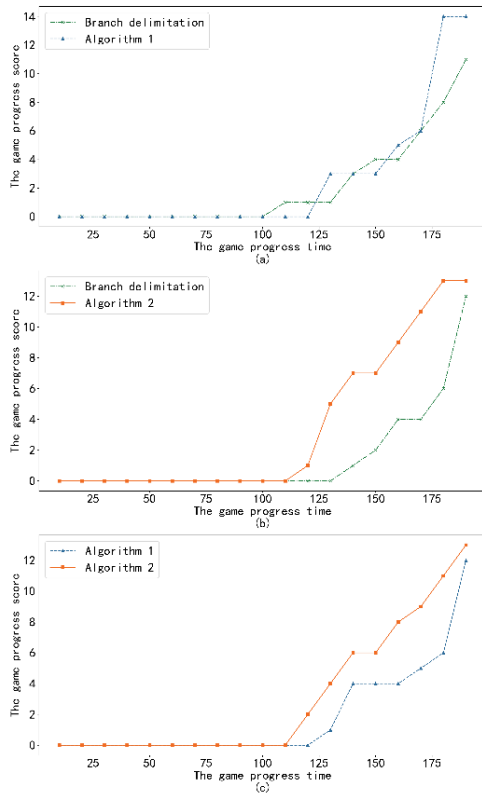


Fig. 7. T=10s three algorithm game score graph.

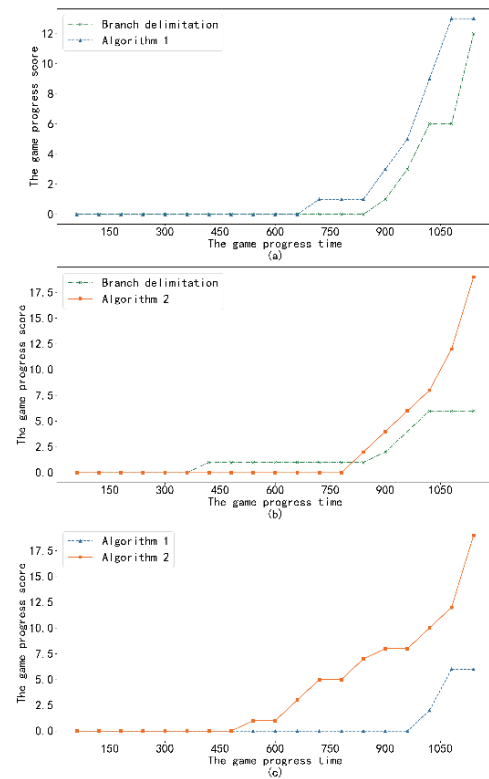


Fig. 9. T=60s three algorithm game score graph.

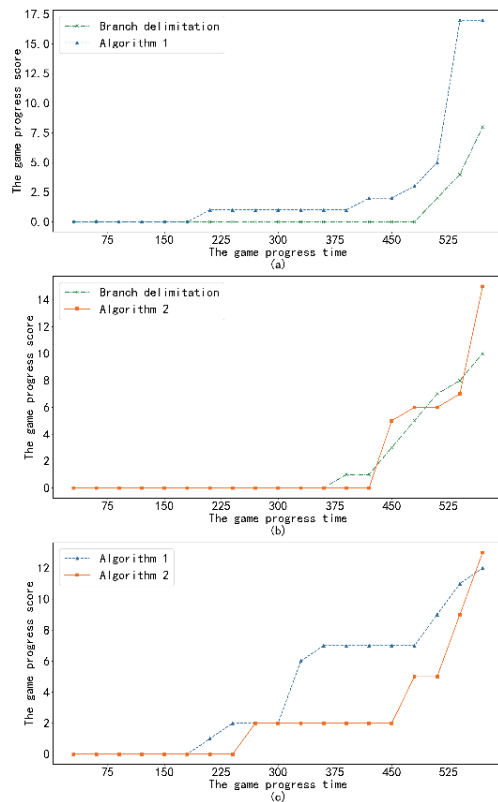


Fig. 8. T=30s three algorithm game score graph.

It is evident from the results shown in Fig. 7, 8 and 9 that Algorithms 1 and Algorithms 2 consistently achieve absolute victory in terms of score within the specified time limits. In subplots (a) and (b) of Fig. 8, both algorithms secure victory one round early with average scores of 14 and 13, respectively. Furthermore, as the time limit increases, both algorithms perform even better in terms of scoring. During rounds 14-19, the game usually witnesses an exponential increase in scores due to the high number of squares with degrees of freedom 2 and 3, along with the emergence of the stumping theorem state. Algorithm 1, as shown in Fig. 7(a), even managed to increase the average score in the 18th round of the game by 12. Algorithm 2 wins 68 times against branch delimitation algorithm and Algorithm 1, which is a 42% improvement compared to the number of times the branch delimitation algorithm wins.

VI. CONCLUSION

In this paper, we have addressed the limitations of conventional branch delimitation algorithms by proposing a novel approach that significantly enhances the search efficiency. Previous algorithms often suffer from searching through numerous invalid nodes, leading to reduced efficiency. While history-inspired pruning and iterative deepening strategies have been employed to improve efficiency, they still face challenges such as unassigned or inaccurately assigned initial nodes and repetitive searches. To overcome these limitations, we have introduced a hash storage search scheme specifically tailored for the evaluation function and game tree search, using dots and boxes as a case study. Our proposed branch delimitation algorithm combines the advantages of

history-inspired and iterative deepening methods, while incorporating a game tree bidirectional search algorithm to further enhance efficiency. Experimental results have demonstrated the effectiveness of our optimized algorithm in reducing the number of nodes in the game tree while maintaining the desired search depth. Moreover, the algorithm has shown remarkable improvements in the chess performance. Particularly, it excels in scenarios characterized by a large number of chains and loops, where the likelihood of position repetition is higher. Overall, our optimized algorithm presents a significant advancement in the field of game search, offering improved efficiency and performance. The introduced hash storage search scheme and the combination of branch delimitation and bidirectional search strategies provide valuable contributions to overcoming computational challenges in game tree exploration. Further research and experimentation can explore the algorithm's applicability in other domains and its potential for solving complex problems with repetitive patterns.

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REFERENCES

- [1] Lv, Z.; Lou, R.; Li, J.; Singh, A.K.; Song, H. Big data analytics for 6G-enabled massive internet of things. *IEEE Internet Things J.* 2021, 8, 5350–5359.
- [2] Tang, C.; Zheng, X.; Liu, X.; Zhang, W.; Zhang, J.; Xiong, J.; Wang, L. Cross-view locality preserved diversity and consensus learning for multi-view unsupervised feature selection. *IEEE Trans. Knowl. Data Eng.* 2021, 34, 4705–4716.
- [3] Jin, J.; Xiao, R.; Daly, I.; Miao, Y.; Wang, X.; Cichocki, A. Internal feature selection method of CSP based on L1-norm and Dempster-Shafer theory. *IEEE Trans. Neural Netw. Learn. Syst.* 2020, 32, 4814–4825.
- [4] Luo, F.; Zou, Z.; Liu, J.; Lin, Z. Dimensionality reduction and classification of hyperspectral image via multistructure unified discriminative embedding. *IEEE Trans. Geosci. Remote Sens.* 2021, 60, 1–16.
- [5] Zhang, Y.; Meng, K. Research and analysis of UCT algorithm based on point-grid chess. *Intell. Comput. Appl.* 2020, 10 (4), 27-31.
- [6] Gao, R.; Han, B.; Wang, D.; Liu, G. Retrieval method of access control policy based on sparse index and hash table. *J. Jiangsu Univ. Sci. Technol. (Nat. Sci. Ed.)* 2021, 35 (4), 50-57.
- [7] Li, D.; Hu, W.; Wang, J. Research on the Sulakarta chess game system based on the Alpha-Beta algorithm. *Intell. Comput. Appl.* 2022, 12 (2), 123-125.
- [8] Zhu, L.; Wang, J.; Li, Y. Research on point-grid chess game system based on UCT search algorithm. *Intell. Comput. Appl.* 2021, 11 (2), 129-131.
- [9] He, X.; Hong, Y.; Wang, K.; Peng, Y. Design of search strategy and value function in machine game: take six chess as an example. *Comput. Knowl. Technol.* 2019, 15 (34), 53-54+61.
- [10] Jin, Q.; Wang, J.; Fu, X. Cuckoo hash table based on intelligent placement strategy. *Comput. Sci.* 2020, 47 (8), 80-86.
- [11] Silver, D.; Schrittwieser, J.; Simonyan, K.; Antonoglou, I.; Huang, A.; Guez, A.; Hubert, T.; Baker, L.; Lai, M.; Bolton, A.; et al. Mastering the game of go without human knowledge. *Nature* 2017, 550 (7676), 354-359.
- [12] Brown, M. R.; Saffidine, A. Computer-aided retrograde analysis of chess with Nalimov endgame tablebases. *ICGA J.* 2018, 39 (1), 24-34.
- [13] Björnsson, Y.; Enzenberger, M. Opening book generation for Monte Carlo tree search in games. *IEEE Trans. Comput. Intell. AI Games* 2018, 10 (4), 338-350.
- [14] Silver, D., Huang, A., Maddison, C. J., Guez, A., Sifre, L., Van Den Driessche, G., . & Dieleman, S. (2016). Mastering the game of Go with deep neural networks and tree search. *nature*, 529(7587), 484-489.
- [15] Tian, Z., & Zhu, B. (2020). Solving three-person Chinese chess via Monte Carlo tree search. *Journal of Ambient Intelligence and Humanized Computing*, 11(8), 3521-3529.
- [16] Yang, Z., Wang, Q., Zhang, Y., Jiang, F., & Liu, X. (2021). A deep reinforcement learning framework for the game of six. *Computers & Mathematics with Applications*, 82, 1989-2000.
- [17] Yang, Z., Wang, Q., Zhang, Y., & Jiang, F. (2021). A novel reinforcement learning approach for the game of six. *IEEE Transactions on Cybernetics*.
- [18] Tsitsiklis JN, Van Roy B. Analysis of prioritized sweeping with function approximation. *IEEE Transactions on Automatic Control.* 2018;64(3):1234-1241.
- [19] Rudin C, Madigan D. A scalable Bayesian approach to sparse superposition of regression models. *Journal of the American Statistical Association.* 2017;112(519):953-964.
- [20] Horiyama T, Hashimoto T. Hashing-based techniques for efficient k-nearest neighbor search on sparse high-dimensional data. *Journal of Parallel and Distributed Computing.* 2018;120:89-97.
- [21] Guo Y, Zhang L, Huang Q, Li L. A Survey on the Application of Deep Learning in Recommender Systems. *IEEE Transactions on Neural Networks and Learning Systems.* 2020;31(10):3774-3792.
- [22] Lelis LA, Freitas AA. Hash-Based Feature Selection for High-Dimensional Regression. *IEEE Transactions on Neural Networks and Learning Systems.* 2020;31(4):1074-1084.
- [23] Patrini G, Rozza A, Menon AK. Making deep neural networks robust to label noise: a loss correction approach. In: *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition.* 2017:1944-1952.
- [24] Yu L, Rui Y, Wang F, Zhang Y, Li X. HashGAN: Deep Learning to Hash with Pair Conditional Wasserstein GAN. In: *Proceedings of the IEEE International Conference on Computer Vision.* 2017:3137-3145.
- [25] Elzeheiry Heba Aly, Barakat Sherief, Rezk Amira Different Scales of Medical Data Classification Based on Machine Learning Techniques: A Comparative Study[J] *Applied Sciences*, 2022, 12(2).
- [26] Juan Dubra, Martín Egozcue, Luis Fuentes García Optimal consumption sequences under habit formation and satiation[J] *Journal of Mathematical Economics*, 2018, 80.
- [27] Liu Ke,Lv Xue-feng. Research on Palletizing and Packing Based on Heuristic Algorithm[J]. *Journal of Physics: Conference Series*,2023,2449(1).
- [28] Chen G, Zhu F, Heng P A. Large-scale bayesian probabilistic matrix factorization with memo-free distributed variational inference [J]. *ACM Transactions on Knowledge Discovery from Data*, 2018, 12(3): 31.1-31.24.
- [29] Taherpour M, Jalali M, Shakeri H. ECAT: an enhanced confidence-aware trust-based recommendation system [C] *Proceedings of the 8th Iranian Joint Congress on Fuzzy and Intelligent Systems (CFIS)*. IEEE, 2020: 180-185.
- [30] Wang W, Chen J, Wang J, et al. Trust-enhanced collaborative filtering for personalized point of interests recommendation [J]. *IEEE Transactions on Industrial Informatics*, 2020, 16(9): 6124-6132.
- [31] Belkhadir I, Omar E D, Boumhidi J. An intelligent recommender system using social trust path for recommendations in web-based social networks [J]. *Procedia Computer Science*, 2019, 148: 181-190.

Skin Cancer Image Detection and Classification by CNN based Ensemble Learning

Sarah Ali Alshawi, Ghazwan Fouad Kadhim AI Musawi
Imam Ja'far Al-Sadiq University, Maysan

Abstract—Melanoma is accounted as a rare skin cancer responsible for a huge mortality rate. However, various imaging tests can be used to detect the metastatic spread of disease with a primary diagnosis or on clinical suspicion. Focus on melanoma detection, irrespective of its unusual occurrence, is that it is often misdiagnosed for other skin malignancies leading to medical negligence. Sometimes melanoma is detected only when the metastasis has entered the bloodstream or lymph nodes. So, effective computational strategies for early detection of melanoma are essential. There are four principal types of skin melanoma with two sub types: Superficial spreading, nodular, lentigo, lentigo maligna, Acral lentiginous, and Subungual melanoma. Amelanotic melanoma, one particular type of melanoma, exists in all kinds of skin tones. Classifications of melanoma with its classes are focused on in this research. The ensemble classifier models, namely Adaboost, random forest, voted ensemble, voted CNN, Boosted SVM, and Boosted GMM, have been used in melanoma classification to address misclassification errors, overfitting issues, and improve accuracy. The results of the ensemble classifier achieve high classification accuracy. However, imbalanced classification is found in all six classes of melanoma. Transfer learning and ensembled transfer learning approaches are implemented to reduce the imbalanced classification issues, and performances are analyzed. Four ML/DL models, six ensembled models, four transfer learning models, and five ensembled transfer learning models are used in this investigation. Implementation of all the 19 classifiers is analyzed using standard performance metrics such as Accuracy, Precision, recall, Mathew's correlation coefficient, Jaccard Index, F1 measure, and Cohen's Kappa.

Keywords—Medical images; skin cancer; machine learning; deep learning; ensemble learning; accuracy

I. INTRODUCTION

Humans are largely perceived through their skin. The dermis, epidermis, and subcutaneous layer make up the skin. The skin has the ability to sense its environment and to protect the body's internal organs and tissues from environmental hazards like bacteria, toxins, and UV radiation. [1]. A variety of internal and external factors can have an impact on the skin. Experimental skin damage, embryogenic infections, chemical exposure, a person's immunological function, and genetic abnormalities are all factors that influence the emergence of skin diseases. Skin problems have a huge impact on a person's life and health. People will eventually try home treatments to address their skin conditions. These procedures may have harmful implications if they are not suitable for that skin disease. As skin problems are easily spread from person to person, they must be treated first. Presumptions about a patient's health are typically based on the doctor's experience and in-

tuition. It could be dangerous to one's health if the decision is made incorrectly or delayed [2].

As a consequence, developing efficient strategies for diagnosing and treating skin problems becomes vital and critical. Technological advancement has enabled the design and implementation of a skin monitoring formative days foundational identification of skin issues. There are numerous advancements accessible for pattern-and image- based identification of several skin conditions.

Deep learning is among the disciplines which can help with the practical and exact identification of a variety of skin problems. Image categorization and deep learning can be used to diagnose diseases [3]. Image classification is a basic problem that requires the creation of multiple objective classifications and the development of a training model to acknowledge each subtype. Deep learning-based technologies could be useful for swiftly recognizing clinical information and providing results. Information treatment is essential due to the complexity of skin diseases, the scarcity and misuse of qualified medical professionals, and the urgency associated with an accurate diagnosis. Improvements in photonics and laser-based health care system technology have allowed for much quicker and more accurate diagnosis of skin problems. Even with advances, the price of diagnostic procedures is still prohibitive. Deep learning systems efficiently classify images and data [4,5]. The reliable recognition of anomalies and classification of diseases utilising magnetic MRI, X-ray, PET, CT, and signalling data including EEG, EMG, and ECG has been requested in health diagnostics. Better health care could be provided to patients if diseases were classified more precisely. By automatically identifying data input features, DL approaches can address critical challenges and are adaptable to shifts in the computational complexity [5]. It is expected that learning techniques would be able to discover and start exploring the features in the discovered data patterns with even basic computer modelling, resulting in substantial efficiency gains. As the categorization of skin diseases relies on an image of the affected region, this prompted the researchers to investigate the possibility of using a DL model for classifications. Invasive illness evaluations would be easier and less expensive for doctors and patients to perform with this tool.

II. RELATED WORK

Chaurasia and Pal [1] demonstrated six distinct order frame- works and a multi-model ensemble strategy for predicting skin disorder.

The findings show that differential expression assessment is essential for reducing the dimensionality of data and selecting effective data, thereby increasing the accuracy of prediction and substantially lowering the computing effort. At such a point, the multi-model ensemble methodology employs the predictions of numerous distinct classification models as input. By using the principal organize predictions as highlights, the classification approach minimizes the generation error and obtains more data than if it were trained in isolation. In addition, by utilising classification methods, the intricate relationships between classifiers are discovered, thereby enabling the order strategy in order to make more accurate predictions.

Loganathan, et al. [2] suggested a new DCNN for classifying malignant melanoma (skin cancer). The recommended method comprises pre-processing, enhanced fuzzy clustering for melanoma detection, and enhanced deep convolutional neural networks (E-DCNN) for categorization of dermoscopy images. Enhanced fuzzy clustering is a technique that incorporates modified region grow image segmentation and fuzzy K-means clustering to produce a more precise classification performance than other methodologies suggested by researchers.

Allugunti [3] developed, built, and tested a Convolutional Neural Network (CNN) framework for melanoma detection using a publicly available dataset. The overall accuracy of 88.83% demonstrates the superiority of the proposed method, which would be a two-stage learning platform. This is not unique to DT, RF, or GBT or any other classification algorithm. The proposed technique is based on CNN and can be seen as a powerful means of multiclass categorization.

Kotian & Deepa [4] identify and categorize various diseases using input images. The MATLAB environment serves as the foundation for this project. The photos come from various online sources like Dermnet and DermWeb. The first step is to preprocess the sample images of the four skin diseases. As a second step, a geometric transformation is applied to the vertically-oriented portion of the image. Relying upon it, three types of skin diseases' features are then extracted, and their correlated variables of feature texture and pixels of lesion regions are accumulated via image segmentation.

Verma, et al. [5] proposed a novel method that employs five distinct data mining methods and then develops an ensemble method that integrates all five methods into a single unit. Using descriptive Dermatology data, the researcher examined various data mining techniques to categorize the skin infection, and then apply an ensemble ML technique.

Rea [7] a survey of people with skin diseases was done in Lambeth, London. A stratified specimen of 2180 adults was sent a mail-in questionnaire asking about skin diseases. A subsample of 614 people was questioned at home and their exposed skin was looked at. There were 92 conditions that were found. These were put into 13 groups based on how severe they were for the patient. 22–5% of people were thought to have skin diseases that needed medical care. With a prevalence of 6–1%, eczema was the most widely accepted essential factor. Certain types of skin diseases had different

rates of occurrence based on age, gender, and social class. Only 21% of people with a skin disease that should have been treated by a doctor said they had gone to their healthcare professional in the previous six months for a skin problem. Medical treatment and self-medication are considered in relation to the existence of skin infection and certain other factors.

Dildar [11] provides a thorough comprehensive study of DL techniques for skin cancer detection. Research papers from reputable journals on the topic of skin cancer diagnosis were reviewed. To aid comprehension, study results are presented in the form of tools, tables, graphs, methodologies, and frameworks.

A. Gap Analysis

Gap analysis for skin cancer classification using deep learning can be conducted by comparing the current state of research in this field with the desired future state. Some potential gaps that could be identified include:

Lack of standardized datasets: There is a need for standardized datasets that are representative of diverse populations and cover different types and stages of skin cancer [1].

Limited generalizability: Many deep learning models developed for skin cancer classification have been evaluated on small datasets or datasets from a single institution. There is a need for models that can be trained on larger and more diverse datasets and can generalize well to different populations [4, 5, 6].

Limited availability of models in clinical practice: Although deep learning models have shown excellent performance in skin cancer classification, they are not yet widely used in clinical practice. There is a need to develop models that are easy to use, reliable, and can be integrated into clinical workflows [7, 8].

Limited attention to ethical considerations: There is a need for greater attention to ethical considerations in the development and deployment of deep learning models for skin cancer classification, including issues related to bias, privacy, and informed consent [9, 10].

III. PROPOSED APPROACH

A. Melanoma Detection using Boosted SVM

Ensembles with an infinite hypothesis are constructed using an infinite ensemble framework. This framework learns all the possible weight combinations for all the possible hypotheses. All the hypotheses are embedded in the kernel of the SVM model. The base classifier is trained by fixing the initial weights, and the error due to misclassification is calculated using the weighted method. Now similar to the boosting algorithm weight of each classifier is adjusted, and the ensemble classifier is computed using the weighted component sum classifier as, where is the weight and is the base classifier. Ensemble majority voting model is shown in Fig. 1.

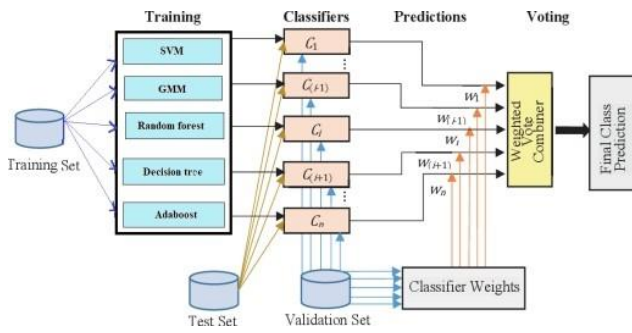


Fig. 1. Ensemble majority voting model.

SVM was developed from the theory of Structural Risk Minimization. In SVM, two essential parameters are to focus on, namely Gaussian width and the regularization parameters [2]. Boosted SVM is applied over the training dataset, and the weights are updated until convergence if the error rate exceeds 0.5. The weighted normal strategy determines the error component (ϵ_m). Only the limited weights of misclassified perceptions are taken as the numerator, separated by the total limited weights [3]. Each SVM is prepared to depend upon the dataset because testing and validation errors decrease as data quantity increases. In both the sections mentioned above, the weight update procedure is addressed by taking into account the distance from each group centroid to each misclassified observation. The modified weights for each misclassified observation are assigned concerning the distance from the centroid of the clusters.

$$G_m = \sum_{j=1}^m \alpha_j * S_j \quad (1)$$

B. Melanoma Detection using Boosted GMM

Using GMM for Ensemble comes under the standard category of clustering ensemble. It is a model-based Ensemble. A model-based Ensemble assumes that the model's clusters will help optimize the relevance between the data and the underlying model. GMM is a probabilistic model [11] frequently used for density estimation, regression, and classification problems. GMM as a classifier is constructed as discussed in Section III. Then the Gaussian mixture components of each object class are compared with the corresponding class object probability. A threshold is fixed to recognize the object with maximum similarity for the specific object class. To generalize different object components and increase the similarity of objects in each class Adaboost algorithm is applied to create a model-based ensemble GMM framework. Here each component in GMM is considered a weak classifier with low accuracy and high redundancy. Adaboost algorithm combines all the weak classifiers into a robust classifier with effective multiclass object recognition.

C. Melanoma Detection using Ensemble CNN

A sequential voting ensemble could be created using convolution neural networks. Theory and implementation of voted ensembles are similar to Section III.C, with one significant difference. Here instead of using different classifier models, we use three models of CNN, and the highest voted prediction is taken as output. Here for each model, three convolution layers, three batch normalization layers are used. Finally, the dense layer with 256 units and softmax layer are

used as the output layer. The Ensemble CNN model is shown in Fig. 2.

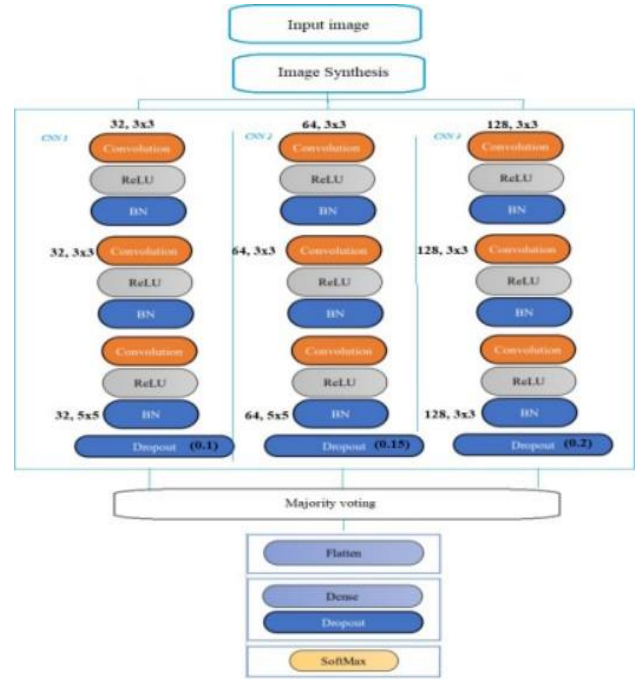


Fig. 2. Proposed CNN model.

Here for the CNN ensemble, three individual models are developed with many ReLU filters. Three models have 32, 64, and 128 filters consecutively. Here the optimizer used is Adam, and the output activation function is softmax. The batch size is 20, and the number of epochs is 30, with 1000 steps for each epoch. An adaptive learning rate is used for each iteration. Dropout for the three models is 0.1, 0.15, and 0.2. Ensemble CNN model is trained using 24000 images, tested using 12000 images, and validated using 12000 images with equally distributed images among each class. During the training of the CNN models, subsamples of the dataset are used. Errors for each subsampled data point are calculated such that if the error is more significant than a threshold, those points are discarded, and training is continued. Also, all three models' features are aligned with highest to lowest priority features. Based on which zero variance features are removed, and features are sent to the next layer.

IV. RESULTS

Improving the accuracy of the classification process and decreasing the misclassification error are two main concerns in ensemble models. This chapter implements six ensemble models for melanoma classification based on the general category aspects. Bagging, boosting, majority voting, infinite ensemble framework, and cluster ensembles are implemented using Random Forest, Adaboost, Majority voting, Boosted SVM, and Boosted GMM classifiers. The Ensemble CNN model is a sequential model developed based on a majority voting ensemble. The ML models used in Section III are SVM, GMM, decision tree, and deepconvnet. These are taken as base models in ensemble models. The basic parameter attributes are tested in Section III, and hyper parameter tuning of the ensemble models is investigated in Section IV. The hyper-

parameters which could be fine-tuned for ensemble models are n estimators, learning rate, and m-features. Since deep learning models are analyzed, m features are not fine-tuned for our investigation. And since n- estimators and learning rates are related, these two parameters are considered for hyperparameter tuning and optimization of the ensemble models. The performance of the classifiers in melanoma prediction is assessed using metrics like accuracy, precision, recall, F1 score, MCC, Jaccard Index, and Kappa. Also, six classes of Melanoma are classified here. In this Stratified 10- fold, cross-validation is used for calculating the performance estimates. Stratification ensures that each class is represented with the same proportions roughly as in the entire data set. Ensemble diversity is used in the datasets to achieve better accuracy and avoid overlapping features in the dataset during clustering. The investigation has carried over 10000 melanoma images generated by GAN. Training of the classifier model has been done with 1000 superficial spreading Melanoma, 1000 Nodular Melanoma, 1000 lentigo melanoma, 1000 acral lentiginous Melanoma, 1000 subungual Melanoma, and 1000 amelanotic Melanoma images. For testing 2000 and validation, 2000 images are used. The entire process has been carried over the python platform. Since CNN models require more datasets to avoid overfitting, it is trained using 24000 images, tested using 12000 images, and validated using 12000 images with images equally distributed among each class.

A. Performance Analysis of Random Forest Classifier

In this investigation, a random forest classifier is implemented for melanoma prediction. Ensemble pruning is done here to reduce the complexity of the network, and the maximum number of features is set to auto. Due to pruning, the random state is fixed to zero. Even though hyperparameter tuning is not necessary for random forest classifiers, the number of estimators varies between 50,100 and 150. The number of estimators (n-estimators) indicates the number of trees or samples required to find the optimum solution. However, it doesn't indicate that the higher the number of trees higher the accuracy. Increasing the number of trees leads to higher computational time. Also, the classifier model's performance will drop for a higher number of estimators. So, choosing the optimum number of estimators is done using the trial-and- error method for our investigation. The minimum sample leaf is restricted to 10, 25, and 50. For each of the six

classes of Melanoma, namely superficial spreading Melanoma, Nodular Melanoma, lentigo melanoma, acral lentiginous Melanoma, subungual Melanoma, and amelanotic Melanoma combinations of n estimators and minimum sample leaves were fixed. The performance of the classifier is tested. The random forest classifier's performance is best for melanoma classification with an accuracy of 90.23 for the n estimator minimum leaf combination of 100:50. It is found that for a smaller number of estimators, Random forests suffer from underfitting problems. Performance analysis of random forest classifier is shown in Table I.

B. Performance Analysis of Adaboost Classifier

Adaboost, one of the popular boosting algorithms, is known to reduce outliers and overfitting issues. It also helps in improving the performance and robustness of the classifier. For Adaboost classification, different n estimators for different learning rate combinations are investigated to improve accuracy. N estimators used are 50,100,150 and learning rates are 0.01, 0.001 and 0.0001.

Adaboost classifier performs well with an accuracy of 96.78 for a learning rate of 0.01 with 50 estimators. Since base estimators affect the performance of the Adaboost classifier, svc is used as the base estimator. Performance metrics for melanoma detection using the Adaboost classifier are shown in Table II.

C. Performance Analysis of Ensemble Voted Classifier

Ensemble voted classifier is implemented using the majority voting method. For ensemble networks, pretrained base learners are necessary. GMM and SVM classifiers are implemented using the same settings discussed Decision tree, AdaBoost, and Random Forest classifier's performance vary over the number of estimators, and the learning efficiency differs for each model. So, ensemble majority voted model has been implemented for different estimator learning rate combinations with a fixed threshold of 0.5. Here the combined majority voting is calculated. For each class prediction, if the vote probability is more significant than 0.5, then the majority vote among the classifier output is chosen. If the probability of none of the classifiers is above 0.5, then the model is again restarted for other weights. Performance analysis of the Ensemble voted classifier in Table III shows that the classifier achieves better accuracy of 96.32 for a learning rate of 0.01.

TABLE I. PERFORMANCE ANALYSIS OF RANDOM FOREST CLASSIFIER

Estimators	Learning rate	Precision	Recall	Accuracy	F1-score	MCC	Jaccard Index	Kappa
	10	68.34	69.89	70.4	69.11	48.49	65.66	0.638
50	25	68.57	69.99	74.82	69.27	49.91	69.33	0.712
	50	70.12	71.34	71.27	70.72	51.52	70.49	0.712
	10	73.87	74.21	76.89	74.04	57.34	73.79	0.728
100	25	74.56	75.11	79.45	74.83	68.34	74.99	0.731
	50	86.54	88.31	90.23	87.42	87.31	89	0.771
	10	86.34	88.19	89.87	87.26	86.25	88.17	0.771
150	25	86.36	88.24	89.93	87.29	86.78	88.51	0.764
	50	86.47	88.29	89.97	87.37	86.91	88.81	0.76

TABLE II. PERFORMANCE ANALYSIS OF ADABOOST CLASSIFIER

estimators	Learning rate	Precision	Re-call	Accuracy	F1 score	MCC	Jaccard Index	Kappa
50	0.01	93.21	94.78	96.78	93.99	95.78	93.29	0.836
	0.001	93.2	94.27	96.41	93.73	94.21	93.02	0.827
	0.0001	92.65	93.56	96.17	93.1	92.87	92.13	0.824
100	0.01	93.19	93.21	94.71	93.2	88.34	91.22	0.821
	0.001	93.02	92.16	91.34	92.59	79.48	90.67	0.817
	0.0001	92.89	92.11	92.65	92.5	87.49	89.54	0.802
150	0.01	91.56	91.83	90.47	91.69	77.92	87.48	0.798
	0.001	90.18	91.27	90.65	90.72	72.85	88.01	0.783
	0.0001	89.91	90.42	88.73	90.16	68.79	83.17	0.779

TABLE III. PERFORMANCE ANALYSIS OF ENSEMBLE VOTED CLASSIFIER

Estimators	Learning rate	Precision	Recall	Accuracy	F1-score	MCC	Jaccard Index	Kappa
50	0.01	92.56	93.89	96.32	93.22	93.67	90.45	0.892
	0.001	91.89	92.57	95.48	92.23	91.42	89.93	0.879
	0.0001	90.43	91.27	93.71	90.85	87.17	89.92	0.879
100	0.01	90.12	90.17	92.87	90.64	82.39	89.74	0.872
	0.001	88.67	89.36	91.28	89.01	80.39	87.95	0.865
	0.0001	84.31	86.29	87.91	85.29	78.59	84.77	0.847
150	0.01	83.37	86.17	87.59	84.75	71.44	84.9	0.823
	0.001	81.29	85.99	86.71	83.57	68.53	83.01	0.796
	0.0001	76.15	75.82	82.19	75.98	52.31	79.02	0.747

D. Performance Analysis of Boosted SVM Classifier

From the previous investigation on SVM, it has been proved that the RBF kernel works well on melanoma images for a gamma value of 10. The same parameters are used in the boosted SVM classifier for different n estimators and learning rates. Even though the AdaBoost classifier works well only for 50 n estimators, boosted SVM gives better accuracy of 98.37 with a 0.01 learning rate. MCC is also significantly improved compared to conventional SVM and AdaBoost classifier models. Performance metrics of boosted SVM classifier for melanoma classification are shown in Table IV.

TABLE IV. PERFORMANCE ANALYSIS OF BOOSTED SVM CLASSIFIER

Estimators	Learning rate	Precision	Recall	Accuracy	F1-score	MCC	Jaccard Index	Kappa
10	0.01	96.48	92.34	97.16	94.36	89.48	88.28	0.873
	0.001	95.39	92.58	96.9	93.96	89.27	88.15	0.873
	0.0001	92.56	93.26	96.15	92.91	89.1	88.01	0.873
25	0.01	99.78	95.76	98.37	97.73	96.93	89.96	0.886
	0.001	98.89	95.61	97.93	97.22	96.73	89.46	0.881
	0.0001	98.1	94.92	97.61	96.48	96.2	89.31	0.879
50	0.01	97.67	94.36	97	95.99	95.91	89.18	0.871
	0.001	97.41	94.21	96.49	95.78	95.63	89.03	0.868
	0.0001	97.18	94.2	96.12	95.67	95.42	88.97	0.861

E. Performance Analysis of Boosted GMM Classifier

GMM model works best as a density estimator in clustering, and the EM algorithm is applied for Classification. To maximize the robustness of the GMM classifier AdaBoost algorithm is used here. Boosted GMM classifier is analyzed for different estimators and learning rates, and the best parameter setting for the classifier is fixed. It is found that the boosted GMM classifier works best at 25 estimators for a learning rate of 0.01 to provide an accuracy of 96.17. GMM shows a gradual performance improvement compared to other classifiers. Performance metrics of boosted SVM classifier for melanoma classification are shown in Table V.

TABLE V. PERFORMANCE ANALYSIS OF BOOSTED GMM CLASSIFIER

Estimators	Learning rate	Precision	Recall	Accuracy	F1-score	MCC	Jaccard Index	Kappa
10	0.01	90.18	89.76	95.89	89.97	83.85	84.95	0.723
	0.001	90.04	89.69	95.64	89.86	83.48	84.89	0.798
	0.0001	89.93	89.52	95.39	89.72	89.21	84.73	0.799
25	0.01	90.65	92.87	96.17	91.75	92.9	86.15	0.827
	0.001	90.57	92.74	96.13	91.64	92.84	86.02	0.819
	0.0001	90.43	92.69	96.08	91.55	92.77	85.99	0.811
50	0.01	90.39	92.34	96.01	91.35	92.68	85.81	0.804
	0.001	90.31	92.38	95.98	91.28	92.52	85.71	0.801
	0.0001	90.28	92.1	95.91	91.18	92.41	85.62	0.798

F. Performance Analysis of Ensemble CNN Classifier

Ensemble CNN is a sequential voting approach implemented using three different CNN models for variable learning rates. This model provides a more stable melanoma prediction accuracy than other ensemble approaches. Even though the implementation of this Ensemble is similar to the majority voting ensemble, this model performs better due to its distinctive feature extraction. This model extracts low and high-frequency features irrespective of the CNN type unless fixed features from previous models. Also, three different models have different dropout rates and kernel counts, preserving overfitting issues in the CNN model. Model converges earlier without much misclassification error. Performance metrics of the ensemble CNN model, as shown in Table VI, indicate the accuracy of 98.67 for melanoma classification. The network performs best with a learning rate of 0.0001 for 25 estimators, which is relatively less than other ensemble models.

Performance metrics for the classifiers mentioned above for independent classes of Melanoma are shown in Table VII. Based on the classifier performance, it is clear that all the classifiers perform better in classifying superficial spreading Melanoma, Nodular Melanoma. Due to colossal variation and differences in the structural properties in different stages of other types of other types of melanomas, the accuracy of the classifiers is less compared to superficial spreading and nodular Melanoma. Subungual Melanoma is present in nails and nail beds. Properties of this Melanoma sometimes resemble typical characteristics of vitamin deficiency. So,

classifiers require extreme robustness to achieve better accuracy. Amelanotic Melanoma is one particular type of Melanoma present in all skin variants. Also, amelanotic Melanoma in certain stages resembles superficial spreading Melanoma and nodular Melanoma.

The ensemble classifiers implemented in this work produce better accuracy than the single classifiers. Adaboost and Boosted SVM classifiers perform better for all five types of Melanomas except amelanotic Melanoma. The other three classifiers, namely boosted GMM, Random Forest, and Ensemble voted classifiers, are performing better in superficial spreading, nodular, and lentigo melanoma classification but is moderate in the other two types despite the best hyperparameter settings, as shown in Table VII. Ensemble CNN models can provide consistent performance for all six types of melanoma classification with slight variation for amelanotic Melanoma.

The convergence plot in Fig. 3 shows the robustness of the ensemble models in melanoma classification. The maximum number of epochs used is 30 to check the training and validation accuracy. Out of six ensemble classifier models used, Ensemble CNN, Adaboost, and Boosted SVM classifiers resulted in better convergence. However, the Ensemble CNN model shows overfitting during validation even though accuracy is higher. Further improvements in the network model and data selection need to be made to avoid overfitting issues. Boosted GMM and Random Forest models are showing underfitting of data points. Ensemble voted model shows the best fit from the 28th epoch.

TABLE VI. PERFORMANCE ANALYSIS OF ENSEMBLE CNN CLASSIFIER

Estimators	Learning Rate	Precision	Recall	Accuracy	F1-score	MCC	Jaccard Index	Kappa
25	0.01	90.57	92.74	96.13	91.64	92.84	86.02	0.834
	0.001	90.65	92.87	96.17	91.75	92.9	86.15	0.839
	0.0001	99.96	99.86	98.67	98.15	97.34	92.71	0.899
50	0.01	90.43	92.69	96.08	91.55	92.77	85.99	0.832
	0.001	90.39	92.34	96.01	91.35	92.68	85.81	0.832
	0.0001	90.31	92.28	95.98	91.28	92.52	85.71	0.832
100	0.01	90.28	92.1	95.91	91.18	92.41	85.62	0.832
	0.001	89.93	89.52	95.39	89.72	83.21	84.73	0.832
	0.0001	90.04	89.69	95.64	89.86	83.48	84.89	0.832

TABLE VII. PERFORMANCE ANALYSIS OF ENSEMBLE CLASSIFIERS

Classifiers	Melanoma classes	Precision	Recall	Accuracy	F1 score	MCC	Jaccard Index	Kappa
Superficial spreading		99.82	95.83	98.41	97.78	96.94	90	0.886
Nodular		99.8	95.76	98.41	97.74	96.93	89.96	0.886
Boosted	Lentigo maligna	99.78	95.68	98.37	97.69	96.93	89.96	0.886
SVM	Acral lentiginous	99.62	95.68	98.37	97.61	96.91	89.95	0.883
Subungual		99.58	95.62	98.37	97.56	96.87	89.91	0.881
Amelanotic		99.58	95.62	98.31	97.56	96.81	89.91	0.88
Superficial spreading		90.65	92.92	96.25	91.77	92.95	86.46	0.827
Nodular		90.65	92.92	96.25	91.77	92.95	86.46	0.827
Boosted	Lentigo maligna	90.65	92.9	96.23	91.76	92.95	86.38	0.827
GMM	Acral lentiginous	90.62	92.87	96.19	91.73	92.93	86.29	0.819
Subungual		90.58	92.87	96.17	91.71	92.9	86.15	0.812
Amelanotic		90.58	92.81	96.17	91.68	92.9	86.15	0.812
Superficial spreading		86.54	88.31	90.23	87.42	87.31	89	0.771
Nodular		86.54	88.31	90.23	87.42	87.31	89	0.771
Random	Lentigo maligna	86.54	88.29	90.22	87.41	87.26	89	0.771
forest	Acral lentiginous	86.51	88.27	90.2	87.38	87.24	88.97	0.769
Subungual		86.5	88.25	90.19	87.37	87.21	88.89	0.766
Amelanotic		86.5	88.25	90.19	87.37	87.21	88.86	0.757
Superficial spreading		93.54	94.89	96.93	94.21	95.86	93.47	0.836
Nodular		93.51	94.81	96.84	94.16	95.81	93.41	0.836
Adaboost	Lentigo maligna	93.21	94.78	96.78	93.99	95.79	93.29	0.836
Classifier	Acral lentiginous	93.21	94.77	96.78	93.98	95.78	93.31	0.836
Subungual		93.2	94.77	96.78	93.98	95.78	93.29	0.836
Amelanotic		93.19	94.77	96.78	93.97	95.78	93.29	0.836
Superficial spreading		92.59	93.93	96.36	93.26	93.71	90.62	0.892
Ensemble	Nodular	92.56	93.89	96.36	93.22	93.65	90.62	0.892
voting	Lentigo maligna	92.55	93.86	96.32	93.20	93.61	90.57	0.887
classifier	Acral lentiginous	92.51	93.82	96.31	93.16	93.56	90.51	0.883
Subungual		92.49	93.84	96.29	93.16	93.51	90.45	0.881
Amelanotic		92.49	93.81	96.29	93.15	93.51	90.45	0.881
Superficial spreading		99.96	99.86	98.67	99.91	97.34	92.71	0.899
Ensemble	Nodular	99.96	95.86	98.67	97.87	97.34	92.7	0.899
CNN	Lentigo maligna	99.94	95.78	98.64	97.82	97.29	92.68	0.897
classifier	Acral lentiginous	99.94	95.78	98.64	97.82	97.29	92.68	0.892
Subungual		99.89	95.78	98.64	97.79	97.29	92.63	0.892
Amelanotic		99.86	95.71	98.61	97.74	97.27	92.59	0.892

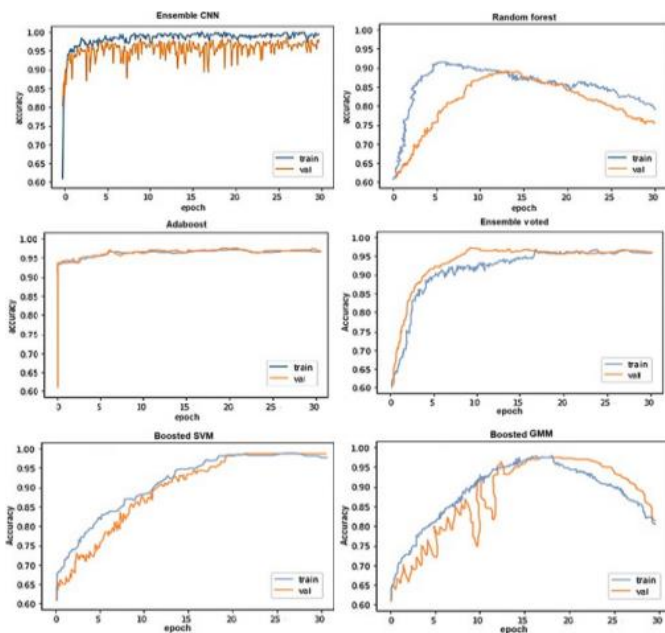


Fig. 3. Accuracy vs. epoch plot for convergence analysis.

V. CONCLUSION

Ensemble learning models as classifiers for melanoma classification. Bagging, boosting, majority voting, infinite ensemble framework, and cluster ensembles are implemented using Random Forest, Adaboost, Majority voting, Boosted SVM, Boosted GMM classifiers, and Ensemble CNN models.

The performance of the classifiers in melanoma prediction is assessed using metrics like accuracy, precision, recall, F1 score, MCC, Jaccard Index, and Kappa. Also, six classes of Melanoma are classified here. In this Stratified 10-fold, cross-validation is used for calculating the performance estimates. Stratification ensures that each class is roughly represented with the same proportions as in the entire data set. Ensemble diversity is used in the datasets to achieve better accuracy and avoid overlapping of features in the dataset during clustering. Ensemble models can perform well for five classes with consistent accuracy out of six classes. The boosted SVM and Adaboost classifiers have higher performance than boosted

GMM, random forest, and Ensemble voted classifiers. Ensemble CNN seems to outperform other ensemble models with an accuracy of 98.67. Though the execution time of ensemble classifiers is high, such a complex network is easier to train, and the network converges ideally. The system's complexity is one point that needs to be considered in the proposed model for further improvement. Also, it was observed that an increase in the number of images in the training dataset increased the size of the feature set, which led to overlapping features.

REFERENCES

- [1] Aggarwal, "Automated skin lesion classification using ensemble of deep neural networks," *International Journal of Computer Assisted Radiology and Surgery*, vol. 13, no. 12, pp. 1925–1936, 2018.
- [2] Jha, "A review of deep learning methods for skin lesion classification in dermatology," *Skin Research and Technology*, vol. 27, no. 4, pp. 453–467, 2021.
- [3] Esteva, "Dermatologist-level classification of skin cancer with deep neural networks," *Nature*, vol. 542, no. 7639, pp. 115–118, 2017.
- [4] Pala, "Classification of skin cancer images using a hybrid deep learning model," *Journal of Ambient Intelligence and Humanized Computing*, vol. 12, no. 11, pp. 12 797–12 806, 2021.
- [5] Islam, "Multi-class skin lesion classification using a deep residual network with spatial pyramid pooling," *Computer Methods and Programs in Biomedicine*, vol. 197, pp. 105 742–105 742, 2020.
- [6] G. R. Praveena and M. S. Indhumathi, "Skin lesion classification using deep learning: A review and future directions," *Biomedical Signal Processing and Control*, vol. 70, pp. 102 900–102 900, 2021.
- [7] Y. Wang, "A novel skin cancer classification approach using deep convolutional neural networks with attention mechanism," *Computerized Medical Imaging and Graphics*, vol. 97, pp. 101 996–101 996, 2023.
- [8] Wei, "Interpretable classification of skin lesions using attention-based convolutional neural networks," *Journal of Medical Systems*, vol. 46, no. 1, pp. 5–5, 2022.
- [9] Lin, "Skin cancer classification using transfer learning and optimized convolutional neural networks," *IEEE Access*, vol. 10, pp. 41 113–41 121, 2022.
- [10] Kourou, "Deep learning for skin cancer classification: A comparison study," *IEEE Transactions on Medical Imaging*, vol. 39, no. 7, pp. 2349–2358, 2020.
- [11] Codella, "Skin lesion analysis toward melanoma detection: A challenge at the 2017 International Symposium on Biomedical Imaging (ISBI), hosted by the International Skin Imaging Collaboration (ISIC)," *Proceedings of the IEEE International Symposium on Biomedical Imaging*, pp. 168–172, 2018.

Krill Herd Algorithm for Live Virtual Machines Migration in Cloud Environments

Hui Cao¹, Zhuo Hou^{2*}

HeNan Open University, Zhengzhou, Henan, China, 450046¹

Henan Vocational College of Agriculture, Zhengzhou, Henan, China, 450046²

Abstract—Green cloud computing is a modern approach that provides pay-per-use information and communication technologies with a minimal carbon footprint. Cloud computing enables users to access computing resources without the need for local servers or personal devices to operate applications. It allows businesses and developers to access infrastructure and hardware resources conveniently. Consequently, this results in a growing demand for data centers. It becomes crucial in maintaining economic and environmental sustainability as data centers use disproportionate energy. This points to sustainability and energy consumption as being important topics for research in cloud computing. This paper introduces a two-tiered VM placement algorithm. A queuing model is proposed at the first level to handle many VM requests. Models such as cloud simulation are easily implemented and validated using this model. It also provides an alternate method for allocating tasks to servers. Next, a multi-objective VM placement algorithm is proposed based on the Krill Herd (KH) algorithm. Basically, it maintains a balance between energy consumption and resource utilization.

Keywords—Cloud computing; migration; virtualization; energy consumption

I. INTRODUCTION

Virtualization is a major technology that underpins cloud computing. In order to offer access to mainframe computers in an interactive manner, IBM developed this technology in the 1960s, where multiple users (and applications) could utilize expensive hardware simultaneously [1]. Storage technologies and computing power have made computing resources more abundant, cheaper, and powerful than ever before due to rapid technological advancements [2, 3]. This development has led to the development of cloud computing, where computing resources are provided on an on-demand basis over the Internet [4]. Virtualization technology can be utilized in modern cloud computing environments in order to minimize energy costs and optimize resource utilization [5]. Multiple operating systems can be run on one physical machine using virtualization technology. Operating systems are run on separate Virtual Machines (VMs) controlled by hypervisors [6]. The rapid advancement of emerging technologies such as the Internet of Things (IoT) [7, 8], big data [9, 10], artificial intelligence [11, 12], Blockchain [13], machine learning [14-17], and 5G communication technology [18] has resulted in significant challenges associated with traditional cloud computing data centers, including complex operation and maintenance, inefficient configuration, high construction costs, and an absence of effective unified business monitoring tools.

Live VM migration is one of the key advantages of virtualization, as it facilitates resource management in cloud environments [19]. A VM can seamlessly migrate between physical machines (source hosts) and destination hosts, even as it is running [20]. Load balancing is the primary goal of live VM migration, which migrates VMs from heavy hosts to under-loaded ones [21]. It also provides power management since it consolidates light-load VMs onto fewer servers, resulting in reduced IT operations costs and power consumption [22]. Live VM migration also provides hotspot and cold spot mitigation. In order to meet SLA requirements for VMs, active resource consumption needs to be monitored [23]. Cold spots are physical machines with low threshold values, while hot spots are physical machines with high threshold values. By combining proactive and reactive techniques, hot and cold spots can be detected before they occur and mitigated, thereby maintaining system performance [24]. Server consolidation is another advantage of live VM migration. In this technique, VMs are packed onto a small number of physical machines, and the spare or ideal machine can be powered off or placed in sleep mode, thus reducing both server usage and power consumption [25].

VM migration is the process of moving a VM from one physical host (source node) to another host (target node). VMs are transferred from their source hosts to their destination hosts without interrupting network connections. The original VM continues to run during live migration. Live VM migration is relatively quick, making it ideal for fast migrations. The proposed system aims to migrate VMs from overloaded to underloaded physical machines within a short period of time. The term "live migration of VMs" refers to the process of migrating the VM while it is running in its original state. Live VM migration is beneficial for fast migration since it provides a short amount of migration time [26].

This paper introduces a two-tiered VM placement algorithm. A queuing model is proposed at the first level to handle many VM requests. Models such as cloud simulation are easily implemented and validated using this model. It also provides an alternate method for allocating tasks to servers. Next, a multi-objective VM placement algorithm based on the KH algorithm is proposed. Basically, it maintains a balance between energy consumption and resource utilization. The proposed research aims to achieve the following objectives:

- Generating resource utilization profiles for PMs.
- Using the KH algorithm to identify overloaded and underloaded physical servers.

- Migrating VMs with minimal downtime.
- Reducing the amount of energy required for physical resources.

II. RELATED WORK

Farahnakian, et al. [27] presented an architecture based on the Ant Colony Optimization (ACO) algorithm for dynamic VM consolidation that reduces the energy consumption of cloud data centers while improving quality of service. Kansal and Chana [28] proposed an energy-aware VM migration approach for cloud computing based on the Firefly algorithm. By migrating over-loaded VMs to under-loaded nodes, the energy efficiency of data centers is improved. By comparing the proposed technique with other techniques, the efficacy of this technique is demonstrated. By cutting an average of 73 % of migrations and reducing 35 % of hosts, the data center has achieved an average reduction in energy consumption of 45 %.

Fu, et al. [29] presented a layered VM migration algorithm. Cloud data centers are initially divided into several regions based on bandwidth utilization rates. VM migrations balance network load between regions, resulting in load balancing of cloud resources. Experiments indicate that the proposed algorithm is shown to be able to effectively balance network resource load in cloud computing. Chien, et al. [30] have proposed a novel VM migration algorithm based on the reduction of migrations in cloud computing that can enhance efficiency, meet user requirements, and prevent service level agreements (SLA) violations. The proposed algorithm was found to be more effective than existing algorithms based on experimental results. A threshold algorithm was proposed by Kaur and Sachdeva [31] to allocate tasks to the most capable machine and host and to maintain checkpoints on VMs. Overloaded VMs need to migrate tasks to another VM. This study proposes a weight-based approach for migrating cloudlets between VMs.

Xu and Abnoosian [32] presented a hybrid optimization algorithm based on genetic and particle swarm optimization algorithms for improving VM energy consumption and execution time during VM migration. In the hybrid algorithm, GA is utilized to overcome the limitations of the PSO algorithm, which suffers from slow convergence and limited global optimization. According to the results, the proposed method has improved energy consumption by an average of 23.19% compared to the other three methods. Results also revealed a 29.01% improvement in execution time over the other three methods. Zhou, et al. [33] introduce an energy-efficient algorithm for VM migrations. In this algorithm, host location, VM selection, and trigger time are optimized when memory and CPU factors are taken into account. It migrates some VMs from lightly loaded hosts to heavily loaded hosts using virtualization technology. Energy is conserved by switching idle hosts to the low-power mode or shutting them down. This algorithm reduces SLA violations by 13% and saves 7% of energy over the Double Threshold (DT) algorithm.

VM migration provides an effective and efficient approach to managing cloud resources by providing flexibility in terms

of security guaranteeing [34-36], network traffic optimization [37, 38], reduction of SLA violations [39-41], migration cost minimization [42, 43], and energy minimization [44-46]. However, these approaches do not take into account the performance reduction that occurs when VMs are migrated. Several performance-aware VM migration methods have been proposed [47-49]. However, their performance optimization focused not on maximizing VM performance but on reducing SLA violations or migration downtime. Specifically, the works [39-41] attempted to reduce SLA violations or migration downtime rather than optimize VM performance, and Zhang and Zhou [50] guaranteed that running tasks would meet the VM processing time constraint. Çağlar and Altılar [51] aimed to minimize power consumption while meeting performance requirements rather than maximizing VM performance for their users. Moreover, none of the above VM migration techniques provided a specific performance model to describe how VM performance declines over time.

III. SYSTEM MODEL

A VM request must be arranged for deployment on physical servers. A scheduler determines a server from the available servers to place the specific VM. A queuing model is proposed to schedule the placement of VMs. In Section III A, the queuing structure is explained. Section III B discusses the KH-based VM placement algorithm.

A. Single Queue Single Service Facility

The queuing scheme follows a single queue single service facility - M/M/1 queue. VM requests are processed according to a FIFO discipline before being forwarded to the data center for placement. Assume μ and λ reflect service and arrival metrics in the queue at various intervals. $(N-1)$ VM requests are handled in this way. In the stable situation, P_n represents the likelihood of having n VM requests.

$$\lambda_n = \begin{cases} \lambda, & n = 0, 1, \dots, n-1 \\ 0, & n = N, N+1 \end{cases} \quad (1)$$

$$\mu_n = \mu, \quad n = 0, 1, \dots \quad (2)$$

$$\rho = \frac{\lambda}{\mu} \quad (3)$$

$$P_n = \begin{cases} \rho^n P_0, & n \leq N \\ 0, & n > N \end{cases} \quad (4)$$

Using P_n , the expected number of VM requests in the system (R_s) is determined as follows.

$$R_s = \sum_{n=1}^N n P_n = \frac{\rho[(N+1)\rho^N + N\rho^{N+1}]}{(1-\rho)(1-\rho^{N+1})}; \quad \rho \neq 1 \quad (5)$$

$$R_s = \sum_{n=1}^N n P_n = \frac{N}{2}; \quad \rho = 1 \quad (6)$$

The number of VM requests in the queue (R_q) is determined by $R_q = \lambda T_q$, in which T_q indicates the estimated time required to place the VM. In addition, T_s represents the estimated time for placing the VM in the system. These parameters are determined by Eq. (7) and Eq. (8). Hence, Eq. (9) can be used to calculate the total time required to place a VM request.

$$T_s = \frac{R_s}{\lambda} \quad (7)$$

$$T_q = T_s - 1 \quad (8)$$

$$T = T_q + T_s \quad (9)$$

B. VM Allocation using the KH Algorithm

Appropriate mapping of VMs to hosts is essential for optimizing key performance indicators, including resource wastage and power consumption. The mapping of VMs to proper PMs is known as VM allocation. The VM array $\{vm_1, vm_2, vm_3, \dots, vm_n\}$ comprises n VMs, each requesting resources in the memory and CPU dimensions. A host array $\{H_1, H_2, \dots, H_p\}$ signifies the total number of PMs. A krill matrix is used to model the VM request set. Power consumption and resource waste are optimized simultaneously in the proposed method. The following subsections provide mathematical definitions of the parameters mentioned above in order to optimize them.

1) *Power consumption calculation:* Total power consumption is calculated using Eq. (10), where ut_i stands for host utilization, $power_i^{\min}$ denotes the minimum power consumption at minimum utilization, and $power_i^{\max}$ refers to the maximum average power consumption at maximum utilization. As determined by Eq. (11), efficiency is the percentage of total power consumed to total workload.

$$pow_i = (pow_i^{\max} - pow_i^{\min}) \times ut_i + pow_i^{\min} \quad (10)$$

$$E_{pwr} = \frac{\text{Total workload}}{\text{Power consumed}} = \frac{ut_{cpu}}{(pow^{\max} - pow^{\min}) \times ut_{cpu} + pwr^{\min}} \cdot ((pow^{\max} - pow^{\min}) + pow^{\min}), \quad 0 \leq E_{pow} \leq 1 \quad (11)$$

In this case, efficiency ranges between 0 and 1, with higher efficiency indicating better server utilization. Eq. (12) calculates the aggregate efficiency.

$$E_{tot} = E_{res} + E_{pwr} \quad (12)$$

$$0 \leq E_{tot} \leq 2$$

2) *Resource wastage calculation:* Due to the VM's unpredictable resource usage pattern, server utilization is stochastic in nature. An important criterion for determining the appropriate utilization of a server is the proper use of its resources across all dimensions. Eq. (13) calculates the total amount of resources wasted by a host, where r^{\min} signifies the normalized wastage. Eq. (14) provides a formula for determining the efficiency of a given assignment.

$$waste_i = \sum_{d \neq \min} (r^d - r^{\min}) \quad (13)$$

$$E_{res} = ut_{cpu} \cdot ut_{mem}; \quad 0 \leq E_{res} \leq 1 \quad (14)$$

E_{res} measures the efficiency of resource utilization. The goal is to maximize the utilization of resources in a variety of dimensions. Physical machines are measured in terms of their CPU and memory. A higher efficiency indicates better packing of VMs. This efficiency ranges from 0 to 1. Eq. (15)

can be used to calculate the utilization of the i^{th} host along the d^{th} dimension, where cap_i^d represents the physical host's capacity and $alloc(H_i)$ represents the set of VMs allocated to the i^{th} host.

$$ut_i^d = \frac{\sum_{vm_i \in alloc(H_i)} vm_i^d}{cap_i^d}; \quad d \in \{CPU, mem\} \quad (15)$$

3) *Formulation of the problem:* Numerous engineering problems have been solved using the KH algorithm. VMP can also be viewed as an optimization problem. The inspiration comes from the KH algorithm, where the krills continually move around the environment in search of food sources. Each VM corresponds to a krill, and the optimum food source corresponds to an optimal host for placement. According to Eq. (16), the global solution is a configuration that fulfills the requirements. The KH algorithm is used to obtain a suboptimal solution to the VM placement problem.

$$\min \sum_{i=1}^p waste_i \quad \text{and} \quad \sum_{i=1}^p pow_i \quad (16)$$

Virtual machines are assigned to physical machines based on the following criteria.

- **Placement constraints:** The constraint ensures that a VM will be distributed to only a single host if all required resources are available.
- **Capacity constraints:** This condition ensures that VM resource requirements do not exceed the total resources all the hosts can share in the federation.
- **Assignment constraints:** VMs will be placed on servers that meet all their requirements under this constraint. These constraints can be expressed in mathematical terms as follows:

4) *Krill herd algorithm:* The KH algorithm employs swarm intelligence to solve continuous optimization problems. In comparison to existing algorithmic techniques, it appears to perform better or provide comparable results. Compared to other swarm-intelligence algorithms, this algorithm requires few control parameters and is easy to implement. The KH algorithm models the krill population searching for food within a multidimensional search space with the locations of individual krills serving as decision variables, whereas the distance between the krills and the rich food represents an objective cost. Based on Fig. 1, the KH optimization process comprises three stages, including the movement of other krill individuals, foraging motion, and physical diffusion. These actions can be expressed as a mathematical expression by Eq. (17), where D_i stands for physical diffusion, F_i denotes foraging motion, and N_i signifies other krill movements [52].

$$\frac{dX_i}{dt} = N_i + F_i + D_i \quad (17)$$

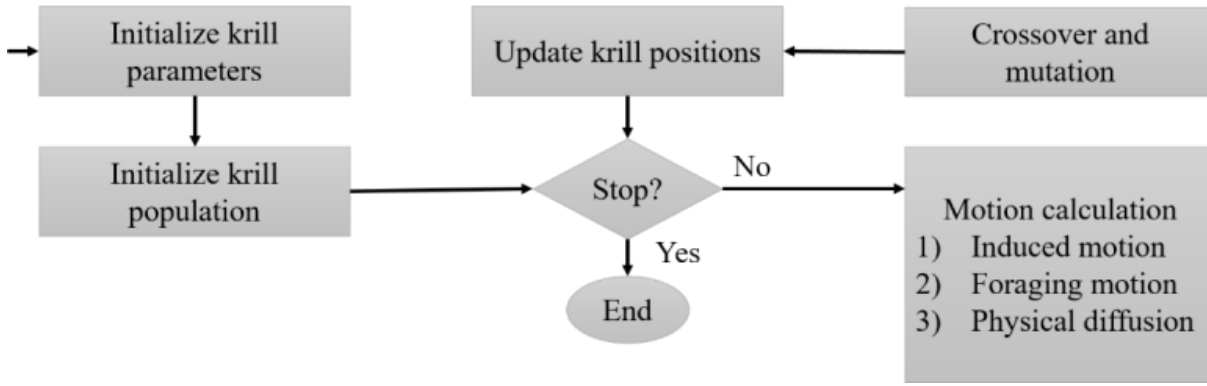


Fig. 1. Flowchart of KH algorithm.

There are three components to the first motion, namely the target effect, the local effect, and the repellent effect. A mathematical representation of the krill i can be derived as follows:

$$N_i^{new} = N^{max} a_i + \omega_n N_i^{old} \quad (18)$$

$$a_i = a_i^{local} + a_i^{target} \quad (19)$$

In the above equations, a_i^{target} indicates the effect of target direction, a_i^{local} represents the local effect, N_i^{old} refers to the last motion induced, ω_n corresponds to the inertia weight ranging from 0 to 1, and N^{max} refers to the maximum speed induced. Food location and previous experience can be described as two aspects of the foraging process. This can be expressed as follows for the i^{th} krill.

$$F_i = V_f \beta_i + \omega_f F_i^{old} \quad (20)$$

$$\beta_i = \beta_i^{food} + \beta_i^{best} \quad (21)$$

In Eq. (20) and Eq. (21), V_f refers to the foraging speed, ω_f represents the inertia weight between 0 and 1, F_i^{old} indicates the last foraging motion, β_i^{food} indicates the food's attractiveness, and β_i^{best} reflects the best fitness of the i^{th} krill. Each krill moves between high- and low-density levels based on Eq. (22), in which d represents a random array of values between 0 and 1 while D^{max} determines the diffusion speed.

$$D_i = D^{max} \left(1 - \frac{I}{I_{max}}\right)^\delta \quad (22)$$

IV. EXPERIMENTAL RESULTS

Cloudsim is the most popular toolkit for simulating cloud environments and conducting simulation-based evaluations. Cloud computing can be continuously exhibited, simulated, and investigated on this completely adaptable platform. In this way, the research community and industry-based designers have the ability to focus on detailed system design. A description of the simulation process is provided in Table I. The simulation was repeated 40 times with up to 200 virtual machines and 200 hosts. This section examines the efficiency

of the proposed algorithm in two scenarios and compares it with previous algorithms. In the first scenario, the proposed algorithm's energy consumption is compared to previous algorithms. The results demonstrate that the proposed algorithm is more efficient than previous methods that require fewer hosts and migrations. Fig. 2 illustrates the energy consumption of First Fit Decreasing (FFD), ACO, and Firefly Optimization (FFO) algorithm. Fig. 3 and 4 depict convergence and stability graphs, respectively. As depicted in Fig. 5, the proposed method produces fewer migrations than the FFO, ACO, and FFD. Fig. 6 illustrates the method's stability for the second scenario.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Number of physical machines	10-200
Number of virtual machines	10-200
VM size	2 GB
VM RAM	1-4 GB
VM MIPS	1000-2500
PM ram	4 GB
Bandwidth	2 Gbps

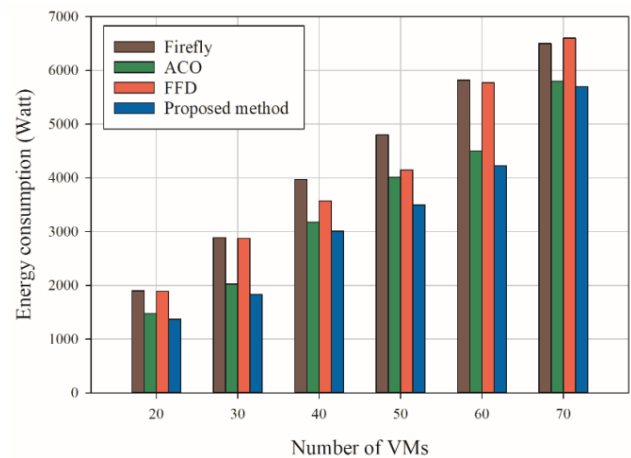


Fig. 2. Energy consumption comparison.

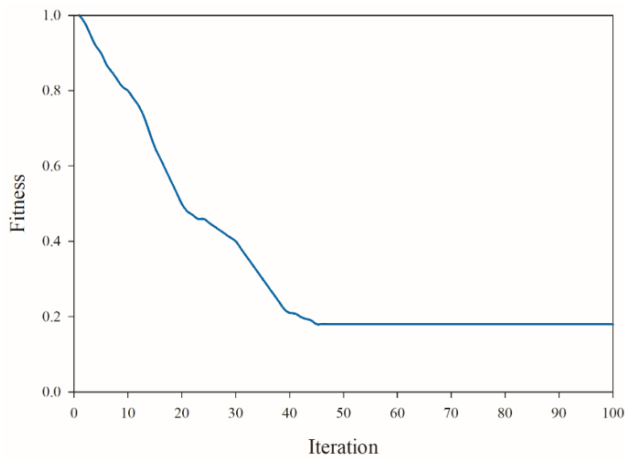


Fig. 3. Coverage graph for the first scenario.

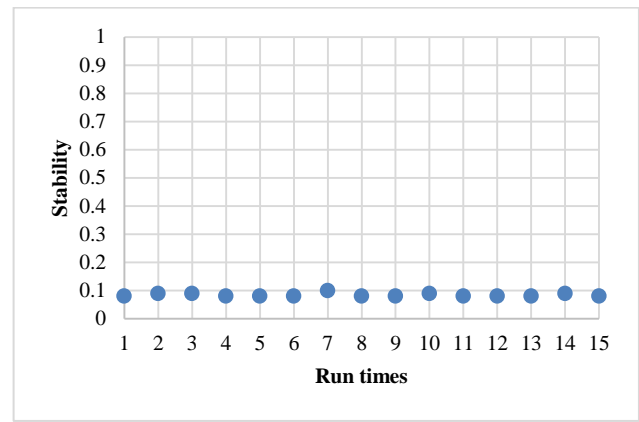


Fig. 6. Stability for the second scenario.

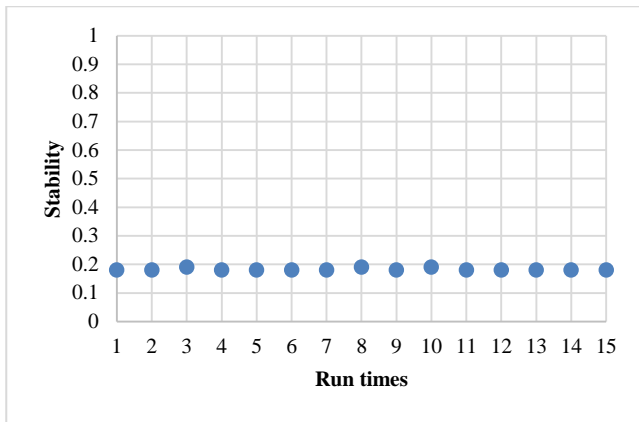


Fig. 4. Stability for the first scenario.

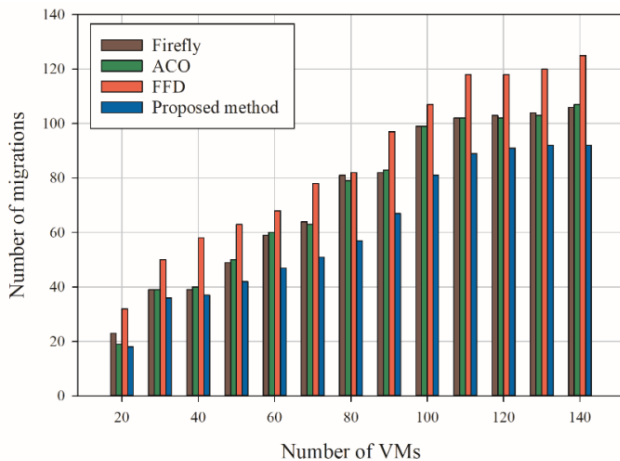


Fig. 5. Number of migrations vs. number of VMs.

V. CONCLUSION

Cloud computing provides unlimited computing resources that can be accessed from anywhere, anytime, on demand. Recent research in cloud computing emphasizes the importance of energy efficiency in data centers. Cloud architecture is characterized by high power consumption and inadequate utilization of physical resources. An idle VM tends to consume 50% to 70% of the total server energy, resulting in an imbalance and insufficient power for the active VMs. This paper proposed a new VM migration method based on the KH algorithm that minimized energy consumption and maximized the utilization of computational resources. The algorithm reduces power consumption by putting idle machines into sleep mode. It also minimizes the number of migrations compared to previous works.

REFERENCES

- [1] B. Pourghebleh, A. A. Anvigh, A. R. Ramtin, and B. Mohammadi, "The importance of nature-inspired meta-heuristic algorithms for solving virtual machine consolidation problem in cloud environments," *Cluster Computing*, pp. 1-24, 2021.
- [2] V. Hayyolalam, B. Pourghebleh, M. R. Chehrezad, and A. A. Pourhaji Kazem, "Single-objective service composition methods in cloud manufacturing systems: Recent techniques, classification, and future trends," *Concurrency and Computation: Practice and Experience*, vol. 34, no. 5, p. e6698, 2022.
- [3] P. S. Priya, P. Malik, A. Mehbodniya, V. Chaudhary, A. Sharma, and S. Ray, "The Relationship between Cloud Computing and Deep Learning towards Organizational Commitment," in *2022 2nd International Conference on Innovative Practices in Technology and Management (ICIPTM)*, 2022, vol. 2: IEEE, pp. 21-26.
- [4] S. Sefati, M. Mousavinasab, and R. Zareh Farkhady, "Load balancing in cloud computing environment using the Grey wolf optimization algorithm based on the reliability: performance evaluation," *The Journal of Supercomputing*, vol. 78, no. 1, pp. 18-42, 2022.
- [5] S. Bharany et al., "Energy efficient fault tolerance techniques in green cloud computing: A systematic survey and taxonomy," *Sustainable Energy Technologies and Assessments*, vol. 53, p. 102613, 2022.

- [6] S. Vinoth, H. L. Vemula, B. Haralayya, P. Mamgain, M. F. Hasan, and M. Naved, "Application of cloud computing in banking and e-commerce and related security threats," *Materials Today: Proceedings*, vol. 51, pp. 2172-2175, 2022.
- [7] A. Mehbodniya et al., "Energy-Aware Routing Protocol with Fuzzy Logic in Industrial Internet of Things with Blockchain Technology," *Wireless Communications and Mobile Computing*, vol. 2022, 2022.
- [8] M. Mohseni, F. Amirghafouri, and B. Pourghebleh, "CEDAR: A cluster-based energy-aware data aggregation routing protocol in the internet of things using capuchin search algorithm and fuzzy logic," *Peer-to-Peer Networking and Applications*, pp. 1-21, 2022.
- [9] H. Kosarirad, M. Ghasempour Nejati, A. Saffari, M. Khishe, and M. Mohammadi, "Feature Selection and Training Multilayer Perceptron Neural Networks Using Grasshopper Optimization Algorithm for Design Optimal Classifier of Big Data Sonar," *Journal of Sensors*, vol. 2022, 2022.
- [10] B. Pourghebleh and N. J. Navimipour, "Data aggregation mechanisms in the Internet of things: A systematic review of the literature and recommendations for future research," *Journal of Network and Computer Applications*, vol. 97, pp. 23-34, 2017.
- [11] M. Sarbaz, M. Manthouri, and I. Zamani, "Rough neural network and adaptive feedback linearization control based on Lyapunov function," in *2021 7th International Conference on Control, Instrumentation and Automation (ICCA)*, 2021: IEEE, pp. 1-5.
- [12] C. Han and X. Fu, "Challenge and Opportunity: Deep Learning-Based Stock Price Prediction by Using Bi-Directional LSTM Model," *Frontiers in Business, Economics and Management*, vol. 8, no. 2, pp. 51-54, 2023.
- [13] S. Meisami, M. Beheshti-Atashgah, and M. R. Aref, "Using Blockchain to Achieve Decentralized Privacy In IoT Healthcare," *arXiv preprint arXiv:2109.14812*, 2021.
- [14] R. N. Jacob, "Non-performing Asset Analysis Using Machine Learning," in *ICT Systems and Sustainability: Proceedings of ICT4SD 2020, Volume 1*, 2021: Springer, pp. 11-18.
- [15] M. Sadi et al., "Special Session: On the Reliability of Conventional and Quantum Neural Network Hardware," in *2022 IEEE 40th VLSI Test Symposium (VTS)*, 2022: IEEE, pp. 1-12.
- [16] J. Akhavan, J. Lyu, and S. Manoochehri, "A deep learning solution for real-time quality assessment and control in additive manufacturing using point cloud data," *Journal of Intelligent Manufacturing*, pp. 1-18, 2023.
- [17] P. Alipour and S. E. Charandabi, "Analyzing the Interaction between Tweet Sentiments and Price Volatility of Cryptocurrencies," *European Journal of Business and Management Research*, vol. 8, no. 2, pp. 211-215, 2023.
- [18] R. Singh et al., "Analysis of Network Slicing for Management of 5G Networks Using Machine Learning Techniques," *Wireless Communications and Mobile Computing*, vol. 2022, 2022.
- [19] K. Ramana, R. Aluvalu, V. K. Gunjan, N. Singh, and M. N. Prasadhu, "Multipath Transmission Control Protocol for Live Virtual Machine Migration in the Cloud Environment," *Wireless Communications and Mobile Computing*, vol. 2022, 2022.
- [20] Y. Kumar, S. Kaul, and Y.-C. Hu, "Machine learning for energy-resource allocation, workflow scheduling and live migration in cloud computing: State-of-the-art survey," *Sustainable Computing: Informatics and Systems*, vol. 36, p. 100780, 2022.
- [21] S. E. Motaki, A. Yahyaouy, and H. Gualous, "A prediction-based model for virtual machine live migration monitoring in a cloud datacenter," *Computing*, vol. 103, no. 11, pp. 2711-2735, 2021.
- [22] K. J. Naik, "An Adaptive Push-Pull for Disseminating Dynamic Workload and Virtual Machine Live Migration in Cloud Computing," *International Journal of Grid and High Performance Computing (IJGHPC)*, vol. 14, no. 1, pp. 1-25, 2022.
- [23] A. Gupta, P. Dimri, and R. Bhatt, "An Optimized Approach for Virtual Machine Live Migration in Cloud Computing Environment," in *Evolutionary Computing and Mobile Sustainable Networks*: Springer, 2021, pp. 559-568.
- [24] M. Noshay, A. Ibrahim, and H. A. Ali, "Optimization of live virtual machine migration in cloud computing: A survey and future directions," *Journal of Network and Computer Applications*, vol. 110, pp. 1-10, 2018.
- [25] M. H. Shirvani, A. M. Rahmani, and A. Sahafi, "A survey study on virtual machine migration and server consolidation techniques in DVFS-enabled cloud datacenter: taxonomy and challenges," *Journal of King Saud University-Computer and Information Sciences*, vol. 32, no. 3, pp. 267-286, 2020.
- [26] T. He, A. N. Toosi, and R. Buyya, "Performance evaluation of live virtual machine migration in SDN-enabled cloud data centers," *Journal of Parallel and Distributed Computing*, vol. 131, pp. 55-68, 2019.
- [27] F. Farahnakian et al., "Using ant colony system to consolidate VMs for green cloud computing," *IEEE Transactions on Services Computing*, vol. 8, no. 2, pp. 187-198, 2014.
- [28] N. J. Kansal and I. Chana, "Energy-aware virtual machine migration for cloud computing-a firefly optimization approach," *Journal of Grid Computing*, vol. 14, no. 2, pp. 327-345, 2016.
- [29] X. Fu, J. Chen, S. Deng, J. Wang, and L. Zhang, "Layered virtual machine migration algorithm for network resource balancing in cloud computing," *Frontiers of Computer Science*, vol. 12, no. 1, pp. 75-85, 2018.
- [30] N. K. Chien, V. S. G. Dong, N. H. Son, and H. D. Loc, "An efficient virtual machine migration algorithm based on minimization of migration in cloud computing," in *International Conference on Nature of Computation and Communication*, 2016: Springer, pp. 62-71.
- [31] G. Kaur and R. Sachdeva, "Virtual machine migration approach in cloud computing using genetic algorithm," in *Advances in Information Communication Technology and Computing*: Springer, 2021, pp. 195-204.
- [32] Y. Xu and K. Abnoosian, "A new metaheuristic-based method for solving the virtual machines migration problem in the green cloud computing," *Concurrency and Computation: Practice and Experience*, vol. 34, no. 3, p. e6579, 2022.
- [33] Z. Zhou, J. Yu, F. Li, and F. Yang, "Virtual machine migration algorithm for energy efficiency optimization in cloud computing," *Concurrency and Computation: Practice and Experience*, vol. 30, no. 24, p. e4942, 2018.
- [34] D. Sun, J. Zhang, W. Fan, T. Wang, C. Liu, and W. Huang, "SPLM: security protection of live virtual machine migration in cloud computing," in *Proceedings of the 4th ACM international workshop on security in cloud computing*, 2016, pp. 2-9.
- [35] J. Doyle, M. Golec, and S. S. Gill, "Blockchainbus: A lightweight framework for secure virtual machine migration in cloud federations using blockchain," *Security and Privacy*, vol. 5, no. 2, p. e197, 2022.
- [36] A. Celesti, A. Salici, M. Villari, and A. Puliafito, "A remote attestation approach for a secure virtual machine migration in federated cloud environments," in *2011 First International Symposium on Network Cloud Computing and Applications*, 2011: IEEE, pp. 99-106.
- [37] W. Zhang, S. Han, H. He, and H. Chen, "Network-aware virtual machine migration in an overcommitted cloud," *Future Generation Computer Systems*, vol. 76, pp. 428-442, 2017.
- [38] X. Fu, C. Zhang, J. Chen, L. Zhang, and L. Qiao, "Network traffic based virtual machine migration in cloud computing environment," in *2019 IEEE 3rd Information Technology, Networking, Electronic and Automation Control Conference (ITNEC)*, 2019: IEEE, pp. 818-821.
- [39] M. Jalali Moghaddam, A. Esmaeilzadeh, M. Ghavipour, and A. K. Zadeh, "Minimizing virtual machine migration probability in cloud computing environments," *Cluster Computing*, vol. 23, pp. 3029-3038, 2020.
- [40] L. Liu, S. Zheng, H. Yu, V. Anand, and D. Xu, "Correlation-based virtual machine migration in dynamic cloud environments," *Photonic Network Communications*, vol. 31, pp. 206-216, 2016.
- [41] A. R. Hummida, N. W. Paton, and R. Sakellariou, "Scalable virtual machine migration using reinforcement learning," *Journal of Grid Computing*, vol. 20, no. 2, p. 15, 2022.
- [42] X. Wang, X. Chen, C. Yuen, W. Wu, M. Zhang, and C. Zhan, "Delay-cost tradeoff for virtual machine migration in cloud data centers," *Journal of Network and Computer Applications*, vol. 78, pp. 62-72, 2017.
- [43] A. Zhou, S. Wang, X. Ma, and S. S. Yau, "Towards service composition aware virtual machine migration approach in the cloud," *IEEE Transactions on Services Computing*, vol. 13, no. 4, pp. 735-744, 2019.

- [44] J. A. Jeba, S. Roy, M. O. Rashid, S. T. Atik, and M. Whaiduzzaman, "Towards green cloud computing an algorithmic approach for energy minimization in cloud data centers," in *Research Anthology on Architectures, Frameworks, and Integration Strategies for Distributed and Cloud Computing*: IGI Global, 2021, pp. 846-872.
- [45] S. K. Kosuru, D. Midhunchakkaravathy, and M. A. Hussain, "An intelligent energy minimization algorithm with virtual machine consolidation for sensor-based decision support system," *Measurement: Sensors*, p. 100778, 2023.
- [46] S. Sohrabi, A. Tang, I. Moser, and A. Aleti, "Adaptive virtual machine migration mechanism for energy efficiency," in *Proceedings of the 5th International Workshop on Green and Sustainable Software*, 2016, pp. 8-14.
- [47] A. A. Khan, M. Zakarya, R. Buyya, R. Khan, M. Khan, and O. Rana, "An energy and performance aware consolidation technique for containerized datacenters," *IEEE Transactions on Cloud Computing*, vol. 9, no. 4, pp. 1305-1322, 2019.
- [48] X. Zhang, Y. Zhao, S. Guo, and Y. Li, "Performance-aware energy-efficient virtual machine placement in cloud data center," in *2017 IEEE International Conference on Communications (ICC)*, 2017: IEEE, pp. 1-7.
- [49] V. Mongia and A. Sharma, "Energy Efficient and Performance Aware Multi-Objective Allocation Strategy in Cloud Environment," in *2020 International Conference on Advances in Computing, Communication & Materials (ICACCM)*, 2020: IEEE, pp. 368-373.
- [50] P. Zhang and M. Zhou, "Dynamic cloud task scheduling based on a two-stage strategy," *IEEE Transactions on Automation Science and Engineering*, vol. 15, no. 2, pp. 772-783, 2017.
- [51] İ. Çağlar and D. T. Altılar, "Look-ahead energy efficient VM allocation approach for data centers," *Journal of Cloud Computing*, vol. 11, no. 1, pp. 1-16, 2022.
- [52] A. L. a. Bolaji, M. A. Al-Betar, M. A. Awadallah, A. T. Khader, and L. M. Abualigah, "A comprehensive review: Krill Herd algorithm (KH) and its applications," *Applied Soft Computing*, vol. 49, pp. 437-446, 2016.

Using the Term Frequency-Inverse Document Frequency for the Problem of Identifying Shrimp Diseases with State Description Text

Luyi-Da Quach¹, Anh Nguyen Quynh², Khang Nguyen Quoc³, An Nguyen Thi Thu⁴
FPT University, Cantho city, Vietnam^{1, 2, 3}
RMIT University, Ho Chi Minh city, Vietnam⁴

Abstract—With the increasing demand for research on shrimp disease recognition to assist far-off farmers who need the proper assistance for their shrimp farming, shrimp disease prediction research is still in the initial stage. Most current methods utilize vision-based models, which mainly face challenges: symptom detection and image quality. Meanwhile, there are few researches which are language-based to get over the issues. In this study, we will experiment with natural language processing based on recognizing shrimp diseases; based on descriptions of shrimp status. This study provides an efficient solution for classifying multiple diseases in shrimp. We will compare different machine learning models and deep learning models (SVM, Logistic Regression, Multinomial Naive Bayes, (a4) Bernoulli Naive Bayes, Random forest, DNN, LSTM, GRU, BRNN, RCNN) in terms of accuracy and performance. The study also evaluates the TF-IDF technique in feature extraction. Data were collected for 12 types of shrimp diseases with 1,037 descriptions. Firstly, the data is preprocessed with standardised Vietnamese accent typing, tokenized words, converted to lowercase, removed unnecessary characters and stopwords. Then, TF-IDF is utilized to express the text feature weight. Machine learning-based and deep learning-based models are trained. The experimental results show that Random forest (F1-Score micro: 98%) and DNN (Validation accuracy: 84%) are the most efficient models.

Keywords—TF-IDF; machine learning; deep learning; CNN; shrimp disease classification

I. INTRODUCTION

Shrimp is the most commonly consumed worldwide, accounting for 15.5% of total global aquaculture production. Production of shrimp-related goods has increased globally over the past 16 years (from 2000 to 2016) by more than 20%. In which, Vietnam accounted for 9% of total export value (ranked 2nd in the world)[1]. Shrimp farming production has increased significantly to meet a market need, but needs to increase more to keep up with the demand[2]. Research [3] shows that the top five shrimp-farming countries are Ecuador, India, Indonesia, Thailand and Vietnam.

Shrimp farming also faces many challenges due to resource use issues in shrimp farming and shrimp diseases. Diseases in shrimp aquaculture have hindered the sector from growing, directly influencing management and production costs. In 2012, an infectious disease, acute hepatopancreatic necrosis syndrome (AHPNS) or early mortality syndrome (EMS), severely damaged the shrimp farming region, with

one-sixth of the area in Thailand and Vietnam affected[4]. In 2013, in India, the epidemic caused a loss of INR 10,221 million, 48,717 tons and 2.15 million working days were lost[5]. In 2016, white spot disease caused more than \$8 billion in damage and cumulative mortality can reach 90-100% over a period of 3 to 10 days[6].

Most of the current studies have focused on using image processing or machine learning methods to detect shrimp diseases based on the visual features of shrimp. There is research related to disease recognition in shrimp, such as biochemical diagnosis or image-based AI methods. Firstly, diseases can be detected by biochemical techniques performed in the laboratory with measures such as CRISPR to detect white spot virus, acute hepatopancreatic necrosis disease (AHPND)[7], [8], amplification of recombinase polymerase to detect acute hepatopancreas, hemocyte iridescent virus [9], [10], PCR method to detect AHPND[11], etc. There is also an advance in shrimp disease identification methods by applying artificial intelligence algorithms on shrimp disease images, such as: using CNN architecture to create ShrimpNet[12]–[14] to detect yellow head disease in shrimp. This shows that the result of detection of diseases in shrimp is quite impressive, but there are limitations in terms of time and precision. These methods require high-quality images of shrimp and may fail to capture the subtle or complex symptoms that are expressed in natural language. Moreover, these methods may not be easily accessible or affordable for small-scale farmers who lack the necessary equipment or expertise.

Because of the above reason, we propose a novel approach to detect shrimp diseases from text, based on the textual symptom descriptions that can be obtained from various sources. There are also a few papers that have performed text-based classification of shrimp diseases, but they only used a few machine learning models and achieved not high results[32]. Therefore, we conduct this research with different machine learning models and deep learning models (SVM, Logistic Regression, Multinomial Naive Bayes, Bernoulli Naive Bayes, Random forest, DNN, LSTM, GRU, BRNN and RCNN), and improve the accuracy. We hope that our research will contribute to the advancement of NLP applications in the field of aquaculture and provide a valuable tool for shrimp farmers and experts to diagnose shrimp diseases in an efficient and reliable way. We perform in-depth exploratory research on:

- Shrimp disease data is collected from texts describing the status of shrimp on the farm. This is something that farmers often describe in daily farm management through observation. The study collected 1,037 symptom descriptions of 12 common diseases in Vietnamese (attached data set). For example, the description is “Shrimp is a weak, limp, soft shell, intestines without food, swimming sluggishly on the water surface, on the shore, slow to grow; hepatopancreas is more yellow than usual; gills, tail swollen.”
- Data preprocessing with standardised Unicode and Vietnamese accent typing, tokenising words, converting to lowercase, removing unnecessary characters and stopwords.
- Then, the study combined TF-IDF technique with machine learning (ML) and deep learning (DL) algorithms.

The remainder of this article is organized as follows: in Section II, we give a brief review of this domain research and re-evaluate the descriptive dataset of related studies. Section III describes the data processing steps, the dataset¹, TF-IDF technique, training process and popular ML/DL algorithms. The experimental method is described in Section IV. The results after implementing the system are covered in Section V. The discussion and conclusion are presented in Section VI and Section VII respectively.

II. LITERATURE REVIEW

A. Traditional Methods

Currently, a variety of techniques are utilized to identify diseases. The issue in this field can be broken down into two different classification techniques: biochemistry and AI-based. Many researchers focus their work on computer vision for categorization using AI; moreover, more attempts have been made with text recognition, particularly regarding shrimp diseases.

The conventional method, which is often used, relies on visual inspection, observation, and testing on shrimp samples to identify the disease's presence[15]. High accuracy is used when using this technique. The drawback of this approach is that it necessitates a laboratory, time, and specialist topic knowledge.

Another option is to utilise test kits, such as bacterial test kits, viral test kits, and antigen test kits to detect infections in shrimp. This method has several advantages, including high accuracy, simplicity, speed, and convenience, but it also has disadvantages, including the difficulty of distinguishing many different diseases.

The following technique, which uses PCR and immunoglobulin analysis, is based on genetic analysis to identify disease resistance. RFLP (Restriction Fragment Length Polymorphism)[16], [17], RAPD (Random Amplification of Polymorphic DNA)[18], and SSR (Simple Sequence

Repeat)[19], [20] are examples of specific approaches. The benefits of this procedure are the same as those of test kits and conventional methods. But it still has high cost, complexity, and inability to detect all diseases.

To sum up, the biochemical approach also has advantages for swiftly detecting diseases in shrimp. However, it has the drawback of requiring time to assess the severity of the sickness and choose the best approach.

B. Method of using Artificial Intelligence

Artificial intelligence is an approach that has been widely used recently, especially in research on shrimp disease classification based on images, genetic data, chemical data, etc. This method can be divided into different categories. The first is an image-based shrimp disease classification method using deep learning models such as Convolutional Neural Network (CNN)[12], [13], [21], YOLO model [22], and machine learning[23], [24]. The effectiveness of this strategy depends mainly on the picture size and quality. The environment is the major obstacle affecting the accuracy of the results and data processing. Next, the study uses machine learning algorithms to accurately detect the disease in shrimp by identifying its early symptoms. This shows that it is possible to identify diseases in shrimp using natural language processing techniques and methods.

Some encouraging findings have been made regarding the classifying diseases using natural language processing. In the medical field, more than 20,000 findings use an NLP-based approach to classify diseases. The majority of trials[25]–[28] produced accurate disease diagnosis outcomes. There are about 9,000 studies agriculture employing NLP to enhance agricultural development and productivity. In studies on crops [29], [30], rice[31] have achieved promised accuracy (over 90%) by disease description and support chatbot system. In addition, research [32] has shown the first steps in approaching using NLP to identify diseases in shrimp with basic machine learning techniques with an accuracy of over 80%. It proved that the use of NLP in diagnosing of shrimp diseases is essential.

NLP techniques have been increasingly developed. Among them, there are processing techniques such as tokenization to divide sentences or paragraphs into smaller ones, stop word removal from removing words that have no critical meaning, stemming used to remove suffixes from meaningless words, lemmatization to return words to their infinitive form (lemma), part-of-speech (POS) tagging to classify each word in a sentence into word type parts, named entity recognition (NER) to recognize and classify named objects, sentiment analysis to analyze emotions in text, topic modelling to find the main themes in a corpus, word embeddings to convert words into vectors[33]. Data processing techniques in NLP are commonly used in text classification, automatic translation, chatbots and many other fields.

In conclusion, research into several sectors demonstrates the effectiveness of NLP in text processing. However, no studies currently combine NLP data processing methods with ML and DL analyses to identify shrimp diseases. As a result, data collecting and diagnostic processing related to shrimp

¹Dataset: <https://github.com/nqanh312/shrimp-diseases-dataset>.

sickness are crucial, which is considered the study’s novelty, which makes an important contribution to the establishment of a system to answer farmers' questions regarding shrimp diseases (Fig. 1).



Fig. 1. Some statuses of shrimp farmers describe to seek treatment on the social network Facebook.

III. MATERIALS AND METHODS

In this paper, we conduct a research on term frequency/inverse document frequency (TF-IDF) approach to extract characteristic words to construct the sentence embedding. Then, we apply the sentence embedding based machine learning and deep learning to categorize the documents into 1 type of diseases. Our proposed method comprises of following steps as shown in Fig. 2.

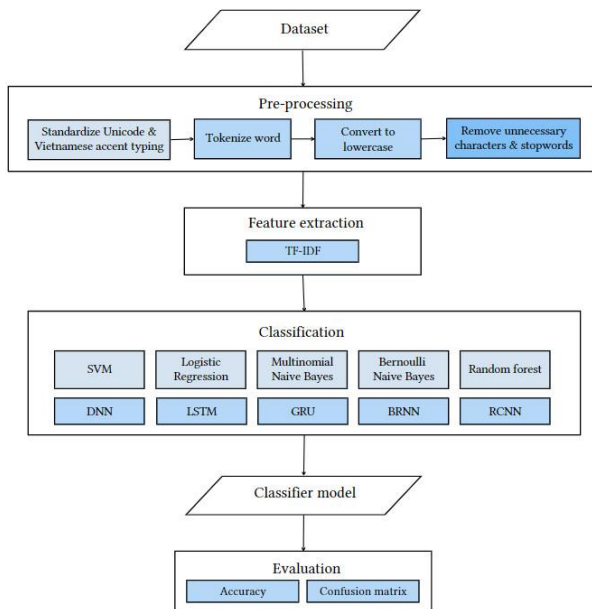


Fig. 2. System components are proposed in this research.

C. Dataset

We prepared a novel dataset which was collected from the internet, the majority of which came from certain aquaculture pages, as there isn't an available dataset of infected shrimp. We perform statistics on the frequency of occurrence of the words shown in Fig. 3.

The collection of 1,037 documents includes descriptions of diseased shrimps, as seen in Table I. We gathered altogether, which are then utilized to train and test our model.

D. Data Pre-Processing

Preparing sentences for analysis is a step that transforms an input into understandable data. Steps that sentences pass:

- All of the data is processed using the most straightforward and efficient method of text preprocessing—lowercase.
- Stemming is a heuristic technique that correctly transforms words into their root form by chopping off the ends of words.
- Stopword removal: removes poor information terms from the text so that the work can concentrate on the keywords.
- Turning a text into a standard form is known as normalization. This stage removes distracting text elements, including abbreviations, typos, and words that are not commonly used.
- Remove any letters, numbers, or text fragments that can interfere with text analysis by doing noise reduction. The result is shown in Fig. 4.

TABLE I. STATISTICS OF DATA USED IN THIS RESEARCH

No.	Name	Quantity
1	Acute hepatopancreatic necrosis	74
2	Black gill	77
3	Filamentous bacterial	77
4	Infection with vibrio	91
5	Infectious myonecrosis	101
6	Loose shell	139
7	Luminous bacteria disease	81
8	Plaque disease in shrimp	90
9	Taura	72
10	VitaminC deficiency in shrimp	78
11	White feces	79
12	Yellow head	78
Total		1.037

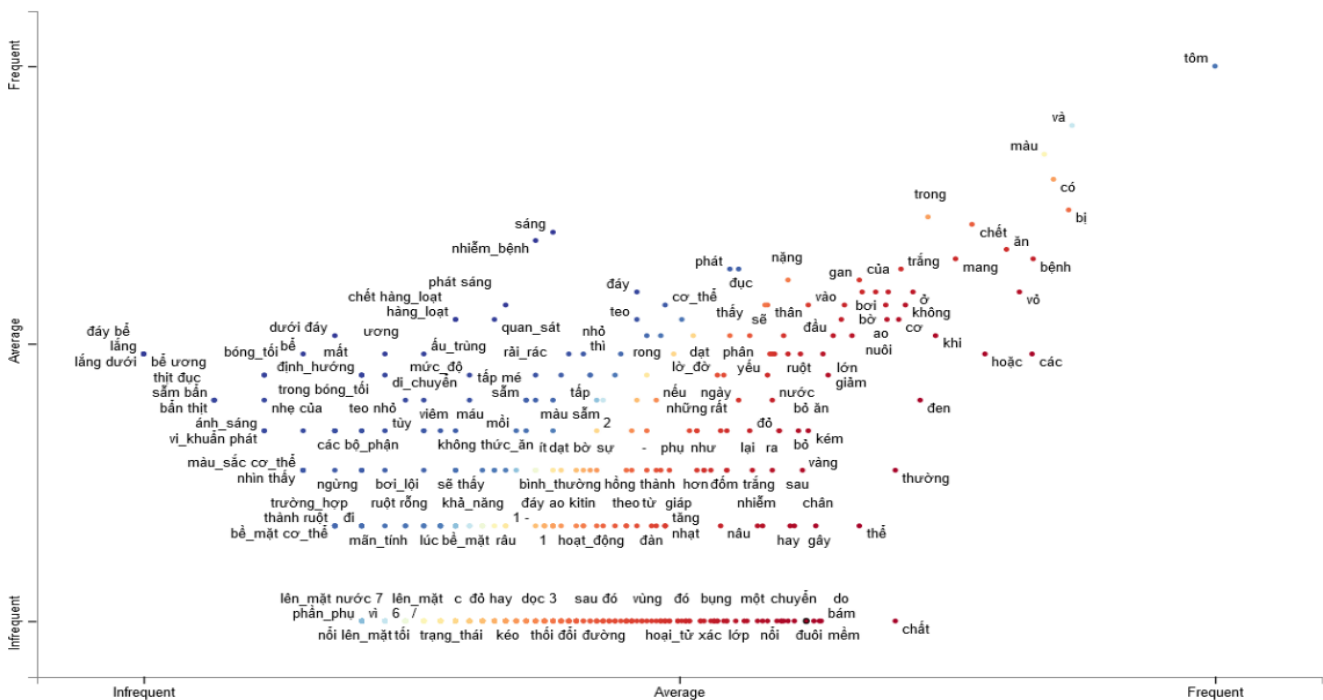


Fig. 3. List of words and its frequency.

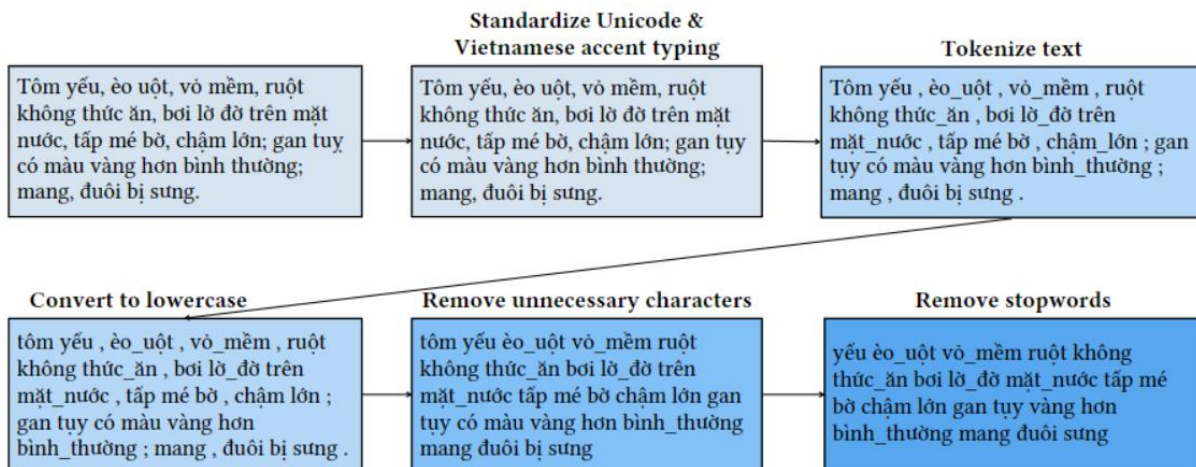


Fig. 4. The result of the preprocessing.

C. Feature Extraction with TF-IDF

By converting text into vector space (VSM) or sparse vectors, the TF-IDF method is frequently used in text data mining to estimate a word's significance [34]. Sentence embedding:

- The number of words in a set of documents is counted by TF-IDF. We typically assign a score to each word to show how much weight it has in the corpus and document. This approach is every now and again utilized in data recovery and text mining.
- Frequency of Term (TF): Using the heuristic that a term's importance is proportional to how frequently it appears in a document, it shows how important a word is to a document.

IDF:

- Outlines the genuine significance of an expression. It is pointless for terms like stopwords, which frequently show up in certain records, to be critical (the, that, of, and so on). Stopwords ought to have stayed away since they dark the unique circumstance. They are ignored by IDF because of the way it operates.
- It penalizes the word used frequently throughout documents.
- The appropriate term receives a more excellent IDF score, while the stopword receives a lower weight.

In this research, the frequency of words related to shrimp diseases tf_{Shp} is the number of words t_{Shp} compared to d_{Shrp} .

$$tf_{Shp}(t_{Shp}, d_{Shrp}) = \frac{f_{Shrp}(t_{Shrp}, d_{Shrp})}{\max\{f_{Shrp}(w_{Shrp}, d_{Shrp}) : w_{Shrp} \in d_{Shrp}\}} \quad (1)$$

In which:

- $tf_{Shp}(t_{Shp}, d_{Shrp})$: term frequency of t_{Shp} in d_{Shrp} .
- $f_{Shp}(t_{Shp}, d_{Shrp})$: number of the t_{Shp} appears in d_{Shrp} .
- $\max\{f_{Shp}(w_{Shrp}, d_{Shrp}) : w_{Shrp} \in d_{Shrp}\}$: the maximum of number of terms related to shrimp diseases in d_{Shrp} .

The IDF of a term indicates the percentage of corpus documents that contain the term. Words that are only found in a small number of documents, such as technical jargon terms, are given more excellent relevance ratings than words that are used in all documents, such as a, the, and. $idf_{Shp}(t_{Shp}, D_{Shp})$ is calculated as the following formula:

$$idf_{Shp}(t_{Shp}, D_{Shp}) = \log \frac{|D_{Shp}|}{|\{d_{Shp} \in D_{Shp} : t_{Shp} \in d_{Shp}\}|} \quad (2)$$

In which:

- $idf_{Shp}(t_{Shp}, D_{Shp})$: inverse document frequency idf_{Shrimp} of term t_{Shp} in D_{Shp} .
- $|D_{Shp}|$: number of document in the corpus $|D_{Shp}|$
- $|\{d_{Shp} \in D_{Shp} : t_{Shp} \in d_{Shp}\}|$: number of documents d_{Shp} in the corpus D_{Shp} contain the term t_{Shp} .

The $tf - idf(t_{Shp}, d_{Shp}, D_{Shp})$ is calculated by multiplying TF and IDF scores:

$$tf - idf(t_{Shp}, d_{Shp}, D_{Shp}) = tf_{Shp}(t_{Shp}, d_{Shp}) \times idf_{Shp}(t_{Shp}, D_{Shp}) \quad (3)$$

D. Training

The classification model will be trained using machine learning (ML) algorithms and deep learning (DL) models using the training dataset. The model will learn from labeled data, which have been digitized into feature vectors through feature extraction. On this processed data set, parameters will be learned and optimized by machine learning and deep learning algorithms. The classification model will receive data (extracted features) after learning to predict results and return the appropriate label as a result (Fig. 5).

In addition to dividing the models/algorithms used into two types of deep learning/machine learning. They can be divided into three other categories based on structured data, i.e. regression algorithms, binary classifiers and multiclass classification algorithms on structured data.

Types of regression algorithms include Linear Regression (LiR), Random Forest (RF). LiR is used to predict the value of a continuous variable based on different input variables[35]. The RF algorithm builds multiple decision trees and combines their predictions to make the final prediction[36].

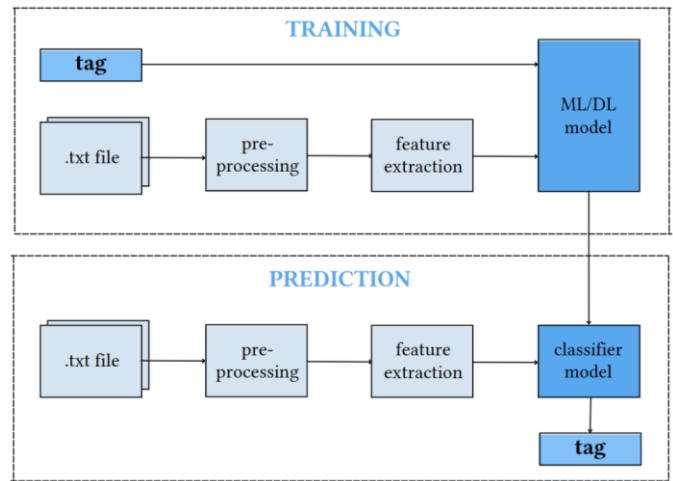


Fig. 5. Illustrate the process of using ML/DL for training and recognition.

Types of binary classification algorithms include Logistic Regression (LoR), and Bernoulli Naive Bayes (BNB). LoR is based on the sigmoid function to predict the probability of a linearly combined data sample of the input feature; the advantage of this algorithm is that it is simple and can explain the results[37]. Similar to LoR, BNB calculates the probability of each input feature, but it will conditionally consider each class based on the probabilities[38].

Types of multi-class classification algorithms on structured data include Support Vector Machine (SVM), Deep Neural Network (DNN), Long Short-Term Memory (LSTM), Gated Recurrent Unit (GRU), Bidirectional Recurrent Neural Network (BRNN), Recurrent Convolutional Neural Network (RCNN), Multinomial Naive Bayes (MNB). In which SVM classifies data by finding the best boundary[39], DNN uses many hidden layers to learn complex features of data [40]. LSTM uses an artificial neural network to record and store previous information to predict outcomes[41]. GRU has similar characteristics to LSTM. Still, it uses fewer parameters[42], BRNN uses two symmetric neural networks to learn data features [43], RCNN combines recurrent neural network and convolutional neural network to process sequence data[44], MNB is also based on the assumptions of BNB but features independent and differentiated input Multinomial distribution on each class[45].

In general, each predictive model has its advantages and limitations, depending on the specific data set and intended use. However, these models are all predictive and can be applied to the dataset after vectorization using the TF-IDF technique.

IV. EVALUATION

To evaluate the performance of the model, we use a confusion matrix which comprises four building blocks, namely True Positive (TP), True Negative (TN), False Positive (FP), and False Negative (FN).

TP and TN allude to situations where the forecasts are exact and negative. Positively false predictions are called FP, while negative false predictions are called FN. We use the confusion matrix to evaluate our model to generate additional

distinct metrics. Accuracy, Precision, Recall, and the F1 score are the precise metrics calculated using the formulas below.

1) *Accuracy*: Accuracy is one of the evaluating metrics and is informally interpreted in Eq. (4). It is the proportion of specifically classified shrimp diseases and the total number of shrimp diseases in the test set. The result shows how good the model works. The higher score of accuracy the more accurate our method is:

$$Accuracy = \frac{TruePositive+TrueNegative}{TotalPredictions} \quad (4)$$

2) *Precision*: The proposition of classified disease (TP) and the ground truth (the sum of TP and FP) defines the precision. It calculates the percentage of accurately classified disease as Eq. (5).

3) *Recall*: The percentage of correctly classified disease among all diseases belonging to that class Eq. (6).

4) *F1-score*: The following Eq. (7) is used to calculate the metric: the symphonic average of precision and recall. F1-score will be in (0,1], as F1 score higher as better model is.

$$Precision = \frac{TruePositive}{TruePositive+Falsepositive} \quad (5)$$

$$Recall = \frac{TruePositive}{TruePositive+Falsenegative} \quad (6)$$

$$F1 - Score = 2 \frac{Precision*Recall}{Precision+Recall} \quad (7)$$

In this study, we used Micro avg: F1-score is calculated by considering all classes' total number of true positives, false negatives and false positives. This method is often used to measure the correct prediction ratio of the model over the entire dataset. This research belongs to the case of a multi-class classification problem with the condition that each sample belongs to only one class; test accuracy will be equal to the F1-score micro.

The confusion matrix shows and summarizes a better view of the performance of a classification algorithm. It evaluates

the results of the classification problem by considering both the accuracy and generality of the prediction for each class. The accurate/false prediction is shown as a percentage of each class.

V. RESULT

This experiment is based on Intel(R) Core(TM) i5-10210U CPU @ 1.60GHz, RAM 8 Gbytes. In this research, we adopted machine learning and deep learning method in natural language processing to classify deceases of shrimps. The model's performance was evaluated using accuracy and F1-score micrometric on the validation and test dataset. The result is shown in Table II.

According to the Table II, it is found that:

- Machine learning method: SVM has the highest accuracy score on the validation data (0.83), while Random forest obtained the highest F1-score micro on the test data (0.96). This shows that SVM works for matching better while Random forest has better generalization
- Deep learning: DNN has the highest accuracy score on both validation and test set. It is proved in Table II that DNN outperforms other models in shrimp classification. Other models, such as LSTM, GRU, BRNN, and RCNN, all have close results, with the micro F1-score ranging from 0.93 to 0.97.

Moreover, we used a confusion matrix for each algorithm and model to evaluate the confusion among shrimp diseases. Based on Fig. 6, the research found that the confusion of the models on acute hepatopancreatic necrosis, Filamentous bacteria, Infection with vibrio, Taura, and Vitamin C deficiency in shrimp, White feces, Yellow heads are quite low, while Plaque disease in shrimp confusion prediction obtained a high rate. The results prove that DNN is the most suitable model for shrimp disease classification.

TABLE II. ACCURACY AND F1-SCORE RESULTS OF ML ALGORITHMS AND DL MODELS ON SHRIMP DISEASE DATASET

Methods	SVM	LoR	MNB	BNB	RF	DNN	LSTM	GRU	BRNN	RCNN
Validation accuracy (without TF-IDF)	0.725	0.727	0.724	0.646	0.779	0.738	0.542	0.479	0.665	0.671
Validation accuracy (using TF-IDF)	0.825	0.800	0.725	0.763	0.788	0.838	0.575	0.575	0.788	0.750
F1-score micro (without TF-IDF)	0.896	0.858	0.808	0.704	0.917	0.971	0.779	0.742	0.854	0.842
F1-score micro (using TF-IDF)	0.963	0.908	0.821	0.767	0.975	0.971	0.929	0.950	0.967	0.971

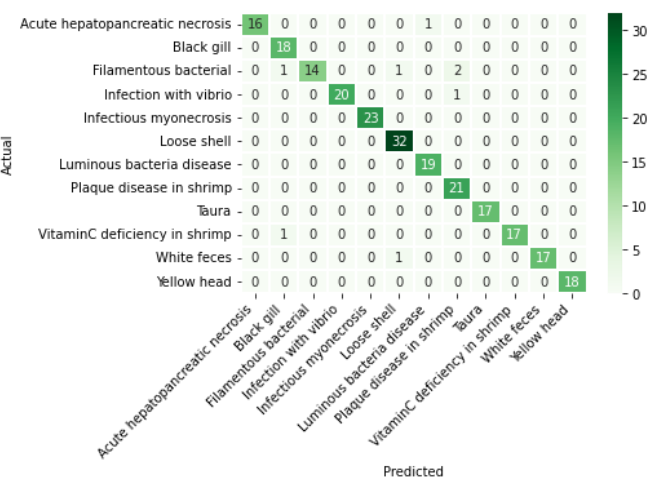
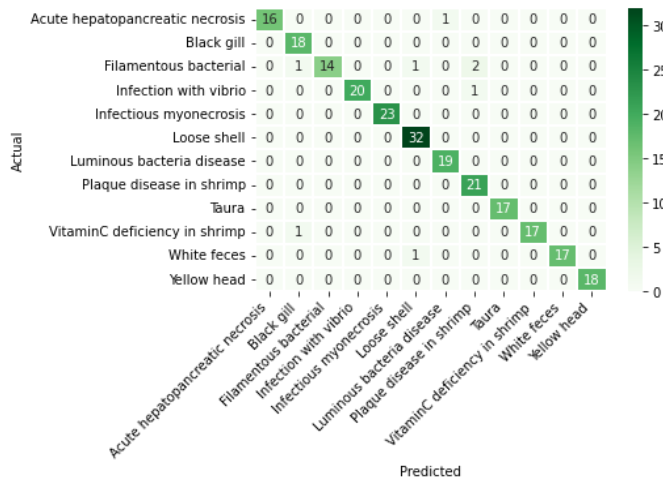
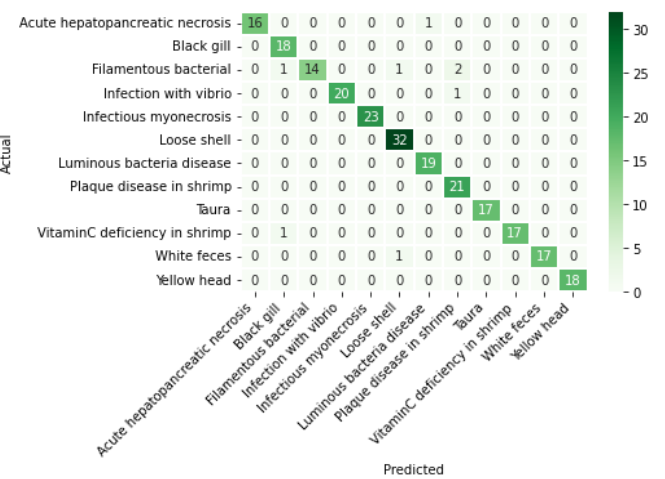
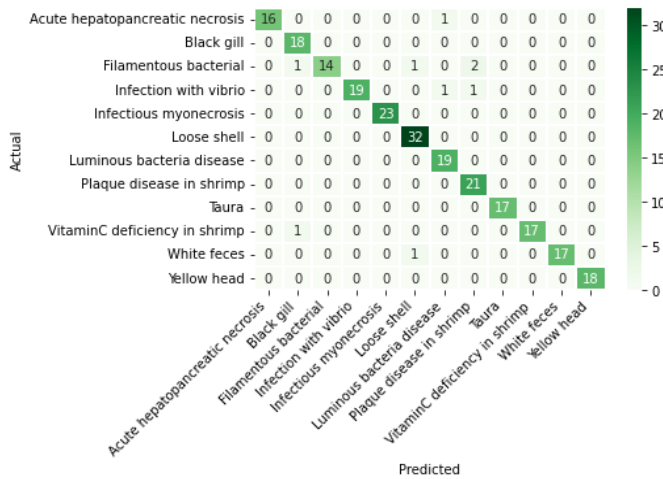
VI. DISCUSSION

In this section, we will discuss the results obtained and the remaining limitations of the study. Based on the accuracy and validation accuracy results, the research finds that the test data set has a different distribution from the validation dataset and is more suitable for the model, leading to a difference in the error in the test data model. However, when comparing ML algorithms and DL models, the performance of DL is higher in this problem. This can be explained by the ability of DL models to learn complex and semantic features of expressions. DL models also have the advantage of dealing with unbalanced data so that minority classes can be correctly classified.

In machine learning algorithms, the algorithm with the highest results on the test set is RF. The algorithm can minimise overfitting and increase the diversity of decision trees. The SVM, LoR and NB algorithms are all based on

linear classifier architecture. Although these algorithms are easy to implement, they are not suitable due to the nonlinearity of shrimp disease data.

Deep Neural Network gives the best results among deep learning models because of their ability to represent non-linear features of the data. However, this model is challenging to train and adjust parameters and does not use sequence information of disease expression description in shrimp. Thus may need to understand the significance of this model regarding contextual meaning. The models based on Recurrent Neural Network architecture (LSTM, GRU, BRNN and RCNN), although capable of using information about the sequence of expression, have problems of vanishing gradient or exploding gradient when training because of long-term dependence between time steps in the data series (if the link weights between steps are too small or too large, the gradient will disappear or explode when propagating back through the long sequence).



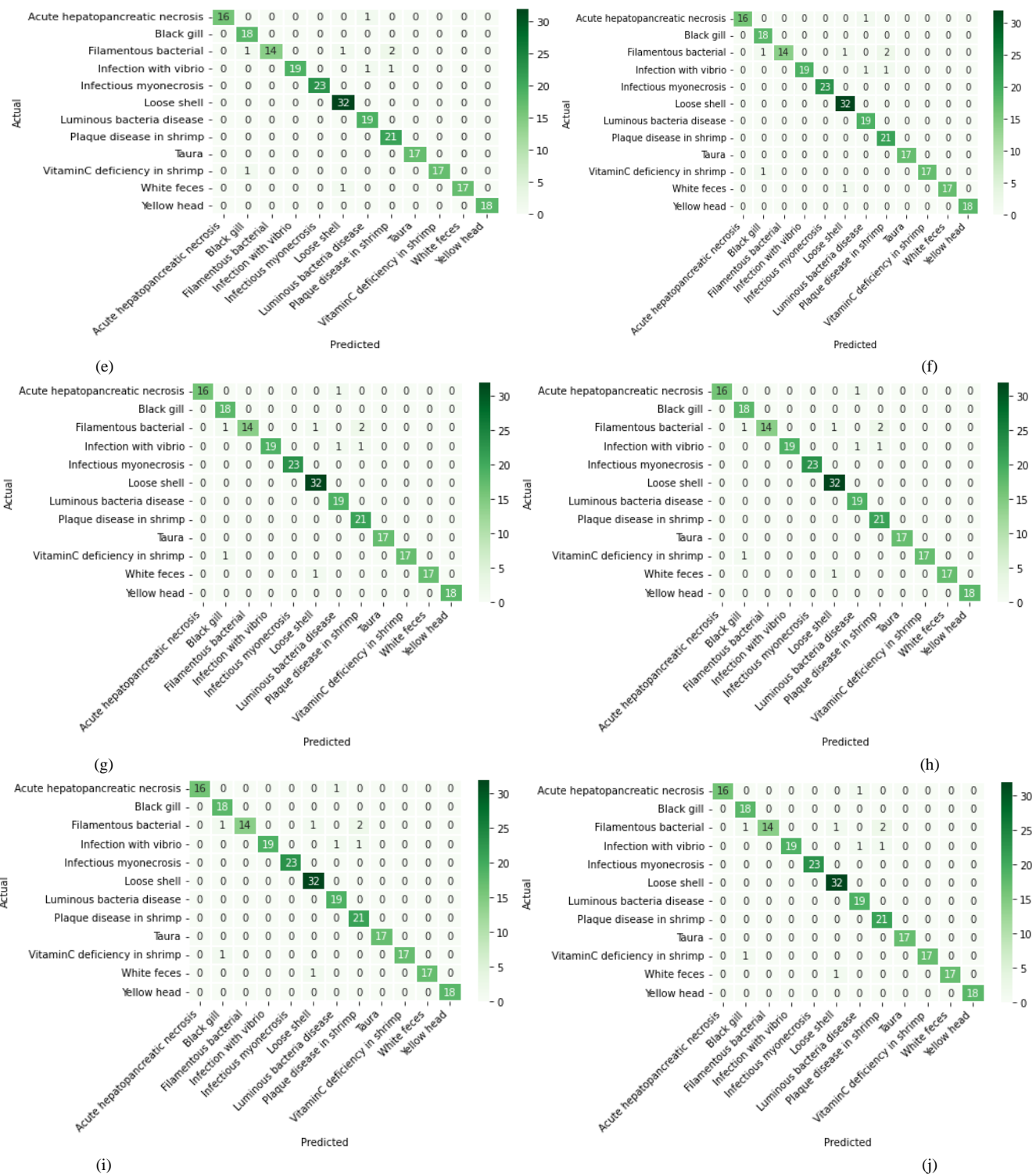


Fig. 6. Confusion matrix of algorithms: (a)SVM, (b)LoR, (c)MNB, (d)BNB, (e)RF, (f)DNN, (g)LSTM, (h)GRU, (i)BRNN, (j)RCNN.

VII. CONCLUSION

This research classified shrimp diseases based on deep learning and machine learning methods. We preprocessed 1.037 samples of 12 prevalent shrimp diseases and divided them into three groups: training data, test sets, and validation sets. After training, the model is put through its paces on the

validation and test sets. Compared to other models, the outcome demonstrates that DNN achieves the highest performance on this data.

This study applies the theoretical results of natural language processing (NLP) to analyze shrimp description and classify shrimp disease to enhance the productivity and

sustainability of aquaculture by providing timely and accurate diagnosis of shrimp diseases. Another motivation is to reduce the economic losses caused by shrimp diseases and increase the competitiveness of the shrimp industry. Furthermore, NLP can facilitate the prevention and treatment of shrimp diseases by offering instant services recommendation and early interventions. Additionally, NLP can advance the scientific knowledge and innovation in the field of NLP and its applications for aquaculture. However, this study still has some limitations that need to be overcome. First, the data size is relatively small and uneven across disease classes. This can affect the generalization ability of algorithms and models. Second, we only use TF-IDF as a feature extraction method for machine learning algorithms. TF-IDF is a simple and effective method, but it cannot represent the semantic meaning of the expression. Therefore, in the future, we will continue to collect more data to assess the methods on different datasets, and use other feature extraction methods, such as word2vec or BERT, to compare with TF-IDF.

REFERENCES

- [1] N. M. Khiem, Y. Takahashi, K. T. P. Dong, H. Yasuma, and N. Kimura, "Predicting the price of Vietnamese shrimp products exported to the US market using machine learning," *Fish Sci*, vol. 87, no. 3, pp. 411–423, May 2021, doi: 10.1007/s12562-021-01498-6.
- [2] F. Asche et al., "The economics of shrimp disease," *Journal of Invertebrate Pathology*, vol. 186, p. 107397, Nov. 2021, doi: 10.1016/j.jip.2020.107397.
- [3] C. E. Boyd, R. P. Davis, and A. A. McNevin, "Comparison of resource use for farmed shrimp in Ecuador, India, Indonesia, Thailand, and Vietnam," *Aquaculture Fish & Fisheries*, vol. 1, no. 1, pp. 3–15, Dec. 2021, doi: 10.1002/aff2.23.
- [4] T. Pongthanapanich, K. A. T. Nguyen, and C. M. Jolly, "Risk management practices of small intensive shrimp farmers in the Mekong Delta of Viet Nam," *FAO Fisheries and Aquaculture Circular*, vol. C1194, pp. 1–20.
- [5] M. Salunke, A. Kalyankar, C. D. Khedkar, M. Shingare, and G. D. Khedkar, "A Review on Shrimp Aquaculture in India: Historical Perspective, Constraints, Status and Future Implications for Impacts on Aquatic Ecosystem and Biodiversity," *Reviews in Fisheries Science & Aquaculture*, vol. 28, no. 3, pp. 283–302, Jul. 2020, doi: 10.1080/23308249.2020.1723058.
- [6] S. Yaemkasem, V. Boonyawiwat, M. Sukmak, S. Thongratsakul, and C. Poolkhet, "Spatial and temporal patterns of white spot disease in Rayong Province, Thailand, from October 2015 to September 2018," *Preventive Veterinary Medicine*, vol. 199, p. 105560, Feb. 2022, doi: 10.1016/j.prevetmed.2021.105560.
- [7] T. J. Sullivan, A. K. Dhar, R. Cruz-Flores, and A. G. Bodnar, "Rapid, CRISPR-Based, Field-Deployable Detection Of White Spot Syndrome Virus In Shrimp," *Sci Rep*, vol. 9, no. 1, p. 19702, Dec. 2019, doi: 10.1038/s41598-019-56170-y.
- [8] P. Naranit, P. Aiamsa-at, T. Sukonta, P. Hannanta-anan, and T. Chaijarasphong, "Smartphone-compatible, CRISPR -based platforms for sensitive detection of acute hepatopancreatic necrosis disease in shrimp," *Journal of Fish Diseases*, vol. 45, no. 12, pp. 1805–1816, Dec. 2022, doi: 10.1111/jfd.13702.
- [9] H. N. Mai, L. F. Aranguren Caro, R. Cruz-Flores, and A. K. Dhar, "Development of a Recombinase Polymerase Amplification (RPA) assay for acute hepatopancreatic necrosis disease (AHPND) detection in Pacific white shrimp (*Penaeus vannamei*)," *Molecular and Cellular Probes*, vol. 57, p. 101710, Jun. 2021, doi: 10.1016/j.mcp.2021.101710.
- [10] Z. Chen, J. Huang, F. Zhang, Y. Zhou, and H. Huang, "Detection of shrimp hemocyte iridescent virus by recombinase polymerase amplification assay," *Molecular and Cellular Probes*, vol. 49, p. 101475, Feb. 2020, doi: 10.1016/j.mcp.2019.101475.
- [11] T.-D. Mai-Hoang et al., "A novel PCR method for simultaneously detecting Acute hepatopancreatic Necrosis Disease (AHPND) and mutant-AHPND in shrimp," *Aquaculture*, vol. 534, p. 736336, Mar. 2021, doi: 10.1016/j.aquaculture.2020.736336.
- [12] W.-C. Hu, H.-T. Wu, Y.-F. Zhang, S.-H. Zhang, and C.-H. Lo, "Shrimp recognition using ShrimpNet based on convolutional neural network," *J Ambient Intell Human Comput*, Jan. 2020, doi: 10.1007/s12652-020-01727-3.
- [13] N. Duong-Trung, L.-D. Quach, and C.-N. Nguyen, "Towards Classification of Shrimp Diseases Using Transferred Convolutional Neural Networks," *Adv. sci. technol. eng. syst. j.*, vol. 5, no. 4, pp. 724–732, 2020, doi: 10.25046/aj050486.
- [14] T. Q. Bao, T. C. Cuong, N. D. Tu, L. H. Dang, and L. T. Hieu, "Designing the Yellow Head Virus Syndrome Recognition Application for Shrimp on an Embedded System," *EIRJ*, vol. 6, no. 2, pp. 48–63, Apr. 2019, doi: 10.31273/eirj.v6i2.309.
- [15] T. H. O. Dang, T. N. T. Nguyen, and N. U. Vu, "Investigation of parasites in the digestive tract of white leg shrimp (*Litopenaeus vannamei*) cultured at coastal farms in the Mekong Delta," *CTUJS*, vol. 13, no. Aquaculture, pp. 79–85, Jun. 2021, doi: 10.22144/ctu.jen.2021.020.
- [16] T. Kobayashi et al., "Microbiological properties of Myanmar traditional shrimp sauce, hmyin-ngan-pya-ye," *Fish Sci*, vol. 86, no. 3, pp. 551–560, May 2020, doi: 10.1007/s12562-020-01415-3.
- [17] P. Pérez-Barros, N. V. Guzmán, V. A. Confalonieri, and G. A. Lovrich, "Molecular identification by polymerase chain reaction-restriction fragment length polymorphism of commercially important lithodid species (Crustacea: Anomura) from southern South America," *Regional Studies in Marine Science*, vol. 34, p. 101027, Feb. 2020, doi: 10.1016/j.rsma.2019.101027.
- [18] S. Thiyagarajan, B. Chrisolite, and S. V. Alavandi, "Degenerate primed randomly amplified polymorphic DNA (DP-RAPD) fingerprinting of bacteriophages of *Vibrio harveyi* from shrimp hatcheries in Southern India," *Microbiology*, preprint, Aug. 2021. doi: 10.1101/2021.08.10.455891.
- [19] J. Zhao et al., "Transcriptome Analysis Provides New Insights into Host Response to Hepatopancreatic Necrosis Disease in the Black Tiger Shrimp *Penaeus monodon*," *J. Ocean Univ. China*, vol. 20, no. 5, pp. 1183–1194, Oct. 2021, doi: 10.1007/s11802-021-4744-x.
- [20] J. Yuan et al., "Simple sequence repeats drive genome plasticity and promote adaptive evolution in penaeid shrimp," *Commun Biol*, vol. 4, no. 1, p. 186, Feb. 2021, doi: 10.1038/s42003-021-01716-y.
- [21] A. Ashraf and A. Atia, "Comparative Study Between Transfer Learning Models to Detect Shrimp Diseases," in 2021 16th International Conference on Computer Engineering and Systems (ICCES), Cairo, Egypt, Egypt: IEEE, Dec. 2021, pp. 1–6. doi: 10.1109/ICCES54031.2021.9686116.
- [22] D. J. A. Amora, D. P. M. Alulod, K. A. B. Debolgado, J. R. M. Magcale, C. R. A. Tobias, and S. U. Arenas, "Design of a P. Vannamei White Spot Syndrome Virus (WSSV) Detection System Utilizing YOLOv5n," in 2022 IET International Conference on Engineering Technologies and Applications (IET-ICETA), Changhua, Taiwan: IEEE, Oct. 2022, pp. 1–2. doi: 10.1109/IET-ICETA56553.2022.9971656.
- [23] M. O. Edeh et al., "Bootstrapping random forest and CHAID for prediction of white spot disease among shrimp farmers," *Sci Rep*, vol. 12, no. 1, p. 20876, Dec. 2022, doi: 10.1038/s41598-022-25109-1.
- [24] L. Đ. Quách, T. N. Phan, T. T. Hùng, and N. C. Ngón, "Kiểm thử giải thuật AI trong nhận diện bệnh tôm qua hình ảnh," *CTUJSVN*, vol. 57, no. CĐ Thủy Sản, pp. 192–201, Jun. 2021, doi: 10.22144/ctu.jvn.2021.078.
- [25] F. B. Putra et al., "Identification of Symptoms Based on Natural Language Processing (NLP) for Disease Diagnosis Based on International Classification of Diseases and Related Health Problems (ICD-11)," in 2019 International Electronics Symposium (IES), Surabaya, Indonesia: IEEE, Sep. 2019, pp. 1–5. doi: 10.1109/ELECSYM.2019.8901644.
- [26] S. Sheikhalishahi, R. Miotto, J. T. Dudley, A. Lavelli, F. Rinaldi, and V. Osmani, "Natural Language Processing of Clinical Notes on Chronic

- Diseases: Systematic Review,” *JMIR Med Inform*, vol. 7, no. 2, p. e12239, Apr. 2019, doi: 10.2196/12239.
- [27] R. Garg, E. Oh, A. Naidech, K. Kording, and S. Prabhakaran, “Automating Ischemic Stroke Subtype Classification Using Machine Learning and Natural Language Processing,” *Journal of Stroke and Cerebrovascular Diseases*, vol. 28, no. 7, pp. 2045–2051, Jul. 2019, doi: 10.1016/j.jstrokecerebrovasdis.2019.02.004.
- [28] [28] T. A. Koleck, C. Dreisbach, P. E. Bourne, and S. Bakken, “Natural language processing of symptoms documented in free-text narratives of electronic health records: a systematic review,” *Journal of the American Medical Informatics Association*, vol. 26, no. 4, pp. 364–379, Apr. 2019, doi: 10.1093/jamia/ocy173.
- [29] [29] L. Li, S. Zhang, and B. Wang, “Plant Disease Detection and Classification by Deep Learning—A Review,” *IEEE Access*, vol. 9, pp. 56683–56698, 2021, doi: 10.1109/ACCESS.2021.3069646.
- [30] A. Sharma, A. Jain, P. Gupta, and V. Chowdary, “Machine Learning Applications for Precision Agriculture: A Comprehensive Review,” *IEEE Access*, vol. 9, pp. 4843–4873, 2021, doi: 10.1109/ACCESS.2020.3048415.
- [31] V. K. Shrivastava, M. K. Pradhan, and M. P. Thakur, “Application of Pre-Trained Deep Convolutional Neural Networks for Rice Plant Disease Classification,” in *2021 International Conference on Artificial Intelligence and Smart Systems (ICAIS)*, Coimbatore, India: IEEE, Mar. 2021, pp. 1023–1030. doi: 10.1109/ICAIS50930.2021.9395813.
- [32] L.-D. Quach, L. Q. Hoang, N. D. Trung, and C. N. Nguyen, “TOWARDS MACHINE LEARNING APPROACHES TO IDENTIFY SHRIMP DISEASES BASED ON DESCRIPTION,” in *KỶ YẾU HỘI NGHỊ KHOA HỌC CÔNG NGHỆ QUỐC GIA LẦN THỨ XII NGHIÊN CỨU CƠ BẢN VÀ ỨNG DỤNG CÔNG NGHỆ THÔNG TIN*, Hanoi, Vietnam: Publishing House for Science and Technology, Oct. 2019. doi: 10.15625/vap.2019.00063.
- [33] S. S. Aljameel et al., “A Sentiment Analysis Approach to Predict an Individual’s Awareness of the Precautionary Procedures to Prevent COVID-19 Outbreaks in Saudi Arabia,” *IJERPH*, vol. 18, no. 1, p. 218, Dec. 2020, doi: 10.3390/ijerph18010218.
- [34] L. Havrlant and V. Kreinovich, “A simple probabilistic explanation of term frequency-inverse document frequency (tf-idf) heuristic (and variations motivated by this explanation),” *International Journal of General Systems*, vol. 46, no. 1, pp. 27–36, Jan. 2017, doi: 10.1080/03081079.2017.1291635.
- [35] D. Maulud and A. M. Abdulazeez, “A Review on Linear Regression Comprehensive in Machine Learning,” *JASTT*, vol. 1, no. 4, pp. 140–147, Dec. 2020, doi: 10.38094/jastt1457.
- [36] M. Schonlau and R. Y. Zou, “The random forest algorithm for statistical learning,” *The Stata Journal*, vol. 20, no. 1, pp. 3–29, Mar. 2020, doi: 10.1177/1536867X20909688.
- [37] E. Y. Boateng and D. A. Abaye, “A Review of the Logistic Regression Model with Emphasis on Medical Research,” *JDAIP*, vol. 07, no. 04, pp. 190–207, 2019, doi: 10.4236/jdaip.2019.74012.
- [38] M. Artur, “Review the performance of the Bernoulli Naïve Bayes Classifier in Intrusion Detection Systems using Recursive Feature Elimination with Cross-validated selection of the best number of features,” *Procedia Computer Science*, vol. 190, pp. 564–570, 2021, doi: 10.1016/j.procs.2021.06.066.
- [39] D. A. Pisman and D. M. Schnyer, “Support vector machine,” in *Machine Learning*, Elsevier, 2020, pp. 101–121. doi: 10.1016/B978-0-12-815739-8.00006-7.
- [40] J. Gawlikowski et al., “A Survey of Uncertainty in Deep Neural Networks,” 2021, doi: 10.48550/ARXIV.2107.03342.
- [41] Y. Liu et al., “A long short-term memory-based model for greenhouse climate prediction,” *Int J Intell Syst*, vol. 37, no. 1, pp. 135–151, Jan. 2022, doi: 10.1002/int.22620.
- [42] Q. Ni, J. C. Ji, and K. Feng, “Data-Driven Prognostic Scheme for Bearings Based on a Novel Health Indicator and Gated Recurrent Unit Network,” *IEEE Trans. Ind. Inf.*, vol. 19, no. 2, pp. 1301–1311, Feb. 2023, doi: 10.1109/TII.2022.3169465.
- [43] S. S. Tng, N. Q. K. Le, H.-Y. Yeh, and M. C. H. Chua, “Improved Prediction Model of Protein Lysine Crotonylation Sites Using Bidirectional Recurrent Neural Networks,” *J. Proteome Res.*, vol. 21, no. 1, pp. 265–273, Jan. 2022, doi: 10.1021/acs.jproteome.1c00848.
- [44] B. Wang, Y. Lei, T. Yan, N. Li, and L. Guo, “Recurrent convolutional neural network: A new framework for remaining useful life prediction of machinery,” *Neurocomputing*, vol. 379, pp. 117–129, Feb. 2020, doi: 10.1016/j.neucom.2019.10.064.
- [45] E. Hossain, O. Sharif, and M. Moshilul Hoque, “Sentiment Polarity Detection on Bengali Book Reviews Using Multinomial Naïve Bayes,” in *Progress in Advanced Computing and Intelligent Engineering*, C. R. Panigrahi, B. Pati, B. K. Pattanayak, S. Amic, and K.-C. Li, Eds., in *Advances in Intelligent Systems and Computing*, vol. 1299. Singapore: Springer Singapore, 2021, pp. 281–292. doi: 10.1007/978-981-33-4299-6_23.

MoveNET Enabled Neural Network for Fast Detection of Physical Bullying in Educational Institutions

Zhadra Kozhamkulova¹, Bibinur Kirgizbayeva², Gulbakyt Sembina³, Ulmeken Smailova⁴, Madina Suleimenova⁵,
Arailym Keneskanova⁶, Zhumakul Baizakova⁷

Almaty University of Power Engineering and Telecommunications, Almaty, Kazakhstan^{1, 5, 6}

Kazakh National Agrarian Research University, Almaty, Kazakhstan²

International Engineering Technological University, Almaty, Kazakhstan⁷

International Information Technology University, Almaty, Kazakhstan³

Center of Excellence AEO "Nazarbayev Intellectual Schools", Astana, Kazakhstan⁴

Abstract—In this article, we provide a MoveNET-based technique that we think may be used to detect violent actions. This strategy does not need high-computational technology, and it is able to put into action in a very short amount of time. Our method is comprised of two stages: first, the capture of features from photo sequences in order to evaluate body position; next, the application of an artificial neural network to activities classification in order to determine whether or not the picture frames include violent or hostile circumstances. A video aggression database consisting of 400 minutes of one individual's actions and 20 hours of videodata encompassing physical abuse, as well as 13 categories for distinguishing between the behaviors of the attacker and the victim, was created. In the end, the suggested approach was refined and validated by employing the collected dataset during the process. According to the findings, an accuracy rate of 98% was attained while attempting to detect aggressive behavior in video sequences. In addition, the findings indicate that the suggested technique is able to identify aggressive behavior and violent acts in a very short amount of time and is suitable for use in apps that take place in the real world.

Keywords—MoveNET; neural networks; skeleton; bullying; machine learning

I. INTRODUCTION

The purpose of this project is to scrutinize the problem of aggressive behavior and bullying in schools in order to propose the best possible solution. According to Olweus [1], school bullying is an unwanted aggressive behavior on the part of one or more other students that exposes a victim to negative actions repeatedly and over time. Negative actions can be carried out by physical contact, by words or in other ways, for instance, making faces and obscene gestures, or often ostracizing the victim from the common social community. Generally speaking, bullying may be identified by the three characteristics that are listed below: (1) It is violence-related behavior or purposeful "harm-doing," (2) it is activity that is carried out "repeatedly over time," and (3) it is behavior that occurs in an interpersonal relationship defined by a real or expected imbalance of power [2]. Scientific evidence suggests that bullying affects future mental health functioning of both victims of bullying and those who cause harm/bullying. Apart

from physical aggression, bullying also includes psychological pressure, intimidation, rumor spreading, extortion, and mockery.

Aggression may take both direct and indirect forms when it comes to bullying. Direct types of bullying, consisting of an overt demonstration of physical power, can take the form of physical or verbal violence. The term "physical bullying" refers to any kind of physical attack, including in particular striking, shoving, kicking, choking, and any harmful action towards the victim. Bullying victims may be subjected to verbal harassment or intimidation when they are called names, threatened, taunted, teased maliciously, or psychologically intimidated by offensive language. Children may be bullied in a variety of ways, including stealing, vandalizing, making offensive looks or gestures, and making faces [3].

The National report "Factors influencing health and well-being of children and adolescents in Kazakhstan" published by the National Center for Public Health of the Ministry of Health of the Republic of Kazakhstan [4] provides results about health, social conditions and well-being of teenagers aged 11 to 15 years. The study is based on HBSC methodology, a WHO collaborative cross-national survey. The report contains information on social and health indicators that are related to the health and well-being of both children and adolescents. And bullying was defined as one of the risk factors affecting the health and well-being of children in this report.

According to the data published in the National report, 17% of teenagers aged 11 to 15 years were bullied at school one or more times per month. 20% of teenagers from the same age group were involved in bullying others at least once. This rate is higher among 11 and 13 year old boys compared to girls.

The goal of this research is to develop Artificial Intelligence (AI) Solutions in order to utilize them as a basis for designing a prototype of a software-hardware complex that can automatically detect cases of aggressive behavior and potential physical bullying in educational institutions.

The remainder of this paper is structured as follows: The next part discusses cutting-edge physical aggression detection, after which a problem statement is presented and described.

The goals and aims of the research are thoroughly explained in the third part. The human skeleton-based physical aggression detection approach is discussed in the fourth part of this article. The procedure of data collecting and the investigation's outcome are laid out in the fifth part of the report. In the sixth part, findings are discussed, and ongoing issues in the field of violence identification in videos are described. The report is brought to a close with the last part, which discusses the plans for and issues associated with physical bullying detection in video. The creation of an automatic and rapid physical aggression detection system in video security cameras based on human skeleton is the key objective of the work. The developed technique makes it possible to recognize violent events in the video without the need for highly processed hardware.

II. RELATED WORKS

The National Center for Educational Statistics (2019) showed that one in five students (20.2%) reported being bullied at school in numerous places, such as a hallway or stairway (43%), in the cafeteria (27%), outside on school grounds (22%), online / text (15%), in the bathroom or locker room (12%), on the school bus (8%) [5].

One of the first systematic studies to collect data on the nature and extent of violence in schools in Kazakhstan was conducted by the United Nations Children's Fund (UNICEF) in 2013, which revealed that 66.2% of schoolchildren were exposed to school violence and discrimination, 63.3% were witnesses, 44.7% were victims, and 24.2% were perpetrators of violence and discrimination against other children in school. [6]

Video analysis is an area of AI and machine learning that has shown good results in recent years and is widely used. Bullying in its various forms poses a serious problem that a vast amount of schoolchildren faces. For various reasons, there are not many scientific investigations in the world which attempt to fix the negative consequences of bullying by means of video analysis. Among the few, slow development in this vector can be mentioned. There are some studies related to cyberbullying and depression detection on online user contents [7-9]. However, there is no evidence about such researches in the Republic of Kazakhstan. This substantiates the novelty of the proposed project.

The current level of development of AI methods for video analysis allows using them to process video footage from school cameras. However, there are not many researchers who study the effectiveness of using AI methods to reduce cases of bullying and its negative effects at school. According to this project, video analysis using AI methods will enable early detection of aggressive behavior. Consequently, the early detection of such cases will facilitate the work of school psychologists in terms of early warning of bullying.

A distinctive feature of this project is its interdisciplinarity: new proposed solutions of AI will push the boundaries of bullying studies to a social phenomenon. The collected data will be used to conduct a psychological study on the effect of bullying on the psychological and emotional health of schoolchildren. The combined use of AI methods and

psychology will provide the results that may find application in those areas of life where video analysis is needed.

Using neural network technologies will allow for the intelligent video footage processing in order to assess human behavior and determine aggressive actions.

In the proposed study, software models of artificial intelligence will be trained on the basis of LGD-3D architecture, a two-stream I3D structure. A recent study examined the problem of recognizing aggressive actions based on RGB video data, the I3D architecture showed better results compared to C3D and R3D in all respects.

For video classification, a method based on a neural network with deep convolutional graphs (DCGN) will be used. According to the results of research, this method is superior to alternative ones, such as LTSM and GRU.

The categorization of activities, in addition to the categorization of facial expressions, is an active topic of study that is, nonetheless, fairly difficult. Large variations in action performance brought on by differences in individual's anatomy, as well as temporal and spatial variations (including differences in the pace at which people do actions), are some of the issues that are linked with the categorization of actions [10]. It might be difficult to tell the difference between activities that are just part of the game (such as wrestling or hurling things at each other), and those that constitute bullying. Either adjusting the system to disregard activities that are related to typical children's games or integrating numerous algorithms might be the answer to this issue (for example, a combination of the classification of emotions and actions).

In recent years, researchers have raised concerns about physical bullying detection [11-13]. Previous researches [11] used the transfer learning approach on the identification of violent conduct. The authors developed a violence detector that was based on transfer learning and tested it using three different datasets. They had an accuracy rate of 80.90 percent on average when it came to identifying violent content (from a video that was obtained from YouTube). Next study [12] investigated the use of information about irregular mobility to identify violent behavior in surveillance cameras. By using of the Motion Co-occurrence Feature, the authors were able to conduct an analysis on the properties of the motion vectors that were produced in the vicinity of the item (MCF). They utilised the CAVIAR database, but, however, the research did not provide any numerical results about the accuracy on average.

The National Autonomous University of Mexico conducted a study using a systematic observation strategy called SDIS-GSEQ [14-15] to describe the behavioral patterns in children who were identified by the program as "victims" and their changes. The purpose of the study was to investigate the effects of the program on these children.

III. PROBLEM STATEMENT

The purpose of this research is to provide a method for rapid identification of violent incidents captured by video security cameras. The scientific contribution made by this study is the invention of a system for the rapid identification of violent behavior. The objective was accomplished by training a

neural network using a tracking by detection method like MoveNet retrieved points from human skeletons. The following goals need to be completed in order to succeed in this endeavor: a) Development of a Video Dataset with aggressive behaviour scenes; b) Extract human skeleton points using MoveNet; c) Train the neural network applying the extracted points d) Evaluate the trained neural network.

IV. DATA

The problem of identifying violent and aggressive conduct may be broken down into a variety of more specific subtasks. Fig. 1 presents the research process as a flowchart for a reference. The flowchart for the study project is divided into its primary components, which are feature extraction, data collection, and classification problem. The section on data characteristics is where the pattern parameters of the perpetrator are defined. The portion responsible for data collection assures the availability of relevant video data, marks up videos according to classifications, stores them in .json format, and trims the marked video sequences that include violent situations in order to produce a dataset. In this section, we present all kinds of data operations from collection to the preparation for neural network training.

A. Data Collection

The first step is to determine the various categories of information that need to be compiled. We came up with different distinct categories of traits to differentiate a victim from an aggressor. These traits may be categorized as either passive or active. In the beginning, we determined their characteristics based on the predetermined classifiers. These characteristics are the ones that should be assessed during the process of data collection. Afterwards, the characteristics of the victim and the aggressive behavior were broken down into 13 different groups.

When searching for video materials that are available for free access on the internet, we applied a variety of search phrases, including "aggression," "physical aggression," "violence," "bullying," "fight," "group fight," and others. After gathering them, the next step was to assign appropriate classes to the spatiotemporal segments included within the videos, and the information about their labeling was saved in the *.json file format. To accomplish this task, we used VGG Image Annotator. Following the completion of the tagging, each of the movies was clipped, and then they were arranged into classes.

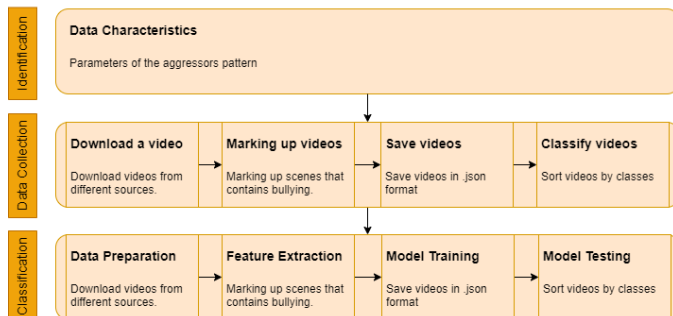


Fig. 1. Flowchart of the research.

B. Dataset

The initial step of our investigation consisted of collecting footage of acts of violence committed by a single individual. There are thirteen categories of violent acts that have been categorized. As a result, there were a total of 80 classifications that were found to belong to either an offender or a victim over the course of the inquiry. In order to put the training model into practice, we needed to determine the activities of a single individual. For such purpose, we broke the project down into 13 courses that each only needs one person to complete. Table I provides an illustration of the thirteen courses that were used in the training of the model. In the course of our research, we developed our very own dataset, which is made up of the thirteen categories that were previously established. The dataset was used for both training and testing of the model that we have suggested. After that, it was put to the test by making use of free datasets of footage of violent acts.

The information shown in Fig. 2 pertains to the videos that were gathered. Videos are gathered in three different formats. Statistical information on the various kinds of video data files that were collected may be seen in Fig. 2(a). The dissemination of video sequences is shown in Fig. 2(b). It was determined that a total of 2,093 short videos illustrating incidents of physical bullying and aggressive behavior should be collected. Approximately 20 hours were spent gathering all of the video data. The following is a list of the file formats that were used to gather the data on the videos:

- video in .mp4 format: 2 017 files;
- video in .mov format: 44 files;
- video in .wmv format: 32 files.

TABLE I. COMPARISON OF THE OBTAINED RESULTS

Class id	Class type
0	Large range of hand movements
1	The head is directed towards the victim
2	The body turned to face the victim
3	The shoulders back and the arms back
4	Hands on hips
5	Takes off the outer clothes
6	Kicking
7	Punching
8	Covering the face
9	Legs pointing in different directions
10	A series of bouncing blows
11	Bend over
12	Finger pointing

Throughout the collected data, we also recorded videos of a single person committing physical aggression actions. Additional films are necessary for the first stages of the neural network training. The whole of the brand new video content clocks in at close to four hundred minutes. There are two distinct categories of violent videos, each of which is defined by its intended purpose. The first category of videos depicts acts of violence in crowded places. The second category deals with secluded violence, which can take place between just two people in uncrowded scene and typically involves one

participant acting as a bullier and the other participant acting as a victim.

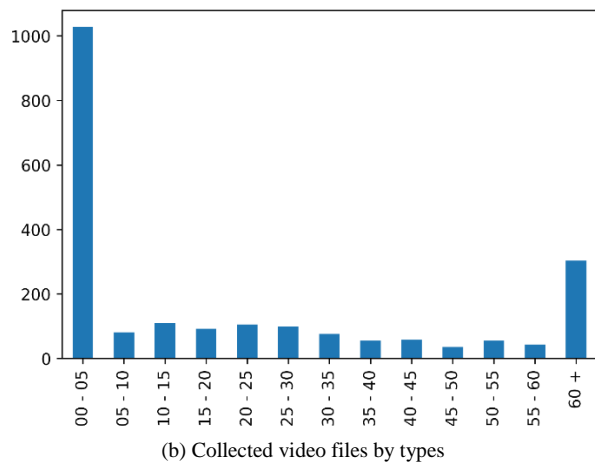
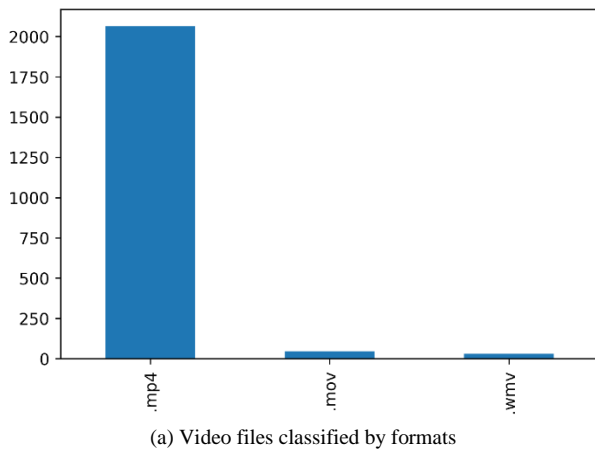


Fig. 2. Collected dataset of videos.

V. MATERIALS AND METHODS

A. The Proposed Approach

In the next paragraphs, we will discuss our methodology, which is known as the tracking by detection. The suggested system's general design is shown in Fig. 3, which may be seen below. The system may be broken down into three different subproblems. In the first step of this process, we approximate the human stance on each image sequence by applying the MoveNet model to the input image sequence. In the second step, we take each frame and retrieve important points as vectors. MoveNet provides a total of 17 important locations for each frame. As a direct result of this, we are able to generate vectors that include 34 individual components. In the subsequent phase, we combine all of the k vectors into a single vector before passing it on to the step that deals with features extraction and activity identification. In the last step, known as stage three, we train a neural network to solve tasks related to action recognition. There are two different kinds of algorithms for determining the location of a human skeleton based on RGB images: top-down and bottom-up. The first ones will trigger a human detector and examine body joints in boundary boxes that have already been determined. Top-down methods include the ones described in MoveNet [22], HourglassNet

[23], and Hornet [24]. There are a few other bottom-up algorithms, such as Open space [25] and PifPaf [26].

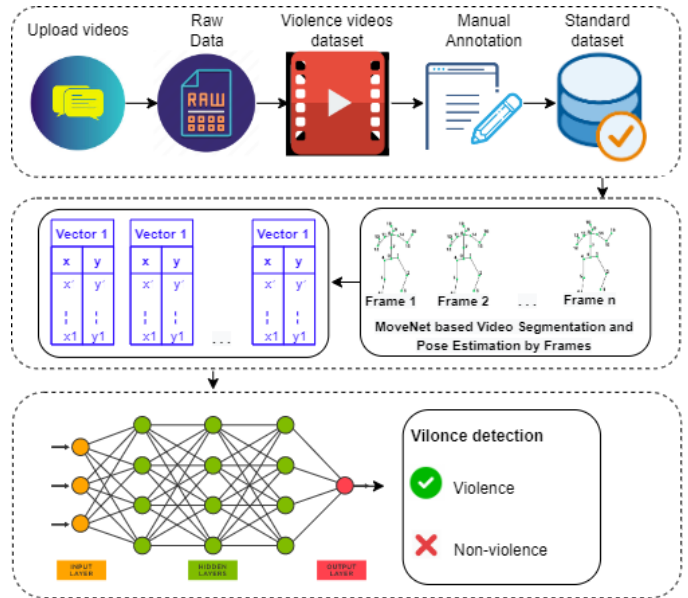


Fig. 3. Flowchart of the study.

We carried out our training using a strategy known as the skeleton approach. The described approach has the potential to reduce the costs associated with processing. A MoveNet based neural network is employed in order to create an accurate appraisal of the figure of either the perpetrator or the victim. Using a MoveNet that has already been pre-trained, a function extraction has the ability to transfer the data obtained in the input space to the target domain. The output of MoveNet represents the human skeleton with 17 primary body points together with their positions and the confidences associated with those sites. There are 17 vital points on the body, including the nose, eyes, ears, shoulders, elbows, wrists, thighs, knees, and ankles. Fig. 4 depicts an instance of 17 key points that MoveNet might obtain and use to train the neural network. These points are applied to the network. The x and y coordinates of the important points are what are used to represent them in the two-dimensional coordinate space.

The following formula illustrates one possible approach to depict the human body:

$$r_b(x_i; \theta), \tag{1}$$

Where θ is neural network parameters, and x_i is training samples. The representation of the human body $rb(x_i; \theta)$ is classified using a layer of fully linked neural networks that have been installed.

It is possible to train the extra neural network by lowering the category cross-entropy loss. This must be done before the network is normalized by the "Softmax" layer. Fig. 5 presents an overview of the architecture of the MoveNet based ANN. In the first step, human activity frames are sent into MoveNet so that crucial points may be extracted. Afterwards, the coordinates of skeleton points are shown and used to represent

them in the feature space. In the final step, the human skeleton's essential points are used to train the network.

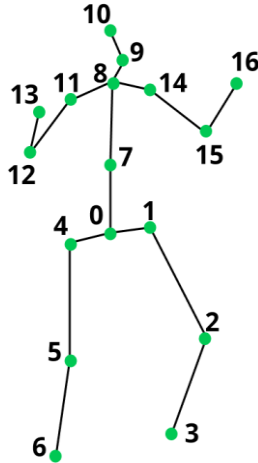


Fig. 4. Extracted points by MoveNet.

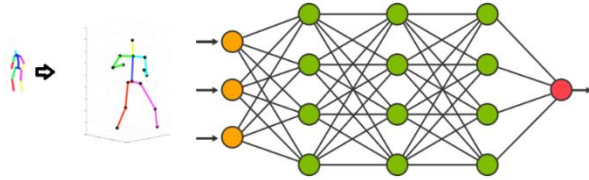


Fig. 5. ANN for MoveNet based physical bullying detection.

As a result, in the first phase of the research, we gather the required data, organized and split it into classes, and afterwards we built a dataset that will be fed into the neural network. The use of MoveNet for the purpose of extracting human skeleton points constitutes the second stage of the study. In order for a neural network to be able to distinguish human activities, we used human skeleton points in the training process. The development of a neural network for the detection of violent actions is the final process of the proposed framework. After that, training and testing the results of the neural network are carried out in order to determine whether or not the proposed approach is suitable for use in the real world.

B. Evaluation

Displaying the outcomes of a prediction model with the help of a confusion matrix is possible. Actual variables are defined by the columns of the confusion matrix, whereas anticipated classes are represented by the rows of the matrix. The matrix displays the number of true positives (TP), false positives (FP), false negatives (FN), and true negatives (TN) for each class. A number of other efficiency measures, including as accuracy, precision, recall, and F1-score, may be computed with the use of the matrix. Formulae like as precision, recall, F-measure, and accuracy are used in order to assess the outcomes of the suggested methodology, and Eq. (2)-(5) provide an illustration of these respective Eq. [27-29].

$$precision = \frac{TP}{TP + FP}, \quad (2)$$

$$recall = \frac{TP}{TP + FN}, \quad (3)$$

$$F1 = \frac{2 \cdot precision \cdot recall}{precision + recall}, \quad (4)$$

$$accuracy = \frac{TP + TN}{TP + FN + TN + FP}, \quad (5)$$

We employed a technique called weight-averaging to combine the metrics that were generated for each class into a single variable. This variable weights the values based on the proportion of the class that they represent. In order to validate the prediction models, we resorted to the tried-and-true train/test split. The data set was separated into eighty and twenty percent halves.

VI. EXPERIMENTAL RESULTS

In this part, we provide the research results into the categories of data collecting, feature extraction, and the identification of violent behavior. First subsection depicts human skeleton points' extraction findings; second portion exhibits violent activities detection results. At the conclusion of the second subsection, we compare the achieved findings with the study results that are now considered cutting edge. The research outcome is discussed with the use of evaluation metrics such as confusion matrices, model accuracy, precision, recall, and F1-score.

A. MoveNet-based Keypoints Detection

In this part of the article, we retrieved points of the human skeleton from the video sequence. The PoseNET model was used to determine the 17 most important locations. Fig. 6 is a demonstration of human skeletal points that have been retrieved from a live video frame. The extraction of human essential points was performed in a time span of every using a frame as a shot. Due to the rapid nature of the changes that occur in a video feed, the relative positions of the combatants may be immediately adjusted in the event of a conflict. As a direct consequence, there may be many sequenced classes for each participant in the fight. Therefore, the ability to make fast decisions is essential for the identification of violence in videos.

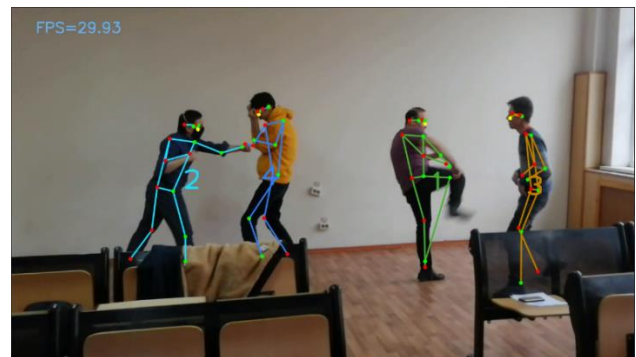
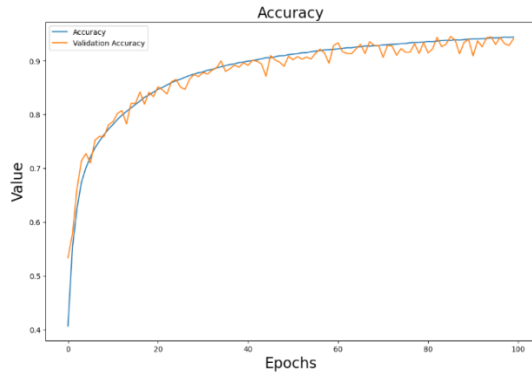


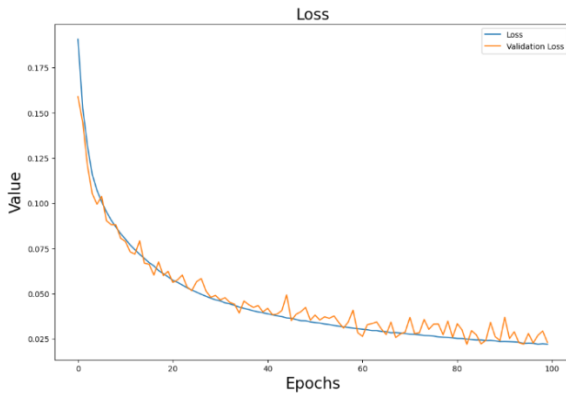
Fig. 6. Testing the proposed framework.

B. Detection of Violent Actions

Throughout the entire period of our experiment, we worked on developing and testing a neural network for violence detection. In order to train the neural network, the MoveNet architecture was applied. Out of the tagged video data, we used it to choose 13 classes for which we then captured further video data. When it came to recognizing aggressive behavior, the constructed action recognition model based on the gathered data performed very well.



(a) Validation and test accuracy



(b) Validation and test loss

Fig. 7. Model testing.

The results of the evaluation of the suggested model are shown in Fig. 7. Fig. 7(a) depicts the validation and testing accuracy of the system for the identification of physical bullying throughout the course of eight training epochs. According to the data, the accuracy reaches 98 percent after 8 training epochs have been completed. The values of the neural network loss function are shown in Fig. 7(b) during the course of eight training epochs. According to the data, the amount of validation that is lost is very little even during the beginning stages of the training process.

Fig. 8 depicts the evaluation of the outcomes of classification for a total of 13 different classes. As it can be seen from the graph, every one of the criteria for the evaluation is of an exceptionally high standard. For instance, the accuracy can range anywhere from 0.92 to 0.98, the recall can go anywhere from 0.89 to 1.0, and the F-measure may go anywhere from 0.92 to 0.99. The confusion matrix for the 13 various categories of aggressive behavior are shown in Fig. 9. According to the confusion matrix, the rate of categorization is

quite high, and there is a slight misunderstanding between the classifications.



Fig. 8. Confusion matrix of different classes' percentage.

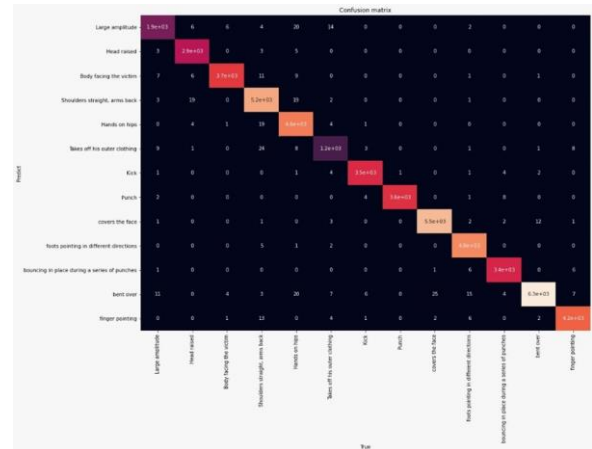


Fig. 9. Confusion matrix for classes.

Fig. 10 illustrates how the proposed framework may be used in a scenario including group fight. In the end, we identify each person's behavior, categorize them, and decide in real time whether they are an aggressor or a victim based on their location, kind of action, and whether they are the bully or the victim. This kind of display of the findings may be helpful for video operators, as it enables them to identify fighting and other forms of physical bullying in real time and to swiftly recognize the attacker and the sufferer in both busy and uncrowded scenes of violence.

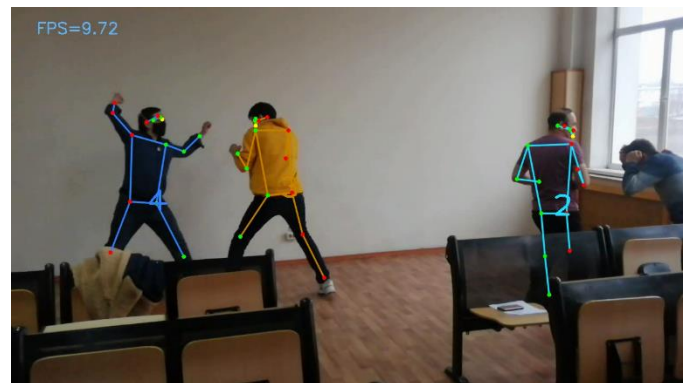


Fig. 10. Model testing.

Table II draws a comparison between the acquired results and the most recent study findings. We analyzed the numerous studies on the detection of physical aggression in the context of three primary assessment criteria: precision, recall, and f-measure. However, the recall and F-score assessment criteria are not used in the majority of the investigations. In situations like this, the Accuracy metric is the most important assessment measure to use when comparing the overall performance of the many recommended methods. In addition, the majority of studies do not include the amount of time spent processing their methods since doing so would be difficult due to disparities in the datasets used and the capabilities of the computer equipment.

TABLE II. COMPARISON OF THE ACHIEVED RESULTS WITH THE OTHER STUDIES

Study	Approach	Precision	Recall	F-score
The proposed approach	MoveNet based physical bullying detection	0.94	0.93	0.93
Fenil et. al., 2019, [11]	Bidirectional LSTM	0.94	-	-
Senst et. al., 2017, [12]	Scale-Sensitive Video-Level Representation	0.91-0.94	-	-
Zhang et.al., 2016, [13]	Linear SVM	0.82-0.89	-	-
Sharma & Baghel, 2020 [19]	ResNet-50 and ConvLSTM	0.924	-	-
Cheng et. al., 2020 [30]	Flow Gated Network	0.8725	-	-
Carneiro et. al., 2019 [31]	Multi-Stream CNN	0.8910	-	-
AlDahoul et. al., 2021 [32]	CNN-LSTM based model	0.7335	0.7690	0.7401
Deepak et. al., 2020 [33]	Gradients based violence detection	0.91	0.88	0.88

The findings demonstrate that the suggested method is capable of being used in real-world implementations for the identification of violent behavior by means of security camera footage. The suggested method is more rapid than the model that relies just on pictures due to the use of skeleton points during the training and testing of the neural network. In addition, the developed system will be useful in a variety of settings, including educational institutions and other locations that have video security cameras installed.

VII. CONCLUSION

This study established a physical violence detection based on MoveNet model, which can be employed in real-time and does not need highly processing hardware. The following is the primary benefit offered by the system that has been suggested. To begin with, it is not necessary to provide the system on a regular basis with huge amounts of video footage and photos. Our proposed technology is able to complete tasks more quickly than other systems on the market since it is based on

the MoveNet key points of the human skeleton. In this particular instance, this characteristic enables the suggested system to be used for applications that take place in real time and in the actual environment.

The proposed study aims to develop methods for the rapid and accurate identification of violent acts in real time by using video security cameras. In order to accomplish this objective, we would like to provide the following three proposals: Determine the different sorts of violent acts that are shown in a video stream that include both of these categories of violent acts. The first section of the data set consists of the aggressive behavior of a single individual that extends over the course of more than 400 hours. The violent acts committed by a single individual were separated into 13 categories, and the films that were included in the dataset were recorded from a variety of perspectives and acquired using a variety of tools. The second section of the dataset consists of violent acts committed in crowded scenes. The neural network is trained using violent behaviors performed by a single individual, while the suggested system is tested using violent actions performed by a group of bullies.

In order to save time, we employed the MoveNet model to extract skeleton points in order to retrieve an artificial neural network using skeleton key points rather than high-volume video. Using a time interval of one second, skeleton points were retrieved from each frame of the movie. Since human key points are being used, there is no need to load an extremely large number of video frames or photos. The findings of the experiment demonstrate an accuracy of between 95 and 99 percent in the identification of violence based on video; consequently, it is safe to assume that the suggested method is suitable for usage in real-world settings.

REFERENCES

- [1] R. Philpot, L. Liebst, K. Møller, M. Lindegaard and M. Levine. "Capturing violence in the night-time economy: A review of established and emerging methodologies," *Aggression and violent behavior*, vol. 46, no. 1, pp. 56-65, 2019.
- [2] A. Ross, S. Banerjee and A. Chowdhury. "Security in smart cities: A brief review of digital forensic schemes for biometric data," *Pattern Recognition Letters*, vol. 138, no. 1, pp. 346-354, 2020.
- [3] D. Sultan, A. Toktarova, A. Zhumadillayeva, S. Aldeshov, S. Mussiraliyeva et al., "Cyberbullying-related hate speech detection using shallow-to-deep learning," *Computers, Materials & Continua*, vol. 74, no.1, pp. 2115–2131, 2023.
- [4] G. Sreenu and M. Durai. "Intelligent video surveillance: a review through deep learning techniques for crowd analysis," *Journal of Big Data*, vol. 6, no. 1, pp. 1-27, 2019.
- [5] P. Vennam, T. Pramod, B. Thippeswamy, Y. Kim and P. Kumar. "Attacks and preventive measures on video surveillance systems: a review," *Applied Sciences*, vol. 11, no. 12, pp. 5571, 2021.
- [6] R. Nawaratne, D. Alahakoon, D. De Silva and X. Yu. "Spatiotemporal anomaly detection using deep learning for real-time video surveillance," *IEEE Transactions on Industrial Informatics*, vol. 16, no. 1, pp. 393-402, 2019.
- [7] Sultan, D., Omarov, B., Kozhamkulova, Z., Kazbekova, G., Alimzhanova, L., Dautbayeva, A., ... & Abdrakhmanov, R. (2023). A Review of Machine Learning Techniques in Cyberbullying Detection. *CMC-COMPUTERS MATERIALS & CONTINUA*, 74(3), 5625-5640.
- [8] Narynov, S., Mukhtarkhanuly, D., & Omarov, B. (2020). Dataset of depressive posts in Russian language collected from social media. *Data in brief*, 29, 105195.

- [9] Anand, M., Sahay, K. B., Ahmed, M. A., Sultan, D., Chandan, R. R., & Singh, B. (2022). Deep learning and natural language processing in computation for offensive language detection in online social networks by feature selection and ensemble classification techniques. *Theoretical Computer Science*.
- [10] Z. Shao, J. Cai and Z. Wang. "Smart monitoring cameras driven intelligent processing to big surveillance video data," *IEEE Transactions on Big Data*, vol. 4, no. 1, pp. 105-116, 2017.
- [11] E. Fenil, G. Manogaran, G. Vivekananda, T. Thanjaivadevel, S. Jeeva et al. "Real time violence detection framework for football stadium comprising of big data analysis and deep learning through bidirectional LSTM," *Computer Networks*, vol. 151, pp. 191-200, 2019.
- [12] T. Senst, V. Eiselein, A. Kuhn and T. Sikora. "Crowd violence detection using global motion-compensated lagrangian features and scale-sensitive video-level representation," *IEEE transactions on information forensics and security*, vol. 12, no. 12, pp. 2945-2956, 2017.
- [13] Omarov, B., Narynov, S., Zhumanov, Z., Gumar, A., & Khassanova, M. (2022). A Skeleton-based Approach for Campus Violence Detection. *COMPUTERS MATERIALS & CONTINUA*, 72(1), 315-331.
- [14] Anand, M., Sahay, K. B., Ahmed, M. A., Sultan, D., Chandan, R. R., & Singh, B. (2022). Deep learning and natural language processing in computation for offensive language detection in online social networks by feature selection and ensemble classification techniques. *Theoretical Computer Science*.
- [15] K. Lloyd, P. Rosin, D. Marshall and S. Moore, "Detecting violent and abnormal crowd activity using temporal analysis of grey level co-occurrence matrix (GLCM)-based texture measures," *Machine Vision and Applications*, vol. 28, no. 1, pp.361-371, 2017.
- [16] P. Bilinski and F. Bremond, "Human violence recognition and detection in surveillance videos," In 2016 13th IEEE International Conference on Advanced Video and Signal Based Surveillance (AVSS), Colorado Springs, CO, pp. 30-36, 2016.
- [17] M. Karim, M. Razin, N. Ahmed, M. Shopon and T. Alam. "An Automatic Violence Detection Technique Using 3D Convolutional Neural Network," *Sustainable Communication Networks and Application*, vol. 55, no. 1, pp. 17-28, 2021.
- [18] A. Naik and M. Gopalakrishna. "Deep-violence: individual person violent activity detection in video," *Multimedia Tools and Applications*, vol. 80, no. 12, pp. 18365-18380, 2021.
- [19] M. Sharma and R. Baghel. "Video surveillance for violence detection using deep learning," In *Advances in Data Science and Management, ICDSM 2019*, pp. 411-420, Singapore, 2020.
- [20] M. Asad, J. Yang, J. He, P. Shamsolmoali and X. He. "Multi-frame feature-fusion-based model for violence detection," *The Visual Computer*, vol. 37, no. 6, pp. 1415-1431, 2021.
- [21] Y. Chong and Y. Tay, "Abnormal event detection in videos using spatiotemporal autoencoder," *Lecture Notes in Computer Science*, vol. 10262, no. 1, pp.189196, 2017.
- [22] B. Schmidt and L. Wang, "Automatic work objects calibration via a global-local camera system Robot," *Computer-integrated manufacturing*, vol. 30, no. 1, pp. 678-683, 2014.
- [23] A. Newell, K. Yang and J. Deng. "Stacked hourglass networks for human pose estimation," in *European conference on computer vision, ECCV 2016, Amsterdam, The Netherlands*, pp. 483-499, 2016.
- [24] K. Shrikhande, I. White, D. Wonglumsom, S. Gemelos, M. Rogge et al. "HORNET: A packet-over-WDM multiple access metropolitan area ring network," *IEEE Journal on Selected Areas in Communications*, vol. 18, no. 10, pp. 2004-2016, 2000.
- [25] A. Zanchettin, N. Ceriani, P. Rocco, H. Ding and B. Matthias. "Safety in Human-Robot Collaborative Manufacturing Environments: metrics and Control," *IEEE Transactions on Automation Science and Engineering*, vol. 13, no. 1, pp. 882-893, 2016.
- [26] Kreiss, Sven, Lorenzo Bertoni, and Alexandre Alahi. "Pifpaf: Composite fields for human pose estimation." *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*. 2019.
- [27] B. Omarov, N. Saparkhojayev, S. Shekerbekova, O. Akhmetova, M. Sakypbekova et al. "Artificial intelligence in medicine: real time electronic stethoscope for heart diseases detection," *CMC-Computers, Materials & Continua*, vol. 70, no. 2, pp. 2815-2833, 2022.
- [28] Kreuzberger, Dominik, Niklas Khl, and Sebastian Hirschl. "Machine learning operations (mlops): Overview, definition, and architecture." *IEEE Access* (2023).
- [29] Méndez, Manuel, Mercedes G. Merayo, and Manuel Núñez. "Machine learning algorithms to forecast air quality: a survey." *Artificial Intelligence Review* (2023): 1-36.
- [30] M. Cheng, K. Cai and M. Li, "Rwf-2000: An open large scale video database for violence detection," in 2020 25th International Conference on Pattern Recognition (ICPR), Milan, Italy, pp. 4183-4190, 2021.
- [31] Carneiro, S.A., da Silva, G.P., Guimaraes, S.J.F., Pedrini, H.: Fight Detection in video sequences based on multi-stream convolutional neural networks. In: 2019 32nd SIBGRAPI conference on graphics, patterns and images (SIBGRAPI) 2019, pp. 8–15. IEEE
- [32] N. AlDahoul, H. Karim, R. Datta, S. Gupta, K. Agrawal et al., "Convolutional Neural Network-Long Short Term Memory based IOT Node for Violence Detection," in 2021 IEEE International Conference on Artificial Intelligence in Engineering and Technology (ICALET), Kota Kinabalu, Malaysia, pp. 1-6, 2021.
- [33] K. Deepak, L. Vignesh and S. Chandrakala, "Autocorrelation of gradients based violence detection in surveillance videos," *ICT Express*, vol. 6, no. 3, pp. 155-159, 2020.
- [34] C. Duan and X. Li. "Multi-target tracking based on deep sort in traffic scene," *Journal of Physics: Conference Series*, vol. 1952, no. 2, pp. 022074, 2021.
- [35] A. Pramanik, S. Pal, J. Maiti and P. Mitra. "Granulated RCNN and multi-class deep sort for multi-object detection and tracking," *IEEE Transactions on Emerging Topics in Computational Intelligence*, vol. 1, no. 1, pp. 1-11, 2021.

Design of a Reliable Transmission Mechanism for Vehicle Data in Mobile Internet of Vehicles Driven by Edge Computing

Wenjing Liu

Chongqing Technology and Business Institute, Chongqing 401520, China

Abstract—In order to meet the business requirements of different applications in heterogeneous, random, and time-varying mobile network environments, the design of a reliable transmission mechanism is the core problem of the mobile Internet of vehicles. The current research is mainly based on the computing power support of roadside units, and large delays and high costs are significant defects that are difficult to overcome. In order to overcome this deficiency, this paper integrates edge computing to design task unloading and routing protocol for the reliable transmission mechanism of mobile Internet of vehicles. Firstly, combined with edge computing technology, a mobile-aware edge task unloading mechanism in a vehicle environment is designed to improve resource utilization efficiency and strengthen network edge computing capacity so as to provide computing support for upper service applications; Secondly, with the support of computing power of edge task unloading mechanism, connectivity aware and delay oriented edge node routing protocol in-vehicle environment is constructed to realize reliable communication between vehicles. The main characteristics of this research are as follows: firstly, edge computing technology is introduced to provide distributed computing power, and reliable transmission routing is designed based on vehicle-to-vehicle network topology, which has prominent cost advantages and application value. Secondly, the reliability of transmission is improved through a variety of innovative technical designs, including taking the two hop range nodes as the service set search to reduce the amount of system calculation, fully considering the link connectivity state, and comprehensively using real-time and historical link data to establish the backbone link. This paper constructs measurement indicators based on delay and mobility as key elements of the computing offloading mechanism. The offloading decision is made through weighted calculation of delay estimation and computing cost, and a reasonable computing model is designed. The experimental simulation shows that the average task execution time under this model is 65.4% shorter than that of local computing, 18.4% shorter than that of cloud computing, and the routing coverage is about 6% higher than that of local computing when there are less than 60 nodes. These research and experimental results fully demonstrate that the mobile Internet of vehicles based on edge computing has good reliable transmission characteristics.

Keywords—Mobile network; internet of vehicles; reliable transmission; edge computing

I. INTRODUCTION

Vehicular ad hoc networks (VANETs) are the basic networking mode of mobile Internet of vehicles. It mainly

relies on a vehicle-to-vehicle (V2V) and vehicle-to-roadside unit (V2R) to provide a variety of data transmission and information interaction services [1]. The concept of Internet of Vehicles is extended from the Internet of Things. With the rapid development of Internet of Things technology and applications, especially the significant progress of sensing technology in the perception layer of the Internet of Things, it provides real-time perception and feedback of operating vehicle and road condition information, providing an essential big data foundation for the research and application of the Internet of Vehicles.

Unlike traditional networks, the mobile Internet of vehicles has unique internal characteristics regarding the network environment, node mobility, channel characteristics, computing power, cache space, and energy constraints. In particular, the dynamic change of topology leads to frequent network segmentation, which is difficult to ensure the end-to-end connected link; In addition, the massive data of diversified new applications have great pressure on the response delay and network load, which poses a severe challenge to the computing power of car coupling network [2]. Therefore, studying the characteristics of mobile vehicle networks and building a reliable transmission mechanism is the core problem to be solved urgently.

Currently, the research and application of reliable transmission mechanisms of mobile vehicle networks far lag behind the industrial technology demand, which does not match the current development of mobile vehicle networking. On the other hand, the research of introducing edge computing into a reliable transmission of mobile Internet of vehicles has been widely concerned and applied. The overall research status in this field is briefly described below.

As early as 2009, the United States released the intelligent transportation strategic research plan. In 2016, China released the development plan for the innovation of the mobile Internet of vehicles, focusing on the deployment and promotion of common key technologies, standards, infrastructure construction, platform experimental verification, application, and promotion, and successively launched a series of standards and specifications for the mobile Internet of vehicles industry, including Tencent, Alibaba, and Baidu has also established corresponding cooperation with various car enterprises. International academic circles, such as IEEE, have founded IEEE Transactions on vehicular technology and other top journals, bringing together important innovative research

achievements in the world. Although the research on the reliable transmission of the mobile Internet of vehicles has made great progress, considering the scale of the mobile vehicle network, the rapid movement of vehicles, and the complex channel environment, ensuring the reliable transmission of information is still a very challenging problem [3][4].

Firstly, the location-based routing mechanism is a widely used key technology to solve data transmission. However, the existing related work still has corresponding limitations in node mobility characterization, routing index modeling, and relay node selection. It is mainly reflected in the following:

1) The vehicle network's scale, complexity, and dynamics are not fully considered. The existing routing mechanism is often applicable to local or single network form, resulting in the algorithm falling into optimal local solution and difficulty in adapting to the dynamic changes of mobile vehicle network effectively;

2) Rely on historical traffic information to quickly find routes in sparse scenarios and alleviate the occurrence of local optima while ignoring the positive role of real-time link information in assisting data transmission and avoiding collisions in congested flow scenarios.

Secondly, the effective calculation of data plays a great role in strengthening the performance of vehicle communication, and the calculation of massive data brings great pressure on the network bandwidth. By sinking the cloud computing function to the user side, edge computing will greatly reduce the network load and network delay; the current research work has the following deficiencies:

1) Most of the existing computing unloading mechanisms rely on the assistance of roadside unit RSU and fail to fully explore a large number of idle intelligent vehicle resources to improve the edge performance of the network;

2) Although some edge computing designs consider the impact of intermittent connection caused by vehicle movement on computing unloading, they do not make full use of the service opportunities created by vehicle movement, ignoring that service vehicles far away (vehicles providing computing services) still have the opportunity to enter the communication range of task vehicles (vehicles requiring data computing) and participate in task computing.

To sum up, it is an important research and application direction of the current mobile vehicle networking to effectively combine data communication with calculation to provide computational support for the routing and distribution of mobile vehicle network data with the formulation of calculation unloading decisions [5] and to achieve the reliable transmission of mobile vehicle network data.

The rest of this paper will be organized as follows: Section II gives research contribution of this paper, Section III presents design of edge task unloading mechanism, Section IV elucidates edge routing design, Section V concludes the paper.

II. RESEARCH CONTRIBUTION OF THIS PAPER

It is estimated that the scale of the Internet of vehicles industry will reach 200 billion yuan in 2025. Benefiting from the development of new generation communication technology, the mobile Internet of vehicles has strong ubiquitous interconnection ability, intelligent processing ability, and big data processing ability. It organically connects the traffic elements of the on-board network, including people, vehicles, roads, and clouds, breaks through the limitations of single-vehicle information perception and processing, and achieves the purpose of strengthening safety, improving efficiency, improving the environment and saving energy, It has become the core field of scientific and technological innovation and industrial development in the world, and has spawned a series of new technologies, new products, and new services.

Firstly, in terms of the outstanding feature of the dynamic topology of the mobile Internet of vehicles, different from the traditional wireless mobile network, the rapid movement of vehicle nodes is easy to cause the interruption of transmission links and affects the successful reception of information. Urban buildings, obstacles, and random channel environments exacerbate signal transmission instability, making the traditional network transmission mechanism difficult to work in the environment of the Internet of vehicles. Because the traditional network data transmission protocol is difficult to adapt to the frequent changes of topology and high-speed movement of nodes in the vehicle environment and is limited by the communication range of vehicles and the scale of vehicle network, in the design of multi-hop information transmission mechanism widely used in the industry, path selection and relay node selection are two key problems. This paper constructs a delay model based on the distribution and motion characteristics of road nodes, and weights the calculation of delay and computational cost for the next hop forwarding node's routing selection. The experiment shows that the coverage can be improved by 6% in sparse scenarios.

Secondly, in terms of the outstanding characteristics of the massive data of the mobile Internet of vehicles, the endless on-board applications pose a severe challenge to the computing power of the mobile Internet of vehicles, especially the new services promoted by communication technology and equipment manufacturing, such as augmented reality (AR) and automatic driving. A single vehicle with limited resources cannot meet the computing requirements of the above services. The on-board network based on cloud computing can improve service performance by integrating communication and computing resources, but it will lead to unpredictable delays. Therefore, this paper introduces vehicular edge computing (VEC). By taking delay and mobility as the key elements of the measurement indicators to build the measurement indicators of an effective calculation unloading mechanism, a weighted calculation model based on weight is designed, and experimental data validation is carried out to make up for the shortcomings of local computing and cloud computing.

In short, the mobile Internet of vehicles is the key technical means to realize the smart city and intelligent transportation. In view of the prominent characteristics and application challenges of its lack of dynamic topology and computing power, this paper designs a reliable transmission mechanism for the mobile Internet of vehicles driven by edge computing, which provides a certain reference value for scientific research and application.

III. DESIGN OF EDGE TASK UNLOADING MECHANISM

Most current research relies on roadside service units with rich computing and storage resources or integrates multiple edge servers to calculate vehicle unloading tasks. However, deploying edge servers in all sections will bring huge economic costs. The ideal way is to unload the computing tasks of task vehicles to multiple service vehicles. The service vehicle executes each subtask and feeds back the results to the task vehicle [6]. After receiving all the calculation results, the task vehicle starts to run the application. Therefore, from the perspective of vehicle unloading mechanism research, this paper integrates the parked idle vehicle resources to provide edge computing power and overcomes the defect that the influence of vehicle mobility on the unloading decision is not fully considered in the existing unloading mechanism. In the design of the unloading mechanism, the core measurement indicators introduced include response delay (including local processing time, data upload time, processing time, and feedback time), incentive mechanism (encouraging vehicles participating in task computing to overcome the selfishness of nodes), mobility (establishing a mobile model to predict and evaluate the effective link time of vehicles).

A. Search and Optimization of Service Vehicles

By adding its computing resource information to the beacon, the service vehicle indicates its availability to the surrounding vehicle nodes and brings the one-hop and two-hop vehicles relative to the task vehicle into the search range (Fig. 1). It is necessary to study and design the construction method of the service vehicle group according to distance, moving direction, speed, and angle, and optimize and model the service vehicle group by using the result measurement index of throughput according to time delay [7].

Vehicles exchange speed and position information with each other through periodic broadcast beacons. Service vehicles can indicate their availability to surrounding vehicles by adding their computing resource information to the transmitted beacon information[8]. When a task vehicle needs to process a task, it can find the service vehicle that can be used to participate in the calculation and unloading by listening to the beacon information from the surrounding nodes.

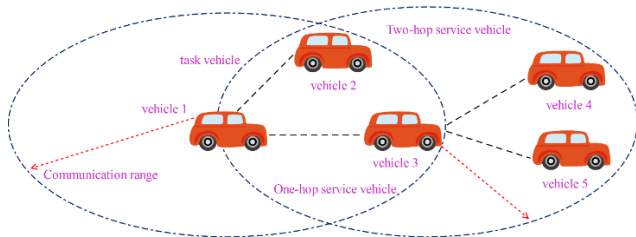


Fig. 1. Example of a two-hop search range.

1) *One-hop service vehicles*: For a task vehicle, the vehicles within its one-hop range are called one-hop vehicles, which are candidate service vehicles. This is because the task vehicle can directly communicate with vehicles within one hop, which provides favorable conditions for task unloading in the workshop. When both vehicle 2 and vehicle 3 are within the communication range of vehicle 1, vehicle 1 can unload tasks to vehicle 2 and vehicle 3 directly through workshop communication to seek assistance.

2) *Two-hop service vehicles*: Vehicles within the two-hop range of mission vehicles are potential service vehicles, such as vehicle 4 and vehicle 5, which are called two-hop service vehicles. Due to the limitation of communication range, although the two-hop vehicle cannot directly communicate with the task vehicle, with the help of vehicle mobility, the two-hop vehicle has the opportunity to travel within the communication range of the task vehicle so that it can serve the task vehicle. In the initial stage, although the task vehicle. Such as, vehicle 1 cannot directly communicate with its two-hop vehicle, but it can indirectly obtain the speed, location, computing resources, and other information of the two-hop vehicle through the relay of one-hop vehicles, such as vehicle 2 and vehicle 3. Based on the obtained information, the task vehicle can judge whether the two-hop vehicle meets the conditions of task unloading. If a two-hop vehicle is selected as a service vehicle to assist the task vehicle in processing the task, it first needs to obtain the task of unloading the task vehicle through the relay of the one-hop vehicle [9]. After the selected two-hop vehicle completes the assigned task, once it enters the communication range of the task vehicle, it will feed back the result to the task vehicle.

3) *Service collection optimization*: We introduce the concept of expected throughput (ET), the expected value of throughput between vehicle user nodes and sink nodes during road movement. ET comprehensively considers the average level of throughput within the physical coverage of sink nodes, which can be used to measure the effectiveness of service integration scheme optimization [10].

The expected throughput parameter can help design performance test scenarios. Based on the estimated throughput data, it can correspond to the frequency and number of transactions in the test scenario. After the test is completed, it can measure whether the algorithm achieves the expected goal according to the actual throughput.

If P_i is set as the actual link throughput when $T(x)$ is equal to T_i , the corresponding probability can be seen from the concept of ET:

$$ET = \sum_{i=1}^N P_i T_i \quad (1)$$

To get the value of ET, we need to solve each P_i first. Let L be the distance between the sink node and the vehicle user node, and $T(x)$ represents the throughput of the actual link. According to the knowledge of probability theory, the corresponding probability when $T(x)$ is equal to T_i is:

$$P_i = P(l_i < L < l_{i+1}), i=1,2,\dots,N-1; \quad (2)$$

$$P_i = P(0 < L < l_i), i=N \quad (3)$$

According to the research results of reference [11], the specific form of the Formula (2) and (3) can be expressed as (4) and (5):

$$P_i(i \neq N) = \frac{(1+2\ln a)(a_i^2 - a_{i+1}^2)}{a^2} - \frac{2a_i^2 \ln a_i - 2a_{i+1}^2 \ln a_{i+1}}{a^2} + \frac{(1+2\ln a)(a_{2N-i}^2 - a_{2N-i+1}^2)}{a^2} - \frac{2a_{2N-i}^2 \ln a_{2N-i} - 2a_{2N-i+1}^2 \ln a_{2N-i+1}}{a^2} \quad (4)$$

$$P_i(i = N) = \frac{(1+2\ln a)(a_N^2 - a_{N+1}^2)}{a^2} - \frac{2a_N^2 \ln a_N - 2a_{N+1}^2 \ln a_{N+1}}{a^2} \quad (5)$$

Where $a_i, a_{i+1}, a_{2N-i}, a_{2N-i+1}$ are the change points when t_i is the link throughput.

B. Modeling and Analysis of Link Connectivity

The connectivity time between vehicle nodes is used to describe the connectivity of links, which represents the duration of effective links when the workshop distance is less than the vehicle communication range. It is necessary to study and design the network connectivity model under the relative position of one hop or two hops, opposite or reverse driving, to provide a basis for selecting service vehicles for task unloading [12].

For vehicles A and B, if the workshop distance between them is less than the communication range of the vehicle, there is an effective link between the two vehicles. Therefore, we can use the connectivity time of the workshop to describe the connectivity of the link.

Suppose (x_A, y_A) and (x_B, y_B) are their respective coordinates, and V_A and V_B are their respective velocities. At the same time, D_{AB} is defined as the initial distance between two vehicles:

$$D_{AB} = (x_B - x_A) \quad (6)$$

According to the respective states of the two vehicles, we calculate the connection time between the two vehicles through the following two cases.

1) *Driving in the same direction:* If $V_A > V_B$, the direct connection time between the two vehicles can be expressed as:

$$T_{liffe} = \frac{R + D_{AB}}{|V_B - V_A|} \quad (7)$$

Where R is the communication radius of the two vehicles.

Otherwise, the connection time of the two vehicles can be expressed as follows:

$$T_{liffe} = \frac{R - D_{AB}}{|V_B - V_A|} \quad (8)$$

2) *Driving in different directions:* When two vehicles are driving in opposite directions, the connection time of the two vehicles can be expressed as:

$$T_{liffe} = \frac{D_{AB} + \sqrt{R^2 - (y_A - y_B)^2}}{V_B + V_A} \quad (9)$$

Otherwise, the connection time of the two vehicles can be expressed as follows:

$$T_{liffe} = \frac{D_{AB} - \sqrt{R^2 - (y_A - y_B)^2}}{V_B + V_A} \quad (10)$$

C. Edge Unloading Algorithm

It is defined here that edge service vehicles have different computing power, and the computing power of edge service vehicles is expressed by C_e . The vehicle generates a calculation task T_A at A:

$$T_A = \{D_{in}, D_{out}, C_{comp}, T_{max}\} \quad (11)$$

where D_{in} represents the data amount of the task, D_{out} represents the output amount of the result, C_{comp} represents the calculation amount of the task, and T_{max} represents the maximum completion time that the task can tolerate.

1) *Upload phase:* We use t to represent the period when the number of hops does not change, which is determined by the vehicle's movement. In a period t , the equivalent bandwidth BW does not change, so in a period t_x , the amount of uploaded data $D_{upx} = t_x \times BW_x$. We assume that at a time t_i , the number of hops changes n times. When the first $(n-1)$ change is completed, it is t_j .

$$\sum_{x=0}^{n-1} D_{upx} + (i - j) BW_n = D_{in} \quad (12)$$

When the above formula is satisfied, the task upload is completed, and the whole-time span T_U is recorded as the upload time of the task.

2) *Calculation stage:* Take the calculation unloading of the task once, that is, switching from task vehicle A to service vehicle B as an example. Here, E_A represents the computing power of vehicle A and E_B represents the computing power of vehicle B.

Then the task calculation time T_C is:

$$T_C = C / E_A \quad (13)$$

The download time of the calculation result is:

$$T_D = D_{out} / BW_A \quad (14)$$

Where BW_A represents the equivalent bandwidth of the result downloaded from task vehicle A to service vehicle B.

Then the task completion time is:

$$T_{comp} = T_C + T_D \quad (15)$$

3) *Download phase:* The principle is the same as that of the upload stage, so in a certain period t_x , the amount of downloaded data $D_{Dx} = t_x \times BW_x$. We assume a time t_1 , when the number of hops changes n times, and the time when the $(n - 1)$ st change is completed is t_2 .

$$\sum_{x=0}^{n-1} D_{Dx} + (t_1 - t_2) BW_n = D_{out} \quad (16)$$

When the above formula is satisfied, the task upload is completed, and the whole-time span T_D is recorded as the download time of the task.

To optimize the completion time of tasks in unloading, the problem optimization model is as follows:

$$\text{Min } [T_U + T_C + T_D] \quad (17)$$

D. Edge Unloading Simulation

The statistical data of this experiment is obtained from five groups of simulation experiments based on six vehicle nodes. Under the constraints of the same amount of task calculation, compare the simulation results of the average task execution time and average task completion time of the 2-hop experimental scenario, and keep two decimal places for all parameters.

It can be seen from the Fig. 2 that in terms of average task execution time, the execution time of tasks under the edge unloading calculation mode is the shortest, which is 62.38 seconds, and compared with the average task execution time calculated by itself of 179.4 seconds, it is shortened by 65.4%; The execution time in the cloud is 76.46 seconds, which is 57% shorter than the vehicle's own calculation. This is because once the task is generated, the calculation amount is a fixed value, sorted according to the calculation power: edge > cloud > itself.

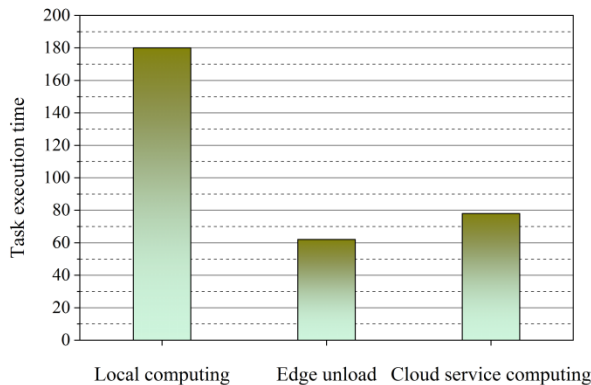


Fig. 2. Task unloading algorithm performance results.

The experimental results show that when only the task execution time is considered, the task will not be calculated locally and should be unloaded to the edge node with strong computing power. It can be seen that the execution time and communication time of the generated tasks need to be considered. When the tasks in the cloud are executed and coordinated, although the cloud has rich computing resources, if a large number of tasks are uploaded to the cloud for execution, it is bound to increase the burden on the cloud in the core network.

IV. EDGE ROUTING DESIGN

It is designed to build a delay model based on road section nodes' distribution and movement characteristics. Combined with the connectivity model established in the previous discussion, it is necessary to introduce the road section (as shown in Fig. 3) evaluation mechanism for the evaluation of road weight and then establish a backbone link composed of a series of intersection edge nodes and in road edge nodes for all roads. The intersection edge node is responsible for calculating and distributing the road weight, while the inner edge node is

used for transmitting information [13]. The optimal path selection algorithm is designed according to the road weight. According to the complexity, the node can calculate the route itself or through task unloading to avoid local optimization and data congestion.

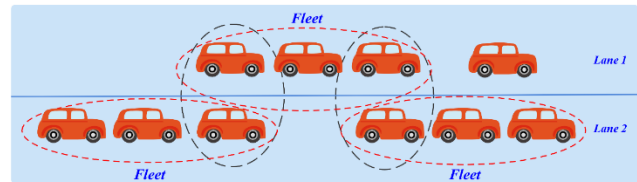


Fig. 3. Example of road section composition.

A. Algorithm Framework

V2V communication mostly adopts two specific data packet formats, including cooperative sensing messages. It is mainly used to periodically broadcast vehicle information and distributed environment notification message [14][15]. It is based on event triggers and is mostly used for vehicle safety alarms and emergency notifications. The cooperative sensing message can periodically broadcast application requests and network transport layer requirements (network heartbeat) according to the specified broadcast frequency. Its broadcast frequency is determined by the communication management entity based on the application scenario and network status. By analyzing the received data packet, the vehicle node can obtain other vehicle information within its driving range so as to obtain the network topology information and vehicle node information in this area, including vehicle position, direction, speed, stability, i.e., acceleration and destination, etc.

The broadcast of security alarm messages and other burst service information is mostly sent through data packets. It has the highest access priority and simple Dayton format design and can flexibly transmit various business applications [16]. The data format of the emergency message mainly consists of starting characters, identification code, data unit, and check code, with a total length of 25 bytes.

This routing mechanism design applies the advantages of real-time traffic estimation in vehicle and road condition information prediction to the broadcast routing protocol, fully considers the relevant factors affecting vehicle communication, is committed to maintaining the improvement of the overall performance of the network, and designs a comprehensive weighted multi-hop broadcast routing algorithm based on real-time traffic estimation.

The design idea of the algorithm can be summarized as follows: firstly, the real-time traffic estimation algorithm with excellent performance is used to accurately predict the target road condition and vehicle behavior, including the vehicle density, vehicle speed, vehicle geographical location and destination of the road section; Secondly, the target vehicle uses the relevant information obtained from real-time traffic estimation to design a comprehensive weighting algorithm, which maps the network topology and node information into weight factors, and uses the comprehensive weighting algorithm to obtain the weighted value of each node in the target road section relative to the information source node; Thirdly, the ranking of the reliability of forwarding nodes is

realized according to the size of the comprehensive weighted value, and the two nodes with the highest reliability (optimal and suboptimal nodes) are encapsulated into the broadcast packet as the destination forwarding nodes, so as to suppress the number of forwarding nodes; Finally, the forwarding node parses the broadcast packet. Suppose it can parse its own relevant information. In that case, it uses the weight mapping algorithm to map the corresponding weighted value into the forwarding waiting time. The optimal forwarding node has the shortest waiting time to effectively reduce the forwarding delay and ensure the real-time effectiveness of the broadcast information [16]. In addition, to maximize the network's reliability, the algorithm also introduces a timeout retransmission mechanism.

B. Flow Design Algorithm

In this algorithm, in order to effectively overcome the network dynamics caused by the high-speed mobility of vehicles, effectively estimate the network topology and estimate the real-time traffic; In order to reduce the number of forwarding nodes and avoid the broadcast storm, a comprehensive weighting algorithm is introduced to select trusted relay nodes; And to ensure the real-time performance of secure broadcast messages, an adaptive waiting slot mechanism based on comprehensive weighted value mapping is needed[17][18]; For ensuring the reliability of security alarm message propagation, the packet timeout retransmission mechanism is introduced[19][20]. The main implementation process of the algorithm is shown in the figure below. The algorithm mainly includes the related processing between nodes and candidate forwarding nodes. The detailed implementation process can be summarized as follows:

Step1- Broadcast: The vehicle node broadcasts relevant messages regularly to make the node become an information source node;

Step2- Determine impact factors: The information source node performs real-time traffic estimation on its on-board nodes' relevant information, outputs the nodes' pre-judgment information, and determines the relevant impact factors.

Step3-Comprehensive weighting: The information source node maps the relevant influence factors of each node into weight factors and uses the comprehensive weighting algorithm to calculate the comprehensive weighting value of each node, which is used as the basis for the selection of the next hop forwarding node.

Step4-Select the optimal forwarding node: The information source node selects the optimal and secondary forwarding nodes according to the weight value, encapsulates the relevant nodes' identification (and corresponding weight) into the secure broadcast packet, and the information source node sets a timeout retransmission timer.

Step5-Broadcast data analysis: After receiving the broadcast data packet, other nodes within the communication range parse it. Suppose they parse the identifier that matches themselves (they are determined as candidate nodes).

Step6-Weight mapping: The candidate node maps the corresponding weight to the forwarding waiting time. The larger the weight, the smaller the forwarding waiting time;

Step7-Waiting for timeout processing: If the same packet is received within the waiting time, the waiting time will be stopped, and the packet will be discarded directly. If the same packet is still not received after the waiting timeout, the candidate node will forward the packet.

Step8-Timeout Retransmission: If the information source node receives the same broadcast packet, the timeout retransmission timer will stop. Otherwise, if the retransmission timer times out, it will broadcast the packet again.

Step9-Update forwarding node set: The candidate node forwards the packet and resets the forwarding hops of the packet. At this time, the forwarding node becomes a new information source node and repeats the process. After the final packet exceeds the forwarding times, stop forwarding and discard it.

C. Relay Selection Strategy

The one-hop communication distance R of the information source node is evenly divided into N segments according to the distance from near to far. If the relative distance between the target node and the information source node is D_R , the given time slice of the vehicle in each section can be expressed as:

$$T_d = S_{ij} * \vartheta \quad (18)$$

Where, ϑ is the estimated one-hop relay delay, including the access delay and propagation delay of the channel, and S_{ij} is the number of time slices corresponding to the location of a given target node, i.e.:

$$S_{ij} = N \left[1.8 - \frac{\text{MIN}(D_R, R)}{R} \right] \quad (19)$$

$$N = R / 2r \quad (20)$$

here r is the relay selection radius.

The definition of the number of time slices S_{ij} is mainly based on the fact that the selection mechanism of the default waiting time T_d is a delay redundancy process. When the waiting time T_d is too large, the packet transmission delay will increase, but it is easier to avoid redundant data forwarding at the same time; When the waiting time T_d is too small, it will lead to frequent packet forwarding and increase redundant data, but it can also reduce the packet transmission delay and ensure the timeliness of the information. Therefore, considering the actual scenario and optimization mechanism, the confirmation of N can be realized through the above formula 20. Select the default waiting time t to be at least greater than $N/2$ time slices to weigh the real-time performance and efficiency.

For the optimal forwarding node, because it corresponds to the maximum weighted value and the range of weighted value σ_i is between (0,1), we can design an adaptive forwarding waiting time determination mechanism:

$$T_r = T_d * (1 - \sigma_i) \quad (21)$$

This waiting time confirmation mechanism ensures that the optimal forwarding node forwards packets at the fastest speed. When the weight of the optimal forwarding node tends to the maximum value of 1, the T_r value tends to 0, indicating that this node fully meets the forwarding conditions. Therefore, the node hardly needs to wait and can directly forward packets. The waiting time of the suboptimal forwarding node will also be shorter than that of the slot persistence algorithm, that only depends on the confirmation of geographical location information, so it can effectively ensure the real-time performance of the forwarded packet. The dual guarantee of the optimal and suboptimal nodes can effectively improve the reliability of packet forwarding. Moreover, the optimal and suboptimal gradient waiting time settings can effectively avoid the collision of forwarded packets in competing channels.

D. Experimental Simulation of Routing Effect

In the simulation, the target road section with 80 vehicle nodes is set, and the contracting rate is 2 packet / s. Count the number of nodes receiving data packets at a specific time within the two-hop range, and calculate the corresponding coverage. It can be seen from the simulation results that the algorithm can achieve high area coverage in a very short time. With the increase in forwarding nodes, the network load index will increase and finally form a broadcast storm, resulting in serious network congestion. Therefore, it takes a long time to cover the road far enough effectively. The algorithm effectively suppresses the number of forwarding nodes, avoids the occurrence of a broadcast storm, and effectively improves the real-time performance of packet broadcasting.

The following Fig. 4 shows the comparison of experimental data:

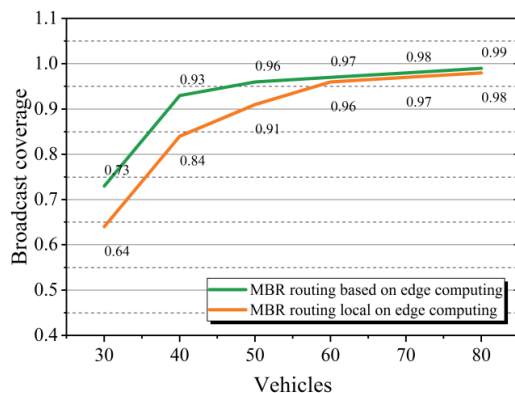


Fig. 4. Relationship between vehicle density and broadcast coverage.

As can be seen from the experimental data in Fig. 4, the real-time packet forwarding performance of the MBR routing algorithm based on edge computing is higher than that of the routing algorithm supported by local computing.

V. CONCLUSION

This paper constructs the measurement index of effective computing unloading mechanism, takes the delay and mobility as the key elements of the measurement index, discusses the reasonable allocation of weights, takes into account one-hop and two-hop vehicle nodes, and analyzes the impact of mobility in relative operation direction on link connectivity. In

the aspect of task unloading decision-making, this paper analyzes how the task vehicle selects the task unloading object from the service vehicle set and how to allocate the task. This paper expounds on the weighted calculation design of time delay and calculation cost, how to localize or unload the adaptive decision task to one-hop / two-hop vehicles, and carries out the corresponding experimental verification. Finally, it explains how the mobile vehicle network constructs the backbone link composed of intersection edge nodes and inner edge nodes, as well as the calculation method and simulation experiment of the weight of each section.

The experimental simulation shows that the average task execution time under this model is 65.4% shorter than that of local computing, 18.4% shorter than that of cloud computing, and the routing coverage is about 6% higher than that of local computing when there are less than 60 nodes. These research and experimental results fully demonstrate that the mobile Internet of vehicles based on edge computing has good reliable transmission characteristics. However, there are still shortcomings in the study of dense vehicle nodes in complex scenarios. Further in-depth analysis of unloading and routing mechanisms in various types of road scenarios is needed, and the idle computing power of stationary vehicle nodes has not been included in the task calculation application.

In addition, with the vigorous development of various applications, some studies consider using the advantages of the global perspective of software-defined network (SDN) to provide rich traffic conditions and network information for vehicles to reduce the control cost of the workshop; There are also attempts to introduce UAVs into the mobile vehicle network, rely on the mobile and high-altitude characteristics of UAVs to improve link connectivity and provide relay services.

With the increase in the number of intelligent networked vehicles and the popularization of application services, it will also be necessary to consider the scenario of multi-level tasks, meet the development trend of differentiated services in terms of delay, energy, and economic cost, and provide differentiated resource allocation for different service levels.

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REFERENCES

- [1] F. Yang, J. Li, T. Lei, & S. Wang. Architecture and key technologies for Internet of Vehicles: a survey[J]. Journal of Communications & Information Networks, 2017, 2(2), pp.1-17.
- [2] H. Peng, Q. Ye & X. S. Shen. SDN-based resource management for autonomous vehicular networks: A multi-access edge computing approach[J]. vol(18), 2019, IEEE Wirel. Commun.
- [3] J. Zhang, M. Ren, H. Labiod, and L. Khoukhi, Link duration prediction in VANETs via AdaBoost[C], IEEE Global Communications Conference, 2017, 86(2), pp. 1-6.
- [4] M. Al-Rabayahn & R. Malaney. A new scalable hybrid routing protocol for VANETs[J]. IEEE Trans. Veh. Technol., 2012, 61(6), pp.2625 – 2635.

- [5] Q. Ding, B. Sun & X. Zhang. A traffic-light-aware routing protocol based on street connectivity for urban vehicular ad hoc networks[J]. IEEE Commun. Lett., 2016, 20(8), pp.1635 – 1638.
- [6] R. Kaur, T. P. Singh and V. Khajuria, Security Issues in Vehicular Ad-Hoc Network (VANET)[C], 2018 2nd International Conference on Trends in Electronics and Informatics (ICOEI), 2018, pp.884-889.
- [7] Y. R. B. Al-Mayouf, N. F. Abdullah, O. A. Mahdi, S. Khan, M. Ismail, M. Guizani, & S. H. Ahmed. Real-time intersection-based segment aware routing algorithm for urban vehicular networks[J]. IEEE Trans. Intell. Transp. Syst, 2018, 19(7), pp.2125 – 2141.
- [8] M. H. Eiza, T. Owens & Q. Ni. Secure and Robust Multi-Constrained QoS Aware Routing Algorithm for VANETs[J]. IEEE Trans. Depend. Sec. Comput , 2016, 13(1) , pp.32 – 45.
- [9] L. LIU, C. CHEN, J. FENG, T. T. XIAO & Q. Q. PEI. A Survey of Computation Offloading in Vehicular Edge Computing Networks, ACTA ELECTRONICA SINICA[J], Vol. 49 No. 5, May 2021.
- [10] J. Zhang & K. B. Letaief. Mobile edge intelligence and computing for the Internet of vehicles [J]. Proceedings of the IEEE, 2020, 108 (2) , pp.246-261.
- [11] H. ZHAO, H. X. PENG, J. ZHU & D. Z. LI. Optimal Trunk Node Selection Based on Group-Based Acknowledgement Mechanism in Vehicular Networks[J], Journal of Northeastern University, Vo l. 34, No. 1 Jan. 2013.
- [12] Y. Ge, S. Wen, Y. H. Ang & Y. C. Liang . Optimal relay selection in IEEE 802. 16j multihop relay vehicular networks[J] . IEEE Transactions on Vehicular Technology, 2010, 59(5) , pp. 2198 -2206.
- [13] F. Samie, V. Tsoutsouras, L. Bauer, S. Xydis, D. Soudris & J. Henkel. Computation offloading and resource allocation for low-power IoT edge devices [C]// 2016 IEEE 3rd World Forum on Internet of Things (WF - IoT) . Reston, VA, USA, IEEE, 2016, pp.7-12.
- [14] Y. Liu, H. Yu, S. Xie & Y. Zhang. Deep reinforcement learning for offloading and resource allocation in vehicle edge computing and networks [J]. IEEE transactions on vehicular technology, 2019, 68 (11) , pp. 11158-11168.
- [15] X. Xu, Y. Xue, X. Li, L. Qi, & S. Wan. A computation offloading method for edge computing with vehicle- to- everything [J]. IEEE access, 2019, 7, pp.131068-131077.
- [16] X. Yang, X. Yu, H. Huang and H. Zhu, Energy Efficiency Based Joint Computation Offloading and Resource Allocation in Multi-Access MEC Systems[J], IEEE Access, 2019, 7, pp.117054-117062.
- [17] S. Wang, J. Xu, N. Zhang and Y. Liu, A Survey on Service Migration in Mobile Edge Computing[J], IEEE Access, 2018, 6, pp.23511-23528.
- [18] M. Singh and S. Kim, Security analysis of intelligent vehicles: Challenges and scope[C], 2017 International SoC Design Conference (ISOCC), 2017, pp. 13-14.
- [19] F. Zhang, T. Luo, & J. Li. A multi-hop broadcast routing based on real-time traffic estimates for vanet[D], 03, 2015.
- [20] J. Fan, L. Bin, and F. Chao, Mobile relay deployment in multi-hop relay networks[J], Computer Communications, 2017, 112(1), pp.14-21.

Design of Intrusion Detection System using Ensemble Learning Technique in Cloud Computing Environment

Rajesh Bingu*, S. Jothilakshmi

Research Scholar, Department of Information Technology, Annamalai University, Chidambaram, Tamil Nadu 608002-India

Abstract—The key advantage of the cloud is that it fluidly propagates to fulfil changeable requirements and provides an environment that is repeatable and can be scaled down instantly when needed. Therefore, it is necessary to protect this cloud environment from malicious attacks such as spamming, keylogging, Denial of Service (DoS), and Distributed Denial of Service (DDoS). Among these kinds of attacks, DDoS has the capability to establish a high flood of malicious attacks on the cloud environment or Software Defined Networking (SDN) based cloud environment. Hence in this work, an ensemble based deep learning technique is proposed to detect attacks in cloud and SDN based cloud environments. Here, the ensemble model is formed by combining K-means with deep learning classifiers such as Long Short term Memory (LSTM) network, Convolutional Neural Network (CNN), Recurrent Neural Network (RNN), Gated Recurrent Unit (GRU) and Deep Neural Network (DNN). Initially, preprocessing with data cleaning and standardization is applied to the input data. Meanwhile, a random forest is implemented for extracting the minimum significant features. After that, the proposed ensemble based approach is utilized for detecting the intrusion. This approach is used to enhance the performance of the deep learning classifiers without much computational complexity. This model is trained and evaluated using two datasets as CICIDS 2018 and SDN based DDOS attack datasets. The proposed approach provides better intrusion detection performance in terms of F1 measure, precision, accuracy, and recall. By using the proposed approach, the accuracy and precision value attained is 99.685 and 0.992, respectively.

Keywords—Cloud; distributed denial of service; intrusion detection; ensemble; recurrent neural network; convolutional neural network; random forest; gated recurrent unit; K-means clustering; long short term memory

I. INTRODUCTION

Cloud Computing (CC) is a different kind of Internet-based infrastructure for providing Information Technology and various resources such as storage services, hardware equipment, operating system, network infrastructure, and entire software applications to users at low cost [1]. It has the advantage of scalability, higher cost efficiency, faster development, and minimal management effort [2]. The introduction of the cloud is a watershed moment in technological advancement for quick information processing. When a new computing system is introduced, scholars and researchers are concerned about its protection. Securing information processing across any information system has

become critical to a knowledge acquisition system's success. Always CC or grid computing enables rapid and location-independent information processing. Because of the location-independent processing, the trust is a major issue among Cloud users when using their resources is a major issue [3], [4].

The complex architecture of CC is vulnerable to several kinds of attacks. Compared to a single Intrusion Detection System (IDS), the detection accuracy is improved with a cooperative IDS system. It is due to limited knowledge of attack patterns or implications [5]. The only solution to this type of threat is the development of effective IDS [6]. The approaches of attack detection by the IDS are of two types, they are signature based and behavior based. Out of these two approaches, the most traditional way of discriminating the normal traffic the malicious traffic is signature based. This approach is capable of achieving higher accuracy, but it is prone to a new type of attack [7], [8].

But the behavior-based IDS achieves better results for a new type of malicious attacks. Hence, the behavior-based IDS performs well when compared to signature-based IDS in terms of detection rate and seems to be the most preferable for deployment [9]. Moreover, the classification of the IDS can also be made based on the location of its deployment, and it is two types they are host based and network based [10]. The host based IDS (HIDS) is installed in the space which is nearer to the host in order to capture the intruders, whereas the network-based IDS (NIDS) tends to capture the intruders at the network level [11]. Nowadays, most cloud space is associated with software defined technology to empower its accessibility and reliability for all application services. In this regard, this hybrid environment creates more chances of launching a high flood of malicious attacks [12].

The anomaly based IDS detects the deviation by analyzing the current system with a predefined normal profile. But it is affected by the issue of false alarms in real world implementation [13]. The hybrid IDS provides protection by combining both anomalies based and signature based detection. It is resolved with the issue of intelligent false alarm technique by involving adaptive algorithms [14]. The performance enhancement of IDS is challenged by considering the features such as access independence, elasticity, sufficient computing power, and scalability. In a distributed system, several applications require shorter response times, and it might require large quantity for heavy

load networks [15]. Due to the delay, these applications are not sufficient to support the applications of CC. In recent years, machine learning (ML) has been used in various fields to resolve issues related to high false alarms and low detection rates [16].

An extreme learning machine (ELM) is a new ML that falls into local minima, and the training is extremely fast. Better scalability and generalization in the learning process are obtained with Support Vector Machine [17]. It is used in several areas for resolving classification and regression problems. To get an optimal representation of the input data, deep learning based approaches such as RNN, Artificial Neural Networks (ANN), Deep Belief network (DBN), Deep Boltzmann Machines (DBM), and Autoencoder are commonly used [18]. The performances of this algorithm are further enhanced with the hybrid combination of AlexNet, FractalNet, GoogLeNet, Visual Geometry Group (VGG), and Dense CNN [19], [20]. Based on the position and orientation of the input data, the classification process is hard, and the performance is varied for each network based on the input data. In order to select the optimal deep learning classifier, the ensemble based architecture is proposed. It contains several DNN classifiers in which the better result is taken into consideration. Hence it's right to design an intrusion detection framework for SDN based cloud platforms. To accomplish this task, in this research work, the proposed DL model has been trained and evaluated using two kinds of dataset, i.e., the first dataset is cloud based attack, and the second Dataset is SDN based cloud DDoS attack.

1) *Research gap:* Most of the prior researches particularly focused on machine or deep learning based approaches and the architecture based on its application. Most of them are based on systematic mapping for providing meaningful and comprehensive research. To the best of our knowledge, there are no researches based on the feasibility of utilizing ensemble learning. In addition to that, no researches include the comparison of the classifiers used in ensemble based technique through systematic mapping. None of the researches consider intrusion detection based on attack type, evaluation metric, and dataset characteristics, and strength and weakness of deep learning approaches. The proposed approach is developed with the consideration of above mentioned research gaps.

The overall contribution of the work can be described as listed below.

- Removing inconsistent or missing values to make the data easier to process. For the traffic instance of the dataset, data pre-processing techniques such as standardization and data cleaning have been applied.
- Extracting the minimal set of discriminative features from the pre-processed data using a random forest algorithm. The complexity and storage space are reduced with a minimal set of discriminative features.
- Clustering the dataset with the K-means algorithm eliminate incorrect detection.

- Classifying the traffic clusters as benign and malicious using the proposed ensemble based deep learning approach. Also, performing multi label classification with these clusters for efficient feature identification. The accuracy is improved with optimal selection of deep learning approach.
- Comparative analysis of the five deep learning classifiers has been done using various performance metrics such as accuracy, precision, recall and F1-measure.

The paper organization is given as follows. Section II describes the related work, and Section III describes the proposed methodology. The experimental results of the proposed intrusion detection are given in Section IV. Section V describes the significant aspects of the proposed methodology and conclusion.

II. RELATED WORK

The work related to the proposed intrusion detection system is described as follows.

Loheswaran Karuppusamy et al. [21] had proposed a Chronological Salp Swarm Algorithm-based Deep Belief Network (CSSA-DBN) for detecting intrusion into a cloud environment. The optimal solution was obtained with the fitness, which accepts a minimum error value for providing better performance. The accuracy, sensitivity, and specificity obtained with the CSSA-DBN approaches are 0.9618%, 0.9702%, and 0.9307%, respectively.

Idhammad et al. [22] proposed an ensemble classifier-based intrusion detection model is ideally suited for the cloud environment. The model used in this work was trained and assessed using the CICIDS-001 dataset, and it is currently running on the Google Cloud platform. Here, Naive Bayes and the random forest method are used to build the ensemble classifier. This system took 0.23 seconds to run and had an average accuracy of 97% and a false positive rate of 0.2%. Jaber et al. [23] developed with ensemble classifiers that are made up of fuzzy c-means clustering and SVM classifiers. The hybrid algorithm FCM-SVM was evaluated with NSL-KDD Dataset for detecting anomalies with higher accuracy.

S. Krishnaveni et al. [24] recommended a univariate ensemble feature selection method to find an appropriate reduced feature set from an incursion dataset. To create robust classifiers using a voting mechanism, single classifiers were fused. With performance indicators like FAR and ROC, this technique performed admirably enough. Nguyen et al. [25] proposed a security framework for SDN enabled cloud environment by combining the intrusion detection model based on three different nodes such as edge, fog and cloud. By developing policies, a collaborative and network intelligent architecture is created for anomaly detection. Better anomaly detection performance in SDN-based cloud IoT networks helped to reduce the bottleneck issue.

Using the Ant Lion optimization strategy, T. Thilagam et al. [26] proposed an improved Recurrent Convolutional Neural Network (RCNN) for intrusion detection. With a classification accuracy and a small error rate are 94% and

0.0012, network layer threats are well categorized. Smitha Rajagopal et al. [27] had developed a Meta classification technique with binary and multi-label classification. Robustness has been improved with an optimal set of hyperparameters and discriminative features of Azure machine learning. The efficiency of the approaches was validated, and an accuracy of 99.8% was achieved for the UNSW NB-15 dataset.

Abusitta et al. [28] proposed a cooperative intrusion detection framework for the cloud environment, and it was designed using a stacked autoencoder and multilayer perceptron. The decision making was enabled with an aggregation algorithm, in which the detection accuracy was achieved by up to 95%. Ammar Aldallal et al. [29] developed SVM with GA and fitness for evaluating accuracy. SVM was deployed with varying hyperparameters such as kernel, degree, and gamma. In cloud computing, a high level of symmetry was reached between attack detection, information security, and the discovery of bad things.

Mayuranathan et al. [30] proposed an effective intrusion detection model based on RHM-RBM. Here the author utilized Random Harmony Search (RHS) optimization model for feature selection and Restricted Boltzmann Machines (RBM) for classification purposes to yield better results. The security issues related to the network layer have been resolved with enhanced detection accuracy and low computational complexity.

At the end of the survey analysis, it can conclude that most of the existing solution does not rely on the ensemble-based approach using a deep learning algorithm to enhance its efficiency without much computational complexity. Hence in this work, an ensemble based deep learning technique has been deployed. To achieve this, clustering followed by a classification task has been carried out. By doing so, the unsupervised technique (clustering) collaborates with the supervised technique (classification). A convolutional neural network and the K-means clustering procedure are used to carry out this strategy. Convolutional neural networks (CNN) and the other four deep learning algorithms (DNN, RNN, GRU, and LSTM) are evaluated in terms of performance.

III. PROPOSED METHODOLOGY

In Fig. 1, the components involved in the proposed model have been elucidated, and its data flow can also be visualized. The modules involved in the proposed model are the data pre-processing layer, feature extraction layer, clustering process and classification. Each module has been explained in the following subsection

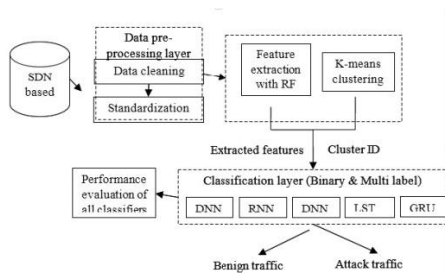


Fig. 1. Overall architecture of the proposed intrusion detection system.

A. Data Pre-Processing

In the data pre-processing layer, the instances of the two datasets are manipulated accordingly to ease the classification process. These instances have undergone two pre-processing techniques, such as data cleaning and standardization.

1) *Data cleaning*: In the CICIDS-2018 Dataset, some columns with infinity values were stripped away, including ‘Dst Port’, ‘Timestamp’, ‘Bwd PSH Flags’, ‘Fwd PSH Flags’, ‘FlowByts/s’, ‘Bwd URG Flags’, ‘Fwd URG Flags’ and ‘Flow Pkts/s’. Two protocol columns have been used instead of feature protocol for binary classification. They are named Protocol 17 and Protocol 6 by implying the feature in a categorical type. The ‘protocol’ column has been used without alteration for the multiclass classification. Likewise, for the SDN DDoS dataset, the null values are removed for all the features.

2) *Standardization*: To get a normal distribution with a mean of zero and a standard deviation of one, standardized measures are applied to each input variable independently by subtracting the mean and dividing by the standard deviation. In standardization, the values are scaled in column wise manner using the standard scalar format. This process facilitates the classification process, which is easily performed using deep learning.

B. Feature Reduction

The random forest algorithm has been utilized for feature extraction in this work. Random forest is an effective unsupervised machine learning technique that falls within the area of embedded methods. For the predictor variable, the subset is chosen for dividing the internal node based on predetermined constraints, considered an optimization issue. The classification is based on entropy, which specifies the lower bound of the random variable. The entropy is computed as follows for each internal node of the decision tree.

$$F = -\sum_{j=1}^d q_j \times \log(q_j) \quad (1)$$

Where, d represents the amount of unique classes and the prior probability for the class is represented as q_j . This value is increased to obtain more information in each decision tree split.

The embedded method combines both the quality of the filter and wrapper method. Furthermore, it can be used for classification and feature extraction. So Random Forest inherently has a built-in feature selection approach. Since it is well suited for feature selection, a Random forest has been used for the feature selection task. The reduced features of the SDN based dataset can be listed as dt, bytecount, packetins, pktperflow, byteperflow, pktrate and Protocol. In CICIDS 2018 dataset, the features are reduced, and it can be elucidated as ‘Fwd Seg Size Min’, ‘SubflowBwd Pkts’, ‘Tot Bwd Pkts’, ‘Fwd Pkt Len Std’, ‘Flow IAT Mean’, ‘Init Fwd Win Byts’, ‘Bwd Pkt Len Max’, ‘URG Flag Cnt’, ‘FIN Flag Cnt’, ‘Bwd Pkt Len Std’, ‘Pkt Size Avg’ and ‘RST Flag Cnt’. Fig. 2 and Fig. 3 show the robust feature set of the SDN based dataset

and cloud dataset correspondingly. Here, random forest is evaluated with 5-fold cross validation to extract some meaningful features from the two datasets separately.

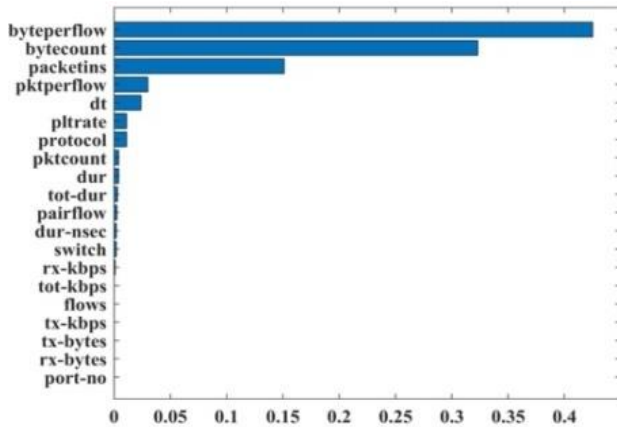


Fig. 2. Significant feature in SDN dataset by random forest.

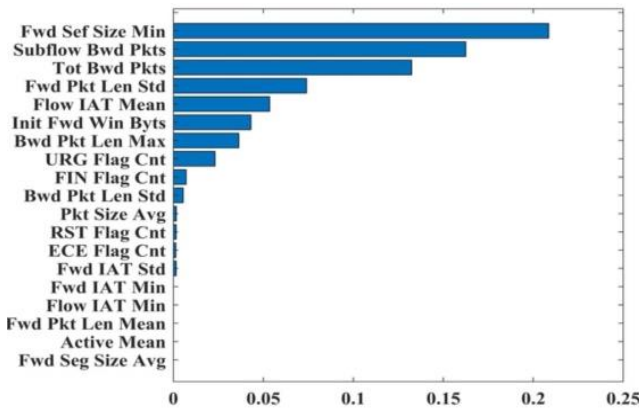


Fig. 3. Significant feature in CICIDS 2018 dataset by random forest.

C. Clustering Layer

The process of clustering is to group the instances given in the dataset into many clusters. This process assigns each instance a unique cluster ID. This was done based on a pattern extracted by the K-means clustering algorithm. Therefore, along with the reduced features yielded by the random forest, the Cluster id was also given to the Deep learning classifiers to improve its performance. The working principle of the K-means clustering process is given below:

1) *K-means clustering algorithm*: K-means clustering always work in an unsupervised manner by grouping the instances in the dataset without a label for the training and testing process. Based on the predefined value, the number of clusters is generated by this clustering algorithm. This algorithm forms the clusters based on their centroid value. The main goal of the clustering algorithm is to shorten the distance between the data instances and the groups to which they belong. This step is repeated continuously until the algorithm finds the better clusters. At the end of the process, ‘K’ number of clusters has been obtained, whereas k is a predetermined value. The procedure of the K-means algorithm is given as follows.

Algorithm 1: K-means clustering

Step 1: Specify the number of clusters k .

Step 2: Assign k centroids randomly.

Step 3: repeat, until the position is not varied.

Step 3.1: Closet centroid is assigned with each point.

Step 3.2: For each cluster, a new centroid is computed with mean value.

D. Classification Layer

At this level, the reduced features, as well as the cluster ID were given as input for the classification process. To classify the normal traffic instances from the malicious traffic instances, five deep learning techniques were implemented separately for this task. These five deep learning were analyzed comparatively for both binary and multiclass classification. To perform binary classification, SDN Dataset was used for training and testing purposes, while CICIDS 2018 was used for the same purpose for multiclass classification. A detailed explanation for these five DL classifiers is given in the following sub-sections.

1) *Convolutional Neural Network (CNN)*: Convolutional Neural Network is also known as Convnets and is mainly used for image processing and object detection purposes. This CNN has several layers the process goes through to get the desired output. The architecture of CNN consists of many layers, namely Convolution Layer, Rectified Linear Unit, Pooling Layer, and Fully Connected Layer. The input goes through all of these layers, each of which contains a variety of operators and filters to get the right output.

The convolution layers are interpreted with the sub-sampling layers to minimize the computation time. In the convolution layer, the feature map from the previous layer is mixed with kernels that can be provided, and the resulting feature map is sent to the activation function. The convolution is combined with multiple feature maps in each output map. In general, it is represented as,

$$y_k^u = g \left(\sum_{j \in N_k} y_k^{m-1} * l_{j,k}^m + c_k^m \right) \quad (2)$$

Where, N_k is the input map selection which includes the pair of all triplets. For each output map additive bias of C is added. The input is convolved with various kernels for each output map. If the output map k and l are integrated with the output map j . Then the kernel is applied to various output maps k and l .

2) *Deep Neural Network (DNN)*: An artificial neural network (ANN) with numerous hidden layers between the input and output layers is called a deep neural network (DNN). DNNs may simulate complex non-linear interactions just like shallow ANNs. This particular kind of neural network consists of an input, an output, and a deep network of sequential data flow. In order to solve practical problems like

categorization, neural networks take in data, run it through complex calculations, and then output the results.

DNN has several fully connected layers in which nodes of each layer are connected with each node of the previous layer. The DNN is a linear combination of independent variables with corresponding weights and bias terms. The DNN output computation is represented as,

$$A = c + x_1 y_1 + x_2 y_2 \dots + x_p y_p \quad (3)$$

Where, x represents the weights or beta coefficients and y represents the input or independent variable. The loss or error term is computed to find the deviation from actual and predicted values. It has the objective of minimizing the loss function in order to achieve an optimal error term. Based on the previous layer computation, the output is estimated as follows:

$$A = x_{i_0}^T * i_2 + c_{i_0} \quad (4)$$

Where, x_{i_0} is the weight matrix between two layers, C is the bias, and T represents the transpose. After estimating the output, it passes through the activation function for computing the node value. The output error is estimated, and the error is minimized with the optimal weight value.

3) *Recurrent Neural Network (RNN)*: Recurrent neural networks (RNNs) are artificial neural networks where nodes' connections can cycle, allowing output from one node to control how input to that node is processed. The term "recurrent neural network" refers to a group of networks that have an infinite impulse response. Common uses of RNNs include natural language processing, time series analysis, handwriting recognition, machine translation, and photo captioning. RNNs are capable of handling inputs of any length. In contrast to infinite impulse recurrent networks, finite impulse recurrent networks can be unrolled and substituted with tight feedforward neural networks.

In a RNN, the output of a certain layer is fed into the input of the layer before it to predict the output layer. A single RNN layer is created by combining the nodes of several NN layers. The input layer is represented with y , the output layer is represented with Z , and i represents the hidden layer. The output of the model is increased with the network parameters. For the given duration u , the input is estimated with the integration of $y(u)$ and $y(u-1)$. The output of each state is represented as,

$$i(u) = g_d(i(u-1), y(u)) \quad (5)$$

Where, $i(u)$ represents the new state, $i(u-1)$ represents the old state, g_d represents the function with parameter d , and $y(u)$ is the input vector with time u .

4) *Long Short-Term Memory (LSTM)*: It is a kind of RNN that can recall and learn long-term dependencies. Due to their ability to remember past inputs, they are also utilized in time series prediction. They communicate in an original fashion thanks to their chain-like arrangements with four interacting levels. These are employed for purposes other than only time series prediction. Additionally, they are employed in medicinal research, music composition, and voice recognition. It is connected in such a way that directed cycles are formed, and it permits the LSTM output to be used as the input of the current layer. It can also recall previous inputs due to its internal memory.

LSTM is modelled to avoid long term dependencies, and it has three parts. The first eliminates irrelevant information, the second updates or adds new information, and the third pass the updated information. In LSTM, it initially decides to keep the information obtained from the previous step or not. The forget gate equation is represented as follows.

$$f_u = \sigma(y_u * v_g + i_{u-1} * x_g) \quad (6)$$

Where, y_i represent the current timestamp of the input, i_{u-1} represent the hidden state of the previous timestamp, v_g denotes the weight of the input, and x_g is the weight matrix of the hidden state. The sigmoid function is applied to make the forget gate between 0 and 1. Then it is multiplied by the timestamp of the previous layer.

$$d_{u-1} * g_u = 0 \text{ if } f_u = 0 \quad (7)$$

$$d_{u-1} * g_u = d_{u-1} \text{ if } g_u = 1 \quad (8)$$

The significance of new information is quantified with the input gate, and the equation is denoted as,

$$i_u = \sigma(y_u * v_u + i_{u-1} * x_j) \quad (9)$$

Where, y_i represents the input of the current timestamp, v_u represents the weight, and x_j represents the hidden state. The output of the current timestamp is estimated using the activation function of softmax.

$$z = \text{softmax}(i_u) \quad (10)$$

Where, i_u represents the hidden state.

5) *Gated Recurrent Unit (GRU)*: In order to overcome the vanishing exploding gradient problem faced by the Recurrent neural network, many variants of RNN have started to occur. Out of those findings, the GRU(gated recurrent unit), a variant of RNN architecture, has seemed to perform well. The architecture of GRU comprised three gates without any internal cell state. Instead of an internal cell state present in the LSTM architecture has been replaced by a hidden cell state

in the architecture of GRU. The gates used in this architecture can be listed as Update Gate, Reset Gate and Current Memory Gate.

The input of GRU is represented as y_t , a previous timestamp $u - 1$, and the hidden state is represented as i_{u-1} . The new hidden state is the output of the next timestamp; and it contains two gates, namely the reset gate and the update gate. The reset gate is considered a hidden state i_u . The equation for the reset gate is represented as follows.

$$s = \sigma(y * v + i * x) \quad (11)$$

Where, v , x represents the weight, y represents the input. By using the sigmoid function, the values of s is converted within the range between 0 and 1. The update gate is similar to the reset gate, only the weight matrix is varied. To estimate the hidden state i_u , the two state processes are used. Initially, the candidate's hidden state is estimated with the following equations.

$$\hat{i}_u = \tanh(y_u * v_h + (s_u * i_{u-1}) * x_h) \quad (12)$$

The input is taken from the hidden and previous timestamp and multiplied by the output of the reset gate. The overall information is passed through the activation function tanh; the resultant value is the candidate's hidden state. The GRU network is accurate in a longer sequence dataset. The information in GRU is transferred through the cell state and hidden state.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The Python 3.6 software environment was utilized to create the deep learning model and the intrusion detection system based on clustering method for this experiment. Python was installed over the Windows 10 operating system, which is on the laptop and has 2GB ram and 1TB hard disk memory with a 2GHz i3 processor. Initially, the input data is pre-processed with data cleaning and standardization. In data cleaning, the corrupted, incorrectly formatted, incomplete, incorrect, or duplicate data are eliminated within the dataset. Then the data is converted into a simplified format to simplify the intrusion detection process. The features are extracted with 5-fold cross validation of the random forest algorithm. On the other hand, data is grouped into clusters, and each instance is assigned a unique cluster ID. The extracted features and the cluster ID is given to the input of the ensemble classifier. In the proposed algorithms, the parameters are included based on the existing results. In the existing papers, these parameters provide better performance than assigning other parameter. Hence, the parameters are selected for enhancing the intrusion detection performance. By using this parameter optimal level of intrusion detection was attained with the proposed ensemble based approach. Table I provides a description of the implementation parameters used in the suggested technique.

TABLE I. PARAMETERS OF DEEP LEARNING TECHNIQUES

Parameters	Value
Number of clusters	4
Batch Size	Binary:2500, Multilabel:5000
Loss Function	Binary: Binary_crossentropy Multi-label: Categorical_crossentropy
Activation	ReLU
Epoch	150
Verbose	0
Metric	Accuracy
Optimizer	Adam
Epoch	Binary:15 Multilabel:10

A. Dataset Description

1) *SDN based dataset*: This dataset was designed to generate a DDoS attack by the mininet simulator in order to replicate the Software defined networking environment [15]. Here the network traffic was collected at the switch setup in the environment. The instances given in the dataset were broadly classified into two categories: benign and malicious. Hence the benign instances were labelled as 0, whereas the malicious instances were labelled as 1. SDN based datasets are used to train and evaluate the proposed model for binary classification.

2) *CIC IDS 2018*: This is one of the datasets used to train and evaluate the proposed model, which is extracted from the official website [16], and it is simulated in the real time cloud environment to capture cloud based attacks. This dataset is utilized here to perform a multiclass classification of cloud attacks using an ensemble based approach. It has 2830540 instances and 83 attributes. Among these 83 attributes, 80 attributes are utilized for feature extraction procedure.

The benign instances in the dataset were labelled as 0, and bot attack instances were labelled as 1. Likewise, the instances of DoS attacks-SlowHTTPTest, and DoS attacks-Hulk were labelled as 2 and 3, respectively. Table II elucidates the sample distribution of benign and attack instances used for training and testing purposes.

TABLE II. SAMPLES DISTRIBUTION FOR DL MODELS

Type	SDN based DDoS attack dataset (Binary classification)		CIC IDS 2018 dataset (Multi-label classification)	
	Training	Testing	Training	Testing
Benign	25496	10902	646603	161601
Attack	20404	8735	86811	21709
DoS attacks-SlowHTTPTest			34	7
DoS attacks-Hulk.			87117	21811

B. Performance Metrics

In this sub-section, the performance of both binary as well as multi-label classification done by the five classifiers was evaluated and discussed using the below given metrics:

Accuracy: It estimates the classifier performance in overall, which is computed as follows.

$$A_c = \frac{TN + TP}{TN + FN + TP + FP} \quad (13)$$

Where, *TP* represents the true positive, *FP* represents the false positive, *TN* represents the true negative, and *FN* represents the false negative.

3) *Precision:* It represents the capacity of the classification models to classify the significant models of the data set. It is calculated using the ratio of expected positives from all samples. Precision is denoted as follows.

$$P_r = \frac{TP}{FP + TP} \quad (14)$$

4) *Recall:* It represents the capacity of the classification technique for categorizing essential data points in the dataset. It is measured as the ratio of positives from the whole set of positive samples. Recall R_c can be computed as

$$R_c = \frac{TP}{FN + TP} \quad (15)$$

5) *F-measure:* It uses the mean value to combine the result of precision and recall. F-measure F_m is measured as,

$$F_m = \frac{2}{1/P_r + 1/R_c} \quad (16)$$

6) *Receiver operator characteristic curve:* ROC curves are a useful visual tool for comparing different classifiers. It describes the trade-offs that could be made between a false positive rate (FPR) and a true positive rate (TPR). The model's ROC curve accuracy is evaluated using the Area Under the Curve (AUC).

Where the performance monitors used in the above-mentioned equations can be defined as

- **TP (True Positive):** It is defined as the count of the attack instances successfully predicted as an attack by the classifier.
- **TN (True Negative):** It is defined as the count of the benign instances successfully predicted as benign by the classifier.
- **FP (False Positive):** It is defined as the count of the benign instances wrongly predicted as an attack by the classifier.
- **FN (False negative):** It is defined as the count of the attack instances wrongly predicted as benign by the classifier.

In Table III, the values of the performance metrics for the binary classification have been enumerated. In this table, each classifier is implemented with and without clustering separately. The clustering process is carried out using the K-means algorithm. By observing the values for the five classifiers, it shows that the accuracy value without K-means ranges from ~72% to ~77%. But with K-means implementation for the five classifiers achieves better results for accuracy; it ranges from ~93% to ~99%. Hence it is clearly shown that the binary classification, the implementation of the ensemble approach, performs better than the standalone DL architecture. Out of those five DL classifiers, CNN performs well than the others. In the same way, Table III explores the performance analysis of multi-label classification. Unlike binary classification, the results of the standalone DL algorithm and the ensemble approach show only a minimal gap. Both models yield good results for multi-label classification. In this classification, DNN performs better than all four DL classifiers.

TABLE III. PERFORMANCE ANALYSIS OF BINARY AND MULTI-LABEL CLASSIFICATION

Algorithm Used	Binary classification				Multi-label classification			
	Accuracy	Precision	Recall	F1-measure	Accuracy	Precision	Recall	F1-measure
K-Means+CNN	99.685	0.992	0.999	0.995	99.685	0.996	0.996	0.996
CNN	77.911	0.799	0.574	0.668	97.906	0.979	0.979	0.978
K-Means+DNN	99.178	0.980	0.998	0.989	99.735	0.997	0.997	0.997
DNN	77.821	0.780	0.596	0.676	97.244	0.972	0.972	0.971
K-Means+RNN	93.262	0.894	0.936	0.915	99.649	0.996	0.996	0.996
RNN	72.162	0.606	0.802	0.691	94.111	0.790	0.996	0.856
K-Means+LSTM	96.128	0.943	0.958	0.950	99.671	0.996	0.996	0.996
LSTM	75.853	0.890	0.430	0.580	90.076	0.895	0.900	0.895
K-Means+GRU	95.602	0.908	0.986	0.945	99.712	0.997	0.997	0.997
GRU	73.767	0.636	0.756	0.691	97.135	0.973	0.971	0.972

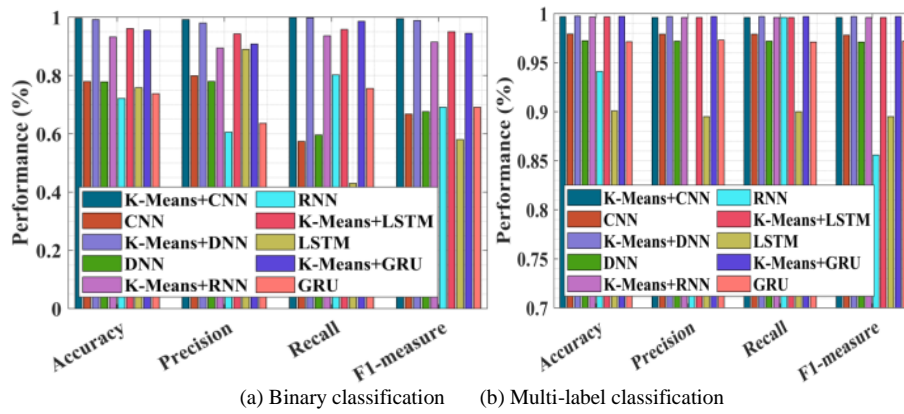


Fig. 4. Comparison of accuracy, precision, recall, and F1-measure with different voting techniques.

The suggested ensemble-based strategy for binary and multi-label classification is compared in Fig. 4 for both cases. It is evaluated in terms of accuracy, F-measure, recall, and precision. For binary classification, better performance is obtained using the K-means+CNN approach. The accuracy, precision, recall, and F1-measure obtained with K-means+CNN approach are 99.685, 0.992, 0.999, and 0.995, respectively. Compared to other deep learning-based approaches, K-means+DNN performs better on multilabel-based classification. K-means with deep learning approaches provide better performance than only deep learning based approaches. If the clustering is not performed for the proposed approach, the performance is lower than 0.8.

Fig. 5 compares the accuracy and loss for the CNN and K-means+CNN techniques. The accuracy improves and the loss decreases as the number of epochs rises. The accuracy of validation is greater than that of training. The optimal value of accuracy is reached with the epoch between 10 and 15. The lower loss value is reached with a higher epoch that is nearer

to 15. The accuracy and loss comparison with DNN and K-means+DNN for binary classification is shown in Fig. 6. Increased accuracy and decreased loss result from more approaches. The optimal accuracy is obtained with the number of epochs 14. When the number of epochs reaches 3, the accuracy rate crosses the value of 0.9. The accuracy below 0.75 is reached, and the loss value is higher up to the number of epochs is 3. When it goes beyond 3, there is a gradual decrease in loss, and the smooth curve is obtained up to 14 epochs.

The accuracy and loss comparison for GRU and K-means+GRU is shown in Fig. 7. There is a gradual increase in accuracy value from 1 to 5 epochs. After 5, the accuracy deviation is low, and it isn't very important. For the GRU approach, this deviation is higher up to 14 epochs. The training accuracy is lower than the validation accuracy in all aspects. When the numbers of epochs are 3, the loss is higher than 0.5 and 0.15 for the validation set and training set of the K-means+GRU approach.

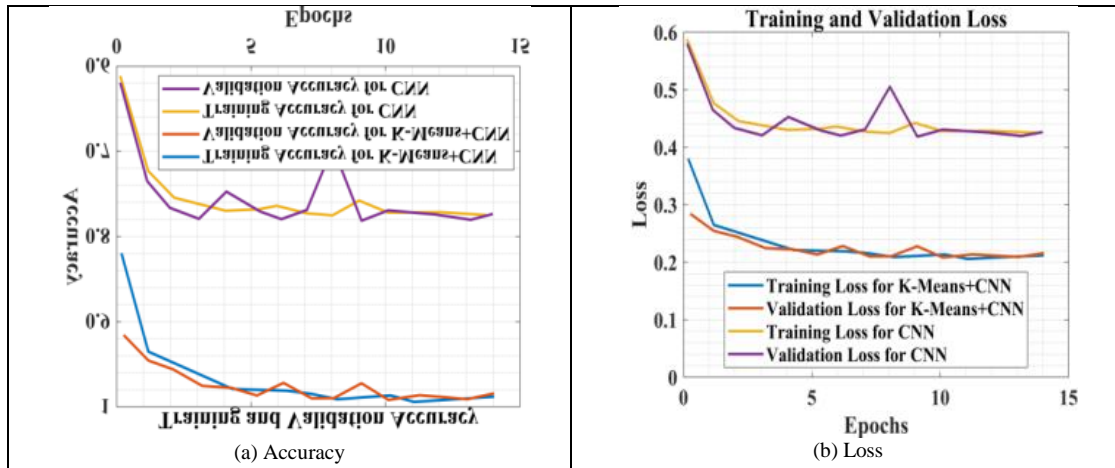


Fig. 5. Accuracy and loss comparison for training and validation set of CNN, and K-means+CNN (Binary Classification).

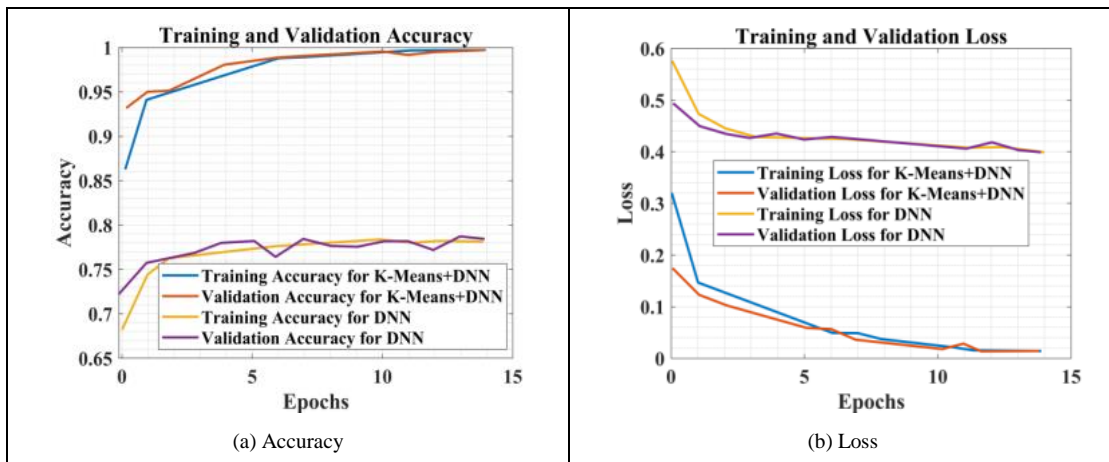


Fig. 6. Accuracy and loss comparison for training and validation set of DNN and K-means+DNN (binary classification).

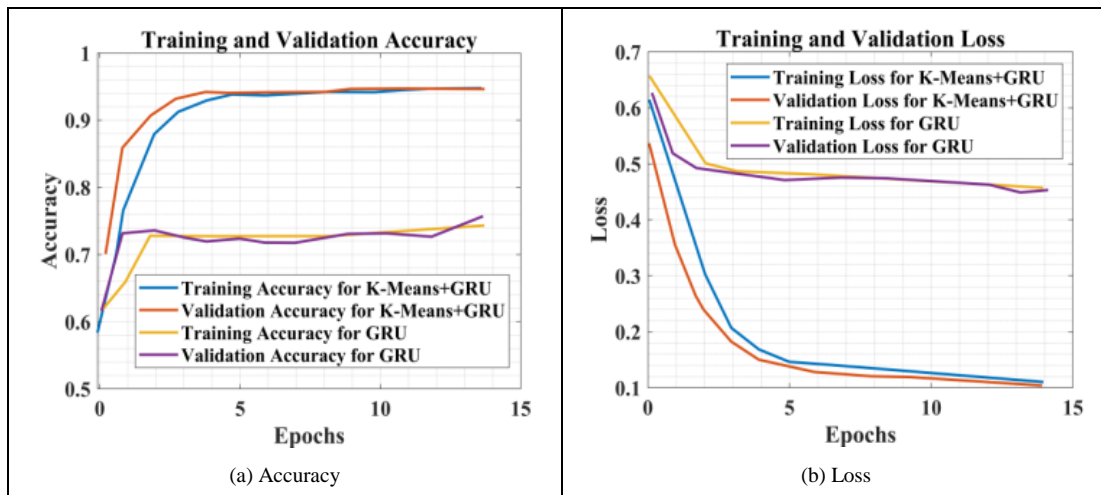


Fig. 7. Accuracy and loss comparison for training and validation set of GRU and K-means+GRU (binary classification)

The accuracy and loss comparison for K-means+LSTM and LSTM approaches are shown in Fig. 8. There is a fluctuation in the accuracy value as the number of epochs is increased in the LSTM approach. The accuracy is above 0.9

for most epochs in the training and validation set of K-means+LSTM approaches. The accuracy loss is higher than 0.5 for LSTM and K-means+LSTM with fewer epochs. The lower loss is reached with the number of epochs 14.

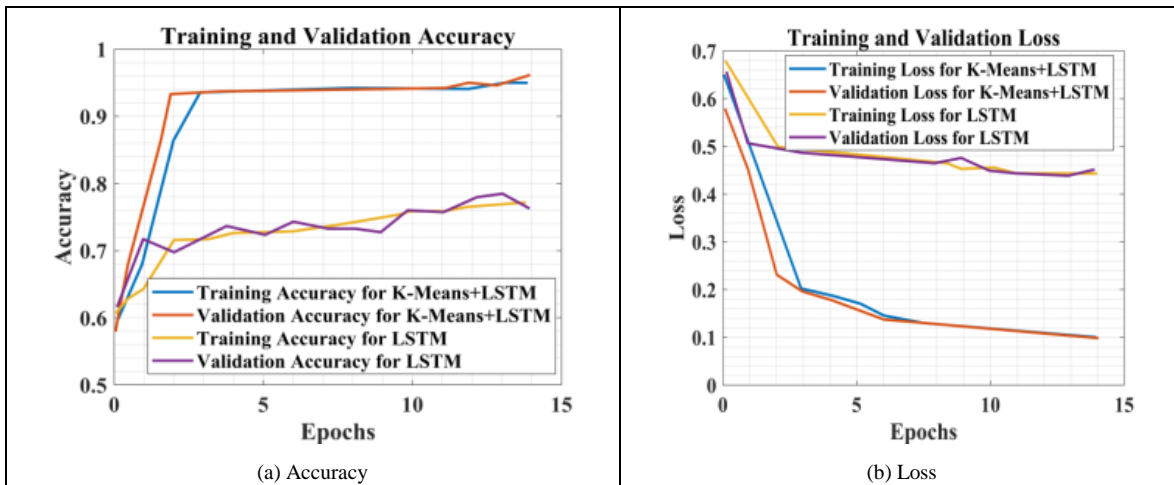


Fig. 8. Accuracy and loss comparison for training and validation set of LSTM, and K-means+LSTM (binary classification).

The performance evaluation of RNN and K-means+RNN for binary classification is shown in Fig. 9. The K-means+RNN and the validation set provide better performance than only RNN and the training set. When the number of the epoch is 3, k-means+ RNN and RNN approaches interfere with each other. When the number of epochs is decreased, the variation in loss for the training and validation sets is also decreased. When the number of epochs is decreased, the loss deviation for training and validation is also decreased. The training and validation loss is less than 0.5 for the K-means+RNN approach. For only the RNN approach, the training and validation loss is less than 0.3.

The accuracy and loss comparison for the multi-label classification of K-means+CNN is shown in Fig. 10. For all epochs, the validation accuracy is higher and nearer to 1. But, for the training set, the accuracy is lower with a reduced number of epochs. The accuracy value is between 0.85 and 0.9 for the CNN approach of the training and validation set. It is

increased to the level between 0.95 and 0.99 for the numbers of epochs are 8. The loss value is lower for the validation set of the K-means+CNN approach. For the training set, it is higher with lower epochs. For lower epochs, the loss value is between 0.5 and 0.6. The loss is reduced to 0.1 for the number of epochs between 8 and 10.

The accuracy and loss comparison for the DNN and K-means+DNN approaches is shown in Fig. 11. The accuracy value is higher with the validation set of K-means+DNN approaches. The training accuracy is lower than the validation set. The higher value is reached with the number of the epoch is 4, and the value remains the same up to 10 epochs. K-means+DNN has a lower training and validation loss than the DNN-based method. The loss is decreased when the number of epochs is increased. The loss value of GRU and K-means+GRU is compared for the training and validation set. The loss is decreased with an increasing number of epochs.

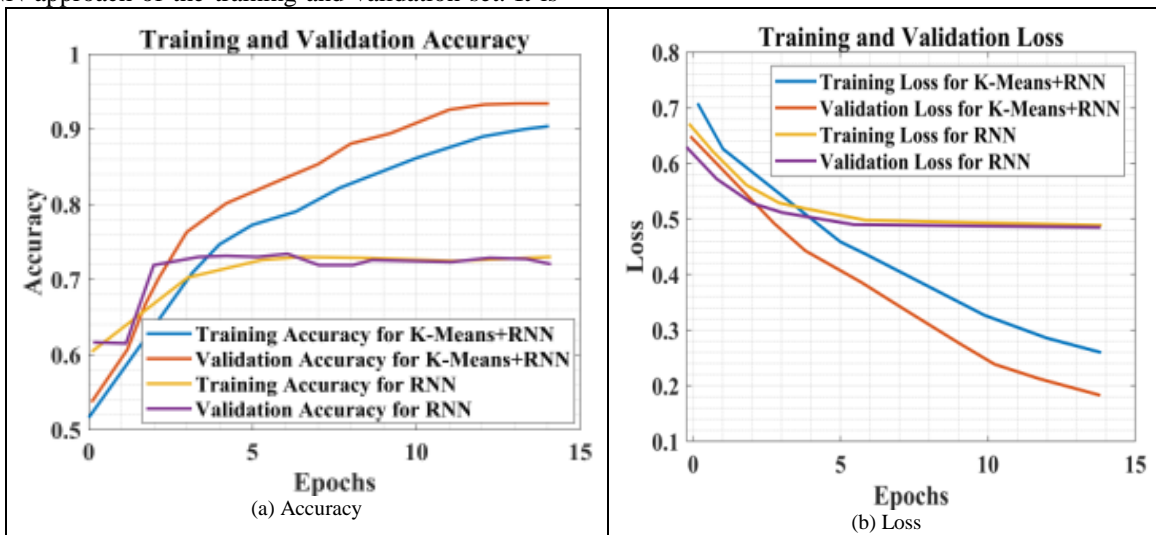


Fig. 9. Accuracy and loss comparison for training and validation set of RNN and K-means+RNN (binary classification).

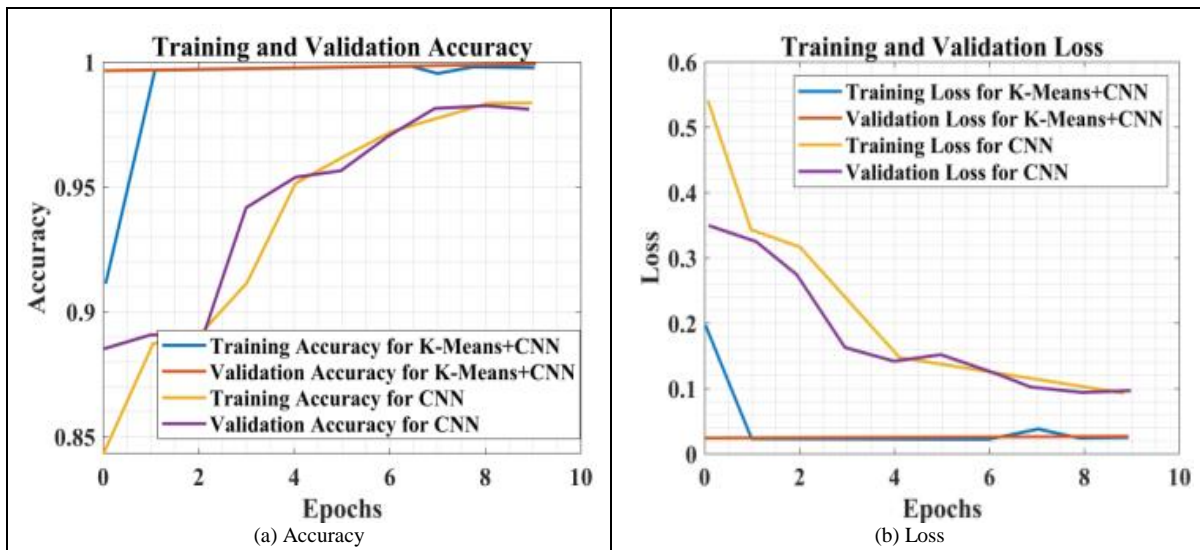


Fig. 10. Accuracy and loss comparison for training and validation set of CNN, and K-means+CNN (multi-label classification).

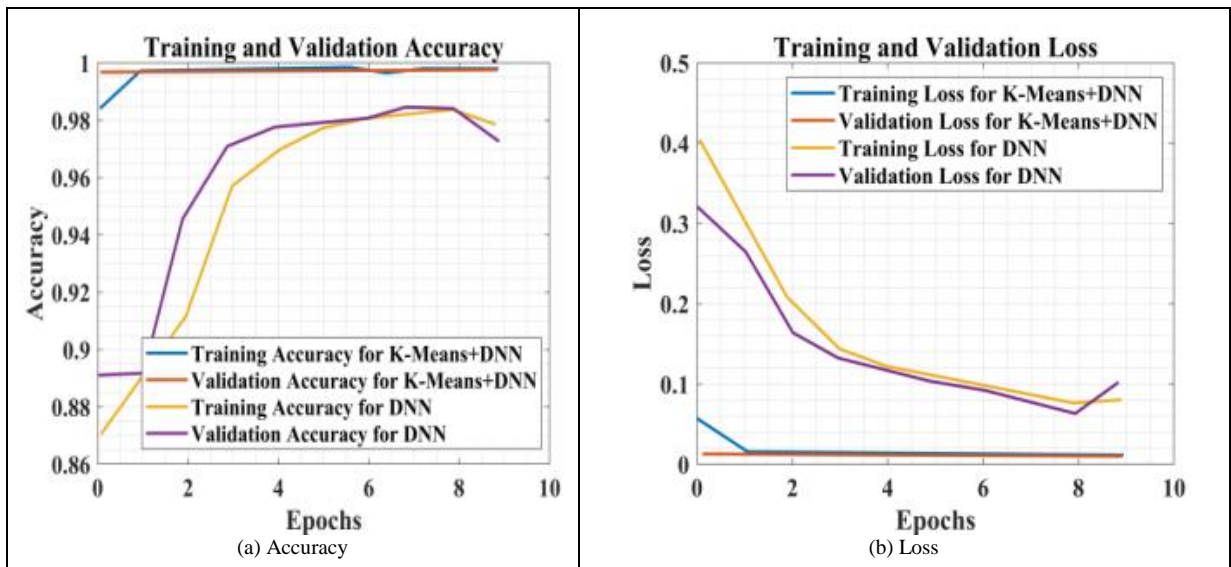


Fig. 11. Accuracy and loss comparison for training and validation set of DNN and K-means+DNN (multi-label classification).

The multi-label classification of the training and validation set for K-means+GRU and GRU based approaches are given in Fig. 12. The accuracy is higher with the K-means+GRU approach, and it is lower with GRU based approach. If the number of the epoch is 1, the training accuracy of K-means+GRU is lower than the validation accuracy.

The accuracy comparisons with multi-label classification for K-means+LSTM and LSTM approaches are shown in Fig.

13. When the number of epochs is 7, the validation accuracy of LSTM highly deviates from the training accuracy of LSTM. The validation accuracy of K-means+LSTM achieves a constant value nearer to 1. With a lower amount of epochs, the accuracy value is lower than 0.9. The value of the training and validation set is lower for K-means+LSTM and higher for LSTM.

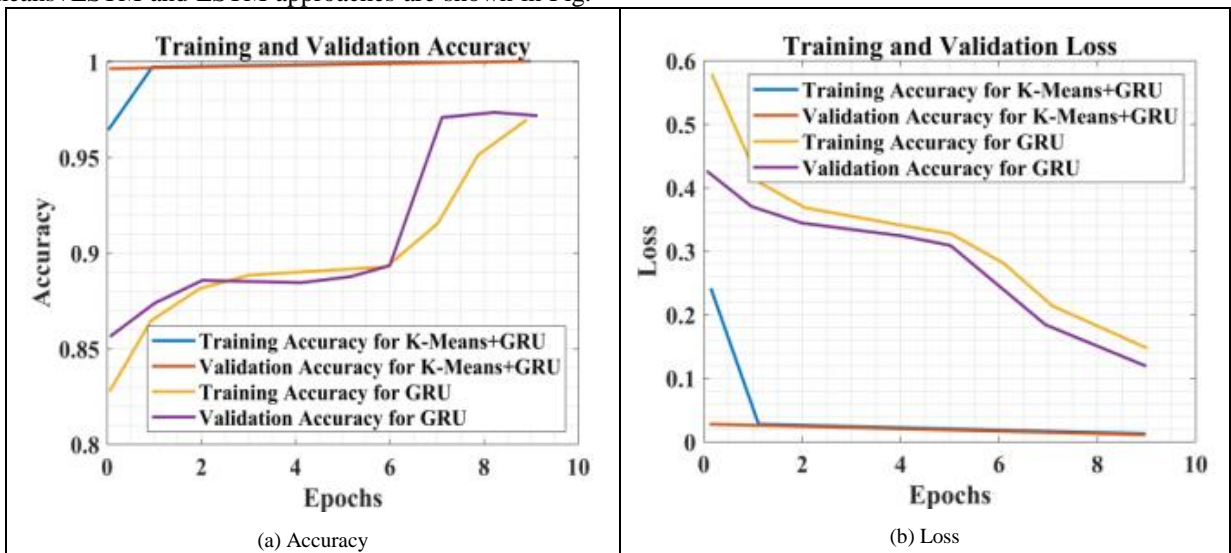


Fig. 12. Accuracy and loss comparison for training and validation set of GRU and K-means+GRU (multi-label classification).

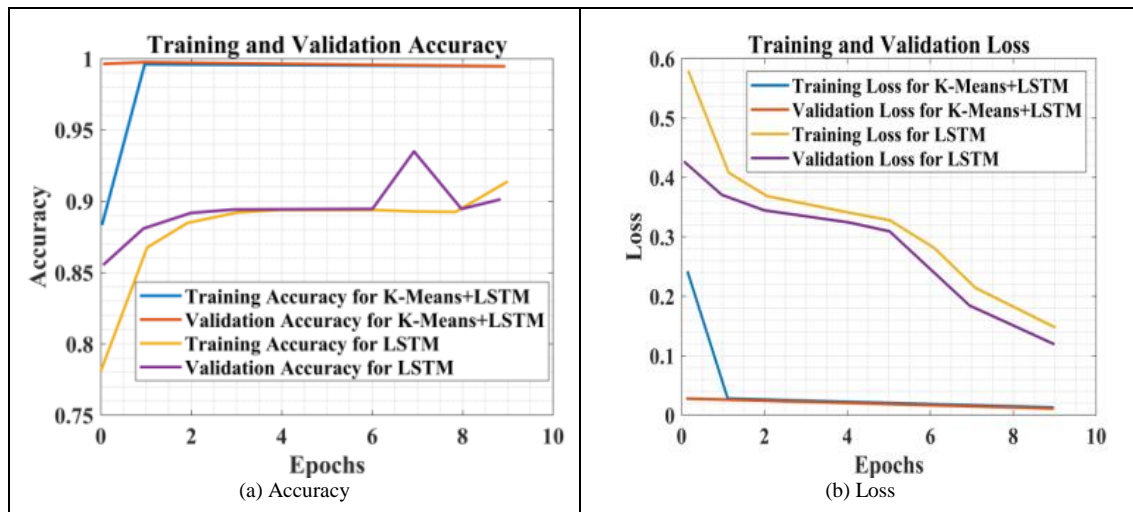


Fig. 13. Accuracy and loss comparison for training and validation set of LSTM and K-means+LSTM (multi-label classification).

The accuracy comparisons of multi-label classification for K-means+RNN and RNN approaches are shown in Fig. 14. The accuracy is higher for the K-means +RNN approach than the RNN approach. The training accuracy is lower than the validation accuracy. By increasing the number of epochs, the accuracy is increased for K-means+RNN and RNN approaches. The loss value is lower for the K-means+RNN approach, whereas it is higher for the RNN approach. When the number of the epoch is 9, the training and validation accuracy for K-means+RNN and RNN is the same.

The confusion matrix for the proposed ensemble-based approach is shown in Fig. 15. For binary classification, the

CNN-based approach provides better detection performance; for multi-label classification, DNN provides better intrusion detection results. The precision recall curve for the ensemble approach is shown in Fig. 16. If the recall value is closer to 1, then the precision also gets closer to 1. The best results from the multi-label categorization are displayed in Fig. 16. Fig. 17 depicts the receiver operating characteristic curve for the ensemble method. It's a graph made up of true positive and false positive numbers. The DNN method of multi-label classification has achieved a macro-average ROC of 1. The ROC curve value reached for class 0 is 1.00, class 1 is 0.99, class 2 is 1.00, and class 3 is 1.00.

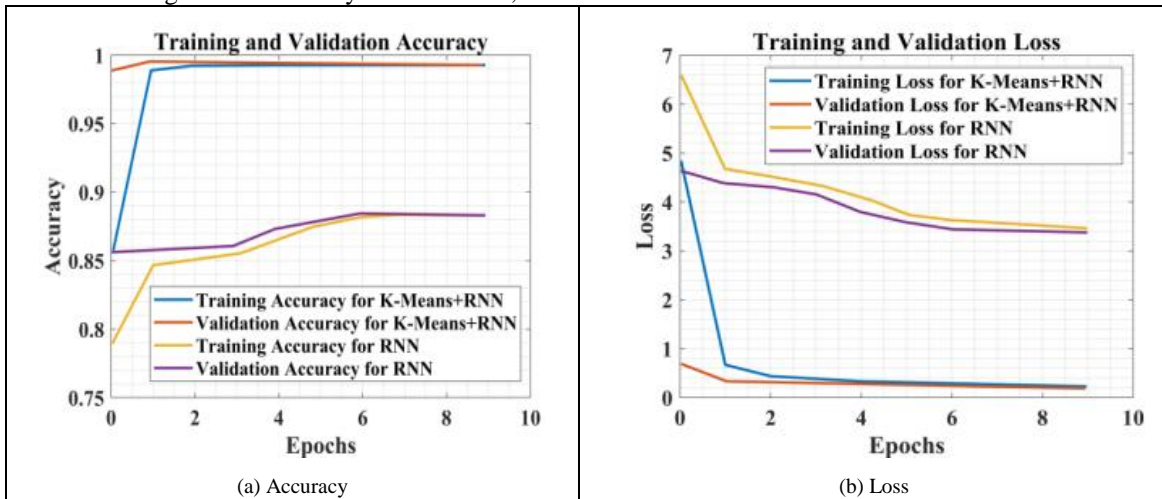


Fig. 14. Accuracy and loss comparison for training and validation set of RNN and K-means+RNN (multi-label classification).

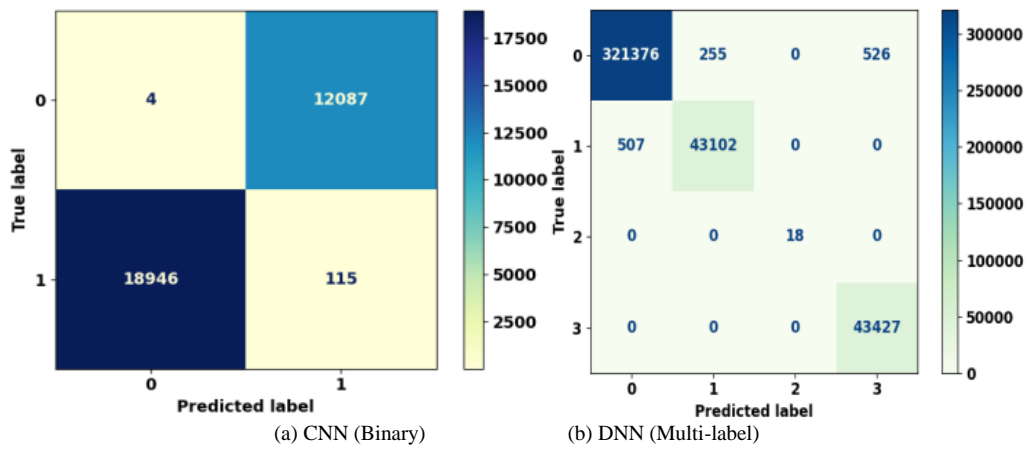


Fig. 15. Confusion matrix for an ensemble approach.

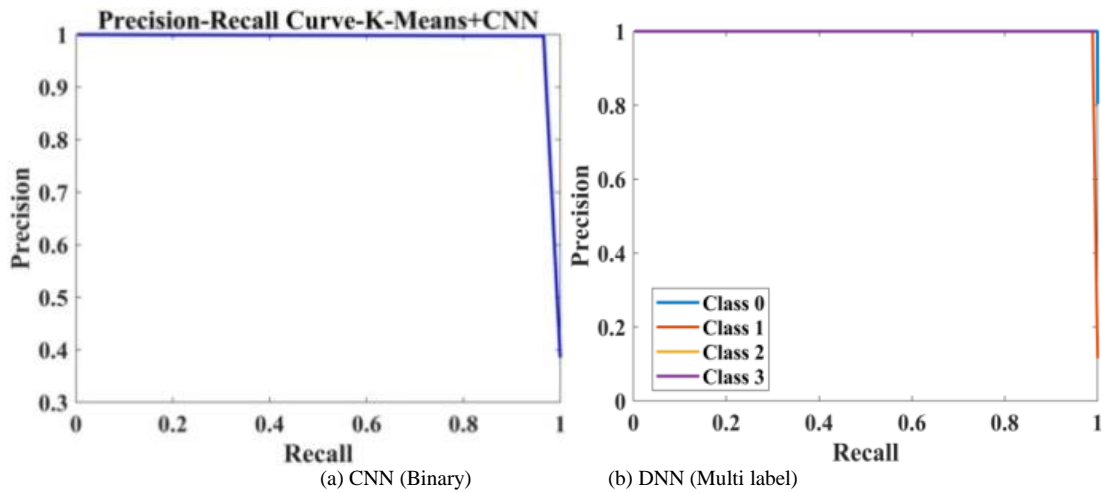


Fig. 16. Precision-Recall Curve for ensemble approach.

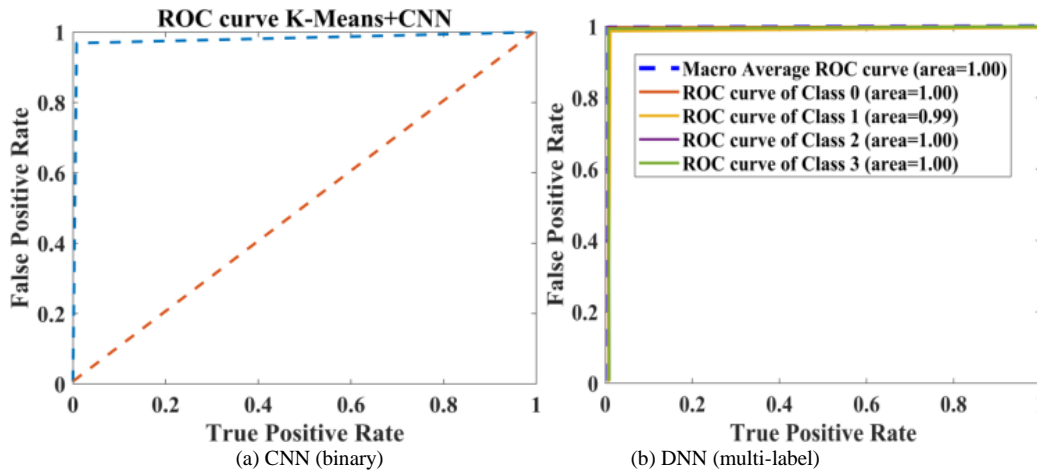


Fig. 17. ROC curve for an ensemble approach.

V. CONCLUSION

In this work, an intrusion detection framework has been designed using the ensemble based deep learning algorithm for the SDN based Cloud environment. This proposed model performs both binary as well as multi-label classification. The feature extraction with a decision tree provides accurate

feature extraction. It reduces overfitting and is a flexible approach to feature reduction. The clustering process makes the interpretation easier than other approaches. By implementing the clustering process, the computational complexity of the DL algorithm got reduced by neglecting the hybrid DL algorithm. With the proposed ensemble approach, higher prediction accuracy is obtained by handling different

models. By using the deep learning approaches, the identical features are correlated and combined for an efficient learning process. The features are automatically learned from the data, and thus, the processing efficiency is increased. The performance of the ensemble based method achieves a higher detection rate of around 99.8% approximately. By deploying the clustering process, the training process also can be reduced to some extent. In future work, the performance is enhanced with the Quality-of-Service requirement.

REFERENCES

- [1] B. Hajimirzaei, N. J. Navimipour, "Intrusion detection for cloud computing using neural networks and artificial bee colony optimization algorithm." *Ict Express* pp. 56-595, no. 1, 2019.
- [2] J. Fontaine, C. Kappler, A. Shahid, E. D. Poorter, "Log-based intrusion detection for cloud web applications using machine learning." In *Advances on P2P, Parallel, Grid, Cloud and Internet Computing: Proceedings of the 14th International Conference on P2P, Parallel, Grid, Cloud and Internet Computing (3PGCIC-2019)*, Springer International Publishing, pp. 197-210, vol.14, 2020.
- [3] S. Agrawal, S. Sarkar, O. Aouedi, G. Yenduri, K. Piamrat, M. Alazab, S. Bhattacharya, P. K. R. Maddikunta, T. R. Gadekallu, "Federated learning for intrusion detection system: Concepts, challenges and future directions." *Computer Communications* pp. 2022.
- [4] Z. Zhang, J. Wen, J. Zhang, X. Cai, L. Xie, "A many objective-based feature selection model for anomaly detection in cloud environment." *IEEE Access* pp. 60218-60231, vol. 8, 2020.
- [5] A. Aldribi, I. Traoré, B. Moa, O. Nwamuo, "Hypervisor-based cloud intrusion detection through online multivariate statistical change tracking." *Computers & Security* pp. 101646, vol. 88, 2020.
- [6] S. Dey, Q. Ye, S. Sampalli, "A machine learning based intrusion detection scheme for data fusion in mobile clouds involving heterogeneous client networks." *Information Fusion* pp. 205-215, vol. 49, 2019.
- [7] I. H. Abdulqadder, S. Zhou, D. Zou, I.T. Aziz, S. M. A. Akber, "Multi-layered intrusion detection and prevention in the SDN/NFV enabled cloud of 5G networks using AI-based defense mechanisms." *Computer Networks* pp. 107364, vol. 179, 2020.
- [8] G. Jakka, I. M. Alsmadi, "Ensemble Models for Intrusion Detection System Classification." *International Journal of Smart Sensor and Adhoc Network* pp. 8, vol. 3, no. 2, 2022.
- [9] V. Kanimozhi, T. Prem Jacob, "Artificial Intelligence outflanks all other machine learning classifiers in Network Intrusion Detection System on the realistic cyber dataset CSE-CIC-IDS2018 using cloud computing." *ICT Express* pp. 366-370, vol. 7, no. 3, 2021.
- [10] [10] S. Ranjithkumar, S. C. Pandian, "Fuzzy Based Latent Dirichlet Allocation for Intrusion Detection in Cloud Using ML." *CMC-Computers Materials & Continua* pp. 4261-4277, vol. 70, no. 3, 2022.
- [11] [11] K. Venkatachalam, P. Prabu, B. S. Balaji, B.G. Kang, Y. Nam, M. Abouhawwash, "Cross-layer hidden Markov analysis for intrusion detection." *CMC-Computers, Materials & Continua, Researchgate.net* pp. 3685-3700, vol. 70, 2021.
- [12] J. Wei, C. Long, J. Li, J. Zhao, "An intrusion detection algorithm based on bag representation with ensemble support vector machine in cloud computing." *Concurrency and Computation: Practice and Experience* pp. e5922, vol. 32, no. 24, 2020.
- [13] A. Meryem, Bouabid E.L. Ouahidi, "Hybrid intrusion detection system using machine learning." *Network Security* pp. 8-19, vol. 2020, no. 5, 2020.
- [14] V. Prabhakaran, A. Kulandasamy, "Integration of recurrent convolutional neural network and optimal encryption scheme for intrusion detection with secure data storage in the cloud." *Computational Intelligence* pp. 344-370, vol. 37, no. 1, 2021.
- [15] Y. Wang, W. Meng, W. Li, Z. Liu, Y. Liu, H. Xue, "Adaptive machine learning-based alarm reduction via edge computing for distributed intrusion detection systems." *Concurrency and Computation: Practice and Experience* pp. e5101, vol. 31, no. 19, 2019.
- [16] G. S. Kushwah, V. Ranga, "Voting extreme learning machine based distributed denial of service attack detection in cloud computing." *Journal of Information Security and Applications* pp. 102532, vol. 53, 2020.
- [17] R. M. Yadav, "Effective analysis of malware detection in cloud computing." *Computers & Security* pp. 14-21, vol. 83, 2019.
- [18] E. Mugabo, Q.Y. Zhang, "Intrusion Detection Method Based on Support Vector Machine and Information Gain for Mobile Cloud Computing." *Int. J. Netw. Secur. Academia.edup* pp. 231-241, vol. 22, no. 2, 2020.
- [19] Z. Chkirbene, A. Erbad, R. Hamila, A. Mohamed, M. Guizani, M. Hamdi, "TIDCS: A dynamic intrusion detection and classification system based feature selection." *IEEE Access* pp. 95864-95877, vol. 8, 2020.
- [20] J. Brugman, M. Khan, S. Kaseera, M. Parvania, "Cloud based intrusion detection and prevention system for industrial control systems using software defined networking." In *2019 Resilience Week (RWS)* pp. 98-104, vol. 1, 2019.
- [21] L. Karuppusamy, J. Ravi, M. Dabbu, S. Lakshmanan, "Chronological salp swarm algorithm based deep belief network for intrusion detection in cloud using fuzzy entropy." *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields, Wiley online library* pp. e2948, vol. 35, no. 1, 2022.
- [22] M. Idhammad, K. Afdel, M. Belouch, "Distributed intrusion detection system for cloud environments based on data mining techniques." *Procedia Computer Science* pp. 35-41, vol. 127, 2018.
- [23] A. N. Jaber, S. U. Rehman, "FCM-SVM based intrusion detection system for cloud computing environment." *Cluster Computing* pp. 3221-3231, vol. 23, no. 4, 2020.
- [24] S. Krishnaveni, S. Sivamohan, S. S. Sridhar, S. Prabakaran, "Efficient feature selection and classification through ensemble method for network intrusion detection on cloud computing." *Cluster Computing* pp. 1761-1779, vol. 24, no. 3, 2021.
- [25] [25] T.G. Nguyen, T. V. Phan, B. T. Nguyen, C. So-In, Z. A. Baig, S. Sanganpong, "Search: A collaborative and intelligent nids architecture for sdn-based cloud iot networks." *IEEE access* pp. 107678-107694, vol. 7, 2019.
- [26] Thilagam, T., and R. Aruna. "Intrusion detection for network based cloud computing by custom RC-NN and optimization." *ICT Express* pp. 512-520, 7, no. 4, 2021.
- [27] S. Rajagopal, P. P. Kundapur, K. S. Hareesha, "Towards effective network intrusion detection: from concept to creation on Azure cloud." *IEEE Access* pp. 19723-19742, vol. 9, 2021.
- [28] A. Abusitta, "A deep learning approach for proactive multi-cloud cooperative intrusion detection system." *Future Generation Computer Systems* pp. 308-318, vol. 98, 2019.
- [29] Aldallal, Ammar, and Faisal Alisa. "Effective intrusion detection system to secure data in cloud using machine learning." *Symmetry* pp. 2306, vol. 13, no. 12, 2021.
- [30] M. Mayuranathan, M. Murugan, V. Dhanakoti, "Best features based intrusion detection system by RBM model for detecting DDoS in cloud environment." *Journal of Ambient Intelligence and Humanized Computing*, pp. 3609-3619, vol. 12, no. 3, 2021.

A Novel Method for Anomaly Detection in the Internet of Things using Whale Optimization Algorithm

Zhihui Zhu^{*1}, Meifang Zhu²

Guangzhou Maritime University, Guangzhou 510725, Guangdong, China^{*1}
Guangdong Lingnan Institute of Technology, Guangzhou 511510, Guangdong, China²

Abstract—The Internet of Things (IoT) is integral to human life due to its pervasive applications in home appliances, surveillance, and environment monitoring. Resource-constrained IoT devices are easily accessible to attackers due to their direct connection to the unsafe Internet. Public access to the Internet makes IoT objects more susceptible to intrusion. As the name implies, anomaly detection systems are designed to identify anomalous traffic patterns that conventional firewalls fail to detect. Effective Intrusion Detection Systems (IDSs) design faces three major problems, including handling high dimensionality, selecting a learning algorithm, and comparing entered observations and traffic patterns using a distance or similarity measure. Considering the dynamic nature of the entities involved and the limited computing resources available, more than traditional anomaly detection approaches is required. This paper proposes a novel method based on Whale Optimization Algorithm (WOA) to detect anomalies in IoT-based networks that conventional firewall systems cannot detect. Experiments are conducted on the KDD dataset. The accuracy of the proposed method is compared for classifiers such as kNN, SVM, and DT approaches. The detection accuracy rate of the proposed method is significantly higher than that of other methods for DoS, probing, normal attacks, R2L attacks, and U2R attacks compared to other methods. This method shows an impressive increase in accuracy when detecting a wide range of malicious activities, from DoS, probing, and privilege escalation attacks, to remote-to-local and user-to-root attacks.

Keywords—Internet of things; anomaly detection; intrusion detection; firewall; whale optimization algorithm; accuracy

I. INTRODUCTION

Scientific and technological advancements in the fields of optical networks [1, 2], Internet of Things (IoT) [3], cloud computing, Complementary Metal-Oxide Semiconductor (CMOS) [4, 5], machine learning [6], 5G connectivity [7, 8], Blockchain [9], artificial intelligence [10, 11], and smart grids [12] have greatly benefited society. In recent years, the internet has grown tremendously and is now used to connect objects. The Internet of Things (IoT) influences almost every aspect of human and industrial life [13, 14]. By linking physical things together, the IoT is expected to bridge various technologies [15]. Wireless technology advancements such as radio frequency identification (RFID), Bluetooth, and WiFi enable better communication among objects and with the internet [16, 17]. A unique identifier can also be assigned to each item [18]. A lack of security mechanisms and the Internet connectivity of

IoT devices makes them vulnerable to attacks [19]. By gaining control over smart devices, an attacker can hack IoT devices and use them maliciously to hack other IoT devices [20]. As part of anomaly detection, intrusion detection examines incoming traffic for abnormality or abnormality [21]. In order to recognize abnormal traffic within a network efficiently, intrusion detection systems need to automate their detection procedures [22]. The majority of network intrusion detection systems analyze incoming traffic using data mining and clustering techniques. A fundamental function of an intrusion detection system is to identify normal or abnormal traffic patterns based on the current traffic pattern [23].

An Intrusion Detection System (IDS) tracks network activity in real-time and alerts or takes proactive action when suspicious transmissions are detected [24]. The main difference between IDS and other network security tools is that IDS can detect ongoing invasions as well as recent intrusions. An intrusion detection system generally distinguishes between normal and anomalous network traffic behavior and determines the type of attack based on a binary classification problem [25]. It is primarily motivated by improving classification accuracy by detecting intrusive behavior. Network information security has gradually gained attention over the past 30 years [26]. IDS systems are currently categorized as anomaly-based detection systems and signature-based detection systems. The signature-based detection system compares the signatures extracted from the subsequent detection systems with those extracted from known attack methods to detect upcoming attacks and notify users. While anomaly-based detection systems are accurate, they are limited in their ability to detect unidentified attacks, such as 0-DAY vulnerabilities and advanced persistent threats.

A classifier based on ensembles is proposed as a method for improving the accuracy of IDS. Twelve experts are trained and tested to form an ensemble. WOA weighs each expert's opinion. As a meta-optimizer, the LUS method finds high-quality parameters based on the behavioral parameters inserted by the user. The weights of each expert are then adjusted using WOA. Seven stages are involved in the system framework: data preprocessing, SVM classification, k-NN classification, decision tree classification, weighting with WOA, and comparison of results. The remainder of the paper is organized as follows. The Section II reviews related work. A detailed description of the proposed method appears in Section III. Section IV reports the results of the experiments. The paper is concluded in Section V.

II. RELATED WORKS

This section will review the existing anomaly and intrusion detection methods and determine their main features and weaknesses.

Alamiyedi, et al. [28] have proposed an IDS scheme based on the Grey Wolf Optimization (GWO) algorithm. The GWO algorithm is employed for feature selection in order to identify the optimum dataset features for accurate classification. Besides, the support vector machine has been utilized in evaluating the accuracy of selected features in attack prediction. Experiments confirm that the offered method has obtained classification accuracy of 94%, 92%, 58%, and 54% for DoS, probing, R2L, and U2L attacks, respectively.

An IDS approach based on a genetic algorithm and Deep Belief Network (DBN) has been presented by Zhang, et al. [29]. When faced with multiple iterations of the genetic algorithm and varying attacks, generating several neurons in each layer and an optimal number of hidden layers, the proposed mechanism uses DBN to achieve a high detection rate while maintaining a compact structure. The performance of the method has been assessed based on the NSL-KDD dataset. The results indicate that the combined IDS and DBN model effectively reduced neural network complexity and improved intrusion detection rates.

Moreover, a random neural network-based IDS for IoT has been developed by Qureshi, et al. [30], in which, with the NSL-KDD dataset, neurons are trained and then tested at different rates of learning. The accuracy of RNN-IDS was increased from 86% to 96% by using two methods to evaluate the proposed approach. Simulation outcomes indicate that the proposed IDS can distinguish anomalous traffic more accurately from normal traffic.

An EFSAGOA method, which combines an Ensemble of Feature Selection (EFS) and Adaptive Grasshopper Optimization algorithm (AGOA), has been introduced by Dwivedi, et al. [31]. At first, in order to determine the highest-ranked attributes, the EFS method was applied to rank attributes. Using the AGOA method, key attributes derived from the reduced datasets were identified for network traffic prediction. To optimize the classification process, AGOA applies Support Vector Machines (SVM) as a fitness function. Additionally, the method was used to optimize the tube size, kernel parameter, and penalty factor of SVM classifiers. Utilizing ISCX 2012 dataset, the performance of EFSAGOA has been evaluated. In comparison to existing methods in ISCX 2012 data, the proposed method produced better accuracy, false alarm rates, and detection rates.

A novel host-based automated framework for IDS in the IoT has been presented by Gassais, et al. [32], in which user and kernel space information are combined with machine learning approaches to identify intrusions of different types. Tracing methods have been utilized to detect the behavior of devices automatically, transform data into numeric arrays, and train machine learning algorithms. Several machine learning algorithms have been implemented to improve detection capability with minimal overhead on monitored devices.

Furthermore, a novel IDS combining deep learning and a dendritic cell algorithm has been proposed by Aldhaferi, et al. [33]. Classifying IoT intrusions and preventing false alarms are the main aims of the approach. By selecting the appropriate set of features from the IoT-Bot dataset, the proposed IDS categorizes signals and then performs classification using the dendritic cell algorithm. The proposed approach demonstrated a better ability to detect IoT attacks, achieving an accuracy rate of 97% and a low false positive rate.

Brown and Anwar [34] have developed a deep neural network-based validation model integrated into an artificial immune system based on human intelligence. The solution provides implementation strategies and a pilot implementation of the core component to address the challenges associated with IoT networks. The suggested approach is suitable for discovering real-time attacks and is adaptable to changing network environments. This mechanism may serve as a baseline for the development of holistic IoT IDS in which each node plays a role in network security.

Finally, Ge, et al. [24] have offered a novel IDS for IoT utilizing a customized deep-learning technique. They have utilized an innovative IoT dataset of real-world attacks, such as data theft and denial of service attacks. They have developed a feed-forward neural network model embedded with multi-class classification layers. Besides, a binary classifier based on a second feed-forward neural network model was built using transfer learning to encode categorical features of high dimensions. For both binary and multi-class classifiers, the proposed method achieves higher classification accuracy.

III. PROPOSED METHOD

In this section, at first, the problem statement is described as well as the adopted network model is explained. Then, the suggested strategy is clarified step by step.

A. Problem Definition

With the rise of IoT applications and smart objects, IoT networks generate more data and traffic, resulting in a rise in IoT vulnerabilities and, consequently, RPL threats. Although RPL offers mechanisms for achieving confidentiality, integrity, and replay protection through encryption of control messages, local and global repairs, and loop detection, it is still susceptible to internal attacks. The RPL network has vulnerabilities beyond its encryption and authentication defenses. The second line of defense for networks is IDSs, which monitor network activity and node behavior for disruption attempts.

B. Network Model

First-line defenses against computer system cyberattacks are security frameworks that enforce industry standards such as authentication, authorization, and confidentiality. Vulnerabilities in system software, operational errors, and other issues may make attacks more likely. IDSs are critical in identifying and alerting system administrators to such attacks. Depending on the configuration, an IDS can be installed on individual hosts, at a central location, or distributed throughout the network. Fig. 1 illustrates how IDS operates in several areas across the network system. The IDS is a kind of IDS

intended to detect attacks on a computer network rather than a single system. It is designed to detect malicious activities such as unauthorized access, data manipulation, and denial of service attacks. It monitors the network for suspicious activities and flags any potential threats, allowing for quick response and mitigation of possible damage. These systems monitor network operations using network telemetry, which may comprise network traffic, network flow metadata, and host event logs to identify attack events. By analyzing this telemetry, the system can detect and classify malicious activity, alerting administrators to potential malicious activity and allowing for remediation of any potential threats [35].

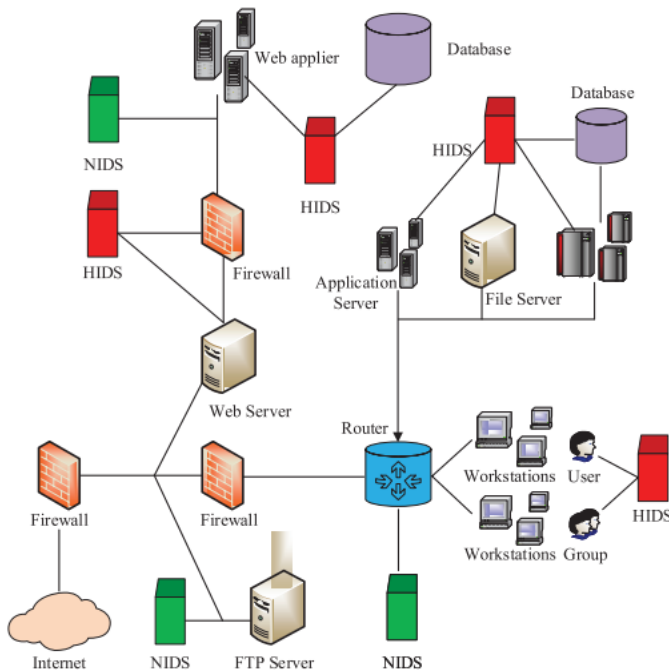


Fig. 1. Intrusion detection system and different places of the network [35].

An IDS funnels all network traffic via its sensors to identify intrusions and anomalies. As network traffic increases, using a single IDS on a network poses congestion issues if the network throughput is too high. Deep Packet Inspection may include significant pattern matching against complicated attack rule signatures. *Pattern matching* is a time-consuming procedure that requires substantially more computer resources than a firewall, which might cause an IDS to become overloaded. When an IDS becomes overburdened and begins dropping or ignoring packet content, it might compromise the network's security. Eventually, some intrusions may go unnoticed since some packets associated with the same attack may evade the IDS's inspection, leading to incomplete packet matching [6]. There are several strategies for handling high levels of network traffic for IDS, including:

C. Proposed Algorithm Description

As stated earlier, this paper aims to improve the accuracy of IDS by developing ensemble-based classifiers. An ensemble of twelve experts is formed after training and testing twelve experts. Each expert's opinion is weighed according to WOA. User-inputted behavioral parameters are a vital indicator of the effectiveness of WOA. Each expert's weights are then adjusted

based on the improved WOA. A seven-stage system framework is designed to simplify the process: preprocessing data, classifying data with five distinct SVM experts, classifying data with five distinct KNN experts, classifying data with five distinct decision tree classifiers, setting weights with WOA, and comparing the results.

1) *Adopted dataset*: Experiments are conducted using the Knowledge Discovery and Data Mining 1999 (KDD99) dataset. Thousands of records describe connections in the dataset. Each TCP/IP connection contains 41 qualitative and quantitative features. Observations are classified as normal or intrusive based on their features. The performance of each classifier must be evaluated on two datasets: training and testing. The data is taken from [36]. The KDD99 dataset contains four types of attacks.

- User to Root (U2R): connects an attacker to the root account after gaining access.
- Remote to Local (R2L): An entry attempt into a computer or network illegally.
- Probe (Probing): Examining the target machine for potential weaknesses.
- Denial of Service (DoS): The attempt to deny authorized users access to a targeted computer's services.

2) *Data preprocessing*: Each observation must have a set of numerical values in order to be classified using the proposed methods. Additionally, each class must be given a numerical value. The proposed classification algorithms are incompatible with three symbolic features of KDD99 data:

- Flag: The connection status flag is represented by this feature.
- Service: It represents a destination service (for example, telnet, FTP, etc.).
- Protocol type: This feature signifies the connection protocol.

Data preprocessing involves two steps: data mapping and state identification.

- State identification: The KDD99 defines states for different features, such as regular connections or attacks. The data has five major classes: R2L, U2R, Probe, DoS, and Normal. Numerical values are assigned to each state.
- Data mapping: Every observation is mapped to a numerical value in the training, validation, and testing datasets. The three features are each given a numerical value between 1 and n, where n represents the symbol count.

3) *SVM classifier*: Support vector machines (SVM) can effectively solve classification and regression problems. This technique has a low generalization error and does not overfit training data. When a model performs poorly outside the

training set, it is referred to as over-fitting or having a high generalization error. SVM is most effective when separating data sets linearly, which means instances in one class are all positioned along the same hyperplane H. SVM chooses the hyperplane H with the shortest distance between every pair of instances in each class. Up to this point, only linearly separable data have been considered. Such a hyperplane may only be possible for some real-life data sets. Such separation can be achieved using SVM based on data mapping to another feature space. In most cases, this transformation involves mapping into high-dimensional spaces. Kernel functions perform these modifications.

A multi-class SVM is extended by training five binary classifiers, one for each class. Suppose $i = (1, \dots, 5)$ belongs to the quintuple $F = (R2L, U2R, DoS, Probe, \text{and Normal})$, and B_i denotes the binary classifier for target class i within F . Binary classifiers are trained on the entire training set for their respective target classes. Training the classifier B_i involves labeling observations belonging to class i as 1 and all other observations as 0. Classifying observations into one of the five classes is referred to as the One-versus-All approach. The 5-classifier set is used to distinguish between binary classifiers. According to Fig. 2, binary classifiers and experts have different relationships illustrated in their output formats. Binary classifiers take input data and output one of two possible classes, while experts take input data and output a continuous value. This difference in output formats reflects the different ways in which the two types of models process data.

In SVM, the RBF kernel function yields the best results [37]. Various RBF functions are employed in experiments to determine the performance of SVM classifiers with RBF kernel functions. In order to maximize the efficiency of the SVM algorithm, six different SVM experts are trained with different RBF parameters. In addition, this approach ensures that ensemble classifiers have a greater variety of experts. The RBF vector defines the selected values for RBF parameters as follows: $RBF = [5, 2, 1, 0.5, 0.2, 0.1]$. RBF vector values determine the accuracy of binary classifiers in each expert system. Six SVM experts are developed based on the RBF vector:

- SVM 1: RBF = 5
- SVM 2: RBF = 2
- SVM 3: RBF = 1
- SVM 4: RBF = 0.5
- SVM 5: RBF = 0.2
- SVM 6: RBF = 0.1

4) *kNN classifier*: An effective and simple tool for object classification is the k-nearest neighbor (kNN) algorithm [38]. Consider observations and targets $(o_1, t_1), \dots, (o_n, t_n)$, where observations $o_i \in R^d$ and targets $t_i \in \{0, 1\}$. For a given i in the training sample, kNN predicts the test vector class based on the class labels of the nearest neighbors. A kNN classifies new points by identifying the points with the most votes based on

the K closest points. The Euclidean distance is a distance metric commonly used in kNN to compare two vectors (points):

$$d^2(x_i, x_j) = \|x_i - x_j\|^2 = \sum_{k=1}^d (x_{ik} - x_{jk})^2 \quad (1)$$

In contrast to SVM, kNN classifiers can solve multi-class problems. However, five binary classifiers are needed to make kNN and SVM experts compatible. Accordingly, kNN expert systems are structured similarly to the SVM expert systems, as shown in Fig. 2. The compatibility of SVM and kNN expertise allows them to be combined into an ensemble expert system. kNN classifiers use the k parameter to determine how many neighbors close to a given observation are in a training set. The accuracy of binary classifiers inside an expert will vary as this parameter is changed. The kNN classifier can be optimized by creating six experts with different values of the k parameter as defined by the k vector: $K = [1, 3, 5, 7, 9, 11]$. The six k-NN experts are created as follows by selecting different k parameters:

- k-NN 1: k=1;
- k-NN 2: k=3;
- k-NN 3: k=5;
- k-NN 4: k=7;
- k-NN 5: k=9;
- k-NN 6: k=11;

5) *Whale optimization algorithm for IDS*: The WOA algorithm is a swarm-based intelligent algorithm for continuous optimization problems. Compared to recent meta-heuristics methods, it exhibits superior performance. It is more straightforward and robust than other swarm intelligence algorithms, making it comparable to other nature-inspired algorithms. A single parameter (time interval) is required to achieve the desired result in practice. WOA involves humpback whales searching for food in a multidimensional space. Humpback whale locations are considered decision variables, while distances between them and food are represented as objective costs. Three operational processes determine a whale's time-dependent location: search for prey, bubble-net attacking method, and shrinking encircling prey [39]. The primary presentation of the WOA is shown in Fig. 3. These operational processes are described and mathematically expressed in the following. A spiral mathematical formulation can describe the bubble-net behavior of humpback whales as follows.

$$\vec{X}(t+1) = \vec{D}' \cdot e^{bl} \cdot \cos(2\pi l) + \vec{X}^*(t) \quad (2)$$

$$\vec{X}(t+1) = \begin{cases} \vec{X}^*(t) - \vec{A} \cdot \vec{D} & \text{if } p < 0 \\ \vec{D}' \cdot e^{bl} \cdot \cos(2\pi l) + \vec{X}^*(t) & \text{if } p \geq 0 \end{cases} \quad (3)$$

In Eq. (3), p is a constant used to explain the logarithmic spiral's shape, and k is a uniformly distributed number. As a global optimizer, if $A > 1$ or $A < -1$, a randomly chosen search agent replaces the best search agent as follows:

$$\vec{D} = |\vec{C} \cdot \vec{X}_{rand} - \vec{X}| \quad (4)$$

$$\vec{X}(t + 1) = \vec{X}_{rand} - \vec{X} \cdot \vec{D} \quad (5)$$

The current iteration nominates x_{rand} arbitrarily from whales. Whales with a minimum fitness function represent the ideal solution. A whale with the best fitness represents the optimal set of weight coefficients $w = (w_1, w_2, \dots, w_n)$, where n denotes the number of experts. This means that each whale has its own set of weight coefficients. Using Eq. (2), every observation x in the sample is classified according to the voting algorithm y . Every observation in the training set is provided with the correct class (target). As a training sample of size m is classified correctly, c is the number of instances where an output is predicted to have the same value as a target T , or $y = T$. Based on the validation sample, $ACC(w) = \frac{c}{m}$ is the fraction of correctly classified observations, $ACC(w) = \frac{c}{m}$, where m is the

number of observations. The accuracy of ensemble classifiers should be maximized, or the error minimized for each whale in order to achieve improved performance.

Weights are generated separately for each class. According to Fig. 2, the ensemble classifier created by WOA weights will have the same structure as an expert. Consequently, five weights need to be generated with WOA, one for each binary classifier in the base expert. Weights are generated based on the validation data. An accurate evaluation of the accuracy of classifiers based on training data is required. It is not acceptable to evaluate model performance using the same data for training since this would lead to strongly biased weights and could easily result in an overfitted model. The fitness value of an expert system cannot also be determined by testing data since it is necessary to use only testing targets to evaluate the performance of each expert system, whether it is a basic classifier or an ensemble. The validation dataset was created by taking a subset from the corrected.gz file used for testing and removing it from all testing datasets. This ensures the independence of the validation process.

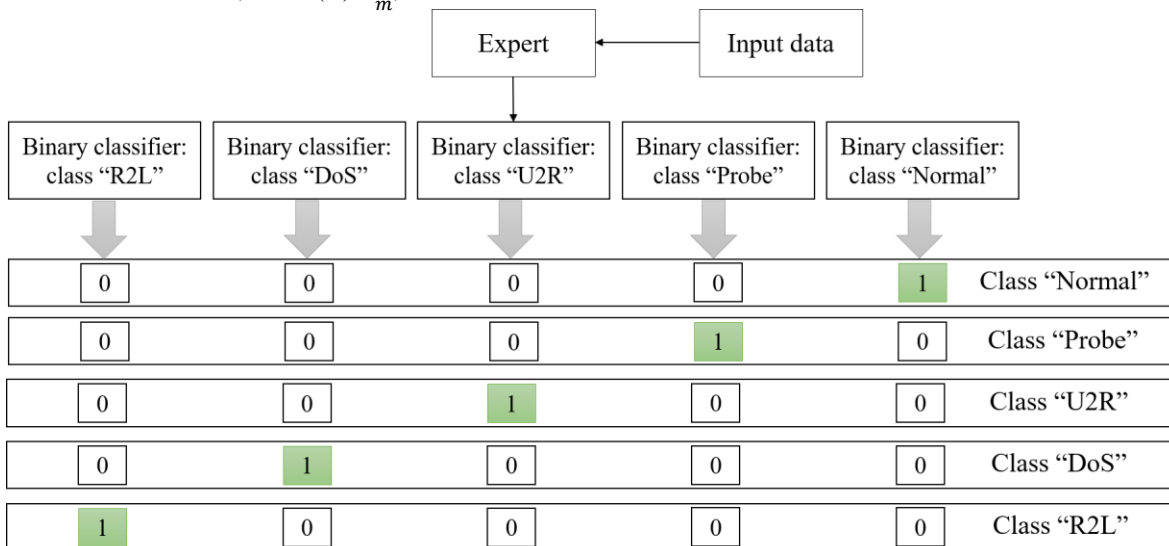


Fig. 2. Expert system structure.

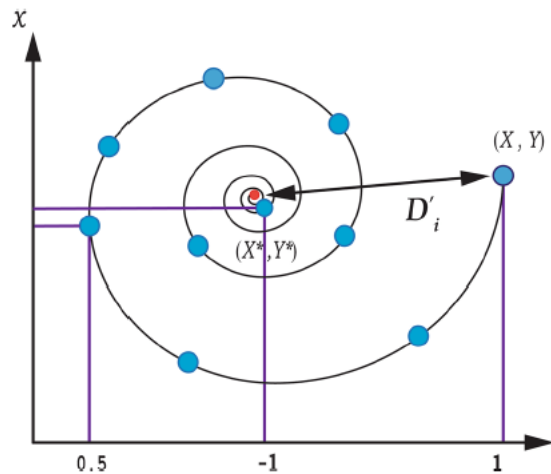


Fig. 3. Position update in a spiral.

IV. EXPERIMENTAL RESULTS

This study was conducted using Matlab-2018 32bit on Windows 7 Professional 32bit, with an Intel Core i5 processor and 8GB of RAM. As mentioned earlier, the KDD-99 dataset is used in the proposed IDS strategy. KDD-99 consists of a large number of records that fall into five different categories. In fact, KDD-99 records fall into one of these five classes. The number of randomly selected records from the KDD-99 dataset is listed in Table I.

It should be noted that the selected dataset is divided into two groups of training and testing datasets. The training dataset is used to train the classifier, while the testing dataset is used to evaluate it. These datasets are shown in Table II and Table III.

A. Detection Accuracy Evaluation

The classification accuracy criterion is one of the main and most significant evaluation criteria for each IDS mechanism. Considering that the dataset considered in this article includes five different classes. As a result, each of the fifteen presented classifiers includes five binary classifiers. According to Eq. (6), it is possible to calculate the classification accuracy of each binary classifier. In this regard, A indicates the classification accuracy of the binary classifier, S indicates the total number of test samples of the desired class, and C indicates the number of correctly identified samples of the same class. The fifteen classifiers will be examined in the following according to their accuracy of identification.

$$A = \frac{C}{S} \quad (6)$$

- Classifiers based on support vector machine: Five different classifiers can be formed based on the SVM. These classifiers include a multi-class SVM based on the RBF kernel function with γ values set to 0.1, 0.2,

0.5, 1, and 2. Table IV shows the accuracy of different SVM-based classifiers.

- Classifiers based on k-nearest neighbor: There are five types of kNN-based classifiers. Classifiers include multi-class kNNs with k values of 1, 3, 5, 7, and 9. The accuracy of these classifiers is shown in Table V.
- Classifiers based on decision tree: There are five types of classifiers based on the C4.5 classification algorithm. These classifiers contain 19, 21, 23, 25, and 27 features. Previous research has determined the number of selected features. In fact, the difference between these five classifiers is the number of selected features. Table VI shows the accuracy of these classifiers.
- Proposed algorithm: The proposed IDS strategy in this paper comprises fifteen different classifiers. By combining these classifiers, the proposed IDS system is designed and built. Each classifier is also given a suitable weight based on the WOA. The proposed system based on the WOA was trained with 70% of the data and tested with 30% of the data. Table VII shows the number of training data, the test results, and the recognition accuracy. This proposed method outperforms fifteen different classifiers regarding average detection accuracy, as shown in Fig. 4.

B. Performance Analysis on the UNSW-NB15 Dataset

This scenario tests the efficiency of the ensemble-based WOA model in terms of accuracy, F-measure, precision, recall, and AUC. The UNSW-NB15 dataset contains 175,341 records for training and 82,332 records for testing. Similarly, to the NSL-KDD dataset, the ensemble classifier with WOA demonstrated superior performance for intrusion detection with an AUC of 99.6%, F-measure of 99%, recall of 99.1%, precision of 99.2%, and accuracy of 99.3%. Fig. 5 compares the ensemble-based WOA model with other approaches.

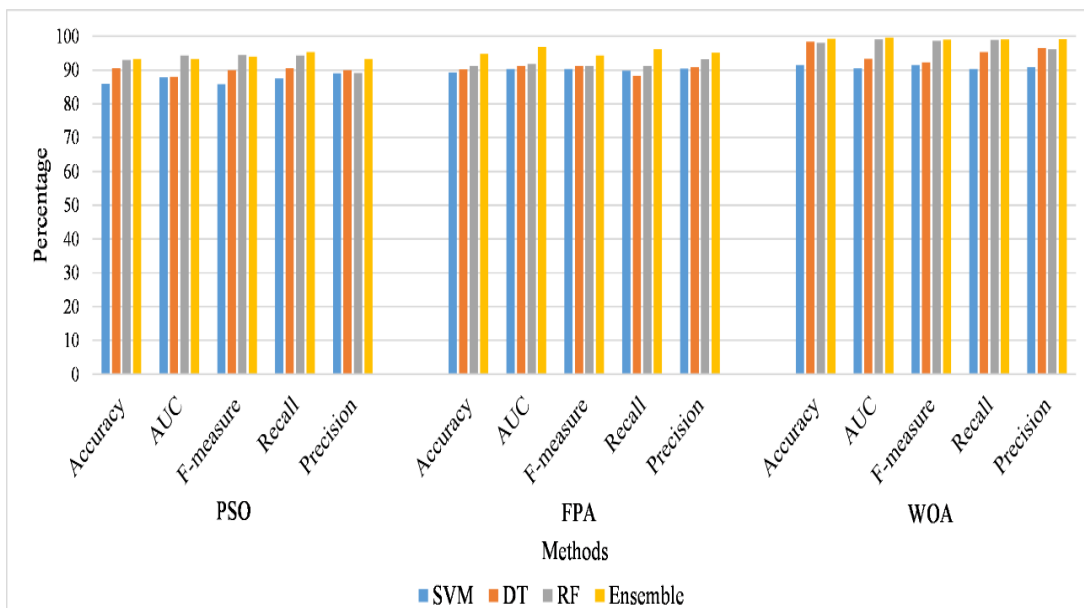


Fig. 4. Comparison results.

TABLE II. THE NUMBER OF RECORDS RANDOMLY SELECTED FROM KDD-99

Class	NC	DoS	R2L	U2R	Probing
Number of records	12500	7231	4876	104	12500

TABLE III. TRAINING DATASET

Class	NC	DoS	R2L	U2R	Probing
Number of records	5000	4107	1126	52	5000

TABLE IV. TESTING DATASET

Class	NC	DoS	R2L	U2R	Probing
Number of records	7500	3124	3750	52	7500

TABLE V. DETECTION ACCURACY OF SVM-BASED CLASSIFIERS

Classifier	NC	DoS	R2L	U2R	Probing
Classifier 1	68.55 %	93.26 %	81.44 %	99.88 %	92.1 %
Classifier 2	73.44 %	94.66 %	81.63 %	99.74 %	93.37 %
Classifier 3	76.69 %	98.88 %	81.43 %	99.45 %	94.31 %
Classifier 4	82.16 %	98.17 %	81.8 %	99.55 %	94.58 %
Classifier 5	76.55 %	94.55 %	81.18 %	99.18 %	94.69 %

TABLE VI. DETECTION ACCURACY OF KNN-BASED CLASSIFIERS

Classifier	NC	DoS	R2L	U2R	Probing
Classifier 6	81.74 %	97.8 %	83.93 %	99.65 %	96.2 %
Classifier 7	81.28 %	97.36 %	83.45 %	99.73 %	95.29 %
Classifier 8	76.44 %	93.54 %	83.44 %	99.77 %	92.3 %
Classifier 9	76.16%	92.18 %	83.55 %	99.78 %	92.32 %
Classifier 10	76.1 %	92.44 %	83.56 %	99.80 %	92.33 %

TABLE VII. DETECTION ACCURACY OF CLASSIFIERS BASED DECISION TREE

Classifier	NC	DoS	R2L	U2R	Probing
Classifier 11	78.37 %	90.45 %	81.65 %	99.1 %	92.5 %
Classifier 12	79.41 %	91.04 %	81.9 %	99.21 %	93.48 %
Classifier 13	80.55 %	91.5 %	82.48 %	99.43 %	94.51 %
Classifier 14	80.6 %	94.31 %	82.13 %	99.47 %	95.88 %
Classifier 15	81.73 %	95.77 %	83.82 %	99.68 %	95.31 %

TABLE VIII. THE NUMBER OF TRAINING AND TESTING DATA AND THE DETECTION ACCURACY OF THE PROPOSED METHOD

	NC	DoS	R2L	U2R	Probing
The number of records in the training dataset	8750	5062	3413	73	8750
The number of records in the testing dataset	3750	2169	1463	31	3750
Accuracy	90.2 %	98.66 %	89.61	99.9 %	96.83 %

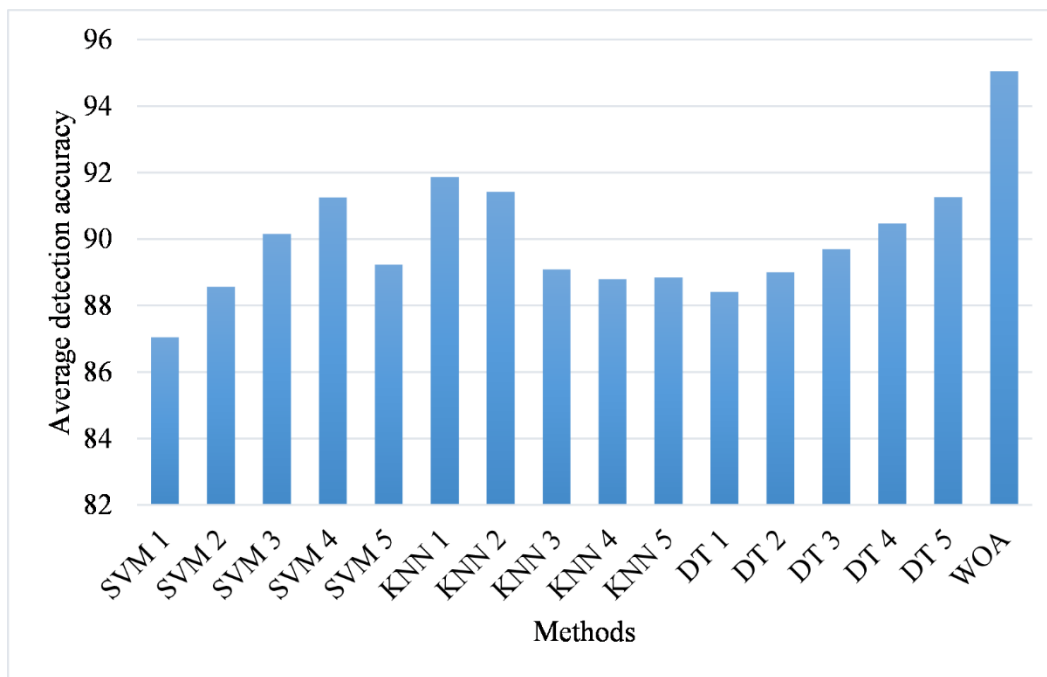


Fig. 5. Detection accuracy comparison.

V. CONCLUSION

The IoT enables physical objects in different domains to become Internet hosts, raising high expectations. Nevertheless, attackers may also use the IoT to threaten the privacy and security of users. Hence, the IoT requires security solutions. IDSs play a critical role in keeping IoT networks accessible and secure. This paper proposed a new strategy to improve the accuracy of IDS by developing ensemble-based classifiers. Twelve experts are trained and tested to form an ensemble. With LUS, user-supplied behavioral parameters are used as meta-optimizers to estimate high-quality parameters. WOA is then used to adjust the weights of each expert. The detection accuracy rates of the proposed method were significantly higher than those of other approaches for attacks, such as DoS, probing, normal, R2L, and U2R. We will investigate the efficiency of the ensemble-based WOA model using other intrusion datasets in the future, and apply this approach to other optimization problems as well.

REFERENCES

- [1] F. Khosravi, M. Tarhani, S. Kurlle, and M. Shadaram, "Implementation of an Elastic Reconfigurable Optical Add/Drop Multiplexer based on Subcarriers for Application in Optical Multichannel Networks," in 2022 International Conference on Electronics, Information, and Communication (ICEIC), 2022: IEEE, pp. 1-4.
- [2] F. Khosravi, G. Mahdiraji, M. Mokhtar, A. Abas, and M. Mahdi, "Improving the performance of three level code division multiplexing using the optimization of signal level spacing," *Optik*, vol. 125, no. 18, pp. 5037-5040, 2014.
- [3] F. Kamalov, B. Pourghebleh, M. Gheisari, Y. Liu, and S. Moussa, "Internet of Medical Things Privacy and Security: Challenges, Solutions, and Future Trends from a New Perspective," *Sustainability*, vol. 15, no. 4, p. 3317, 2023.
- [4] S. Seyedi and B. Pourghebleh, "A new design for 4-bit RCA using Quantum Cellular Automata Technology," *Optical and Quantum Electronics*, vol. 55, no. 1, p. 11, 2023.
- [5] S. Seyedi, B. Pourghebleh, and N. Jafari Navimpour, "A new coplanar design of a 4-bit ripple carry adder based on quantum-dot cellular automata technology," *IET Circuits, Devices & Systems*, vol. 16, no. 1, pp. 64-70, 2022.
- [6] J. Akhavan and S. Manoochehri, "Sensory data fusion using machine learning methods for in-situ defect registration in additive manufacturing: a review," in 2022 IEEE International IOT, Electronics and Mechatronics Conference (IEMTRONICS), 2022: IEEE, pp. 1-10.
- [7] P. He, N. Almasifar, A. Mehbodniya, D. Javaheri, and J. L. Webber, "Towards green smart cities using Internet of Things and optimization algorithms: A systematic and bibliometric review," *Sustainable Computing: Informatics and Systems*, vol. 36, p. 100822, 2022.
- [8] I. Ataie, T. Taami, S. Azizi, M. Mainuddin, and D. Schwartz, "D 2 FO: Distributed Dynamic Offloading Mechanism for Time-Sensitive Tasks in Fog-Cloud IoT-based Systems," in 2022 IEEE International Performance, Computing, and Communications Conference (IPCCC), 2022: IEEE, pp. 360-366.
- [9] S. Meisami, M. Beheshti-Atashgah, and M. R. Aref, "Using Blockchain to Achieve Decentralized Privacy In IoT Healthcare," *arXiv preprint arXiv:2109.14812*, 2021.
- [10] F. Vahedifard, S. Hassani, A. Afrasiabi, and A. M. Esfe, "Artificial intelligence for radiomics; diagnostic biomarkers for neuro-oncology," *World Journal of Advanced Research and Reviews*, vol. 14, no. 3, pp. 304-310, 2022.
- [11] S. A. Saeidi, F. Fallah, S. Barmaki, and H. Farbeh, "A novel neuromorphic processors realization of spiking deep reinforcement learning for portfolio management," in 2022 Design, Automation & Test in Europe Conference & Exhibition (DATE), 2022: IEEE, pp. 68-71.
- [12] S. H. Haghshenas, M. A. Hasnat, and M. Naeini, "A Temporal Graph Neural Network for Cyber Attack Detection and Localization in Smart Grids," *arXiv preprint arXiv:2212.03390*, 2022.
- [13] B. Pourghebleh, N. Hekmati, Z. Davoudnia, and M. Sadeghi, "A roadmap towards energy-efficient data fusion methods in the Internet of Things," *Concurrency and Computation: Practice and Experience*, p. e6959, 2022.
- [14] T. Taami, S. Azizi, and R. Yarinezhad, "An efficient route selection mechanism based on network topology in battery-powered internet of things networks," *Peer-to-Peer Networking and Applications*, pp. 1-16, 2022.

- [15] T. Taami, S. Krug, and M. O'Nils, "Experimental characterization of latency in distributed iot systems with cloud fog offloading," in 2019 15th IEEE International Workshop on Factory Communication Systems (WFCS), 2019: IEEE, pp. 1-4.
- [16] B. Pourghebleh and N. J. Navimipour, "Data aggregation mechanisms in the Internet of things: A systematic review of the literature and recommendations for future research," *Journal of Network and Computer Applications*, vol. 97, pp. 23-34, 2017.
- [17] A. Kumar et al., "Optimal cluster head selection for energy efficient wireless sensor network using hybrid competitive swarm optimization and harmony search algorithm," *Sustainable Energy Technologies and Assessments*, vol. 52, p. 102243, 2022.
- [18] M. Mohseni, F. Amirhafouri, and B. Pourghebleh, "CEDAR: A cluster-based energy-aware data aggregation routing protocol in the internet of things using capuchin search algorithm and fuzzy logic," *Peer-to-Peer Networking and Applications*, pp. 1-21, 2022.
- [19] B. Pourghebleh, K. Wakil, and N. J. Navimipour, "A comprehensive study on the trust management techniques in the Internet of Things," *IEEE Internet of Things Journal*, vol. 6, no. 6, pp. 9326-9337, 2019.
- [20] B. Pourghebleh and V. Hayyolalam, "A comprehensive and systematic review of the load balancing mechanisms in the Internet of Things," *Cluster Computing*, pp. 1-21, 2019.
- [21] A. Mehbodniya, J. L. Webber, R. Neware, F. Arslan, R. V. Pamba, and M. Shabaz, "Modified Lamport Merkle Digital Signature blockchain framework for authentication of internet of things healthcare data," *Expert Systems*, vol. 39, no. 10, p. e12978, 2022.
- [22] A. Kumar, S. A. Alghamdi, A. Mehbodniya, J. L. Webber, and S. N. Shavkatovich, "Smart power consumption management and alert system using IoT on big data," *Sustainable Energy Technologies and Assessments*, p. 102555, 2022.
- [23] H. Hindy et al., "A taxonomy of network threats and the effect of current datasets on intrusion detection systems," *IEEE Access*, vol. 8, pp. 104650-104675, 2020.
- [24] M. Ge, N. F. Syed, X. Fu, Z. Baig, and A. Robles-Kelly, "Towards a deep learning-driven intrusion detection approach for Internet of Things," *Computer Networks*, vol. 186, p. 107784, 2021.
- [25] V. Hayyolalam, B. Pourghebleh, and A. A. Pourhaji Kazem, "Trust management of services (TMoS): Investigating the current mechanisms," *Transactions on Emerging Telecommunications Technologies*, vol. 31, no. 10, p. e4063, 2020.
- [26] A. Mehbodniya, J. Webber, K. Yano, T. Kumagai, and M. F. Flanagan, "Gibbs Sampling Aided Throughput Improvement for Next-Generation Wi-Fi," in 2018 IEEE Globecom Workshops (GC Wkshps), 2018: IEEE, pp. 1-6.
- [27] P. A. A. Resende and A. C. Drummond, "Adaptive anomaly-based intrusion detection system using genetic algorithm and profiling," *Security and Privacy*, vol. 1, no. 4, p. e36, 2018.
- [28] T. A. Alamiydy, M. Anbar, Z. N. Alqattan, and Q. M. Alzubi, "Anomaly-based intrusion detection system using multi-objective grey wolf optimisation algorithm," *Journal of Ambient Intelligence and Humanized Computing*, vol. 11, no. 9, pp. 3735-3756, 2020.
- [29] Y. Zhang, P. Li, and X. Wang, "Intrusion detection for IoT based on improved genetic algorithm and deep belief network," *IEEE Access*, vol. 7, pp. 31711-31722, 2019.
- [30] A.-u.-H. Qureshi, H. Larijani, J. Ahmad, and N. Mtetwa, "A heuristic intrusion detection system for Internet-of-Things (IoT)," in *Intelligent computing-proceedings of the computing conference*, 2019: Springer, pp. 86-98.
- [31] S. Dwivedi, M. Vardhan, S. Tripathi, and A. K. Shukla, "Implementation of adaptive scheme in evolutionary technique for anomaly-based intrusion detection," *Evolutionary Intelligence*, vol. 13, no. 1, pp. 103-117, 2020.
- [32] R. Gassais, N. Ezzati-Jivan, J. M. Fernandez, D. Aloise, and M. R. Dagenais, "Multi-level host-based intrusion detection system for Internet of things," *Journal of Cloud Computing*, vol. 9, no. 1, pp. 1-16, 2020.
- [33] S. Aldhaheeri, D. Alghazzawi, L. Cheng, B. Alzahrani, and A. Al-Barakati, "Deepdca: novel network-based detection of iot attacks using artificial immune system," *Applied Sciences*, vol. 10, no. 6, p. 1909, 2020.
- [34] J. Brown and M. Anwar, "Blacksite: human-in-the-loop artificial immune system for intrusion detection in internet of things," *Human-Intelligent Systems Integration*, vol. 3, no. 1, pp. 55-67, 2021.
- [35] A. Khraisat, I. Gondal, P. Vamplew, and J. Kamruzzaman, "Survey of intrusion detection systems: techniques, datasets and challenges," *Cybersecurity*, vol. 2, no. 1, pp. 1-22, 2019.
- [36] O. Nguyen, "HSSCIoT: An Optimal Framework based on Internet of Things-Cloud Computing for Healthcare Services Selection in Smart Hospitals," *Advances in Engineering and Intelligence Systems*, vol. 1, no. 02, 2022.
- [37] F. Kuang, W. Xu, and S. Zhang, "A novel hybrid KPCA and SVM with GA model for intrusion detection," *Applied Soft Computing*, vol. 18, pp. 178-184, 2014.
- [38] W. Wang, X. Zhang, and S. Gombault, "Constructing attribute weights from computer audit data for effective intrusion detection," *Journal of Systems and Software*, vol. 82, no. 12, pp. 1974-1981, 2009.
- [39] A. Al-Moalimi, J. Luo, A. Salah, K. Li, and L. Yin, "A whale optimization system for energy-efficient container placement in data centers," *Expert Systems with Applications*, vol. 164, p. 113719, 2021.

Autonomous Path Planning for Industrial Omnidirectional AGV Based on Mechatronic Engineering Intelligent Optical Sensors

Yuanyuan pan*

Jiangxi Technical College of Manufacturing, Nanchang 330095, Jiangxi, China

Abstract—With the rapid development of modern industry, the application of automated mechanical and electronic technology is gradually increasing, and the research on automatic path planning is also receiving increasing attention. In this environment of rapid technological progress, rapid growth of the knowledge economy, and fierce competition, industrial intelligence has become an indispensable part of social development. Industrial Automated Guided Vehicle (AGV) has put forward higher requirements for the application of automatic control technology in the planning and research of autonomous path planning. Autonomous path planning with AGV as the service object is currently the most widely used direction in industrial production processes, with the best development prospects and the highest market demand. Optimizing autonomous path planning for AGV is of great significance in promoting the process of industrial modernization and improving industrial production efficiency. In order to solve the problems of low path planning efficiency, excessive reliance on the rich experience and subjective judgment of relevant personnel, and excessive consumption of path planning costs in traditional AGV omnidirectional autonomous path planning, this article attempted to introduce sensor technology to conduct in-depth research on AGV omnidirectional automatic path planning. Based on intelligent optical sensors and combined with ant colony algorithm, the autonomous path planning model for AGV was optimized, and an innovative AGV omnidirectional autonomous path planning model application experiment was conducted in two industrial production enterprises in a certain region. Comparative analysis of experimental data showed that the innovative AGV omnidirectional autonomous path planning model studied in this article had an average improvement of about 17.8% in four evaluation indicators compared to traditional AGV omnidirectional autonomous path planning models.

Keywords—Smart machinery; optical sensors; industrial development; autonomous path planning

I. INTRODUCTION

The development of science and technology is a very complex, lengthy, challenging, and competitive process. In order to adapt to the increasingly competitive modern industrial market, the research on autonomous path planning for systematic omnidirectional AGVs has become the primary task at present. The path planning research that combines the motion transformation of an object or device with the surrounding environment is a flexible design aimed at adapting to external conditions and constraining internal targets. This design idea can achieve response to external environmental

stimuli, allowing the target subject to perform autonomous control to complete specified tasks. In the research of automatic path planning, this article has conducted in-depth research, promoting the industrialization process of cities.

Some scholars have conducted experimental analysis on the autonomous path planning of mechanical equipment and summarized some issues that arise in conventional research. They hope to optimize the research direction of autonomous path planning. Gul Faiza conducted in-depth discussions on the purpose of autonomous path planning research and discussed how to find the optimal and shortest path in the autonomous path planning process [1]. Karamuk Mustafa proposed a high-performance autonomous path traction system by studying the optimization direction of AGV autonomous path planning during the interaction between upper software and lower mechanical components [2]. Pantic Michael proposed a novel autonomous path planning scheme to enable machines and equipment to perform motion planning tasks interacting with the environment in complex industrial production activities [3]. Marosan Iosif Adrian optimized the omnidirectional autonomous path planning system for AGVs by studying the use of autonomous mobile platforms in modern industry and combining various sensor systems [4]. In order to improve the path tracking accuracy and stability of AGV vehicles in complex environments, Liu Yaqiu proposed an improved autonomous path control tracking method, which greatly improves the trajectory deviation phenomenon [5]. The above research summarizes the theoretical framework of autonomous path planning.

The optimization of autonomous path planning models is aimed at adapting to more complex industrial production environments and exploring for this purpose. Seder Marija has developed a new omnidirectional AGV autonomous path planning solution based on an open logistics innovation platform for local manufacturing logistics automation systems. It is suitable for complex and difficult transportation tasks, which can improve the control level of local mobile robots and prove its effectiveness [6]. Zhang Jie analyzed and studied the dynamic control of AGV in local industrial production activities. He combined autonomous guidance of mechanical equipment in the Internet of Things with decentralized decision-making methods for path planning and proposed an AGV design scheme using McNumb wheels for autonomous omnidirectional path planning [7]. Quan Yanming explored the balance and motion trajectory of AGV in industrial production activities, and evaluated the safety and reliability of

autonomous trajectory planning during AGV cargo transportation by combining different production line scenarios, loading situations, and motion states [8]. Shentu Shuzhan focused on optimizing the autonomous positioning of mobile robots in indoor industrial problems. He integrated hybrid navigation systems and optimized them on the basis of traditional mobile robot autonomous positioning systems [9]. The above research summarizes and analyzes the autonomous planning problem of mechanical equipment in industrial production processes.

In addition, some researchers have considered how to improve the stability and reliability of AGV autonomous path planning in complex industrial production environments. Fragapane Giuseppe analyzed the scheduling application of AGV in local internal logistics business and proposed a central control unit design model that dynamically responds to system state and environmental changes [10]. Moshayedi Ata Jahangir explored the autonomous path planning and design process of AGV robots and the obstacles to their application in modern industry. He conducted a comparative analysis of AGV autonomous path planning systems for different construction schemes [11]. Lin Rui studied the application effects of guided logistics robots for pallet transportation in local areas. Through performance evaluation and analysis of the stability of automated guidance and the reliability of path planning, he determined that the research on machine automation is the future trend of industrial production [12]. The above studies have all analyzed autonomous path planning for automatic transportation machines, but no specific research plan has been proposed.

In order to solve the unstable performance of AGV autonomous path planning applied in traditional industrial production activities, it is difficult to plan the optimal path to complete the task. In the automated transportation process of AGV, there are still many issues such as manual manipulation. This article comprehensively analyzed the traditional AGV autonomous path planning system and summarized its advantages and disadvantages. Combining an intelligent optical sensor system based on mechatronics and intelligent algorithms, an autonomous path planning model for omnidirectional AGV was studied. This model not only fundamentally solves the problems encountered in some traditional AGV autonomous path planning models, but also has good autonomous path planning capabilities in complex industrial production environments and difficult industrial transportation tasks. It also has strong risk response capabilities in the face of unexpected transportation problems in industrial production activities, making contributions to the modernization process of industrial production.

II. TECHNICAL APPLICATION OF INTELLIGENT OPTICAL SENSORS IN ROBOT AUTONOMOUS PATH PLANNING MODEL

In recent years, the highly integrated technology of sensors continues to make breakthroughs and innovations. Optical sensors are widely used in more and more fields, such as intelligent control, path planning, mode transformation, and so on. In the application of autonomous path planning, how to improve the accuracy of robot intelligent identification applications in the path is the main research direction at

present. Autonomous path planning requires robots to complete tasks with the most efficient motion trajectory in a complex and dynamic production environment. The best collision free path can be found in known or unknown production environments and relatively efficient path planning can be carried out. It can not only reduce the wear and tear of mechanical equipment during movement, but also improve production and work efficiency in industrial activities, which has extremely high practical significance in the process of industrial modernization [13-14].

In order to conduct better road condition analysis and path planning for complex environments in industrial production activities, intelligent research on autonomous path planning of machinery and equipment is the future trend of industrial development. Industrial production activities often require a large number of industrial raw materials and manufactured products to be transported and transmitted cyclically on the industrial assembly line. Artificial methods are mainly used to analyze road conditions and identify paths in complex industrial production environments, which require subjective judgment and visual identification by professional scholars or experienced staff. It is not possible to enable autonomous learning of transportation equipment, greatly reducing transportation efficiency. It is also difficult to ensure the safety and reliability of the planned transportation path.

With the rapid development of science and technology, complex, diverse, and rapidly changing information abounds in daily life and production work. In order to effectively collect this information and promote the progress of industrial automation and control, intelligent optical sensors have emerged, and are applied on working paths with obstacles, thereby improving the dynamic capture performance of obstacles on the path [15-16]. Based on practical needs, this paper tentatively introduces intelligent optical sensor technology to optimize the design of industrial intelligent production and equipment transportation processes. In industrial transportation operations, optical sensors are used to collect real-time road condition information, and the collected road condition information is fed back to the control center using wireless communication technology. Finally, through learning algorithms, road conditions are analyzed and identified in real time. The autonomous path planning system for robots based on intelligent optical sensors has a higher speed of updating road information and adaptability to complex production environments.

Optical sensors generate varying degrees of electrical signals from different photoelectric effects by collecting information on the intensity of light emitted by the light source on the sensor [17]. This principle enables the conversion of light intensity into quantitative digital data. An autonomous path planning model for intelligent optical sensors is introduced to collect photoelectric signal data in industrial production environments. The collected photoelectric signals are subjected to data analysis and feature extraction before being further optimized for processing. Finally, combined with fuzzy rules, road conditions are intelligently identified. As a result, the process utilizes optical sensors to meet real-time monitoring of road conditions and can plan the optimal path to complete the task, improving the intelligence and accuracy of

road condition analysis and path planning on the basis of traditional path planning models.

III. DEVELOPMENT OF AUTONOMOUS PATH PLANNING RESEARCH FOR INDUSTRIAL OMNIDIRECTIONAL AUTOMATED GUIDED VEHICLE

With the extensive practical application of information collection and intelligent control technology in modern science, autonomous robot movement has developed rapidly. Autonomous path planning technology for robots refers to the optimal path planning for robots in complex work environments that does not encounter any collisions from the starting point to the end of the task and meets constraints while following some movement constraints, such as the shortest straight path, the shortest actual time, and the lowest energy consumption. In the construction of modern industry, optimization research on AGV omnidirectional autonomous path planning technology with AGV as the service object is conducive to improving the production efficiency and development process of modern industry.

AGV is mainly used for automatic transportation of raw materials and finished products in industrial production processes. Due to its simple integration, simple programming, and high efficiency, AGV is widely used in industrial manufacturing systems. The working environment of AGVs is mostly under harsh terrain conditions. AGVs need to choose efficient and collision free planning paths as much as possible while completing specified tasks. During transportation, they need higher travel speeds to improve the efficiency of automatic placement and movement of various objects in complex industrial production environments. The optimization of AGV omnidirectional autonomous path planning is an important development direction for modern industries such as discrete manufacturing.

The traditional AGV autonomous path planning method has a low degree of freedom, requiring relevant staff to visually collect road condition information for transportation tasks in complex industrial production environments. Extensive work experience is used to plan paths and set more rigid paths for AGV through programming and other means. The path planned under the traditional AGV autonomous path planning method is difficult to cope with the complex industrial production environment. In the face of sudden and complex road conditions and path obstacles, it is impossible to continue the task set by the program, resulting in a life-and-death lock phenomenon, requiring a large amount of labor costs to detect and correct errors. This does not achieve the original purpose of freeing manpower, reducing costs, and improving production efficiency.

Traditional AGV path planning requires a large amount of manpower and material resources to collect road information in complex industrial production environments. It relies on the professional knowledge of relevant staff with rich work experience and experts to manually plan the AGV transportation path, as well as embedding the program into the AGV core through programming and other methods. The AGV transportation path set in this way is quite rigid. Whenever encountering overly complex road conditions, structures, or sudden obstacles, AGV deadlock occurs, which is not conducive to the conduct of industrial production activities, causing serious consequences such as delayed delivery of production materials at critical moments, leading to the disconnection of the production chain. The optimization of the AGV omnidirectional autonomous path planning model is conducive to promoting the improvement of industrial production efficiency and the advancement of the modernization process. It is necessary to establish evaluation indicators for the AGV omnidirectional autonomous path planning model. Table I shows some evaluation indicators and their behavioral rules.

TABLE I. EVALUATION CRITERIA AND THEIR EVALUATION RULES

Evaluation indicators	Rules of conduct
Road condition monitoring	Speed of road condition information collection Number of road condition information collected Road condition monitoring response time
Road conditions prediction	Speed of road information prediction Number of road condition information forecasts Predicted response time for road condition information

In the optimized AGV omnidirectional autonomous path planning model, highly integrated intelligent optical sensor components are combined, greatly enhancing the ability to collect road information in complex industrial production environments. Then, the obtained road condition information is subjected to data calculation and model learning using a deepening learning algorithm to achieve road condition prediction in complex industrial production environments, and has a higher risk response ability in the face of sudden path obstacle problems. The optimal path that meets the constraints is determined on the premise of completing the set tasks, which greatly improves the level of intelligence and automation in modern industrial production activities, and also has a high task completion rate during the progress of AGV transportation tasks. The AGV path planning research structure is shown in Fig. 1.

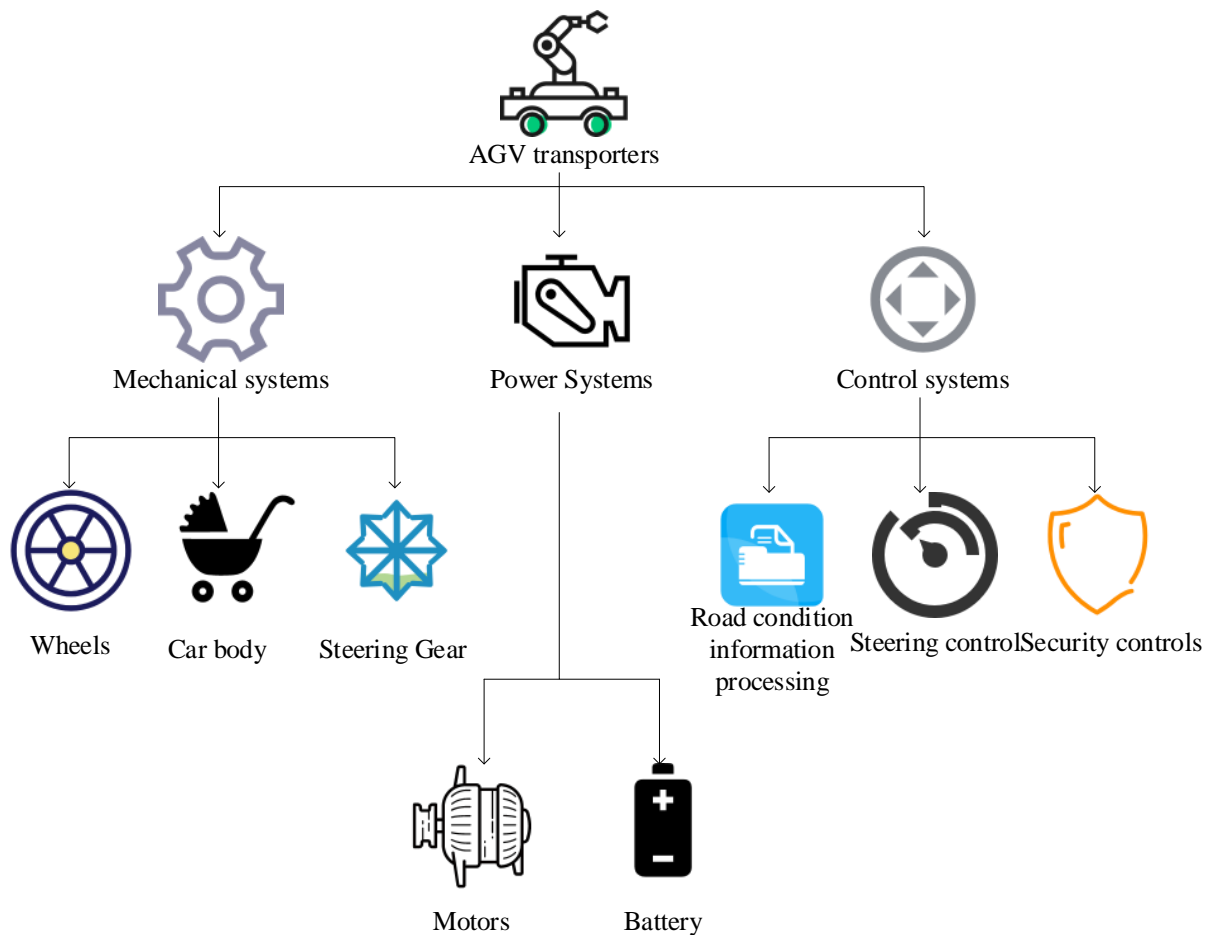


Fig. 1. Structure of the automated guided vehicle path planning study.

IV. APPLICATION OF ANT COLONY ALGORITHM IN AUTOMATED GUIDED VEHICLE OMNIDIRECTIONAL AUTONOMOUS PATH PLANNING

Path planning is one of the important foundations for realizing automatic transportation of AGV, which calculates and classifies the collected data. Then, based on fuzzy rules of data fusion, the optimal path planning is carried out in a complex industrial production environment [18]. In order to overcome the problems of excessive computational cost, difficulty in obtaining optimal solutions, and difficulty in implementing planned paths in complex construction environments, it is possible to solve the path planning problem of a large number of irregular obstacles that hinder AGV from completing industrial transportation tasks in complex industrial production environments. In this paper, an evolutionary ant colony algorithm is used to solve the problem by simulating the process of ants searching for food in nature.

During movement, ant colonies leave a special pheromone secreted on their path. Later, ant colony members make decisions about their direction of travel based on the concentration of pheromones left on the path. The longer the path, the lower the concentration of pheromones. When the ant colony team arrives at the intersection later, they choose a path with a high pheromone concentration to travel, and ultimately find the optimal foraging path through continuous exchange of

information throughout the self-organized travel of the entire ant colony. The ant colony algorithm designed based on this principle can play an important role in the AGV omnidirectional autonomous path planning model [19].

Data collection is the premise and foundation of algorithm calculation. A highly integrated intelligent optical sensor emits light beams from a transmitter on a complex industrial production environment path, and a receiver receives the returned light beams. Different photoelectric signals are generated by varying the intensity of the returned light beams, which are used to reflect the specific road condition information of the complex path in the industrial production environment. The collected road condition information is exchanged with the control center through wireless communication technology, and a large number of collected data samples are used as training samples for learning and calculation by ant colony algorithm. The number of samples is Q . $c_{a,b}(a = 1, 2, \dots, n_1; b = 1, 2, \dots, n_2)$ is the distance between location points a and b in a planar environment, and n_1 and n_2 are two-dimensional vectors corresponding to the planar environment. $J_a(t)$ is the number of environmental samples at position a at time t . $v_{a,b}(t)$

represents the residual pheromone concentration at time t in path (a, b) . The total concentration of pheromones can be calculated by Formula (1).

$$\tilde{v} = \sum_{a=1}^n j_a(t) \quad (1)$$

At the initial moment of the ant colony algorithm calculation, the pheromone concentration content on all paths is quantitatively preset by Formula (2).

$$v_{a,b}(0) = \zeta \quad (2)$$

Among them, ζ is a constant. During the calculation process, sample $q (q=1, 2, \dots, Q)$ determines the next moving direction based on the pheromone concentration on each path. The probability of movement can be calculated by Formula (3).

$$P_{a,b}^q(t) = \begin{cases} (v_{a,b}^\alpha(t) \lambda_{a,b}^\beta(t)) / (\sum_{e \in M_a^q} (v_{a,e}^\alpha(t) \lambda_{a,e}^\beta(t))), & b \in M_a^q \\ 0 & , \text{ other} \end{cases} \quad (3)$$

Among them, $P_{a,b}^q(t)$ represents the probability of a transition from position a to b at time t . $\lambda_{a,b}(t)$ is a local heuristic function for visibility. The parameters α and β represent the influence weights of $v_{a,b}(t)$ and $\lambda_{a,b}(t)$ on the overall sample transfer probability, respectively. M_a^q represents the feasible area of sample q at position a . As time goes on, the pheromone content on the algorithm's decision path gradually decreases. Formula (4) calculates the pheromone content of the path path when the sample movement completes a cycle of movement after u moments.

$$v_{a,b}(t+u) = \theta v_{a,b}(t) + \sum_{q=1}^Q \Delta v_{a,b}^q \quad (4)$$

Among them, θ represents the residual degree after the pheromone gradually decreases on a certain path. $\Delta v_{a,b}^q$ represents the amount of pheromone tracks that the sample remains on path (a, b) during this cycle. Finally, through the tradeoff and comparison of pheromone content and concentration, the optimal path planning decision to complete the task is obtained. The above is the calculation process of ant colony algorithm used in the AGV autonomous path planning model in this article. The application of ant colony algorithm makes the AGV omnidirectional autonomous path planning model more efficient. The computational structure of the ant colony algorithm is shown in Fig. 2.

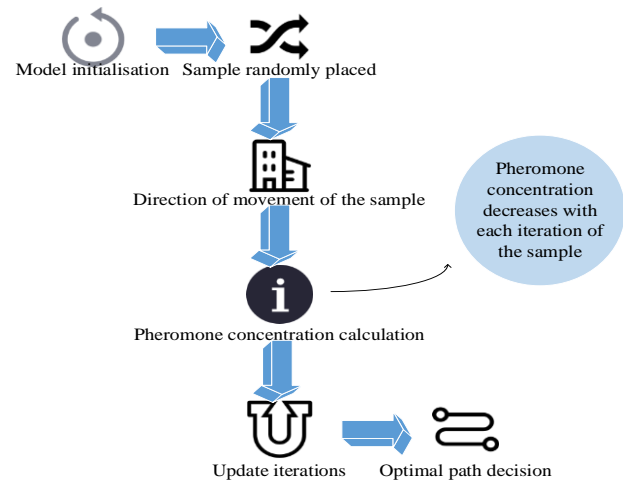


Fig. 2. The computational structure of the ant colony algorithm.

V. APPLICATION EXPERIMENT OF AUTOMATED GUIDED VEHICLE OMNIDIRECTIONAL AUTONOMOUS PATH PLANNING MODEL BASED ON INTELLIGENT OPTICAL SENSORS

With the continuous advancement of industrial modernization, the degree of automation is also gradually improving, and the optimization and upgrading of automatic control systems is the current development trend. The invention of intelligent materials and the development of highly integrated sensor technology pose new challenges to industrial automation. However, in the process of industrial production and transportation, there are still many transportation risks and room for improvement. As an important component of modern industrial development, AGV autonomous path planning and multi-directional parallel control methods are being studied in the direction of high accuracy and reliability.

This article conducts an in-depth analysis of the original AGV omnidirectional autonomous path planning model and identifies the advantages and disadvantages of the traditional AGV omnidirectional automatic path planning model. It proposes solutions to some risks and hidden dangers in the traditional AGV omnidirectional automatic path planning mode. In this paper, based on highly integrated intelligent optical sensors and neural network technology, combined with ant colony algorithm, an omnidirectional autonomous path planning model for AGV was constructed. Laser light was emitted through a transmitter into the industrial production environment, and then the returned refracted light was collected by highly integrated optical sensors. Different light intensities irradiate the photosensitive element to generate different photoelectric signals, and the collected photoelectric signals are exchanged and transmitted by wireless communication technology and the control center. The obtained electrical signal data was injected into the AGV omnidirectional autonomous path planning model as an original sample, and the data was calculated and classified by an ant colony algorithm. Combined with fuzzy rule planning, the optimized path for transportation tasks can be better completed. In this process, real-time monitoring of road information in the industrial production environment was

carried out, and risk issues arising on the planned path were promptly investigated and resolved.

With this model structure and data algorithm, an omnidirectional autonomous path planning model for AGV based on intelligent optical sensors was formed. On the basis of inheriting the advantages of traditional AGV path planning models, optimization was conducted to address the shortcomings of traditional AGV path planning that are not intelligent and reliable, improving the monitoring effect of traditional AGV path planning models on complex industrial production environments and their ability to respond to obstacles and risks in planning paths. This AGV omnidirectional autonomous path planning model improves the objectivity and scientificity of traditional AGV path planning models in path planning tasks. It saves a lot of manpower and material costs, and effectively allocates computing resources, which can open up a new direction for the research of AGV omnidirectional automatic path planning. However, it still requires some experiments to conduct in-depth verification.

First, two local industrial production enterprises, A and B, were tested for AGV omnidirectional autonomous path planning applications. During the experiment, the laser probe of the AGV transportation equipment emits laser light on the path in the industrial production environment, and the probe on the AGV transportation equipment collects the light reflected from the path. Intelligent optical sensors collect different photoelectric signals generated by the returned light shining on photosensitive devices, and generate corresponding digital data through analog-to-digital conversion. The obtained large amount of signal data is transmitted to the control center through wireless communication technology, and the large amount of data is calculated and analyzed by the ant colony algorithm as the original sample to build a learning model. Combining fuzzy rules for optimal path planning, an AGV autonomous planning path that can complete transportation

tasks with the highest efficiency is obtained. While monitoring the industrial production environment in real time, it can conduct sensitive monitoring of light fluctuations for sudden obstacles appearing on the path, thereby effectively and timely avoiding the risk of sudden obstacles.

The managers and relevant staff of the AGV omnidirectional autonomous path planning model of Enterprise A were surveyed with an application satisfaction questionnaire, and the upper limit of the evaluation index for each satisfaction index was 10. Based on the exponential feedback from the model application satisfaction questionnaire, the application satisfaction evaluations of traditional and innovative AGV omnidirectional autonomous path planning models were analyzed using an exponential comparison, as shown in Fig. 3.

Fig. 3(a) shows the four satisfaction evaluation indicators of Enterprise A under the traditional AGV omnidirectional autonomous path planning model. The four evaluation indicators are road condition monitoring, road condition prediction, transportation time, and risk response. The evaluation index sizes of the four satisfaction evaluation indicators were 6, 5, 4, and 5, respectively. Fig. 3(b) shows the four satisfaction evaluation indicators of Enterprise A under the innovative AGV omnidirectional autonomous path planning model. The evaluation index sizes of the four satisfaction evaluation indicators were 6, 6, 5, and 6, respectively. The innovative AGV omnidirectional autonomous path planning model outperformed the traditional model in terms of the evaluation index of all indicators except the satisfaction evaluation index of road condition monitoring. This indicates that intelligent sensor technology is not omnipotent, and tradition does not mean backwardness. In the process of optimizing the AGV omnidirectional autonomous path planning model, it is necessary to proceed from reality, based on the advantages and disadvantages of tradition, to improve the shortcomings and shortcomings.

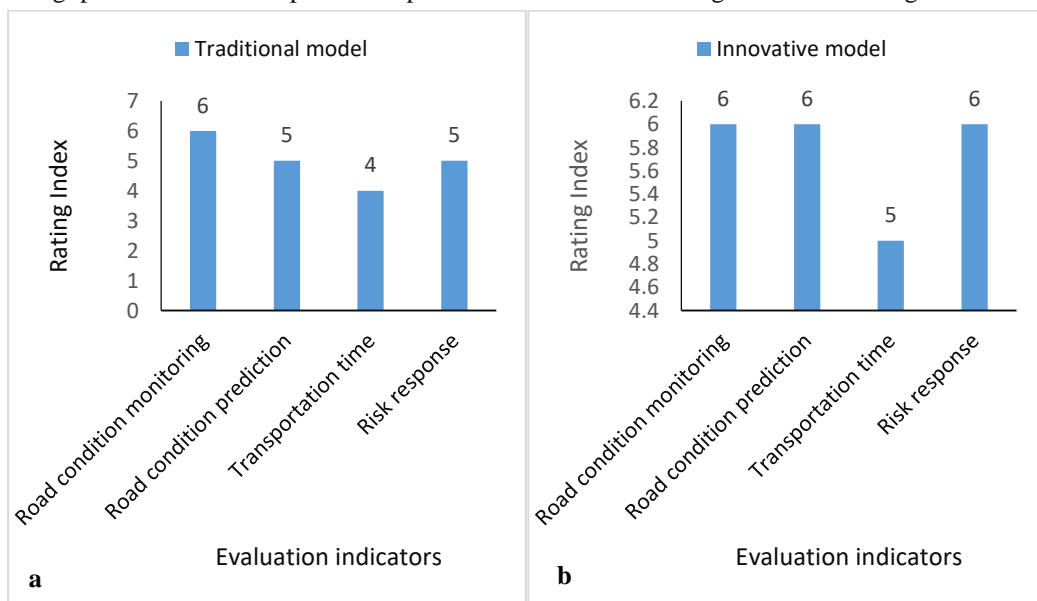


Fig. 3. Satisfactory comparative analysis of the application of traditional and innovative models in Enterprise A, (a). Evaluation of satisfaction with the application of the traditional model in Enterprise A, (b). Evaluation of satisfaction with the application of the innovative model in Enterprise A.

Then, the managers and relevant staff of the AGV omnidirectional autonomous path planning model of Enterprise B were surveyed with an application satisfaction questionnaire. Based on the index feedback from the model application satisfaction questionnaire, an index comparison analysis was conducted on the satisfaction evaluation of the application effect of traditional and innovative AGV omnidirectional autonomous path planning models in Enterprise B. The upper limit of each evaluation index was 10, as shown in Fig. 4.

Fig. 4(a) shows the four satisfaction evaluation indicators for Enterprise B under the traditional AGV omnidirectional autonomous path planning model. The evaluation index sizes for the four satisfaction evaluation indicators, namely, road condition monitoring, road condition prediction, transportation time, and risk response, were respectively 5, 5, 6, and 4. Fig. 4(b) shows the evaluation index sizes of these four satisfaction evaluation indicators for Enterprise B under the innovative AGV omnidirectional autonomous path planning model, which were respectively 6, 6, 7, and 5. As shown in the comparison between Fig. 4(a) and Fig. 4(b), the innovative AGV omnidirectional autonomous path planning model was superior to the traditional AGV omnidirectional autonomous path planning model in terms of four satisfaction evaluation indicators. This indicates that the omnidirectional autonomous path planning model for AGV based on intelligent optical sensors is more efficient than the traditional omnidirectional autonomous path planning model for AGV in terms of overall performance. Electronic information automation technology provides an intelligent and automated development direction for AGV transportation projects in industrial production activities. It improves transportation efficiency in industrial production activities, and contributes to the process of combining industrial automation and information technology.

Finally, this paper analyzed the performance differences between the AGV omnidirectional autonomous path planning model based on intelligent optical sensors and the traditional AGV omnidirectional autonomous path planning model, as shown in Fig. 5.

By summarizing the application performance of traditional and optimized models in Enterprises A and B, the performance differences between traditional and optimized models in four aspects of road condition monitoring, road condition prediction, transportation time, and risk response were analyzed. Fig. 5(a) shows the performance of traditional models in practical applications. In the application process, traditional models have poor performance in coping with risks of sudden problems, and their performance in road condition prediction and transportation time consumption is relatively ordinary. Therefore, there is potential for further optimization in road condition monitoring.

Fig. 5(b) shows the performance of the innovative model in practical applications. From the data shown in the figure, it can be seen that the optimized model has more advantages in performance compared to traditional models. Due to the use of advanced technology and algorithmic processing, innovative models have a more efficient information processing speed, with varying degrees of performance optimization in road condition monitoring, road condition prediction, transportation time, and risk response.

After a comprehensive comparative analysis of the two data, it can be concluded that the innovative AGV omnidirectional autonomous path planning model proposed in this article had an average improvement of about 17.8% in four satisfaction evaluation indicators compared to the traditional AGV omnidirectional autonomous path planning model.

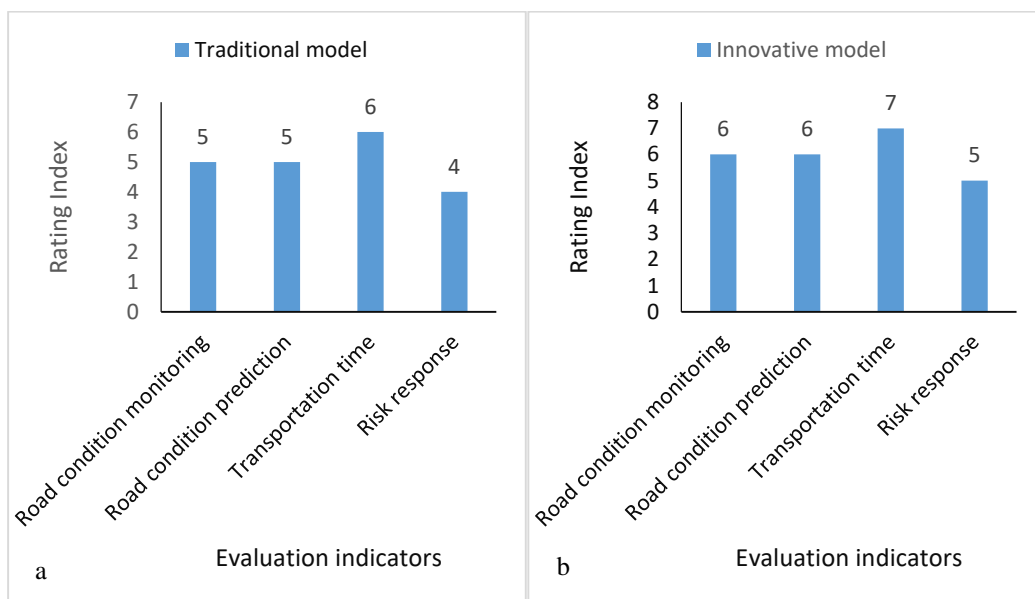


Fig. 4. Satisfactory comparative analysis of the application of traditional and innovative models in Enterprise B; (a). Evaluation of satisfaction with the application of the traditional model in Enterprise B. (b). Evaluation of satisfaction with the application of the innovative model in Enterprise B.

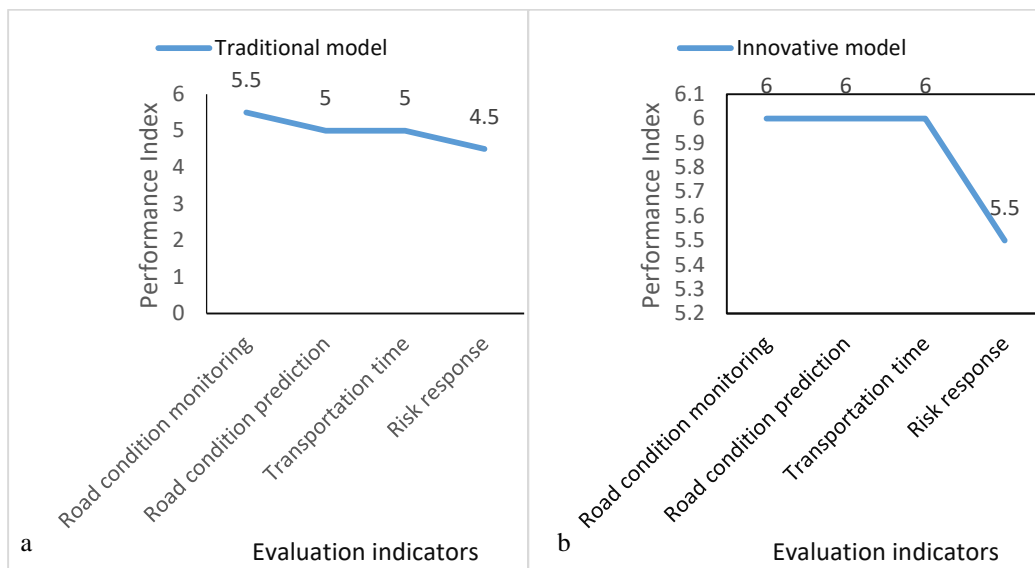


Fig. 5. Comparative analysis of the performance differences between traditional and innovative models, (a). Performance evaluation of traditional model application, (b). Performance evaluation of innovative model application.

VI. CONCLUSION

With the development of modern industry, AGV autonomous path planning technology has become an important field that has attracted much attention. It can not only be used as a new transportation tool for industrial production activities, but also become the most widely used technology carrier for information transmission and processing in future industrial production activities. Although the application of AGV in the field of industrial automated transportation is approaching maturity, there are still many problems, such as complex mechanisms, high costs, and low operating efficiency. With the development and innovation of highly integrated sensor technology, new challenges have been posed to AGV omnidirectional autonomous path planning. In order to solve the problems of high cost in collecting road condition information during the route planning process of traditional AGV autonomous path planning models, rigid route planning for AGV transportation tasks, and untimely response of AGV to unexpected problems arising from planned routes during transportation tasks, based on highly integrated intelligent optical sensors, this paper combines intelligent ant colony algorithm to optimize the AGV omnidirectional autonomous path planning model. In the application process of this model, corresponding countermeasures have been proposed to address the shortcomings and shortcomings of the traditional AGV omnidirectional autonomous path planning model. In the actual industrial production activities, the transportation efficiency of industrial production activities has been improved, and a large amount of manpower and material costs have been saved. At the same time, the complex industrial production environment has been monitored in real time, and sudden obstacles on the AGV transportation path have been risk predicted and timely responded to. Planning a more efficient route on the basis of ensuring the completion of industrial production and transportation tasks has promoted the process of industrial production modernization. This article has

conducted model application experiments using this innovative model in two industrial production enterprises in a certain region, and conducted a satisfaction evaluation questionnaire survey on the application effect of intelligent optical sensors in the AGV omnidirectional autonomous path planning model. Based on the analysis of the satisfaction evaluation index of the experimental results, it can be concluded that this AGV omnidirectional autonomous path planning model using intelligent optical sensors has greatly improved the efficiency of transportation tasks in industrial production activities. It is worth affirming that the optimized AGV omnidirectional autonomous path planning model has a higher level of intelligence compared to traditional AGV omnidirectional autonomous path planning models. Traditional models consume a lot of costs to plan paths that are too fixed, making it difficult to specify safer avoidance plans based on road conditions when facing sudden obstacles and emergency risks. The optimization model in this article can save a lot of time and labor costs while ensuring the progress of transportation operations in the face of complex industrial production environments, and its emergency avoidance ability is also more outstanding. However, research on energy consumption and resource integration is not yet complete, and further exploration is needed. On the basis of inheriting the advantages of traditional path planning, this article has optimized some shortcomings and made contributions to the application of advanced technology in modern industrial development. However, further in-depth research is needed to explore the integration of model computing resources and energy consumption, in order to design an efficient model with faster path planning speed and lower energy consumption.

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REFERENCES

- [1] Faiza, Alhady, S., & Wan, R. "A review of controller approach for autonomous guided vehicle system." *Indonesian Journal of Electrical Engineering and Computer Science* 20.1 (2020): 552-562.
- [2] Karamuk, Mustafa, Ismail SAVCI, and Hakan Ocakli. "A Survey on Traction System Development of Automated Guided Vehicles." *European Journal of Technique (EJT)* 12.1 (2022): 1-12.
- [3] Pantic, Michael. "Mesh manifold based riemannian motion planning for omnidirectional micro aerial vehicles." *IEEE Robotics and Automation Letters* 6.3 (2021): 4790-4797.
- [4] Marosan, Iosif Adrian. "Study Regarding the Autonomous Mobile Platforms Used in Industry." *Acta Universitatis Cibiniensis. Technical Series* 72.1 (2020): 49-56.
- [5] Liu, Yaqiu. "An improved hybrid error control path tracking intelligent algorithm for omnidirectional AGV on ROS." *International Journal of Computer Applications in Technology* 64.2 (2020): 115-125.
- [6] Seder, Marija. "Open platform based mobile robot control for automation in manufacturing logistics." *IFAC-Papers on Line* 52.22 (2019): 95-100.
- [7] Zhang, Jie, Or Aviv Yarom, and Xiaobo Liu-Henke. "Decentralized, Self-optimized Order-acceptance Decision of Autonomous Guided Vehicles in an IoT-based Production Facility." *International Journal of Mechanical Engineering and Robotics Research* 10.1 (2021): 1-6.
- [8] Quan, Yanming. "AGV Motion Balance and Motion Regulation Under Complex Conditions." *International Journal of Control, Automation and Systems* 20.2 (2022): 551-563.
- [9] Shentu, Shuzhan. "Hybrid Navigation System Based Autonomous Positioning and Path Planning for Mobile Robots." *Chinese Journal of Mechanical Engineering* 35.1 (2022): 1-13.
- [10] Fragapane, Giuseppe. "Planning and control of autonomous mobile robots for intralogistics: Literature review and research agenda." *European Journal of Operational Research* 294.2 (2021): 405-426.
- [11] Moshayedi, Ata Jahangir, Li Jinsong, and Liefu Liao. "AGV (automated guided vehicle) robot: Mission and obstacles in design and performance." *Journal of Simulation and Analysis of Novel Technologies in Mechanical Engineering* 12.4 (2019): 5-18.
- [12] Lin, Rui, Haibo Huang, and Maohai Li. "An automated guided logistics robot for pallet transportation." *Assembly Automation* 41.1 (2020): 45-54.
- [13] Fragapane, Giuseppe. "Planning and control of autonomous mobile robots for intralogistics: Literature review and research agenda." *European Journal of Operational Research* 294.2 (2021): 405-426.
- [14] Reis, Wallace Pereira Neves dos, Giselle Elias Couto, and Ordes Morandin Junior. "Automated guided vehicles position control: a systematic literature review." *Journal of Intelligent Manufacturing* 34.4 (2023): 1483-1545.
- [15] Song, Jing. "Automatic guided vehicle global path planning considering multi-objective optimization and speed control." *Sensors and Materials* 33.6 (2021): 1999-2021.
- [16] Fusic, S., and T. Sugumari. "A Review of Perception-Based Navigation System for Autonomous Mobile Robots." *Recent Patents on Engineering* 17.6 (2023): 13-22.
- [17] Sergiyenko, Oleg Yu, and Vera V. Tyrsa. "3D optical machine vision sensors with intelligent data management for robotic swarm navigation improvement." *IEEE Sensors Journal* 21.10 (2020): 11262-11274.
- [18] Patle, B. K., et al. "A review: On path planning strategies for navigation of mobile robot." *Defence Technology* 15.4 (2019): 582-606.
- [19] Li, Junjun. "Three-phase qubits-based quantum ant colony optimization algorithm for path planning of automated guided vehicles." *Int. J. Robot. Autom* 34.2 (2019): 156-163.

A Study on the Evaluation Model of In-depth Learning for Oral English Learning in Online Education

Yanli Ge

Office of Foreign Language, Basic Teaching Department,
Changchun University of Architecture and Civil Engineering, Changchun, 130607, China

Abstract—The trend of globalization in the world is becoming increasingly frequent, and people from different regions are communicating more closely. Therefore, the demand for a second language is constantly expanding, accelerating the development of the field of English oral evaluation and also accelerating the development of online education. The study proposes a text priori based oral evaluation model, which is based on the Transformer model and uses target phonemes as input to the Decoder. The model successfully predicts the relationship between actual pronunciation and error labels. At the same time, a self-supervised oral evaluation model with accent is constructed, which simulates the training process of misreading data by calculating semantic distance. The experimental results show that when the training set ratio reaches its maximum in the Speed Ocean dataset and the L2 Arctic dataset, the F1 values of the proposed method are 0.612 and 0.596, respectively; the length of the target phoneme has a smaller impact on this model compared to other models. Experiments have shown that the proposed deep learning method can alleviate deployment difficulties, directly optimize the effectiveness of oral evaluation, provide more accurate feedback, and also provide users with a better learning experience. This has practical significance for the development of the field of oral evaluation.

Keywords—Spoken English; online education; transformer model; deep learning; evaluation model

I. INTRODUCTION

Deep learning technology has largely enhanced the efficiency of speech recognition. Deep speech recognition technology can recognize the phonemes of students' speech and compare them with the text they read. Compared with traditional evaluation methods, this method only needs to train a single recognition model, without complex modeling or providing additional comparative corpus. This speech recognition technology has become the main solution in spoken language testing [1-2]. However, the current spoken language testing methods based on deep learning mostly focus on speech recognition, mainly from improving the accuracy of speech recognition. These methods tend to use better acoustic models in speech testing to improve the effect of oral testing, thus ignoring the shortcomings of speech recognition in oral testing. The spoken language test algorithm based on speech recognition mainly aims at the phoneme and target phoneme in speech recognition to misread. Its optimization aims at improving the accuracy of speech recognition, rather than directly optimizing the effect of oral test. The misreading result

generated by the algorithm is binary. It misreads the identified phoneme and target phoneme by aligning them, and judges whether to align the target phoneme or not, so it is unable to adjust the severity of the evaluation. At present, most of the mainstream recognition patterns need autoregressive recognition and decoding. This process is not real-time, which is a big defect for students who require fast feedback [3-4]. Therefore, to solve the above problems, a text priori oral evaluation model is proposed. This model uses the Transformer mode as the basis of the oral test, and appends a target text entered by the Decoder. By converting the non-differential calibration to the data preparation stage, the misreading of each target is improved, thus realizing the error recognition of each target. Furthermore, the study further discusses the role of phonemes in speech recognition models, demonstrating the key role of phonemes in English oral teaching. The innovation of this method lies in optimizing the speech recognition model from the perspective of oral phonemes, enabling learners from different regions and accents to learn from online oral teaching. The method proposed in the study can effectively recognize the phonemic features of spoken language, making oral learning more widely applicable and playing an important role in promoting online oral teaching.

II. RELATED WORK

The gradual development of deep learning has become the research object of many international scholars and has achieved certain results. Wang et al. implemented a new fault location by using multiple feature groups for depth and breadth learning. They analyzed suspicious features based on spectrum and mutation by combining the combination features of invariants based on suspiciousness, static measurement, collapse stack tracking and invariants change features. Through testing a real software defect standard, Defects4J, higher early diagnosis performance than traditional methods were confirmed [5]. KotaV et al. adopted neural networks for emotion analysis. Methods CNN, double LSTM, attention mechanism and other methods were used for emotional analysis. CNN can reduce complexity, while dual LSTM can help handle long input text. This method uses the attention mechanism to determine the importance of each hidden state and weight it [6]. Seebeck and other scholars developed a DL method, which can automatically obtain comprehensive retinal sensitivity from OCT volume. The relative error of PWS and multiple sclerosis is 2.34 dB, and the minimum relative error is 5.70 and 3.07. Pearson correlation coefficient is 0.66 and 0.84,

Spearman correlation coefficient is 0.68 and 0.83. Their research showed that predicting the retinal function of each measurement site based on OCT scanning can be used as a new visual function prediction method [7]. Kong and his team developed a second-order one-dimensional phase expansion method. The first step is to encode the phase of one dimension using quasi-Grani matrix. The second step is to use the deep convolution neural network to unwrap the phase. Both simulation and measurement results showed that the phase unwrapping quality of this algorithm is significantly improved when the SNR is less than 4 dB, and it can still maintain good performance under negative SNR [8].

There are many types of oral teaching models in the current research field. Chen S introduced an online oral English teaching platform based on the Internet of Things. This platform adopts the technology of Internet of Things to realize the design of the system structure of online oral English teaching platform and establish a virtual teaching environment. The platform corrects the user's mouth shape and pronunciation through the voice teaching system, and establishes a vocabulary tagging model based on long-term memory. He also introduced the attention mechanism into the long-term memory network. The test results showed that the network delay of the system is between 0.26 seconds and 0.37 seconds, which reduces the development time by 50% and increases the human-computer interface by 13.20% [9]. Liu used speech recognition technology to analyze and deal with differences in phoneme expression in spoken English, and made statistics on some errors and areas to be improved in English. The development and promotion of speech recognition technology can effectively reduce the cost of college oral English teaching and promote the improvement of college students' oral English ability [10]. Xu first proposed the concept of five dimensions of AR situational telepresence, i.e. the sense of scene, immersion, reality, interaction, and social telepresence. Then, combined with the actual situation of English teaching, he put forward a theoretical framework to strengthen the teaching of spoken English. Finally, he made a systematic analysis and discussion on the relationship between the proposed

dimensions. He explored the application of augmented reality technology in classroom and online teaching from three levels of perception, acceptance and application [11].

To sum up, deep learning has been widely used in many fields and has shown strong performance. However, the field of oral evaluation is still in the development stage, so the research applies the deep learning technology to the oral evaluation model for the first time. The purpose of the study is to improve the oral evaluation model and further promote the development of oral evaluation.

III. ORAL ENGLISH LEARNING EVALUATION MODEL FOR ONLINE EDUCATION BASED ON IMPROVED DEEP LEARNING ALGORITHM

A. The Construction of Transformer Oral Evaluation Model based on Text Priors

With the continuous development of computer deep learning technology, the task of speech recognition has been greatly improved. The evaluation model based on in-depth learning of spoken English has been applied in online oral English education [12-14]. The research first proposes a text priori-based oral evaluation model, whose structure is shown in Fig. 1.

The model built in Fig. 1 obtains the error status label of the phoneme by comparing the actual phoneme with the target phoneme. The obtained wrong label can avoid the model from introducing an improbable alignment operation during training, and at the same time, the alignment operation will be transferred to the data preparation stage. This model is significantly different from the spoken language evaluation model using speech recognition. The model used in the research does not use the actual pronunciation phoneme as the input of Decoder, but uses the target phoneme. The prediction expression of actual pronunciation and error label is shown in formula (1).

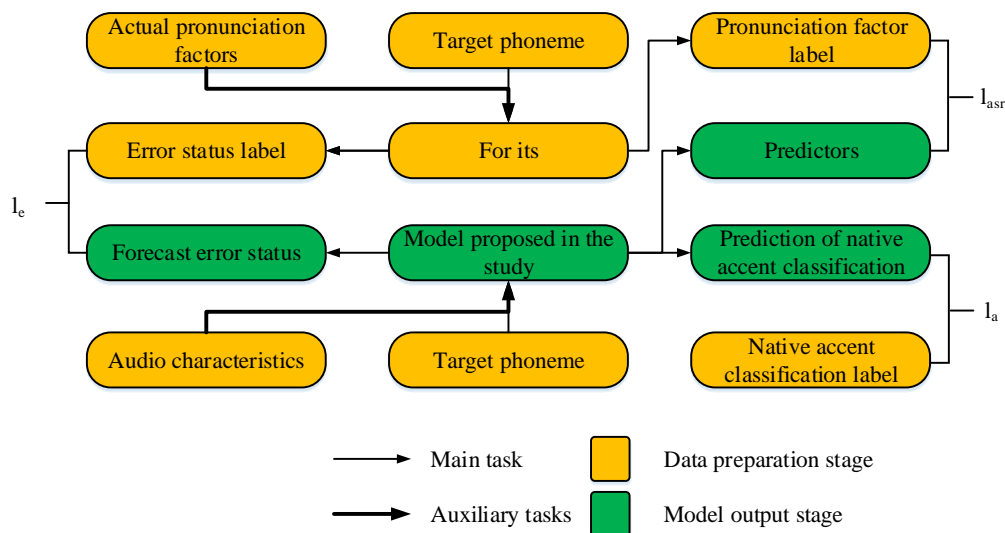


Fig. 1. Work flow of oral evaluation based on text priori.

$$\hat{P}, \hat{E} = Decoder(H, P^{tgt}) \quad (1)$$

In formula (1), \hat{P} represents the actual pronunciation. \hat{E} indicates an error label. P^{tgt} is the target phoneme. H represents the characteristics of audio. When outputting the model, the output length should be paid attention. In the oral language evaluation model of speech recognition, when to output <EOS> determines the output length of speech sequence. Moreover, when the length of speech sequence is aligned with the target text, the model will output an error status sequence, which is the same length as the target text. The model used in the study has used phoneme tagging to align the speech sequence with the target text in the training process, which can also make the length of the error state equal to the target text. The research takes “hi” as an example, and aligns the labeled actual phoneme “HH EY” with the target text phoneme “HH AY” in the data preparation stage, and then obtains the phoneme error status target. For audio features and target phonemes, the output of the model reflects the matching between the two. A two-layer convolutional network is superimposed on the back end of Decoder, and the convolution core size of the network is $3 * 3$. ReLU function is used as the activation function, and the output value is mapped to $[0,1]$ interval through linear layer and sigmoid function. The oral language evaluation model based on text priori is shown in Fig. 2.

Since the evaluation can be differentiated in the output of the evaluation error state, the loss function between the predicted state and the real label can be directly calculated and optimizes the whole model using back-propagation. The research uses Binary Cross-Entropy (BCE) to train the predicted value and label, and its expression is shown in formula (2) [15-17].

$$l_e^{BCE} = BCE(\hat{E}, E) \quad (2)$$

In formula (2), E represents the real label. In the evaluation task, BCE loss does not represent a loss function.

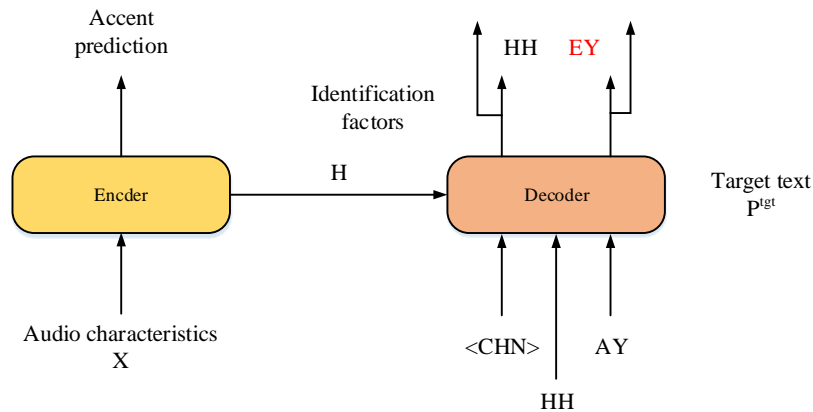


Fig. 2. Structure of spoken language evaluation model based on text priori.

B. Self-Supervised Acoustic Model Construction

In the practice of second language learning, learners are extremely vulnerable to the objective influence of their mother

When the model extracts the relevant acoustic features of the speaker's mother tongue as an auxiliary task, the research adds a module about mother tongue prediction to the output of Encoder. This module predicts the speaker's mother tongue through the input audio features. The input sequence audio features need to be converted into a single classification output, so the research uses the Statistics pooling layer based on mean variance statistics to achieve the above purpose. Its expression is shown in formula (3).

$$\hat{a} = StatisticsPooling(H) \quad (3)$$

In formula (3), \hat{a} represents the single classification output of the sequence audio feature transformation. Cross Entropy (CE) is also used for the training of \hat{a} and a . Its expression is shown in formula (4).

$$l_a = CrossEntropy(\hat{a}, a) \quad (4)$$

The criterion for classifying the error state is the misreading of the target phoneme. The model needs more samples for training, otherwise the model cannot combine the output target with the corresponding audio and target phonemes, and then over-fitting occurs. At present, there are few data sets that can be used in oral evaluation, so the research needs to obtain an acoustic model first. The model can be trained by standard speech recognition dataset. After completing the pre-training task, the research will still require the model to complete the auxiliary task of speech recognition, so as to mine more relations between audio features and phonemes. Finally, the loss function is integrated to obtain the formula (5).

$$\begin{cases} l = l_e + \alpha l_a + \beta l_{asr} \\ l_{asr} = CrossEntropy(\hat{P}, P^{out}) \end{cases} \quad (5)$$

In formula (5), α represents the weight of the auxiliary task of native language recognition. β represents the weight of loss function of speech recognition auxiliary task.

tongue pronunciation, which leads to the deviation of their second language pronunciation from the standard pronunciation. There is unavoidable misreading in oral English

assessment. There is a large error between the text annotation of the Second Language (L2) phonetic feature and the actual pronunciation. Therefore, in the absence of actual pronunciation marking, it is difficult to accurately model L2 speech features based on the text priori oral evaluation model. Self-supervised learning (SSL) is a common machine learning method. It can use auxiliary tasks to accurately mine the supervision information related to itself from the massive unsupervised data without external tag data, and then realize effective network training [18-20]. In recent years, the research on SSL in the voice field has attracted more and more attention. The most classic structure in SSL is the Noise Reduction Auto Encoder (DAE). Its main structure is divided into three parts, namely encoder, bottleneck layer and decoder, as shown in Fig. 3.

According to Fig. 3, the DAE will first learn a compressed feature vector from the original features. Then the decoder will process the feature vector to recover the corresponding original data. The feature vectors in the original feature will be compressed once in the encoder and bottleneck layer respectively. Therefore, the original data recovered by the decoder is no longer accompanied by noise and other influence elements, and will be more representative and typical. From Fig. 1, the DAE will modify the original features before importing them. According to the different types of input features, there are also some differences in the modification methods of features, mainly including transformation, masking, and comparative learning. Transformation refers to converting the original voice input information into spectrum information, and then requiring the network model to recover the original waveform from it. Masking refers to treating the input speech feature as 0 randomly, and the most widely used is the

Bidirectional Encoder Representations from Transformer (BERT) model. Comparative learning can ensure that the model can screen out more typical and distinctive speech features under specified conditions. This modification method no longer only destroys and modifies the original input information, but helps the network model learn valuable representative features by adding interference items. The most typical model is Wav2Vec model. The BERT model and Wav2Vec model are organically combined, and a discrete process is added after the encoder completes the encoding of the original features. This realizes the effective integration of discretization process and comparative learning, and obtains the Wav2Vec2 network model, whose structure is shown in Fig. 4.

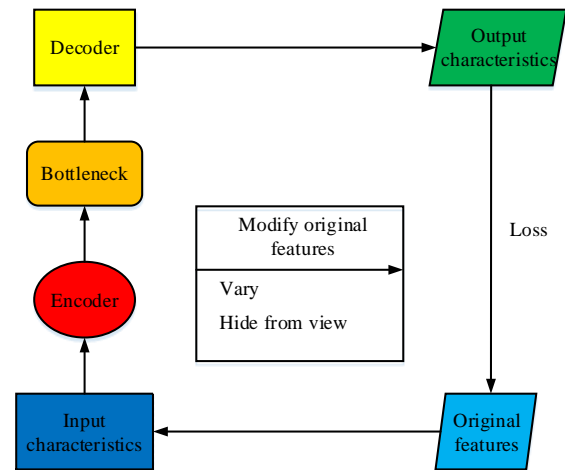


Fig. 3. Network structure diagram of DAE.

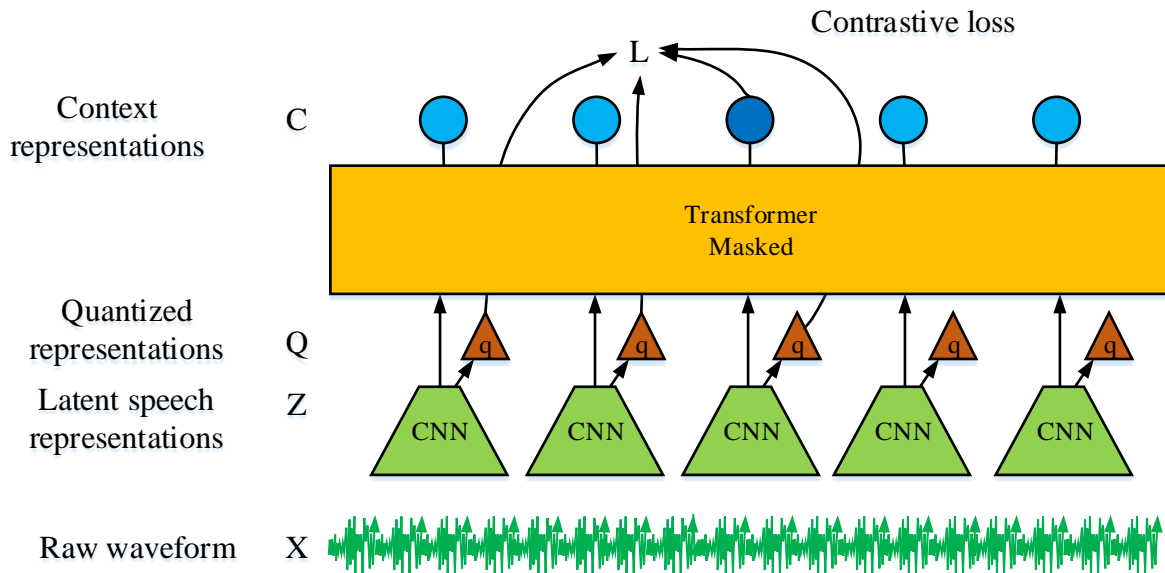


Fig. 4. Structure and training diagram of Wav2Vec2 network model.

Looking at Fig. 4, the original speech feature X can be encoded as Z under the action of the encoder, and Z has a higher degree of abstraction. Then the Wav2Vec2 network

model will enter the discretization process, from which Z can be converted into speech feature Q . Finally, Transformer

can integrate it into a new context feature C . The Wav2Vec2 network model also includes the contrast loss function training model, which can generate a richer discrete code table. On this basis, the discrete acoustic units can be obtained by clustering them with k-Means algorithm, as shown in Fig. 5.

Fig. 5 shows the complete acoustic unit construction process. The circle represents the cluster, the red label and the blue label represent the original acoustic unit and the replaced acoustic unit respectively. Black dots represent each voice data in the training process of the clustering model network. The semantic vector is extracted from the target speech standard and L2 speech feature, and then Class- K speech information is obtained under the clustering effect of k-Means algorithm. Finally, it is converted into discrete acoustic unit sequence- U , as shown in Eq. (6).

$$U = \{u_1, u_2, \dots, u_T\} \quad (6)$$

In formula (6), T is the corresponding length of the discrete acoustic unit sequence, which can replace the original voice features as the input of the network model. For any U , ranking the other $K-1$ acoustic units according to their distance from U , and their corresponding distance is obtained as shown in Formula (7).

$$S^d = \{s_1^d, s_2^d, \dots, s_{K-1}^d\} \quad (7)$$

In formula (7), d is the single semantic distance, that is, the difference between the vector distance of the acoustic unit before and after the replacement in the semantic subspace. It

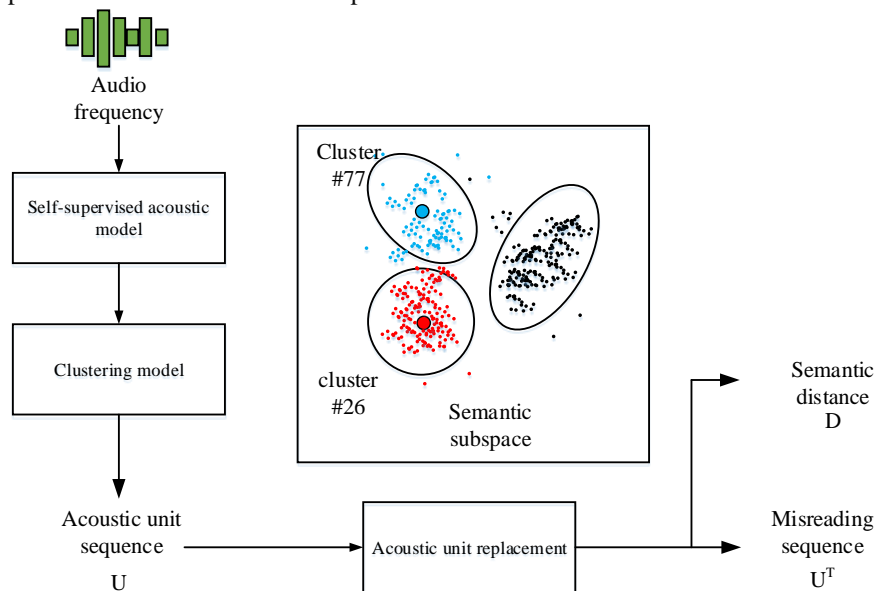


Fig. 5. Self-supervised clustering of original speech features and its replacement.

can accurately reflect the matching degree between the replaced acoustic unit sequence and the original speech features. The research selects the unit closest to k from the dataset as a substitute, and uses normal distribution to select it, as shown in formula (8).

$$k = \min(K-1, \text{int}(\frac{r(K-1)}{3})) \quad (8)$$

The above method can obtain the vector distance difference of the acoustic model in the semantic subspace before and after the replacement. Euclidean distance is selected as the calculation method of distance difference, and the expression is shown in formula (9).

$$d(u, u^r) = \text{MSE}(v, v^r) \quad (9)$$

In formula (9), d refers to the distance difference of the vector. The mute part of the original audio will have a huge distance from other acoustic units after clustering. These outliers will interfere with the model, so the replacement method used in the study should be used under the condition of $d(u, u^r) < H$. If the condition is not met, it will not be replaced. The pre-training process based on acoustic unit replacement is shown in Fig. 6.

In Fig. 6, the original audio is converted into a discrete audio sequence U . Then the new sequence U^r is obtained by replacing the acoustic unit. The distance difference between the two in the quantum space is shown in formula (10).

$$D = \{d_1, \dots, d_T\} \quad (10)$$

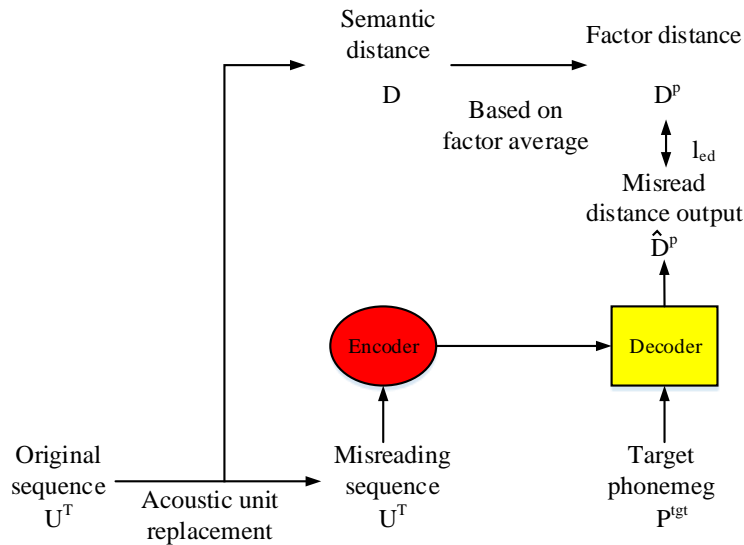


Fig. 6. Pre-training process based on acoustic unit replacement.

To obtain the corresponding distance between phonemes, the initial position of phonemes is searched through the forced alignment tool. Therefore, the corresponding distance of phonemes is shown in formula (11).

$$D^p = \{d_1^p, \dots, d_L^p\} \quad (11)$$

In formula (11), L represents the sequence length of the target phoneme. Finally, the research attempts to predict the distance model of each phoneme with the model, and then make the model learn the degree of deviation from the target text. The loss of the model is expressed by the mean square error function, as shown in formula (12).

$$l_{ed} = MSE(\hat{D}^p, D^p) \quad (12)$$

Formula (13) is the loss function when using the substitution method based on acoustic units for migration prediction.

$$l = l_{ed} + \beta l_{asr} \quad (13)$$

The clustering model is trained in L1 and L2 speech, and the characteristics of standard and non-standard pronunciation

of the target speech are obtained. These features can obtain more fine-grained audio replacement by changing the number of clusters, which greatly increases the authenticity of misread samples.

IV. PERFORMANCE VERIFICATION OF ORAL ENGLISH LEARNING EVALUATION MODEL FOR ONLINE EDUCATION

A. Performance Analysis of Oral Language Evaluation Model based on Text Priori

Before the experimental analysis, the weight of the auxiliary task of mother tongue recognition was set to 0.1. If no native language information is added, the weight is set to 0. The weight of loss function of speech recognition auxiliary task is set to 0.1. The ASR pre-training uses the Librispeech data set. The ratio of training set, verification set and test set is approximately 10:1:1 in this data set. The L2-Arctic data set is used in the oral evaluation task. The data set is divided into training set, verification set and test set according to the ratio of 10:1:4. The test of model performance is mainly evaluated by seven indicators: Phoneme Error Rate (PER), Precision, Accuracy, Recall, F1, False Rejection Rate (FRR) and False Acceptance Rate (FAR). The effect comparison of different models in oral evaluation is Table I.

TABLE I. ORAL EVALUATION OF DIFFERENT METHODS

Model		PER	PRE	ACC	REC
Primitive phoneme	ASR	0.224	0.426	0.787	0.524
	TC-ASR	0.120	0.452	0.833	0.396
	TC-Direct	0.129	0.506	0.824	0.474
Extended phoneme	ASR	0.286	0.403	0.789	0.401
	TC-ASR	0.155	0.569	0.842	0.502
	TC-Direct	0.173	0.500	0.823	0.521
Extended phoneme+	ASR	0.293	0.398	0.786	0.413
	TC-ASR	0.172	0.552	0.838	0.519
	TC-Direct	0.181	0.488	0.818	0.629

Table I shows the performance comparison of different models under different conditions. In Table I, there is a certain gap between the PER, RRE, ACC and REC indicators of ASR model and the other two models. The ACC index of TC-ASR model is higher than TC-Direct, while the remaining three indexes are lower than TC-Direct model. The PER value of TC-Direct model in “extended phoneme+” is 0.181. The ACC value in “extended phoneme” is 0.823. The REC value in “extended phoneme+” is 0.629. The experimental results show that the TC-Direct model has better performance in oral evaluation.

Fig. 7 shows the F1 value result of the translation model. Fig. 7 (a) shows the F1 value of the model in the original

phoneme. The F1 of ASR is 0.464. TC-ASR model is a text priori phoneme level speech recognition model, its F1 value in the original phoneme score is 0.462. The TC-Direct model is a text priori model proposed by the study, and its F1 score in the original phoneme is 0.538. Fig. 7 (b) shows the F1 value of the model in the extended phoneme. The F1 score of ASR model is 0.402. The F1 score of TC-ASR model is 0.533. The F1 of TC-Direct is 0.554. Fig. 7 (c) shows the F1 value of the model in “extended phoneme+”. The F1 score of ASR model is 0.405. The F1 score of TC-ASR model is 0.535. The F1 score of TC-Direct model is 0.549. The experimental results show that the F1 value of TC-Direct model is the highest in the three environments, and the validity of extended phoneme is also shown.

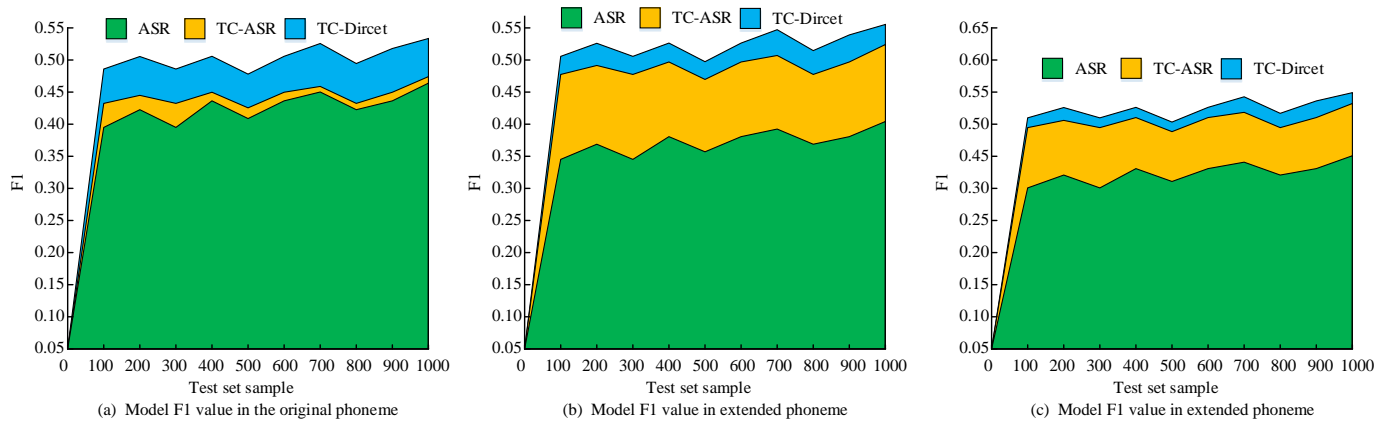


Fig. 7. F1 values of machine translation models in different models.

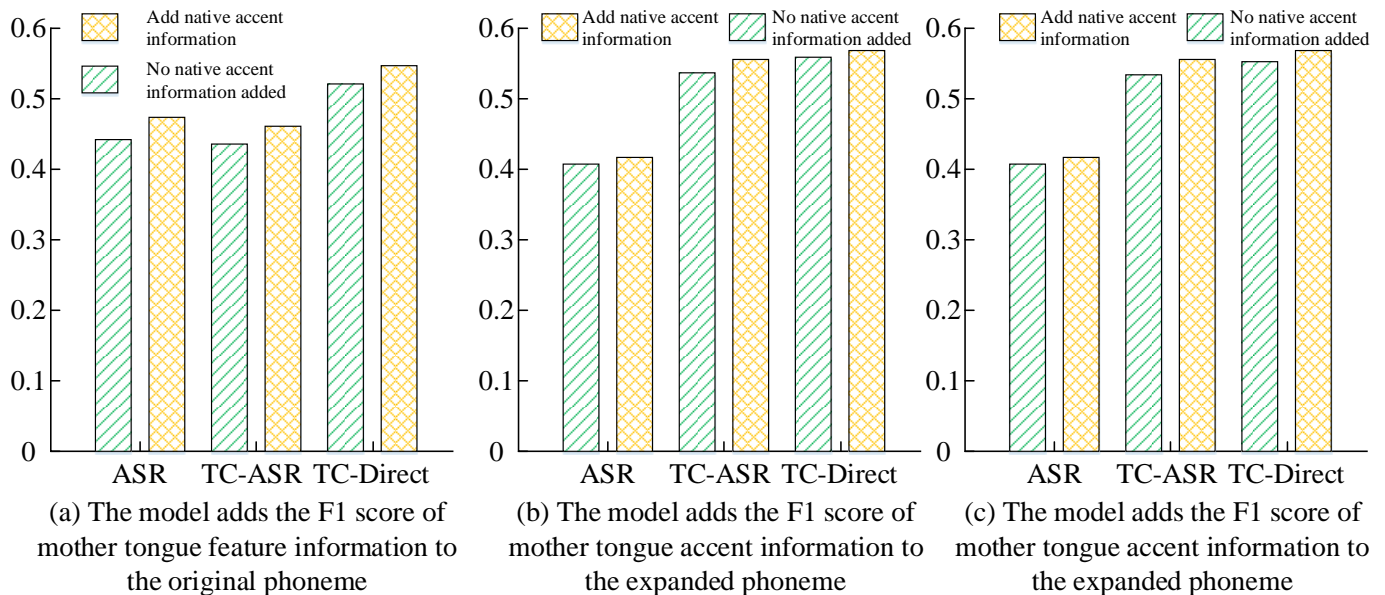


Fig. 8. F1 scores of the model before and after adding mother tongue accent information.

Fig. 8 shows F1 scores of each model after adding native language feature information. Fig. 8(a) shows the F1 score of the model adding native language feature information to the original phoneme. The F1 value of ASR is 0.464 without adding native language accent label; The F1 score of the ASR model is 0.473 when the mother tongue accent label is added. Similarly, the F1 scores of TC-ASR model before and after adding mother tongue information were 0.462 and 0.469 respectively; The F1 scores of TC-Direct model before and after adding mother tongue information were 0.538 and 0.550 respectively. Fig. 8(b) shows the F1 score of the model in which the mother tongue accent information is added to the expanded phoneme. The F1 scores of ASR model were 0.402 and 0.404 before and after the addition of mother tongue accent information. The F1 scores of TC-ASR model before and after adding mother tongue information were 0.533 and 0.551 respectively. The F1 of TC-Direct before and after adding mother tongue information were 0.554 and 0.562 respectively. Fig. 8(c) shows the F1 score of the model in which the mother tongue accent information is added to "extended phoneme+". The F1 scores of ASR model were 0.405 and 0.408 respectively before and after adding native accent information. The F1 scores of TC-ASR model before and after adding mother tongue information were 0.535 and 0.552 respectively. The F1 scores of TC-Direct model before and after adding mother tongue information were 0.549 and 0.555 respectively. From the comparative analysis of model results, TC-Direct model has a higher F1 score compared with other models, indicating that the model has better performance. From the analysis of the results before and after adding the mother tongue accent information, adding the mother tongue accent information can improve the F1 score of the model, indicating that the mother tongue accent information can help the model obtain better recognition performance.

B. Analysis of Influence of Parameters on Model Performance

Adjusting the weight θ between FAR and FRR can make the oral evaluation model different in difficulty, as shown in Fig. 9. Fig. 9(a) shows the change of the Recall-Recision curve of the loss function when adjusting θ . The larger the value of

θ , the effective adjustment range of Focal function is between 0.05 and 0.95. The effective adjustment range of BCE function is about 0.38 to 0.78. The effective adjustment range of F1 function is 0.59 to 0.62. Fig. 9(b) shows the change of the FAR-FRR curve of the loss function when adjusting θ . The effective adjustment range of Focal function is also between 0.05 and 0.95. The effective adjustment range of BCE function is about 0.22 to 0.42. The effective adjustment range of F1 function is 0.37 to 0.39. The experimental results show that Focal loss function has a wider adjustment range, which is a better choice for practical application.

Fig. 10 shows the effect of target phonemes of different lengths on the reasoning duration. Fig. 10(a) shows the reasoning time results of ASR model for different length phonemes. The longer the length of the target phoneme is, the longer the reasoning time of ASR model is, which is in positive proportion. Fig. 10(b) shows the reasoning time results of TC-Direct model for different length target phonemes. The reasoning time of the model is also positively correlated with the phoneme length, but the influence is low. The model has the best performance when the target phoneme length is 25-40.

Fig. 11 shows the effect of the scale of the training set on the performance of the model. Fig. 11(a) shows the F1 value of the model in the L2-Arctic dataset. The F1 of ASR is 0.372 without training; The F1 value is 0.473 when the training set proportion reaches the highest. The F1 value of TC-Direct is 0.596 when the training set proportion is the highest. Fig. 11(b) shows the F1 value of the model in the Speed Ocean dataset. The F1 of ASR is 0.356 without training, and the ratio of training set is 0.446 when it reaches the maximum. The F1 of TC-Direct is 0.612 when the training set proportion is the highest. The F1 value is higher than that of ASR model in both data sets regardless of the proportion of the training set. Comparing the two data sets, the F1 value of ASR in the Speed Ocean data set is slightly lower than that in the L2-Arctic data set. The F1 value of the TC-Direct model in the Speed Ocean dataset is higher than that in the L2-Arctic dataset. Thus, the TC-Direct has wider applicability.

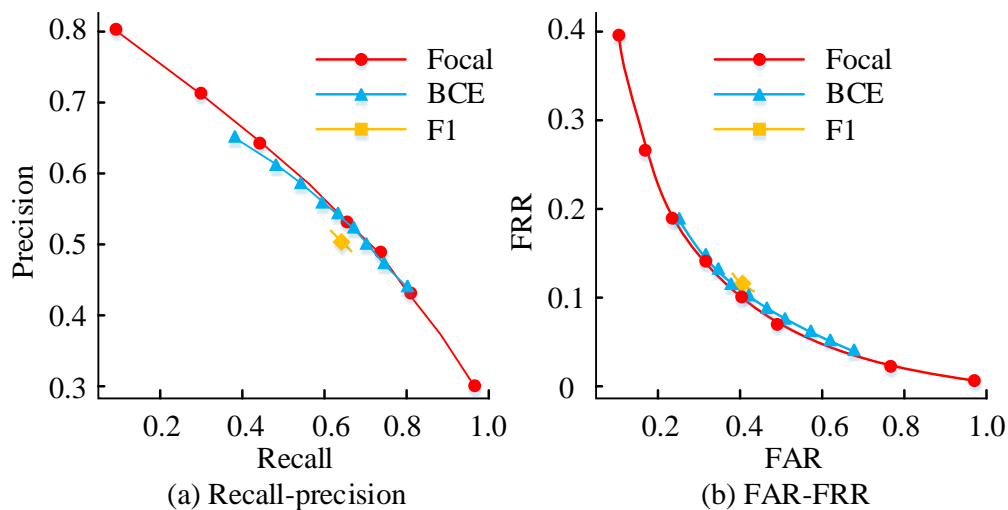


Fig. 9. Influence of the weight between FAR and FRR on the loss function.

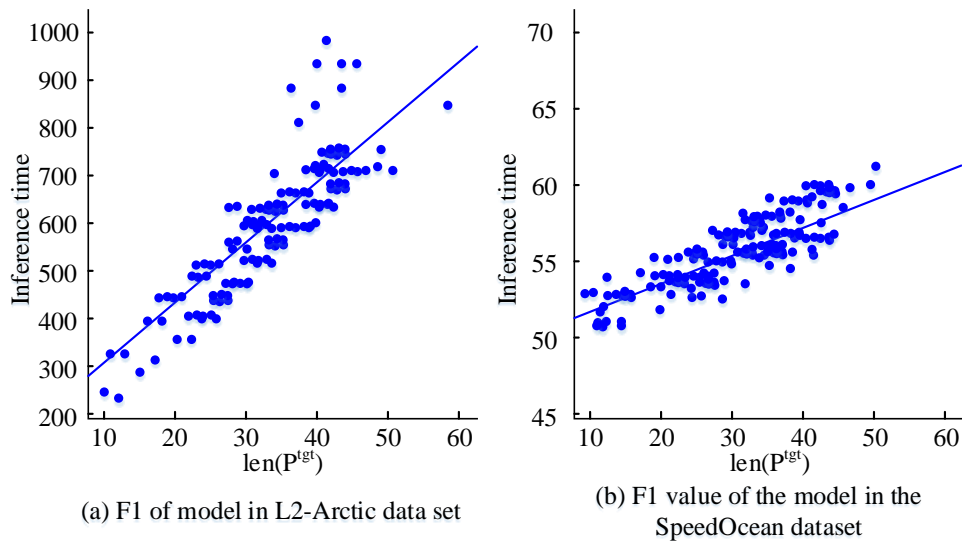


Fig. 10. Reasoning duration results of target phonemes with different lengths.

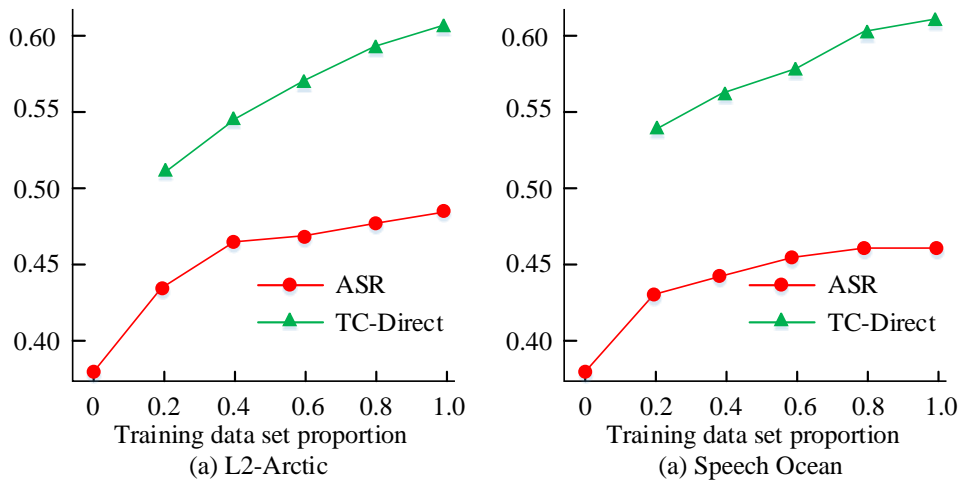


Fig. 11. F1 value of model in different training set proportions.

V. DISCUSSION

The proposed model was experimentally validated through comparative experiments. Analyzing the performance of the model from three datasets, among which the TC-ASR and TC-Direct models have better performance. In the original phonemes, the PER and ACC indicators of TC-ASR are slightly better than those of TC-Direct, but both exceed 0.1; The PER and REC indicators of the TC-Direct model are significantly higher than those of the TC-ASR model. In the "extended phoneme" and "extended phoneme+" models, the TC-ASR model showed lower REC indicators than the TC-Direct model, while the PER, PRE, and ACC indicators were higher than the TC-Direct model. Through the above four indicators, it is difficult to distinguish the performance gap between models. The study continued to use the F1 value to measure the superiority of the model's performance. After introducing the F1 value, the TC-Direct model showed the highest F1 value in all three phoneme conditions, indicating that the model had good performance. Not only that, the study also added native accent information, which can enhance the F1 value of the model, indicating that native accent information

helps the model to perform more accurate recognition. To verify the rigor of the experiment, several parameters were validated. Adjust the weight of parameters, adjust the length of phonemes, and adjust the size of the training set. In the experiment, the weight of FAR-FRR has a direct impact on the performance of the model. If its weight ratio is about, the worse the model performance; The length of phonemes does not directly affect the performance of the model, indicating that the model has a wide range of applications; The performance of the model also depends on the size of the training set, and with sufficient training sets, the model can perform better.

VI. CONCLUSION

For the low performance of the conventional speech recognition oral evaluation model, a text priori-based oral evaluation model is proposed. By using the self-supervised learning method to build the acoustic model, the speech recognition and misreading detection are combined to achieve the purpose of error state prediction. The research verifies the performance of the proposed model through Librispeech dataset, L2-Arctic dataset and Speed Ocean dataset. The

experimental results show that the F1 value of the model in the "original phoneme" is 0.538, the F1 value in the "extended phoneme" is 0.554, and the F1 value in the "extended phoneme+" is 0.549; After adding native accent features, the F1 value of the model is 0.550 in the "original phoneme", 0.562 in the "extended phoneme", and 0.555 in the "extended phoneme+". The proposed model has good F1 values in different phoneme datasets, indicating that the model has good performance in phoneme recognition and can improve the recognition performance of English spoken language. In the experiment, the study also verified the impact of the length of the target phoneme on the model performance, and the results showed that the change in model performance was less affected by the change in the length of the target phoneme. The experiment has verified that the performance of the model has a direct impact on the size of the training set. If the model is trained in sufficient training sets, it cannot continuously increase the F1 value, further improving the model's performance, and indicating that the model has a wider adaptability. However, there are still deficiencies in the study. The research did not explore the speech style when it was used for oral evaluation, so the follow-up research needs to preserve the speech style without accent.

REFERENCES

- [1] N. Wang, X. Zhang, A. Sharma. "A Research on HMM based Speech Recognition in Spoken English". *Recent Advances in Electrical & Electronic Engineering (Formerly Recent Patents on Electrical & Electronic Engineering)*, 2021, 14(6):617-626.
- [2] Q. Zhang. "Recognition of English spoken stressed syllables based on natural language processing and endpoint detection algorithm". *Journal of Intelligent and Fuzzy Systems*, 2020, 39(4):5713-5724.
- [3] F. Jiang, Y. Chiba, T. Nose, A. Ito. "Language modeling in speech recognition for grammatical error detection based on neural machine translation". *Acoustical Science and Technology*, 2020, 41(5):788-791.
- [4] P. M. Cuenca-Jimenez, J. Fernandez-Conde, J. M. Canas-Plaza. "FilterNet: Self-Supervised Learning for High-Resolution Photo Enhancement". *IEEE Access*, 2022, 10:2669-2685.
- [5] T. T. Wang, H. L. Yu, K. C. Wang, X. H. Su. "Fault localization based on wide & deep learning model by mining software behavior". *Future Generation Computer Systems*, 2022, 127:309-319.
- [6] V. R. Kota, S. D. Munisamy. "High accuracy offering attention mechanisms based deep learning approach using CNN/bi-LSTM for sentiment analysis". *International Journal of Intelligent Computing and Cybernetics*, 2022, 15(1):61-74.
- [7] P. Seebeck, W. D. Vogl, S. M. Waldstein, J. I. Orlando, M. Baratsits, T. Alten, T. Ankan, G. Mylonas, Bogunovic H, Schmidt-Erfurth U. "Linking Function and Structure with ReSensNet Predicting Retinal Sensitivity from OCT using Deep Learning". *Ophthalmology retina*. 2022, 6(6):501-511.
- [8] L. Kong, K. Cui, J. Shi, M. Zhu, S. Li. "1D Phase Unwrapping Based on the Quasi-Gramian Matrix and Deep Learning for Interferometric Optical Fiber Sensing Applications". *Journal of Lightwave Technology: A Joint IEEE/OSA Publication*, 2022, 40(1):252-261.
- [9] S. Chen. "Design of internet of things online oral English teaching platform based on long-term and short-term memory network". *International Journal of Continuing Engineering Education and Life-Long Learning*, 2021, 31(1):104-118.
- [10] C. Liu. "Application of speech recognition technology in pronunciation correction of college oral English teaching", *Application of Intelligent Systems in Multi-modal Information Analytics: Proceedings of the 2020 International Conference on Multi-model Information Analytics (MMIA2020)*, Volume 2. Springer International Publishing, 2021: 525-530.
- [11] D. Xu. "Research on the Construction Strategy of the Theoretical Framework of Presence in Oral English Teaching Based on Augmented Reality Technology". *Creative Education*, 2022, 13(10): 3162-3173.
- [12] S. Kummin, S. Surat, F. M. Kutty, Z. Othman, J. Thompson., "The Use of Multimodal Texts in Teaching English Language Oral Skills". *Universal Journal of Educational Research*, 2020, 8(12):7015-7021.
- [13] Y. Hai. "Computer-aided teaching mode of oral English intelligent learning based on speech recognition and network assistance". *Journal of Intelligent and Fuzzy Systems*, 2020, 39(4):5749-5760.
- [14] M. Vojnovic, M. Mijic, D. S. Pavlovic, N. Vojnovic, "Influence of Overpressure Breathing on Vowel Formant Frequencies". *Archives of acoustics: journal of Polish Academy of Sciences*, 2021,46(1):177-181.
- [15] M. F. Biller, C. J. Johnson, "Examining Useful Spoken Language in a Minimally Verbal Child with Autism Spectrum Disorder: A Descriptive Clinical Single-Case Study". *American Journal of Speech-Language Pathology*, 2020, 29(3):1-15.
- [16] X. Liu, H. Zhang, Q. Liu, S. Dong, C. Xiao. "A cross-entropy algorithm based on Quasi-Monte Carlo estimation and its application in hull form optimization". *International Journal of Naval Architecture and Ocean Engineering*, 2021, 13(4):115-125.
- [17] Y. Zhao, Y. Han, Y. Liu, K. Xie, W. Li, J. Yu. "Cross-Entropy-Based Composite System Reliability Evaluation Using Subset Simulation and Minimum Computational Burden Criterion." *IEEE Transactions on Power Systems*, 2021, 36(6):5198-5209.
- [18] C. Munoz, H. Qi, G. Cruz, T. Küstner, R. M. Botnar, C. Prieto. "Self-supervised learning-based diffeomorphic non-rigid motion estimation for fast motion-compensated coronary MR angiography." *Magnetic Resonance Imaging*, 2022, 85:10-18.
- [19] C. Y. Liu, X. Chen, Z. Li, R. Proietti, et al., "SL-Hyper-FleX: a cognitive and flexible-bandwidth optical datacom network by self-supervised learning". *Journal of optical communications and networking*, 2022, 14(2): A113-A121.
- [20] A. A. Baffour, Z. Qin, J. Geng, J. Ding, et al., "Generic network for domain adaptation based on self-supervised learning and deep clustering". *Neurocomputing*, 2022, 476:126-136.

Attribute-based Access Control Model in Healthcare Systems with Blockchain Technology

Prince Arora, Avinash Bhagat, Mukesh Kumar
Computer Applications, Lovely Professional University, Jalandhar, India

Abstract—Blockchain and the healthcare sector have a serious concern with context to scalability, which has a challenge of converting arbitrary values to fixed values. The transfer of arbitrary data coming from diverse resources has another point of concern in the blockchain. In this paper, the author proposed a model that will receive data from diverse sources and will convert it to a fixed type of value. The paper also proposes an access control scheme with various permission and consensus level protocols which will allow a reduction in block size with respect to scalability. The consensus level will allow access to the individual or a group of users and the permission level with respect to each block via considering the access granted to nodes of the blockchain. The addition of various permission and consensus levels will allow only a restricted type of data to pass the model. Once the data is verified and approved by various levels, then the data is all set to be part of the blockchain. The paper introduces a model where the time taken to create a new hash is 0.15625 microseconds. A total number of 64 transactions taken from the data set where the throughput is calculated for individual access are considered. After applying the formula, the calculated throughput is 32.5 microseconds. By the lighter block size data can be made available to the patients. The research is for the patients so they can keep track of their medical history and the deaths due to overdose of the medicines can be reduced.

Keywords—Blockchain; healthcare; permission level; consensus level; scalability

I. INTRODUCTION

Blockchains are incredibly popular nowadays. As the name indicates, a blockchain is a collection of blocks associated with a timestamp. It ensures the irreversibility and immutability of the data block. A blockchain technology is a distributed ledger which allows the data to be stored across the network along with the next hash and previous hash. There are some applications of the blockchain like bitcoin and etherium that ensure the correct transmission of the data over the network. Security and privacy challenges arise in the medical field due to rapid growth in data collection and subsequent analysis by a variety of organizations. The devices that relate to the internet or Internet of Things (IoT) data come from various sources. Scalability is a huge challenge that comes with it. Personal Health Records (PHR) are usually owned by the patients; however, they can also be shared with third-parties based on the patient's approval. Medical professionals can use Electronic Medical Records (EHR) to retain and share patient data, but paper-based medical records cannot be transferred across institutions or locations. Healthcare data collection is expected to reach 4.5 billion dollars by 2030. It is expected to expand at a percentage of 26.9 from 2022 to

2030 [1]. It becomes vital to design an online model which helps the patient and the doctors keep track of all the medicines and treatments given by the doctor to the patient. Consequently, third parties must be limited in their access to this data. Controlling who can and cannot access a system's resources is the major aspect of access control.

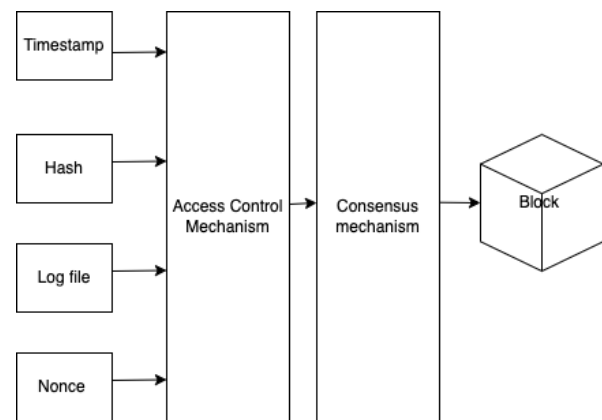


Fig. 1. A log file based access control model.

Personal or medical health data [2] kept by many parties, and which may be required for third-party access to third-party aims (such as medical or insurance companies), is a difficult task to manage. The data collected from heterogeneous sources is difficult to manage for any insurance or medical organization. This is due to the complexity of the data and the need to make it usable for the organization. Obtaining and normalizing the data from diverse sources requires considerable efforts, making it a challenging task for organizations. Interoperability is the major issue that comes up in this matter. The availability of the data cannot be achieved without the attribute-based scheme.

A timestamp embeds the time of the transaction. Fig. 1 explains the basics of the access control model. A hash value is used to ensure the uniqueness of the transaction. A Nonce is a randomly generated 32-bit number that is used by miners to adjust the hashing of a block and make it valid for use. Once the perfect nuance is found, it is connected to the hashed block. The log file is a part of the proposed model that stores the calculation of the address. By using this calculation, the next address can be allocated to the chain of the blockchain model. An access control mechanism is used to collaborate on the attributes of the block. Thus, the blockchain can have a unique value that easily differentiates the block with other blocks.

To resolve the issues related to address control in a huge system like e-Health, a technique is proposed in this study as shown in Fig. 1, which allows data to be accessed with various levels of authorization and granularity. Adding, updating, or removing rights to their data should be easy for the data keepers to do. Permissions should be able to be defined at the user and source level with sufficient precision in such a system.

An overview of access control in e-Health systems, focused on blockchain technologies for access control, is provided in the first section of this paper. In the following section, a breakdown is found for the intended solution architecture. As a next step, few essential components for building a working model are discussed. There are also a few concluding comments that summarize the contributions and hint at future advancements. The issue related to the healthcare field is the huge amount of data coming from diverse resources. Data management is a huge task, and, if any patient wants to fetch their medical history from the offline database, it would be even more difficult to find the data in a quick time. Another issue is the maintenance of centralized storage, which has various overhead issues and a high reliance on servers. To ensure that the data is available on time and at every end, the blockchain technology is used for the work.

Purpose and need of the study: The study is important because once the patient has undergone some treatment from the doctor, it is important that the medical health history being maintained by the patient and the doctor as well. If the patient is not satisfied by the treatment of the doctor, patient changes the doctor and it becomes vital for the patient to know what medicines or injections are already given to the patient, it can be maintained through Electronic Health Records (EHR). With the help of EHR data can be stored, in a blockchain based system which allows the availability of the data at patient end. When the patient changes the doctor, patient should be having the updated medical history available all the time so that it will be easy for the new doctor to understand the patient history. Every doctor who has done any treatment of the patient has to fill the attributes. The system works remotely and ensures the availability of the data. By using this, data can be made available to each end and access can be granted based on access control mechanism used in the proposed model. The model can be embedded with a variety of technologies like: Internet of Things (IoT) and Artificial Intelligence (AI). By associating these technologies with blockchain the medical record collection can be more automated; where if a patient has gone through X-Ray, the record can be automatically recorded in the EHR. A block in the blockchain typically consists of approximately 2000 transactions. To make the node lighter, reducing the size of the transaction can be beneficial. Gas amount is used to operate the blockchain, and a limited amount of gas can be passed. Heavy nodes with duplicate values allow only a few nodes to be connected to the blockchain; on the other hand, light nodes have less total weight, requiring less gas to operate the blockchain, allowing for more nodes to be added to the network [3].

Limitations of blockchain scalability: The scalability of current blockchain technology is limited by its transaction throughput, cost, network latency, data storage, and energy consumption. As the number of transactions grows, the cost of running a blockchain increases and the data stored on it becomes more difficult to manage. Furthermore, the time it takes for a transaction to be validated and added to the blockchain is too long, and the consensus algorithms used by blockchain networks are often very energy intensive. All these factors demote scalability.

The paper is arranged as follows: After the introduction section, the advancement of blockchain for healthcare, in Section II, Literature Review is discussed on blockchain and healthcare. Section III focuses on data sets where various attributes are taken to show the results and it discusses the proposed methodology to achieve the goal. Section IV talks about the evaluation parameter. Section V focuses on how the model can be developed. Section VI focuses on implementation of the proposed model. Section VII presents the results and discussions and Section VIII summarizes the paper.

II. RELATED WORK

To find and analyse the results of the various existing models and compare them with the proposed model, various models are studied. The literature review is discussed in the related work section, where several existing models are there, and the results are compared in the final section. Ayache, M. et al. [2], proposed a Decentralized Accessible Scalable and Secure (DASSCare 2.0) model that works on real-time health monitoring that route all the data from various resources and makes it available to various end users, which allows the collaborative health monitoring and maintains the bills paid by the patient. The model gives an extra edge to other frameworks. Using a distributed database is a consensus of shared and synchronised digital data spread along a set of nodes. Contrary to popular belief, however, not all decentralized ledgers are in fact distributed ledger technology (DLT). The duplicity is high when the data is shared across various blocks.

Karaki, A. et al. [3], proposed a Decentralised Accessible Scalable and Secure (DASSCare) model which is a decentralised framework, which is scalable and accessible. It allows real-time access of data that comes from diverse resources. To maintain this, the generated clinical data is signed. The sign ensures that the type of data coming from diverse resources is of the same type, and then it is considered. This framework solves the problem of real-time access of medical records in healthcare, which is a primary part of the work and ensures that privacy is not compromised.

The healthcare data stored on various resources is a difficult task to be followed. Mira, S. et al. [4] proposed a CrowdMed model that works on managing the data and, to ensure the data is in the correct format, a review team is assigned. The data reviewer resolves two issues: one is to resolve the issues coming from diverse resources and the other is to make data more homogeneous to ensure the scalability of the chain across the network. In this

framework, the patient has full access to the data, so if the patient has taken any medical treatment of his own, the data can be updated by the patient itself.

The CrowdMed model allows the data reviewer to review the data and the data is reviewed at different ends simultaneously. Tampering of data is a prime concern that is associated with the CrowdMed model. To overcome this, Hu, C. et al. [5], developed a scheme CrowdMedII where the smart contract allows only insertion in the model. The healthcare workers are not allowed to update the data. By this, the data quality can be improved and the chances of tampering of data from diverse resources can be made more specific. The disadvantage is also associated with the model, which requires a lot of space.

Developed by Nakamoto, S. [6], the blockchain is a distributed record that serves as the foundation for the Bitcoin digital currency. Digital signatures and digital fingerprints (hashing) are two methods that can be used to ensure the integrity of data and prevent tampering with data. The ledger must be secure from malicious attempts to undermine it as well as from peers submitting incorrect data, computer/network failures that are only partially or fully finished, or even by peers providing incorrect data out of ignorance. The blocks that make up a blockchain contain data on transactions. A digital signature is attached to each one of these transactions. Using this method, a state transaction system (state machine) is implemented, in which every node adds a snapshot to the existing model to various existing models. The peer-to-peer network relies on a proof-of-work concept to move to consensus on a block's validity. There are various alternatives to proving work. The block that is to be pushed inside with various existing timestamps allows the transaction to be a unique transaction.

Blockchain, according to Buterin, V. et al. [7], is divided into three parts: public, private, and consortium. Unlike private blockchains, public blockchains (e.g., Bitcoin) are accessible to anybody who wants to read them, send transactions, and expect them to be added if they are genuine. "Fully-private blockchains" where the participants (e.g., a supply chain) are called "fully-private blockchains" since the write permissions are centralized within a single organization (even if they are spread across multiple facilities). An open blockchain may or may not restrict who has access to perform blockchain queries. To ensure that the access control mechanism is working well, identity is confirmed from where the data is fetched.

Salman, A. et al. [8] granted a controller which indicates that the identity is genuine or not. The address of the sender can be used as a certificate and attached with the complete model to ensure that the transaction is authentic or not. This scheme is an identity-based scheme where the identity of the sender acts as a certificate and allows only the verified transactions to be approved from the end. Nakamoto, S. [5] introduces the concept of "blockchain," a distributed ledger technology that allows data to be transferred from one node to another while retaining a copy in the user's node rather than storing all data in a single shared database. Maesa, D. et al. [9], present a paper which is based on bitcoin. The

access control mechanism is based on the resources that are being used for the transactions of the blockchain. The XACML (Extensible Access Control Markup Language) is used to develop the code of the resources that allows the end resources to access and transform similar types of data.

Castiglione, A. et al. [10], proposed a model that is a device-based model. Various types of data are made available at various points. Different duties are allocated to various devices that play different roles in the transaction. Each device has its own restrictive access control mechanisms that allow only quality data to be inserted into it. To handle IoT devices, Novo, O. [11] proposes a distributed blockchain-based permission method. The work included a unique concept to prevent integrating blockchain with IoT devices, which is the major part of the model. This approach correlates the use of blockchain with IoT, particularly for devices with limited resources. Fair Access is a blockchain-based authorization mechanism described by Ouaddah A et al. [12]. Smart contracts were utilized to exchange access tokens for the fulfilment of access control protocols. The authors incorporated various IoT devices into the blockchain and investigated the issues of real-time permission and the efficiency of the scheme.

Using a smart contract, Xu, R. et al. [13] suggested a decentralized, federated capability-based access control method. The technique was used for multi-hop delegation and was also reliable and scalable. Based on objectives, models, architecture, and mechanisms, Ouaddah. A et al. [14] gave a complete review of various access control methods. The report also focuses on the various taxonomy-based author reviews and the advantages and disadvantages of each are discussed in the model. Novo, O. [15] proposed scalable decentralised access management for IoT devices based on blockchain technology. To avoid network overheads, the architecture removed IoT devices from the blockchain-enabled network. In terms of IoT access control, the system has various advantages, including accessibility, parallelism, lightweight, immutability, scalability, and transparency. This framework has managers that allow IoT devices to be registered and verified. Although this method achieves scalability by distributing query rights through management hubs, it faces various security risks.

Dorri, A. et al. [16] advocated leveraging private blockchain technology to provide a lightweight architecture for protecting the IoT. The proposed method ensures security with an access control permission list and their design, including various models. All the devices based on the model are mined by miners. This approach has control of the policies in the header part of the policy. It does not use a Proof of Work (PoW) concept to ensure its uniqueness. They claimed that the solution's overheads are modest in comparison to the security benefits. By concentrating on user preferences, which can find access and denying methods, Touati, L. et al. [17] suggested an activity control method (a broader version of context-aware access control). For dynamic access policy adaption, ciphertext-policy and a finite state automaton are used to keep track of all the updates in the network. By analysing the logical approach to trust computation from language-

based information received from IoT devices, Mahalle, P. et al. [18] proposed an energy efficient architecture which is both energy efficient and dynamic in nature. An individual or a group with the authority to provide access to privileges and resources can be easily accessed. The Table I compares the different models studied in literature review.

Zhang, R. et al. [19] suggested a sensor network-specific distributed privacy-preserving access control method. It requires users to have a token from the owner and then request sensor data, which is supplied after the token is verified. To prevent the reuse of tokens, which would allow unwanted access, they deploy a distribution token reuse detection system. Their focus was on preserving privacy and they did not consider access control settings for end devices. Access Control In current operating systems, Access Control Lists (ACLs) are a typical method of controlling access. An ACL lists people who have access to an object, as well as the amount of access (or privileges) they have. Alternatively, other systems employ an Access Control Matrix, which consists of rows and columns, where a column denotes an object and a class denotes a subject. Health care is a good example of the use of Oole-Enabled Access Control and privileges linked with those roles are used to determine a user’s access rights in RBAC. The consortium’s XACML can be used to express Attribute Based Access control Model (ABAC) policies Access control systems can be designed and implemented using the XACML standard’s reference architecture that defines the system components and usage flow. More expressive access control policies can be defined using Entity-Based Access Control (EBAC) [27], another commonly used technique. Both attribute value comparisons and relationship traversals along arbitrary entities are supported, so this is possible. There is also an authorisation system that provides realistic policy language and an assessment engine for the system. Application of Blockchain to Access Control One solution to the issue related to access control in e-health is based on blockchain technology. According to Maesa. D et al. [9], the XACML standard architecture can be used to construct Attribute Based Access Control on top of blockchain technology for access control. Using Bitcoin as a base, this strategy can be proven to work.

TABLE I. RESEARCH PAPERS CONSIDERED FOR THE LITERATURE REVIEW PURPOSE

Name of Authors	Model Name	Access Control	Blockchain Enabled	Permission Control
Ayache, M. et al. [2]	DASSCare 2.0	Yes	Yes	No
Wang, T. et al. [23]	Audit Model	Yes	No	Yes
Karaki, A. et al. [3]	DASSCare	Yes	Yes	No
Salman et al. [8]	Access control list	Yes	Yes	No
Novo, O. et al. [11]	Blockchain based	Yes	Yes	No

	permission control method			
Novo, O. et al. [15]	IoT Access Control	Yes	Yes	Yes
Maesa, D. D. F. et al. [9]	Extensible Access Control Markup Language	Yes	Yes	No
Dorri, A. et al. [16]	Permission Control	Yes	Yes	No
Ouaddah, A. et al. [12]	Fair Access	Yes	Yes	No
Bogaerts, J. et al. []	Entity Based Access Control Model	Yes	No	No
Castiglione, A. et al. [10]	Attribute Based Access Control Model	Yes	Yes	No
Zhang, R. et al. [19]	Network Specific Access Control	Yes	Yes	No

However, in the e-Health context, this method does not consider the possibility of having several authorities and/or companies as the resource owners.

A Healthcare Data Gateway (HGD) blockchain model can be used for e-Health by Chen, Y. et al. [20] has the capability to store patient records where patients can keep track of their medical history. The patient’s history is recorded on blockchain as part of this solution. I. Baldine et al. [21], has a solution to the issues raised in the previous paper, despite the uniqueness of this strategy, it is likely to need a significant amount of time and effort to implement, which may put the current utility of this method into question. If the patient is unable to enable the access, or if some governmental regulations require that the data be accessed without the patient’s permission, then this solution has no capacity to do so (e.g., some family members allow the data access). Keeping e-health data on the blockchain will cause its size to explode, far beyond the capacity of currently available hard drives, necessitating the purchase of specialized hardware for full nodes and possibly even leading to the centralization of the blockchain.[28,29]

III. MATERIALS AND METHODS

The dataset which is used for the implementation is taken from Kaggle, which consists of a huge variety of databases related to EHRs. Data is gathered and, as per the model, the data is converted into a decision-based format where the data can be made available for the blockchain construction. The description gives an overview of the dataset and focuses on various attributes used for them [22]. The data set consists of various attributes to maintain the patient records. The data set is based on the chronic kidney disease of the patients, which requires the medical history of the patients to be stored so that if the patient is undergoing some surgery or treatment, the data can be accessed from

the EHR that maintains the history of the patient. The detailed description of the dataset taken into consideration for this study is given in Table II.

TABLE II. DETAILED DESCRIPTION OF THE DATASET USED FOR THIS STUDY

Attribute Name	Domain Values	Attribute Name	Domain Values
Gender	{0=M, 1=F}	HTNmeds	Range = {0, 1}
AgeBaseline	Range = {23, ... ,89}	ACEIARB	Range = {0, 1}
HistoryDiabetes	Range = {0, 1}	CholesterolBaseline	Range = {2.23, ... ,9.3}
HistoryCHD	Range = {0, 1}	CreatinineBaseline	Range = {6, ... ,123}
HistoryVascular	Range = {0, 1}	eGFRBaseline	Range = {60, ... ,242.6}
HistorySmoking	Range = {0, 1}	sBPBaseline	Range = {92, ... ,180}
HistoryHTN	Range = {0, 1}	dBPPBaseline	Range = {41, ... ,112}
HistoryDLD	Range = {0, 1}	BMIBaseline	Range = {13, ... ,57}
HistoryObesity	Range = {0, 1}	TimeToEventMonths	Range = {0, ... ,111}
DLDmeds	Range = {0, 1}	EventCKD35	Range = {0, 1}
DMmeds	Range = {0, 1}	TIME_YEAR	Range = {0, ... ,9}

This is a dataset of electronic medical records of 491 patients collected at Tawam Hospital in Al-Ain city (Abu Dhabi, United Arab Emirates). The patients included 241 women and 250 men, with an average age of 53.2 years. Each patient has a chart of 22 clinical variables, that expresse her/his values of laboratory tests and exams or data about her/his medical history. The attribute starts with patient name and is based on various attributes like doctor and medicine. The patient record is based on the updating done by various doctors and patients. The dataset contains the information of attributes related to the patients and the results are calculated based on that data. The record of the patient can be updated by the doctor and if any medicine is given to him that must be added to the chain. To achieve scalability, the block of the blockchain is compressed by using various hashing techniques. The attributes are defined in the model so to ensure the fixation of the inputs prescribed by the doctor.

IV. EVALUATION PARAMETER

Wang, T. et al. [23], proposed a model. The paper also includes various factors by which the model can be evaluated and compared with the other models that are based on various factors like execution time, latency, and throughput. Xu, Z. et al. [24], evaluates the performance of the model based on the time that it takes to generate the hash, the amount of delay that is required to keep the transaction and the time required to complete the transaction. Description of each evaluation parameter is discussed in Table III.

TABLE III. DIFFERENT EVALUATION PARAMETERS OF PROPOSED MODEL

S. N	Evaluation Parameter	Description of the parameters
1	Execution Time	It is the time taken as the difference between once the transaction is confirmed and the execution of the blockchain.
2	Latency	It is the time taken by the system that waits for the other system to complete the action.
3	Throughput	It is the amount of data that can be shifted from one block to other block of the blockchain in a unit of time.
4	Performance Assessment	It is the measurement done on the models by providing the described hardware and can be calculated based on time frame.

To understand how the proposed model performs, various users can apply operations on the blockchain-based model.

All standard paper components have been specified for three reasons: (1) ease of use when formatting individual papers, (2) automatic compliance to electronic requirements that facilitate the concurrent or later production of electronic products, and (3) conformity of style throughout conference proceedings.

V. PROPOSED ATTRIBUTE-BASED ACCESS CONTROL MODEL

After Access control Data management is used to ensure that the data coming from various sources must have an arbitrary value that is difficult to handle. The model will ensure that the data coming from various resources is converted into fixed values. The model access controller establishes a relationship with various subjects and objects, which ensures the data can be easily stored and passed through the blockchain model and creates a block. The methodology works on various entities like permission levels, data keepers, policies, and records [25, 26]. The proposed attribute-based access control is given in Fig. 2. Classes and entities of the proposed attribute-based access control are discussed below:

Entity (UID): The entity contains the records of the various transactions, read, write or any other. Whether the

entity should be given read, write or read/write access, is maintained in the record file.

Data Keeper: The data keeper keeps track of all the access granted so that it can be compared with the upcoming transactions. It records the various levels of the permissions that can be granted to the various entities of the model. The type of the access granted to the entity is also decided by the data keepers.

Policies are rules and regulations that govern which types of access are granted. Policies are based on permission levels and consensus levels, which are useful for filtering the data. The consensus level policy, which is based on permission level, requires Unique Identity (UID), record and permission level to fetch the data. Once the UID is compared and verified, the permission is granted based on levels and the consensus level policy works on UID, record and the type of permission granted. Various policies can be created to improve the quality of the blockchain model. The policies correlate various data keepers with their permission level. Some exceptional cases, like if a patient wishes to have a medicine without the permission of the doctor, can also be considered in the patient's record history file. The permission level defines various types of permissions that can be read, written, or both read and written. The access, once granted, is compared with the access required by the transaction to be verified and completed.

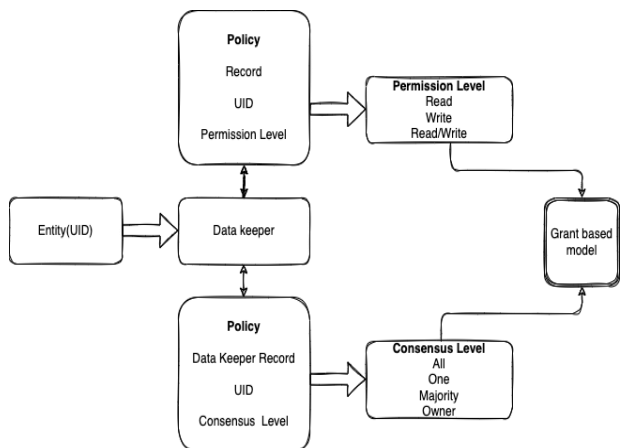


Fig. 2. Proposed attribute based access control model.

Grant based Model Structure: Model of Access Control
 There are many entities and relationships that must be defined before a model can be created. Fig. 3 shows such a model, and it may be used to classify objects into five different types. There are three types of access that can be granted to the model, like Read, Write, and Read/Write. The data keeper keeps a record of all the data and ensures that only authentic people can access it. The data keeper tracks the UID, consensus, and pointer to maintain the integrity of the record as well. This also prepares a policy to provide more validation to the access by checking the record and entity and allocating a certain permission level. The permission level can be read, write, or read and write as well. By ensuring this, the quality of the access mechanism can be enhanced and not every type of transaction can access all types of data in it. Each policy with various

permission levels generates a particular consensus level which allows the model to get restricted input from various channels. The state machine can also be a useful part of the model. This machine gives an inside view of how the permissions are granted by the data keeper. Fig. 3 indicates that once the transaction is inserted into the model, it must pass through various blocks like request, verify, and require.

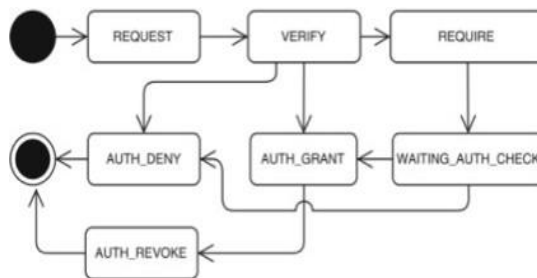


Fig. 3. Grant based access model.

The request block allows the block to be requested and verified by using the properties of the blockchain like: irreversibility and immutability. The verification also checks the hash value of the block. The hash value is compared with the previous block hash value then it is a valid transaction. Once the verification is successful, the access is granted and the transaction is performed. The verify block in the model also has the power to deny the access when the requested block does not match the hash value in further. If the access granted is only a write operation access that usually is given to the doctors of the hospitals then the medical history of patient can be written. Once the updating in the record is done by the doctor then the revoke operation can be performed on the transaction. After the verification of the hash values time stamps are compared with the previous block, if there is a scenario where any other specific requirement is there. The hash value matches but the issues are there in the timestamp, in that case the transaction is sent to the waiting state that will wait for the grant condition to be performed on it. Various parts of the block model for blockchain structure are mentioned in Table IV.

TABLE IV. NUMBER OF CASES AND THE REDUCTION IN EXECUTION TIME

S. N	Components	Description of the components
1	Index	Represents the present index of the block
2	Timestamp	Represents the time when block is generated
3	Previous Hash	The hash of the previous block
4	Digital Sign	Cryptographic hash of the most recent data block
5	Data	This block's content. Access control policies, records information, and individual authorizations are all described in this set of transactional data

6	Nonce	For a block's hash to include leading zeroes, it must have this value set. Iteratively, the value is implemented until it is completed and discovered to meet the requirements. The correct nonce value is proof of effort because it takes time and resources to get it right
7	Hash	<p>Hash of the block data in SHA256 form. The effort of the proof-of-work is defined by the leading sequence of this hash, which must be predetermined. Additionally, the data field must be comprehensive because it serves as a repository for transaction information. There are three sub-fields that make up this data category:</p> <p>a) A record is a piece of data pertaining to a certain state machine transaction, such as the creation, modification, or deletion of an e-Health record.</p> <p>b) Information on the creation and revocation of access policies related to transactions in the state machine shown in Fig. 2. Transactions relating to individual authorization by each of the Record Data Keepers in connection to each Policy.</p> <p>c) There is no need for a central authority because any change in data would result in a new hash, which would invalidate the next blocks on a chain of transactions that is immutable without a central authority. Accountability and auditability are additional possible outcomes. Assuring the authenticity of each block on the blockchain is done by assigning an individual key pair to each entity with access to it</p>

the access that is being demanded by the transaction. The role of patient is just to have a view of the data so the access read is required all the time. Consider a situation where the patient wants to write the medical record but not mentioned in the peers. In that situation, low level access is given. The reason why these protocols are being added to the model is that once the data is being transferred to the block chain the data should be of fixed type that is being approved by various peers.

When the high-level access is being granted, in that case the transaction has passed the peers and it can move to the blockchain as shown in Fig 4. The blockchain easily accepts the type of attribute based fixed transaction. The algorithm also defines some roles which includes insertion, updating and deletion of the data. While working with various operations, the add functions inserts a value along with the parameter passed to the function.

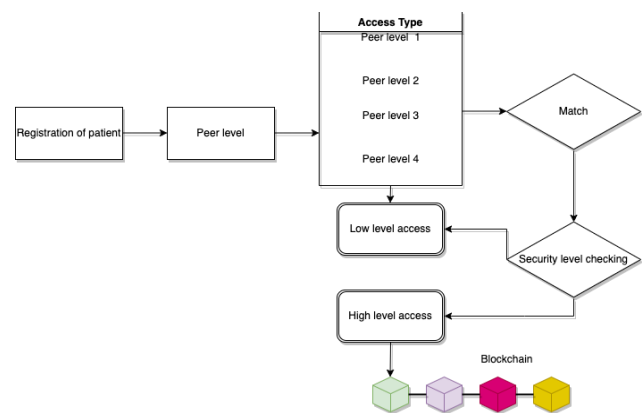


Fig. 4. Methodology of designing attribute-based access control model in healthcare system.

VI. IMPLEMENTATION OF PROPOSED ATTRIBUTE-BASED ACCESS CONTROL MODEL

The model starts with registration of the patient in the system; various peers are the sources from where the data is originated. To ensure that the access control mechanism works well, the levels which are discussed in Fig. 2 ensure the type of the data that will only be allowed to be inserted in the node. In Fig. 4, the security level object ensures the type of the access provided by the system to the framework. The security level checker matches the access type from which the access is being granted and the type of data which comes from various resources with various access rights. If the data matches the access granted and the access demanded by the transaction coming from the source, the access is considered as high-level access. The peer level stores the access related data, when the data requirement comes from any patient or the doctor, it is compared with

The limit for the passing of the arguments can be at most the total number of the patient attributes. Except the doctor one is not allowed to insert the data into the blockchain environment. Once the data is verified, the registration number is updated with 1. Suppose, if the patient has taken medicine after doctor prescription 76 times the new entry where the data is added can be considered as 77, also if the patient has taken medicine by his own consent, the database is required to be updated. The OR gate allows that both the doctor and patient is capable for the necessary modification in the record. The updating can be done with the update function record but more validation check is being added to it. If the sender of the data is the concerned doctor or the patient, then the other condition is checked and verified. The patient ID is compared with the existing ID available of the patient that allows or denies the updating of the data. Once the criteria meet both the conditions, the data can be updated otherwise the data needs to be on hold for the upcoming transaction.

Algorithm 1: Algorithm used for attribute-based access control Model

```
Add Data:
method Add Patient Record (var1, var 2.....n)
if (record.input = = doctor || patient || healthworker)
  Regist_ID = Regist_ID+1
end if
end method
Data added successfully
```

```
Update Data:
method Update Patient Record (var1, var2.....n)
if (record.input = = doctor || patient ||healthworker)
  and if (id = = patient id)
  then Update patient_record
end method
Data updated successfully
```

```
Delete Data:
method Delete Patient Record (patient id)
if (record.input = = doctor)
  and if (id = = patient id)
  then delete patient record & Abort
Set Record =Record-1;
end method
Record deleted successfully
```

The deletion of the data depends on the id verification, the patient ID is compared with the existing ID, once the ID is verified then the deletion of the data can be processed. Inside the method, if the data is sent by the doctor and the patient ID is verified to be true, the account of the patient which is also considered as a block is verified as true as shown in algorithm 1. The record set is decreased by 1. One block in the blockchain contains the record file which consists of the total values used in the block. The value of the record is decremented by 1.

VII. RESULTS AND DISCUSSION

The focus of result is on data calculation and on that basis the performance of the blockchain is calculated. The section explains the metrics based on those metrics the results generated by the models can be compared and evaluated with the other models. The results prove that the performance of the model can be enhanced based on some inputs. The performance can be improved as when the hash value is generated with high participants, the chance of getting the maximum digits of the model can be same. The model allows the performance to be enhanced based on increase in number of users.

Execution Time is the time taken for the process to be completed. It starts with the initialization of the transaction with the completion of the transaction. The hash value is generated by SHA-256 algorithm in the blockchain. The average time taken to generate the hash value is 3ms and if the transactions are 100 transactions, 300 ms would be taken to complete the transactions.

Case 1: Let us take a hash key that is of 64 bits and the generation of 100 hash values will take 300 ms. By applying the proposed model various improvements can be done in the existing blockchain model. This case covers the cases and assumes that if the value of hash next evaluated hash has a single bit change.

Hash Key =
8F434346648F6B96DF89DDA901C5176B10A6D83961D
D3C1AC88B59B2DC327AA4

- Total number of digits used by Hash = 64
- Generation of 100 Hash values will take 300 ms
- Total number of digits for 100 Hash values =6400
- Time consumed for one bit Hash Key generation= 300/6400=0.046875
- Block size generation after applying attribute-based log file model

Case 2: Let us take a Hash Key that is of 64 bits and the generation of 100 hash values will take 300 ms. By applying the proposed model various improvements can be done in the existing blockchain model. This case covers the cases and assumes that if the value of hash next evaluated hash has all the bits changed as written in Table V.

Hash Key =
8F434346648F6B96DF89DDA901C5176B10A6D83961D
D3C1AC88B59B2DC327AA8

- Number of digits modified in the block=1 Ratio of digits =1/64
- Total number of digits used by Hash=64
- Generation of 100 Hash values will take 300 ms
- Total number of digits for 100 Hash values =300
- Time consumed for one bit Hash Key generation= 300/300=1

One out of 100 cases exists in the model the results can be improved by transferring the data from 1/100 which makes 99.015625 to 1. Increase in number of cases will improve the quality of the algorithm as compared to another non-attribute-based model.

Average Execution Time=Total Execution Time/Total number of Transactions.

TABLE V. NUMBER OF CASES AND THE REDUCTION IN EXECUTION TIME

Numbers of Cases	Execution Time	Growth Rate
1	99.015625	0.0984375
2	98.03125	1.96875
3	97.046875	2.953125
4	96.0625	3.9375
5	95.078125	4.921875

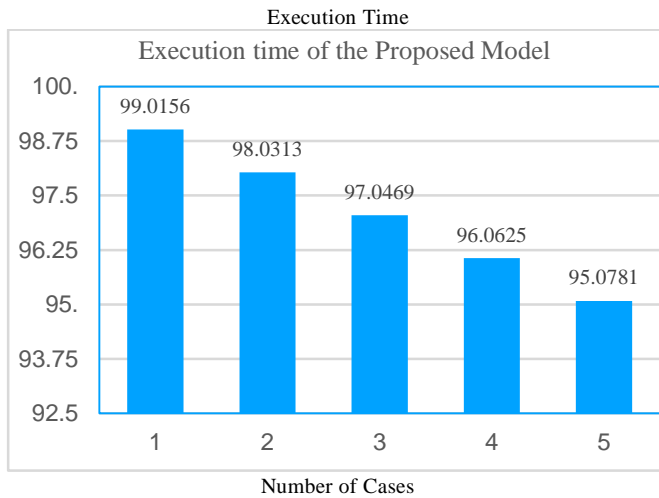


Fig. 5. Execution time of the proposed model.

Average Latency: It can be calculated by the difference between the request sent and the response generated by the model. However, the latency of the model is calculated by JMeter. In Fig 5, it is clearly visible that execution time is reduced after each bit change. The average latency can be measured in the context of milliseconds. The average latency can be measured:

Average Latency = Time taken to update Hash/Number of Hash bits

The performance of the model is also evaluated by accessing the size and cost of the generated Hash value. The transaction payload can also be accessed by the transaction size.

TABLE VI. NUMBER OF CASES AND IMPROVED LATENCY

Hash size	Change in hash bits	Time taken by existing model in ms	Same bits in hash value	Proposed model
64	4	64	60	0.0625
64	3	64	61	0.046875
64	2	64	62	0.03125
64	1	64	63	0.015625
64	0	64	64	0

One Hash code is of 64 bits, the time taken to 1 bit Hash = 1 sec,

Time taken to update 64-bit Hash =64 seconds

Latency of log-based model =1/64=0.015625.

Time taken to generate the 2nd Hash Value=0.015625 + 2nd Hash value

Throughput is the amount of the data to be passed from one location to the other location. The throughput can be referred based on time and data. Only a single hash bit is required to be changed and the throughput time can be reduced by the possible number of favorable cases.

Throughput = Time taken to get result/Number of units.

A total number of 64 transactions taken from the data set where the throughput is calculated for individual access is considered. After applying the formula, the calculated throughput is 32.5 ms. The value of throughput can be considered as 32.5 ms. The average throughput can be considered as 32.5/64 which is 0.5078125ms where 32.5 is the sum of the throughput of the total 64 cases and the number of total cases is 64. The average latency of the 64 units can be calculated as 32.5/64 which is equivalent to 0.5078125ms. The proposed framework works better when the complete data set with 64 different values are applied to it. With the existing model the throughput is considered as 1 ms but the proposed model improves the average throughput by approximately 49 percent. The Table VI demonstrates the reduction in the time taken to construct the hash.

Different parameters are discussed that are based on which comparisons can be made without compromising the security and privacy of the model. After incorporating these parameters, the model can be further optimized as demonstrated in Table VII.

A. Scalability

Scalability is considered as the ability of the system never degrades once the data is increased or decreased. Scalability requires a permanent solution of the problem. The proposed system reduces the block size which makes the chain light in size. The logic behind the model is that the data stored in blockchain is comparatively lighter than the actual data. The log file associated with it keeps the load light and enhances the scalability of the network. This is also ensured that the security is not compromised while enhancing scalability.

B. Access Control

By adding the access control mechanism it is ensured that the restricted amount of data is required to be passed from the model. The definition of the roles is defined and data is passed from the chain. This not only promotes the security but also when the data is verified and passed the mechanism converts it into fix set of values. The fix data is forwarded to the blockchain model easily. This promotes scalability as well as security.

C. Security

The security is one of the prime attributes of the blockchain. The model allows the arbitrary values to be cross verified by the attribute-based model. This proposed model uses various permission and consensus levels to ensure the security of the model. Only authentic data is required to be transmitted from one node to other. Moreover, the data becomes even secure using blockchain technology because of its temper-proof and immutable nature.

TABLE VII. COMPARISON OF PROPOSED MODEL WITH RELATED WORK

Parameter	DASSCAR E 2.0 [2]	Permission Control Model [11]	DASSCare [3]	CrowdMed [4]	Proposed Model
Scalability	High	High	Low	Low	High
Access Control	High	Moderate	Low	Moderate	High
Security	High	Low	Moderate	High	High
Data Integrity	Moderate	High	High	High	High
Access Control	Moderate	High	High	High	High

D. Integrity

Integrity is the trustfulness of the system which can be easily achieved by the blockchain technology. The stored information can never be changed by unauthentic channel. Integrity allows the information to be available to end users like doctors and patients. The developed smart contract does not allow any entry to change the values of the model. The access control model is responsible for managing and making the data available at each end.

E. Data Confidentiality

Data Confidentiality: The patient's medical records are stored and are confidential from any third-party disturbance. All these types of data are made available to the doctors and the patients. The patient data include various reports like blood group, records of X-Rays and Magnetic Resonance Imaging (MRI) scans. Smart contracts make this confidential as it consists of some strict rules placed inside it. The privacy can be ensured by using blockchain as well as the access control mechanism.

VIII. CONCLUSION

A solution to the challenge of managing access control in an e-health ecosystem has been described in this paper. This paper describes a solution to the problem of managing access control in an e-health ecosystem. Access control in e-health is particularly difficult because resources and data are dispersed across various places and institutions. The problem is exacerbated by the fact that not all e-health resources are owned by a single organization or individual. To establish the correctness of the scheme idea, a proof-of-concept had to be built and implemented. Success was largely due to proof-of-concept. Even if they are preliminary, some functional and application tests and validations verify that the technique is sound. Overall, we believe the technique is feasible, with numerous advantages over existing systems when compared. The benefits of this system include, but are not limited to, the fact that access control policies are communicated and synchronised across the consortium's institutions and organizations, assuring

their integrity, transparency, and authenticity. The paper introduces a model where the time taken to create a new hash is 0.15625 microseconds. A total number of 64 transactions taken from the data set where the throughput is calculated for individual access are considered. After applying the formula, the calculated throughput is 32.5 microseconds. By the lighter block size, data can be made available to the patients. The research is for the patients so they can keep track of their medical history; and the deaths due to overdose of the medicines can be reduced. The future work of the proposed model includes finding more computational forces to make the blockchain size lighter and more scalable. Additionally, access control mechanisms should be implemented to ensure the integrity of the data coming from various sources.

REFERENCES

- [1] Cision PR Newswire Prensire <https://www.pnewsire.com/news-releases/us-experienced-highest-ever-combined-rates-of-deaths-due-to-alcohol-drugs-and-suicide-during-the-covid-19-pandemic-301552480.html> (Accessed-on 17/Oct/2022).
- [2] M. Ayache, A. Gawanmeh and J. N. Al-Karaki, "DASS-CARE 2.0: Blockchain-Based Healthcare Framework for Collaborative Diagnosis in CIoMT Ecosystem," 2022 5th Conference on Cloud and Internet of Things (CIoT), 2022, pp. 40-47, doi: 10.1109/CIoT53061.2022.9766532.
- [3] Al-Karaki, Jamal N.; Gawanmeh, Amjad; Ayache, Meryeme; Mashaleh, Ashraf (2019). [IEEE 2019 15th International Wireless Communications and Mobile Computing Conference (IWCMC) - Tangier, Morocco (2019.6.24-2019.6.28)] 2019 15th International Wireless Communications & Mobile Computing Conference (IWCMC) - DASS-CARE: A Decentralized, Accessible, Scalable, and Secure Healthcare Framework.
- [4] Mira Shah, Chao Li, Ming Sheng, Yong Zhang, Chunxiao Xing rowdMed: A Blockchain Based Approach to Consent Management for Health Data Sharing. Print ISBN: 978- 3-030-34481-8 Electronic ISBN: 978-3-030-34482-5 Copyright Year: 2019 <https://doi.org/10.1007/978-3-030-34482-5>.
- [5] Hu.C., Li, C., Zhang, G. et al. CrowdMed-II: a blockchain-based framework for efficient consent management in health data sharing. World Wide Web (2022). <https://doi.org/10.1007/s11280-021-00923-1>.
- [6] Nakamoto, S.: Bitcoin: a peer-to-peer electronic cash system, p. 9 (2008).
- [7] Buterin, V.: On public and private blockchains, August 2015. <https://blog.ethereum.org/2015/08/07/on-public-and-private-blockchains/>. Accessed 06 June 2017.
- [8] Salman, Tara, et al." Security services using blockchains: A state of the art survey." IEEE Communications Surveys Tutorials 21.1 (2018): 858-880.
- [9] Damiano Di Francesco Maesa, Paolo Mori, and Laura Ricci. 2017. Blockchain based access control. In IFIP International Conference on Distributed Applications and Interoperable Systems. Springer, 206– 220.
- [10] Castiglione A.; De Santis, A.; Masucci, B.; Palmieri, F.; Castiglione, A.; Li, J.; Huang, X. Hierarchical and shared access control. IEEE Trans. Inf. Forensics Secur. 2015, 11, 850–865.
- [11] Novo, O. Blockchain meets IoT: An architecture for scalable access management in IoT. IEEE Internet Things J. 2018, 5, 1184–1195.
- [12] Ouaddah, A.; Abou Elkalam, A.; Ait Ouahman, A. Fair Access: A New Blockchain-Based access control framework for the Internet of Things. Secur. Commun. Netw. 2016, 9, 5943–5964.
- [13] Xu, R.; Chen, Y.; Blasch, E.; Chen, G. Blendcac: A smart contract enabled decentralized capability- Based access control mechanism for the iot. Computers 2018, 7, 39.
- [14] Ouaddah, A.; Mousannif, H.; Elkalam, A.A.; Ouahman, A.A. Access control in the Internet of Things: Big challenges and new opportunities. Com- put. Netw. 2017, 112, 237–262.

- [15] O. Novo, "Scalable Access Management in IoT Using Blockchain: A Performance Evaluation," in *IEEE Internet of Things Journal*, vol. 6, no. 3, pp. 4694-4701, June 2019, doi: 10.1109/JIOT.2018.2879679.
- [16] Dorri, A.; Kanhere, S.S.; Jurdak, R.; Gauravaram, P. Blockchain for IoT security and privacy: The case study of a smart home. In *Proceedings of the 2017 IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops)*, Kona, HI, USA, 13-17 March 2017; pp. 618-623.
- [17] Touati, L.; Challal, Y. Poster: Activity-based access control for IoT. In *Proceedings of the 1st International Workshop on Experiences with the Design and Implementation of Smart Objects*, Paris, France, 7-11 September 2015; pp. 29-30.
- [18] Mahalle, P.N.; Thakre, P.A.; Prasad, N.R.; Prasad, R. A fuzzy approach to trust-based access control in internet of things. In *Proceedings of the Wireless VITAE 2013*, Atlantic City, NJ, USA, 24-27 June 2013; pp. 1-5.
- [19] Zhang, R.; Zhang, Y.; Ren, K. Distributed privacy-preserving access control in sensor networks. *IEEE Trans. Parallel Distrib. Syst.* 2012, 23, 1427-1438.
- [20] Chen, Y., Meng, L., Zhou, H., & Xue, G. (2021). A blockchain-based medical data sharing mechanism with attribute-based access control and privacy protection. *Wireless Communications and Mobile Computing*, 2021.
- [21] I. Baldine, Y. Xin, A. Mandal, P. Ruth, C. Heerman, and J. Chase, "Exogeni: a multi-domain infrastructure-as-a-service testbed," in *Testbeds and Research Infrastructure. Development of Networks and Communities*, pp. 97-113, Springer, 2012.
- [22] <https://www.kaggle.com/davidechicco/chronic-kidney-disease-ehrs-abu-dhabi> (Accessed-on 17/Oct/2022).
- [23] T. Wang, Y. Mei, X. Liu, J. Wang, H.-N. Dai, and Z. Wang, "Edge-based auditing method for data security in resource-constrained internet of things," *Journal of Systems Architecture*, vol. 114, p. 101971, 2021.
- [24] Z. Xu and Z. Cai, "Privacy-preserved data sharing towards multiple parties in industrial IoTs," *IEEE Journal on Selected Areas in Communications*, vol. 38, no. 5, pp. 968-979, 2020.
- [25] X. Liu, M. S. Obaidat, C. Lin, T. Wang, and A. Liu, "Movement-based solutions to energy limitation in wireless sensor networks: state of the art and future trends," *IEEE Network*, vol. 35, no. 2, pp. 188-193, 2021.
- [26] W. Jerbi, O. Cheikhrouhou, H. Hamam, H. Trabelsi and A. Guermazi, "A blockchain-based storage intelligent," *2022 International Wireless Communications and Mobile Computing (IWCMC)*, 2022, pp. 635-640, doi: 10.1109/IWCMC55113.2022.9824790.
- [27] Bogaerts, J., Decat, M., Lagaisse, B., Joosen, W.: Entity-based access control: supporting more expressive access control policies. In: *Proceedings of the 31st Annual Computer Security Applications Conference, ACSAC 2015*, pp. 291-300. ACM, New York (2015).
- [28] Sharma, A., Yadav, D. P., Garg, H., Kumar, M., Sharma, B., & Koundal, D. (2021). Bone cancer detection using feature extraction-based machine learning model. *Computational and Mathematical Methods in Medicine*, 2021.
- [29] Kumar, M., Bajaj, K., Sharma, B., & Narang, S. (2021). A Comparative Performance Assessment of Optimized Multilevel Ensemble Learning Model with Existing Classifier Models. *Big Data*.

A New Design of Optical Logic Gates with Transverse Electric and Magnetic

Lili Liu¹, Haiquan Sun^{2*}, Lishuang Hao³, Cailiang Chen⁴

Xuanhua Vocational College of Science & Technology, Zhangjiakou Hebei, 075000, China^{1,3,4}
Hebei University of Architecture, Zhangjiakou Hebei, 075000, China²

Abstract—This paper presents a new design of optical NOR and XNOR logic gates using a two-dimensional-hexagonal photonic crystal (2D-HPhC) that allows for both Transverse Electric (TE) and Transverse Magnetic (TM) polarization modes. The structure is very small in size and has a low delay time. The design includes three inputs (A, B, C) and one output (Q) waveguide, with the NOR gate having a delay period of 0.75 ps and the XNOR gate having a delay period of 0.9 ps. The contrast ratio between the input and output for both gates is 7-8 dB. The XNOR gate has an optimum transmission signal rate of $T = 96\%$. The purpose of the structure is to use a reference input to create the fundamental logic gates NOR and XNOR by adjusting the signal phase angle.

Keywords—Photonic crystal; hexagonal lattice; NOR; XNOR; transverse electric; transverse magnetic

I. INTRODUCTION

Future electronic circuits will have speed constraints due to the growth of telecommunication systems to enhance the speed and bandwidth acceptable for data transfer (frequency). In optical networks and signal processing systems, high-frequency, all-optical logic gates are essential. All-optical logic switches and gates are among the basic components for designing future information processing systems and optical networks. Using optical networks, speed and capacity limits in communication networks are solved [1]. Optical crystals are considered a suitable structure in optically integrated circuits due to their compressibility. For the implementation of all-optical logic gates, several architectures have been suggested thus far. Logic gates through linear and nonlinear photonic crystals have gotten special attention in order to ease the integration of the suggested architectures [2]. A logic gate in a digital system executes a logical operation on one or more rationale inputs before producing a rationale yield. All digital circuits often employ Boolean logic, which is the foundation of this logic. Logic gates use binary logic, mostly made of transistors and diodes in electrical devices.

Photonic crystals are alternating structures on the nanoscale and affect the motion of photons due to changes in the refractive index of the components and the proportional wavelength. This is what semiconductor crystals do with electrons. Similar to how the Schrodinger equation involves electrical potential, the refractive index plays a part in the Helm-Holtz equation. The periodicity in the refractive index, more or less within the crystal, serves as the foundation for photonic crystals. The wavelength of the photons affects how they are emitted inside these structures. Modes are the light

wavelengths that are permitted to move. A group of diffuse fashions forms the bandgap. Unauthorized bands of photonic crystals are called bandgaps. If we have materials of the dielectric material, which have a forbidden band for photons, at a certain frequency range no light can move inside the crystal structure of matter. The most important difference between photons and electrons is their velocity. Electrons belong to the group of fermions due to their incorrect spin, and the Pauli Exclusion Principle governs them. In contrast, photons have the correct spin and are considered bosons, so there is no limit to the number and energy of photons in the crystal. The effect of photons on each other is much less than the interaction of electrons, which reduces losses in dielectrics. Because the shrinkage of optical circuits faced problems such as energy loss, photonic crystals have been proposed to solve this problem. Defects in photon crystal structures can be created and based on the defects in the photon crystal lattice, these structures are divided into three categories: one-dimensional, two-dimensional, and three-dimensional [3].

Due to the use of photonic crystals to make all-optical logic gates and their use in all-optical systems, structures with low losses and high efficiency are required for all-optical logic gates. The proposed structure for all-optical logic gates based on photon crystals should have small dimensions (for integration), low losses, and a suitable distance between to be logic surfaces. In addition to the above, the working wavelengths of the proposed structure should be in telecommunication windows so that these logic gates can be used in filters, switches, sequential circuits, and all-optical composite circuits. Given the importance of processing speed, bandwidth, and dimensions in today's all-optical integrated circuits, it is necessary to provide a structure with such specifications. In this research, we will try to design and simulate a structure with the mentioned capabilities, and the proposed structure will be flexible and will change the type of logic gates with a small change in the arrangement of dielectrics. The initial structure proposed is the NOR logic gate, based on a photonic crystal, the subsequent gates being designed by trial and error and the experience of previous articles in the field.

Today, the demand for high bandwidth to reduce the speed limit of electronic devices is increasing rapidly. Optical signal processing requires complex logic gates. To build all-optical systems, it is necessary for all the components used to be able to work in the optical network. Gates are key components for building all-optical systems. In order to convert digital gates into all-light gates, changes in the original design are needed.

To design all-optical gates, it is necessary to apply an alternating layer of dielectrics, which modulates the signal to produce the desired results. Nonlinear effects can be achieved using various methods such as nonlinear ring mirrors, linear fiber, photon crystals, changing the refractive index of materials, filters, waveguides, or optical semiconductor amplifiers [4]. Optical elements that reduce the size of optical integrated circuits are good candidates for future optical networks and optical computations due to the transmitted wavelength. All-optical communication is one of the solutions to the problem of the speed and size of electronic circuits. Logic gates are one of the most important components in all-optical circuits. In recent years, researchers have developed all-optical logic gates for use in nonlinear effects in optical fibers, but one of the limitations has been a large size, low speed, and size of integrated circuits [5].

Many researchers have been interested in all-optical signal processing techniques recently, but all-optical devices must be fully utilized to use optical transmission capabilities. These devices include optical filters [6, 7], optical multiplexers [8, 9], optical analogue-to-digital converters [10, 11], optical switches [12], optical logic gates [13, 14], optical accelerometers [15], optical half-adders [16], and other similar optical devices. A device known as an "all-optical logic gate" produces logic outputs by performing logic operations on light with light. When one or more lights with light inputs are subjected to logic operations, the device is known as a logic gate. High-speed all-optical logic gates are necessary in the processing of signal as well as optical networks. The complication, speediness, reliability, steadfastness, and straightforwardness of integration of the numerous designs created hence distant to degree the execution of all-optical rationale gates shift. Rationale entryways based on through straight and nonlinear photon precious stones have gotten extraordinary consideration and have been significantly broadened to help in joining the recommended structures [17, 18]. All-optical rationale gates based on photon precious stones may be made, recreated, and fabricated utilizing nanocavity, nonlinear fabric characteristics, ring resonators, and the Mach Zehnder interferometer. On the premise of XOR, XNOR, NAND, and NOT rationale entryways, Nozhat et al. effectively outlined high-contrast nonlinear two-dimensional gem photonics in 2015. The tall differentiate proportion of around 20 dB between "1" and "0" [19] may be a recognizing quality of this rationale entryway in comparison to other rationale gates already formulated. A two-input, two-dimensional photon crystal-based NAND gate with a ring resonator was recommended by Siraj M. The proposition incorporates an add up to zone of 249.75µm², and the delay time is, at best, 3.6 ps [16, 20]. Most newly suggested rationale entryway designs can as it were work within the TM or TE polarization modes. Both the delay time and the auxiliary estimate are significant.

Employing a hexagonal cross section in silicon photon gems on a cover and autonomous of polarization, a strategy for building all-optical rationale entryways is given in this inquire about. An assortment of entryways utilized in this way can join optical rationale gates through the obstructions wonders, utilizing direct blemishes and obstructions between light bars.

II. NUMERICAL METHODS

The finite difference time domain (FDTD) approach may demonstrate light diffusing in a photonic crystal. The center thought behind the limited contrast time space approach is to inexact spatial and worldly subsidiaries utilizing the limited contrast in Maxwell conditions. The microstructure under examination is split into a small number of constant lattice points in the FDTD technique, where the field values are computed. For the expression of spatial and temporal derivatives, magnetic and electric fields use backslash and anterior differences, respectively. For the electric and magnetic regions of Maxwell's Eq. (1) and (2), the derivatives listed below can be used in their place.

$$\frac{\partial E(r,t)}{\partial r_i} \rightarrow \frac{\Delta_i + \hat{E}}{\Delta r_i} = \frac{\hat{E}(r + q_i u_i, t) - \hat{E}(r, t)}{q_i} \quad (1)$$

$$\frac{\partial E(r,t)}{\partial t} \rightarrow \frac{\Delta_i + \hat{E}}{\Delta t} = \frac{\hat{E}(r, t + \delta t) - \hat{E}(r, t)}{\delta t} \quad (2)$$

$$\frac{\partial H(r,t)}{\partial r_i} \rightarrow \frac{\Delta_i - \hat{H}}{\Delta r_i} = \frac{\hat{H}(r, t) - \hat{H}(r - q_i u_i, t)}{q_i} \quad (3)$$

$$\frac{\partial H(r,t)}{\partial t} \rightarrow \frac{\Delta_i - \hat{H}}{\Delta t} = \frac{\hat{H}(r, t) - \hat{H}(r, t - \delta t)}{\delta t} \quad (4)$$

In these equations, q_i denote distance among the grid's lattice points and u_i the unit vectors that constitute the computational grid, are used to measure the geometric space. Reclaimed by fields:

$$\hat{E} = q_i E \rightarrow \text{and} \rightarrow \hat{H} = q_i H \quad (5)$$

The x and z axes of the FDTD simulator's coordinate system are specified to lie in $\Gamma - M$ and $\Gamma - k$ planes, correspondingly. The direction of y is vertical/perpendicular to crystal's surface for fitting the hexagonal configurations' geometry. The rectangular coordinate is regarded for the lattice coordination where the distance of lattice is considered $qx = \sqrt{3} \cdot qz$. The FDTD software accordingly ensures stability.

$$\delta t = 0.99 \sqrt{\frac{3}{7}} \left(\frac{q_x}{c} \right) \quad (6)$$

Where q_x denotes the x-directional lattice distance, the relationship between the spatial grid and worldly steps is illustrated by the statement mentioned above, which states that for a more precise spatial lattice, numerous more worldly steps are vital. The output contrast ratio is yet another factor of significance in the development of logic gates [21]. The ratio of the control for "1" rationale to the control for "0" rationale from the condition is utilized to compute the differentiate proportion for both TE and TM polarizations.

$$\text{ContrasrRatio(CR)} = 10 \log (P_1/P_0)(\text{dB}) \quad (7)$$

Where P_0 stands for the control of the consistent "0," whereas P_1 speaks to the coherent control of "1." In this work, we decide the differentiate proportion for this rationale gate at 1.550 µm wavelength.

III. PHOTONIC BAND STRUCTURE

The behavior of light as it passes through a periodic structure, which generates a number of potential barriers and wells for photons, is referred to as the photonic band structure. Similar to the energy bands for electrons in a solid, the structure produces photonic bands and energy gaps known as photonic band gaps. In order to ascertain the band structure and operating wavelength of photonic structures, it is essential to comprehend the microstructure of photonic bandgap graphs. The band structure of the in-demand unit cell depends on the microstructure of the photonic bandgap graph. In order to create photonic crystals with distinctive optical characteristics, the photonic band structure and the microstructure of photonic bandgap graphs are crucial.

Here, the microstructure of the photonic bandgap graph has been selected to begin with some time recently continuing to the specifics of the plan and displaying. Getting the recurrence crevice is one of the key thoughts within the microstructure of

vitality groups. The working wavelength is the wavelength that can be exchanged from the source to the yield without being scattered, losing vitality, or entering the structure. According to Blah's theory, this requires knowledge of the microstructure's unit cell. The hexagonal photonic crystal's unit cell is seen in Fig. 1.

In arrange to decide the in-demand unit cell's band structure, we must to begin with decide the structure's unit cell. The bandgap structure is seen in Fig. 2. The recommended microstructure within the wavelength run of $\lambda = 1.4874\mu\text{m} \sim 1.621\mu\text{m}$ as appeared, and encompasses a full photonic bandgap within the normalized recurrence run of a $\lambda = 0.3516 \sim 0.3832$.

Remember that the structure has a complete bandgap since the specified gates are polarization-independent. The bandgaps for the TM and TE modes cross across, as seen in the above picture.

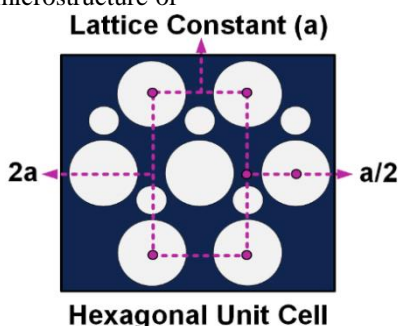


Fig. 1. The hexagonal cell of the planned rationale entryways.

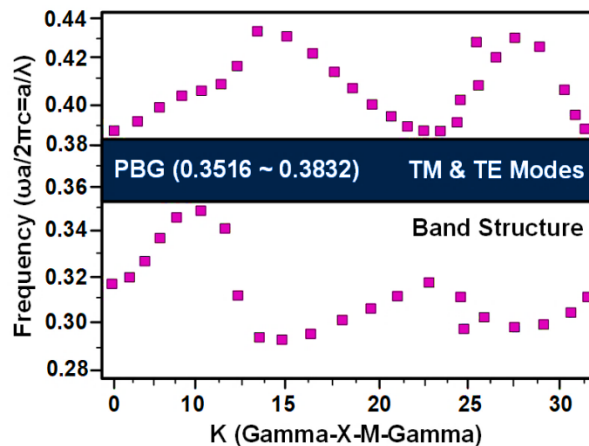


Fig. 2. Photonic band structure.

IV. OPTICAL LOGIC GATE

In expansion to the two essential inputs, another input is included within the plan of rationale entryways to alter the application and increment the applications, such as NOR and XNOR. This extra input permits fluffy control of the optical signals. So, when there are three input waveguides and one yield waveguide, the suggested structure is as takes after. (Fig. 3) The performance of the constructive and destructive interference in the controller waveguide results in the logic gates. On the SOI substrate, the recommended plan comprises

of an $X \times Z$ hexagonal cross section with a number of 17×15 gaps separated into two bunches. The sweep was selected to produce two diverse photonic bandgaps. The two air holes have a radius of $r_b = 0.36a$ for the larger air hole and $r_s = 0.16a$ for the smaller air hole, where (a) is the cross-section steady, which is equivalent to $a=550$ nm. The greater air holes are completely in the middle of the smaller ones. The two-dimensional photonic crystal's holes are partially removed to produce the waveguides. Using the effective refractive index approach, two-dimensional analysis is carried out since three-dimensional computations take more time and memory.

$n(TM) = 2.150$ and $n(TE) = 2.890$ and, respectively are determined as the successful chunk refractive records for the TE and TM modes at the wavelengths= $1.550\mu\text{m}$. The suggested design has been determined to be capable of acting as all-optical logic gates after the microstructure has been tuned for both polarization modes at wavelength.

The suggested structure has four waveguides that serve as input and output ports for designing and simulating all-optical rationale gates with three inputs. The two major input ports are the Q output and a C reference or Controller input. Depending on the staging point, the port's reference signal or control indicator generates a stage contrast between the input indicators, coming about in either helpful or dangerous obstructions between the input indicators. Since the symmetry of the reflect picture around the waveguides, most light is caught in this construction's waveguide locale. Also, the input and yield waveguide borders are changed by the incorporation of more discuss gaps with lower radii. An enormous discuss gap and two littler discuss gaps maximize the optical control

transmission. This method has impressive focal points for optical control transmission to the yield and avoiding optical control misfortune within the structure. Within the following step of the plan, four waveguides with a gap within the center are proposed. Again, this gap is tuned for both TM and TE modes with a polarization-dependent central gap sweep of 0.23. When combined with the reference flag, both input signals provide the highest possible value for TM and TE polarizations, making this sweep ideal for the input flag. The most effective regulation happens once one of the two input signals is propagated on two input waveguides at once, leading to light-generating impedances at the junction of four waveguides when all of the signals are onstage. Since dangerous impedances happens when the signals are out of stage, the portrayed strategy may be utilized to execute the NOR and XNOR optical rationale gates. Less control will be shown within the yield waveguide as a result.

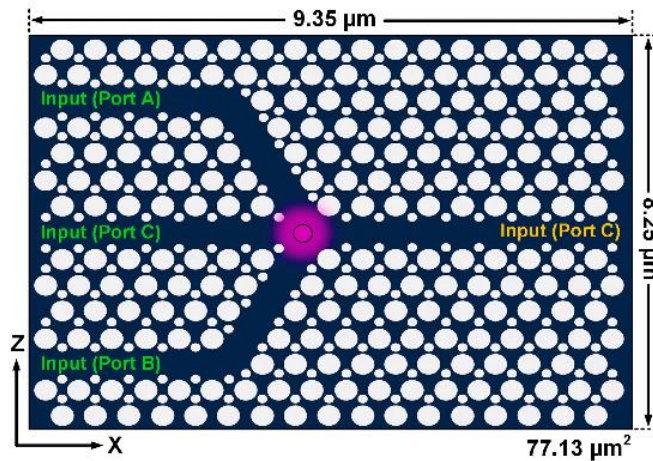


Fig. 3. The proposed of 2D-HPHC structure.

V. RESULT AND DISCUSSION

There are three different kinds of general logic operations that will be executed in this suggested architecture. If a light signal with $\varphi = 0^\circ$ is applied to either the A or B input port and a control signal with $\varphi = 0^\circ$ is applied to the reference port, then a logical "1" is produced. When a light signal with a $\varphi = 0^\circ$ is excited at either the A or B input port and the reference port is stimulated with a control signal with a $\varphi = \pi^\circ$, a logical "0" is produced. And, the highest output power is achieved when the reference port is activated only by the controller signal at either $\varphi = 0^\circ$ or $\varphi = \pi^\circ$ out of phase.

A. NOR Optical Logic Gate

The NOR logic gate, primarily employed in most digital devices' design, follows the reverse OR gate. Four separate states are used to characterize the NOR logic gate's operation [19, 21]. Table I displays this logic gate's potential states and the transmission rate.

Within the 'to begin with' situation, no flag is connected to any of the input ports, and the control flag is connected to the reference harbour with a stage point of $\varphi = \pi^\circ$. When utilizing

TE or TM polarization, the yield harbour, in this occasion, gets "1" rationale at a transmission rate of 67% or 58%, separately. The reference harbour is concurrently energized with the light flag with a stage point of $\varphi = \pi^\circ$ and the control flag by a stage point of 180 degrees ($\varphi = \pi^\circ$) within the moment and third occurrences, separately, and A and B input ports are energized concurrently by the light flag within the moment and third cases. Fig. 4 portrays the introductory state. As watched, the TE-polarization mode has the most reduced delay time or the fastest working speed with a NOR Entryway within the moment state, 0.75ps.

Segments (a) and (b) of Fig. 5 show the field conveyance designs for the TE and TM polarization modes, individually. The consequences illustrate that the planned strategy capacities as a NOR optical rationale gate.

This gate has a signal in each of its reference ports at an angle of 180 degrees ($\varphi = \pi^\circ$), as observed. Also, 7dB is used for the contrast parameter.

B. Optical Logic Gate of XNOR

Within the ‘to begin with’ state, no flag is connected to any input ports, whereas the control flag is connected to the reference harbour with a stage point of $\varphi = 0^\circ$ [18]. Within the moment and third stages, a light flag with a stage point of $\varphi = 0$ is used to individually excite the A as the input port and, subsequently, the second input port B. In contrast, a control signal by a phase angle of $\varphi = \pi^\circ$ is utilized to exclusively energize the primary input harbour A and, hence, the moment input harbour B. In differentiate, a control flag with a stage point of $\varphi = 0^\circ$ fortifies A and B i.e., input ports and reference harbour C within the fourth state. In this occurrence, constructor obstructions is fulfilled since all three light signals are at co-phase in yield harbour 1. Table II lists the findings for every possible combination of TM and TE polarizations. At 1550 nm wavelengths, the difference percentage for this reasonable entrance is 8dB.

The three fundamental states within the TE and TM polarization modes are appeared within the field dissemination in Fig. 6(a) a persistent Gauss a wavelength of 1550 nm. Section (a), which can be seen in the image, simulates the three principal states while applying an optical signal source in TE mode to the microstructure. The inputs in the section receive an optical signal source operating in TM mode (b).

The reenactment discoveries appear that the stage alter point of the reference harbour C is utilized to construct all of the elemental optical rationale entryways utilized in optical coordinates circuits. Another significant benefit of the suggested microstructure is its ability to receive polarization and supply the correct output. The TE-polarization modes and the TM-polarization mode’s respective minimum delay times are one period (ps) and nine periods (ps), respectively.

TABLE I. THE PRECISION RESULTS OF THE NOR LOGIC GATE

(Q)	0	1	0	0
T (TE Mode)	5 %	65 %	11 %	5 %
T (TM Mode)	5 %	58 %	6 %	5 %
Input (A)	0i($\varphi=0^\circ$)	0i ($\varphi=0^\circ$)	1i ($\varphi=0^\circ$)	1i ($\varphi=0^\circ$)
Input (B)	1i ($\varphi=0^\circ$)	0i ($\varphi=0^\circ$)	1i ($\varphi=0^\circ$)	0i ($\varphi=0^\circ$)
Input (C)	1i ($\varphi= \pi^\circ$)	1i ($\varphi= \pi^\circ$)	1i ($\varphi= \pi^\circ$)	1i ($\varphi= \pi^\circ$)

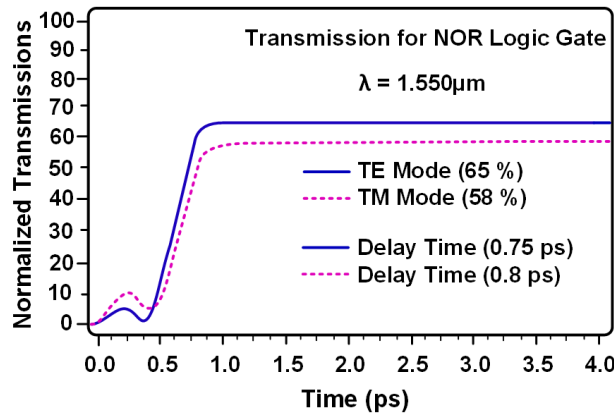
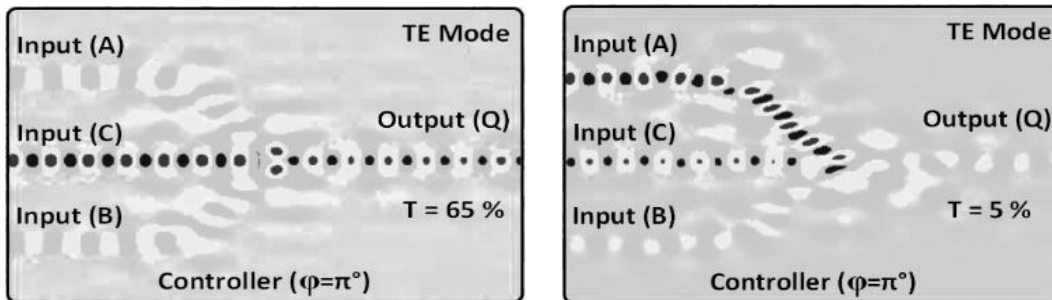


Fig. 4. The time of delay for second state of NOR logic gate.



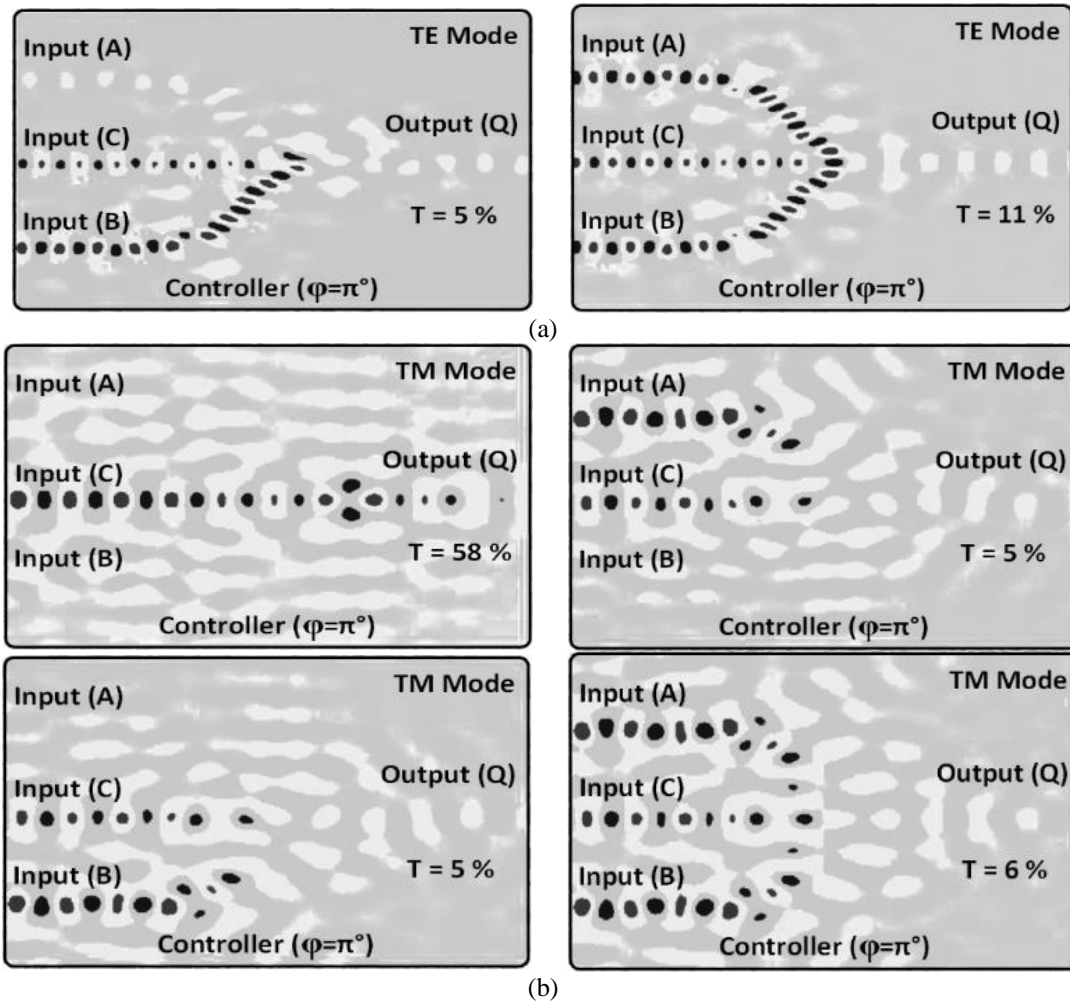
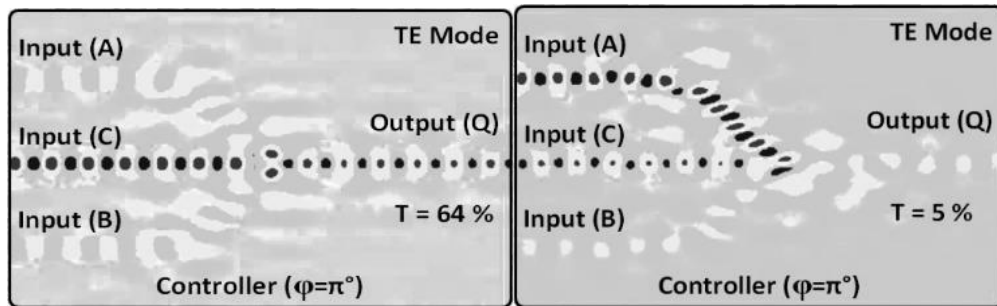


Fig. 5. Field dissemination at NOR rationale entryway, (a) TE mode, (b) TM mode.

TABLE II. THE EXACT NECESSITY OF THE NOR RATIONALE GATE WITH FOUR INPUTS.

(Q)	0	1	1	0
T (TE Mode)	5 %	64 %	96%	5%
T (TM Mode)	5 %	58 %	90 %	5%
Input (A)	0i ($\varphi=0^\circ$)	0i ($\varphi=0^\circ$)	1i ($\varphi=0^\circ$)	1i ($\varphi=0^\circ$)
Input (B)	1i ($\varphi=0^\circ$)	0i ($\varphi=0^\circ$)	1i ($\varphi=0^\circ$)	0i ($\varphi=0^\circ$)
Input (C)	1i ($\varphi=\pi^\circ$)	1i ($\varphi=\pi^\circ$)	1i ($\varphi=0^\circ$)	1i ($\varphi=\pi^\circ$)



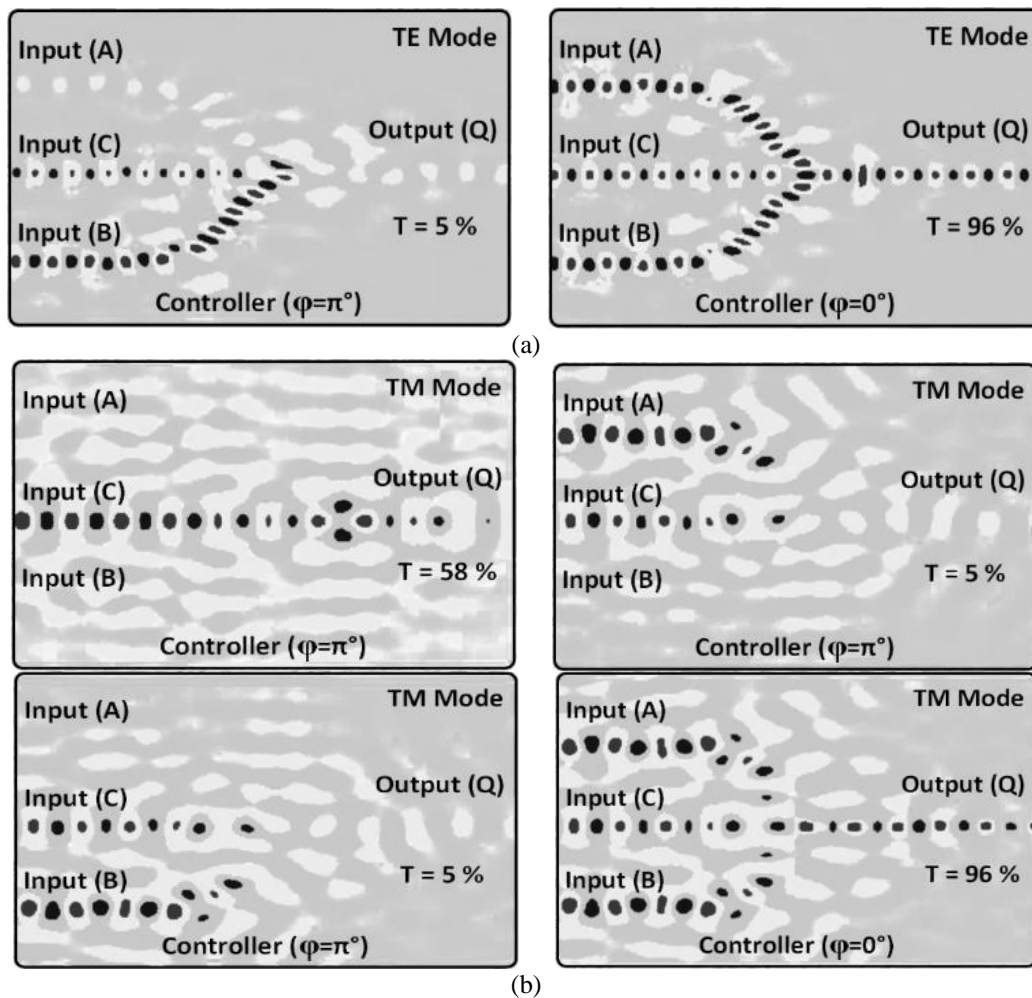


Fig. 6. Field dispersion at XNOR rationale gate, (a) TE mode, (b) TM mode.

VI. CONCLUSION

This paper plans and mimics all base rationale gates (TE/TM) free of polarization modes utilizing a hexagonal photonic gem with silicon dielectric on a separator. Embracing the recommended microstructure will empower the headway of all prior thinks about to a brand-new era of polarization-independent gates. In this paper, a novel optical NOR and XNOR logic gate design is introduced utilizing a two-dimensional-hexagonal photonic crystal (2D-HPHC) that facilitates Transverse Electric (TE) and Transverse Magnetic (TM) polarization modes. The size of the structure is relatively small, and it possesses a low delay time. The design incorporates a waveguide with three inputs (A, B, C) and one output (Q). The NOR gate demonstrates a delay period of 0.75 ps, while the XNOR gate showcases a delay period of 0.9 ps. The contrast ratio between input and output for both gates is 7-8 dB. Furthermore, the XNOR gate displays an optimal transmission signal rate of T = 96%. The work of hexagonal photonic gems, silicon dielectric fabric on cover with a satisfactory thickness, and the span of the gaps within the structure causes the mutual bandgap in equally TM and TE polarization types. The current study is only considered the specific design and parameters of the gates and does not explore other possible configurations or applications of the 2D-

HPHC. Future study could explore the potential of integrating the 2D-HPHC design with other technologies for advanced functionality and performance.

REFERENCES

- [1] Q Gong, X Hu, editors, "Photonic crystals," principles and applications. CRC Press. 6, (2014).
- [2] K Arunachalam, SC Xavier. Optical logic devices based on the photonic crystals," Photonic crystals introduction, applications and theory. 30, pp.63-80, (2012).
- [3] S. Noda, K. Tomoda, N. Yamamoto, and A. Chutinan, "Full Three-Dimensional Photonic Bandgap Crystals at Near-Infrared Wavelengths," Science, 289, pp. 604-606, (2000).
- [4] A. P. Kabilan, X. S. Christina and P. E. Caroline, "Photonic Crystal Based All-Optical or and Xo Logic Gates," in 2010 Second International Conference on Computing, Communication, and Networking Technologies, pp. 1-4. (2010).
- [5] S. Swarnakar, S. Kumar, S. Sharma, and L. Singh, "Design of XOR/and Gate Using 2D Photonic Crystal Principle," in SPIE OPTO, Vol. 10130, pp. 162-172, pp. 11. (2017).
- [6] M. Hosseinzadeh Sani, A Ghanbari, and H Saghaei. "An ultra-narrowband all-optical filter based on the resonant cavities in rod-based photonic crystal microstructure," Optical and Quantum Electronics 52, pp.1-15. (2020).
- [7] M. Youcef Mahmoud, G. Basso, A. Taalbi and Z. M. Chekroun, "Optical Channel Drop Filters Based on Photonic Crystal Ring Resonators", Optics Communications, 285, pp.368-372, (2012).

- [8] H. Alipour-Banaei, F. Mehdizadeh and S. Serajmohammadi, "A Novel 4-Channel Demultiplexer Based on Photonic Crystal Ring Resonators", *Optik - International Journal for Light and Electron Optics*, 124, pp. 5964-5967, (2013).
- [9] M. Reza Rakhshani and M. Ali Mansouri-Birjandi, "Design and Simulation of Wavelength Demultiplexer Based on Heterostructure Photonic Crystals Ring Resonators", *Physica E: Low-dimensional Systems and Nanostructures*, 50, pp. 97-101, (2013).
- [10] M H Sani, S Khosroabadi., & A Shokouhmand, A novel design for 2-bit optical analog to digital (A/D) converter based on nonlinear ring resonators in the photonic crystal structure. *Optics Communications*, 458, 124760. (2020).
- [11] M H Sani, M Hosseinzadeh, S Khosroabadi, and M Nasserian. "High performance of an all-optical two-bit analog-to-digital converter based on Kerr effect nonlinear nanocavities." *Applied optics* 59. 4. (2020). pp.1049-1057.
- [12] T. Ahmadi Tameh, B. M. Isfahani, N. Granpayeh, and A. M. Javan, "Improving the Performance of All-Optical Switching Based on Nonlinear Photonic Crystal Microring Resonators", *AEU - International Journal of Electronics and Communications* (2011)., 65, pp. 281-287.
- [13] P. Andalib and N. Granpayeh, "All-Optical Ultracompact Photonic Crystal and Gate Based on Nonlinear Ring Resonators", *Journal of the Optical Society of America B*, (2009).26, pp.10-16.
- [14] P Sami, Ch Shen, and M Hosseinzadeh Sani. "Ultra-fast all-optical half-adder realized by combining AND/XOR logical gates using a nonlinear nanoring resonator." *Applied Optics*. (2020).59.22. pp.6459-6465.
- [15] M Hosseinzadeh Sani, et al. "A novel all-optical sensor design based on a tunable resonant nanocavity in photonic crystal microstructure applicable in MEMS accelerometers." *Photonic Sensors* (2021).11.4. pp.457-471.
- [16] M. H Sani., A. A Tabrizi, H Saghaei & R Karimzadeh,. An ultrafast all-optical half adder using nonlinear ring resonators in photonic crystal microstructure. *Optical and Quantum Electronics*, (2020) 52(2), pp.1-10.
- [17] Z.-H. Zhu, W.-M. Ye, J.-R. Ji, X.-D. Yuan and C. Zen, "High-Contrast Light-by-Light Switching and Gate Based on Nonlinear Photonic Crystals", *Optics Express*, (2006)14, pp. 1783-1788.
- [18] Y. J. Jung, S. Yu, S. Koo, H. Yu, S. Han, N. Park, "Reconfigurable All-Optical Logic and, Nand, or, nor, Xor and XNOR Gates Implemented by Photonic Crystal Nonlinear Cavities," in *Conference on Lasers and Electro-Optics/Pacific Rim*, Shanghai, p. TuB. (2009), pp.4_3.
- [19] Z. Mohebbi, N. Nozhat and F. Emami, "High Contrast All-Optical Logic Gates Based on 2d Nonlinear Photonic Crystal", *Optics Communications*, (2015) 355, pp. 130-136.
- [20] S Serajmohammadi,. and H. Absalan, all-optical NAND gate based on nonlinear photonic crystal ring resonator, *Information processing in Agriculture*, (2016). 3(2), pp. 119-123.
- [21] A Mohebzadeh-Bahabady, and S. Olyaei, All-optical NOT and XOR logic gates using photonic crystal nano-resonator and based on an interference effect, *IET Optoelectronics*, (2018). 12(4), pp. 191-195.

Weapons Detection System Based on Edge Computing and Computer Vision

Zufar R. Burnayev¹, Daulet O. Toibazarov², Sabyrzhan K. Atanov³, Hüseyin Canbolat⁴, Zhexen Y. Seitbattalov⁵,
Dauren D. Kassenov⁶

Department of Social Disciplines and Pedagogy, The National Defence University named after the First President of the Republic of Kazakhstan - Elbasi, Astana, Kazakhstan¹

Department of Arms and Military Equipment Research, The National Defence University named after the First President of the Republic of Kazakhstan - Elbasi, Astana, Kazakhstan²

Department of Computer and Software Engineering, L. N. Gumilyov Eurasian National University, Astana, Kazakhstan^{3,5}

Department of Electrical and Electronics Engineering, Ankara Yıldırım Beyazıt University, Ankara, Turkey⁴

Department of Education and Science, Ministry of Defense of the Republic of Kazakhstan, Astana, Kazakhstan⁶

Abstract—Early detection of armed threats is crucial in reducing accidents and deaths resulting from armed conflicts and terrorist attacks. The most significant application of weapon detection systems would be found in public areas such as airports, stadiums, central squares, and on the battlefield in urban or rural conditions. Modern surveillance and control systems of closed-circuit television cameras apply deep learning and machine learning algorithms for weapons detection on the base of cloud architecture. However, cloud computing is inefficient for network bandwidth, data privacy and slow decision-making. To address these issues, edge computing can be applied, using Raspberry Pi as an edge device with the EfficientDet model for developing the weapons detection system. The image processing results are transmitted as a text report to the cloud platform for further analysis by the operator. Soldiers can equip themselves with the suggested edge node and headphones for armed threat notifications, plugged into augmented reality glasses for visual data output. As a result, the application of edge computing makes it possible to ensure data safety, increase the network bandwidth and provide the device operation without the internet. Thus, an independent weapon detection system was developed that identifies weapons in 1.48 seconds without the Internet.

Keywords—Internet of Things; gun recognition; edge device; Raspberry pi; military systems control; network analytic

I. INTRODUCTION

Recent world events show that the number of terrorist attacks per year and armed conflicts continues to grow. According to the report of Global Terrorism Index 2022 [1], even developed countries such as the United States of America ranked 30th in the overall terrorism index score, while France and Germany were in 34th and 35th places and the United Kingdom was in 42nd place among 195 countries. More than 20 countries are involved in armed conflicts and civil wars in 2023 [2]. Most of these acts of violence involve armed people whose goal is to seize territories and destroy stability in a region or state. Often enemy strikes and terrorist attacks occur at strategic targets and in public areas. Defence forces and intelligence agencies should monitor the situation to prevent and minimize the consequences of those violent acts. One of

that approaches is early weapons detection.

The conventional surveillance and control system of Closed-Circuit Television (CCTV) cameras involve human as operator and requires manual control of a large number of cameras [3]. Thus, it is requiring a significantly large number of personnel to monitor cameras in vast areas. Modern Weapons Detection Systems (WDS) mainly apply an Artificial Intelligence (AI). The initial task of the first AI recognition and detection systems was to recognize a person and a face [4]. Since the process of face recognition is one of the most important task in the field of Computer Vision (CV) with various promising applications from academic research to intelligence services [5]. Moreover, a human pose [6] can give some information about the probability that a person is going to use a weapon.

This paper describes the process of creating a weapons detection system for military and civil purposes. To avoid the disadvantages of cloud architecture, such as low network bandwidth, threats to data safety and lack of computing resources of a data center, the edge computing architecture has been applied in the development of the weapons detection system. A single-board computer, Raspberry Pi, has been selected as an edge computing device, or it is briefly called an edge device [7, 8]. Our previous studies have shown the excellent results in the application of computer vision and edge computing to number plate recognition system on the Raspberry Pi [9], as well as in the development of an intelligent task offload system [10]. Thus, the Raspberry Pi would be able to complete the task of weapon recognition based on the EfficientDet model and significantly reduce the cost of the technical solution. In order to minimize the possibility of bias or overfitting with subsequent performance degradation [11], some method optimization parameters can be applied.

This study aimed to develop a weapons detection system based on Raspberry Pi with a camera module using the EfficientDet model and edge computing algorithms, as well as notification about armed threats through headphones and the capability of visualization output on the interface of soldiers' augmented reality (AR) glasses and send results to the Internet

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of Things (IoT) cloud platform for further report analyses by an operator.

As a hypothesis, it is assumed that the application of edge computing significantly decreased the volume of transcended data to the cloud, offloading the computing resources of the data center and affording the edge device functioning without an Internet connection.

The paper is organised as follows: Section II reviews the related works in the area of weapon detection and Internet of Things application. Section III presents the EfficientDet and edge computing architectures, the process of building a model for weapons detection and its algorithms. Section IV provides a detailed description of the results for each various experimental case of weapons detection. Section V compares the obtained experimental results with the existing related works. Finally, Section VI summarises all text and indicates a direction for future work.

II. RELATED WORKS

During the last years, object detectors have been greatly improved technologically and allow security forces to identify weapons with fast speed and high accuracy. Nevertheless, there is an issue in practice when it comes to recognising small objects or the reflective surface of the knife [12, 13]. One study has focused on training a model for tilling approach using Single Shot Detector MobileNet V2 and Armed CCTV Footage dataset to detect small weapons [14]. The mean average precision (mAP) of that research was about 0.758 for pistol and knife evaluation. Also, a rather significant problem is the detection of a weapon in the attacker's hand [15] or whether it is hidden from an observer in the other part of the body.

As previously noted, there are many related works describing Deep and Machine Learning methods that are currently used to detect weapons. One of the most widely used classic real-time weapons detection approaches is the Convolutional Neural Networks (CNN). The accuracy and speed of weapon detection by the CNN approach through the transfer learning method using the Visual Geometry Group and fine tuning [16] show a moderate result. This is true that CNN had quite impressive image classification performance, but without enormous data and multiview cameras, it has a problem with overfitting [17]-[19]. Since the architecture of CNN can be transformed in Faster Region CNN due to a feature extractor Inception-ResNetV2 [20], that model type can demonstrate a high per cent of mAP. However, You Only Look Once V2 (YOLO) is faster in testing and training time compared to Faster Region CNN. The other study showed that Region CNN (R-CNN) and Region Fully Convolutional Networks (R-FCN) approaches have increased the speed of weapon detection, according to the experiment conducted by Arif [3]. However, in their experimental part of the study, there were false positive results for the detection of weapons. The next paper has considered CNN approach with applying Transfer Learning and two techniques such as AlexNet and GoogLeNet [21]. Nonetheless, they have the same issue connected with false positive results as previously considered work. To overcome false positive results, Debnath and Bhowmik [12] have developed an Iterative Model Generation

Framework (IMGF), which detects only moving persons with a gun and decreases the consumption of computing resources. Goenka and Sitara [23] have applied Gaussian deblur technique for Mask RCNN to detect guns better in case of a blurred image. Comparing Deep Learning (DL) and Machine Learning (ML) approaches for weapons detection [24] in terms of speed and accuracy, the former is better.

The newest and most accurate model for object detection is YOLO, and it has a lot of versions. The paper described difference between YOLOv3 and YOLOv4 in terms of sensitivity and processing time [25]. The experimental part of following studies confirms the superiority of YOLOv4 over previous YOLOv3 [26]-[28]. Also, this model can be implemented for custom object detection on Jetson Nano GPU from Nvidia with a TensorRT network optimizer [29]. The newer YOLOv5 allows to significantly increase the accuracy of weapons detection [30, 31]. The processing time per frame is 0.010 seconds compared to the 0.17 seconds of the Faster R-CNN [32]. There is also an implementation of the YOLOv5 model on high-cost device Nvidia's Jetson AGX Xavier with an impressive accuracy of 98.56 percent [33]. The applying complex hardware and DL algorithms allow for achieving effective results, but they are expensive and difficult to deploy [34]. Besides YOLO, there is a promising method based on the use of semantic embeddings and a pre-trained Contrastive Language-Image Pre-Training (CLIP) model. The highest accuracy rate of this method was 99.8 percent [35], which is quite competitive with FireNet and YOLO algorithms.

The majority of modern WDS solutions are based on the IoT. The IoT applications automate routine processes and work without human interactions [36]. The IoT technology has a wide range of applications [37], ensuring people's safety in smart homes, industry, transportation and cities [38, 39]. Most IoT solutions use cloud services as a data treatment center, for instance, data collected from sensors of smart farm are sent to the server [40], as well as the video stream data are transmitted to the cloud for further processing [41, 42]. However, some studies point to insufficient network bandwidth [43], massive generated data [44], high power consumption [45, 46], weak network security [47] and data privacy issues [48] because of using the cloud paradigm in the IoT. Those issues of IoT applications are strongly critical for military purposes. Mainly the latest researches are focused on the security of the IoT [49] since the consequences of disabling the network are not measurable. The application of military IoT could be found in the field of battlefield perception, improving the early warning, weapons and equipment management, intelligence sharing ability and support efficiency of the military, logistics support, military training and so on [50, 51]. To be more specific, military IoT studies also consider WDS, such as rope roaming robots for 360 degrees of monitoring a specific area [52], a semi-autonomous robot with WDS and stair climbing functions [53], drones or Unmanned Aerial Vehicles (UAV) for WDS [54] and explosive weapons detector [55]. To partially solve the issue associated with high power consumption, it was advised [56] to use Field Programmable Gate Array (FPGA). However, in order to finally resolve all the above list of issues, it is highly recommended to replace the cloud paradigm with edge computing [57]. FPGA provides high energy-efficient,

accelerating and high performance for complex AI tasks [58]-[60]. Thus, the edge device implements pre-processing data and sends the result to the data server [61] with much lower network bandwidth.

III. MATERIALS AND METHODS

As previously mentioned in the first section, it was decided to apply Raspberry Pi 4 Model B (4 GB) with a camera, which are shown below as edge device in Fig. 1.



Fig. 1. Raspberry Pi with a camera as an edge node.

Headphones and a power bank have been used for audio notifications about armed threats and for the power supply of the Raspberry Pi. Raspberry Pi OS (Raspbian) has been picked as the operating system. 'Thingspeak' has been chosen as the IoT cloud platform for report and analytics formation due to visual infographic capabilities. However, the Message Queue Telemetry Transport (MQTT) without graphical support could be applied for more private message exchanges between publisher and subscribers.

A. Edge Node

The high-level programming language Python has been selected for supporting a computer vision by progressive libraries and frameworks: TensorFlow Lite, Numpy, OpenCV, Python Imaging Library (PIL) and Picamera. Since Raspberry Pi (RPi) have limited CPU and GPU resources to train a model, it was decided to use the computing server of Google Colaboratory, the framework TensorFlow Lite and 1588 images from the Kaggle dataset of various types of weapons [62, 63]. Some samples of weapons for the model training and the flow scheme are illustrated in Fig. 2.

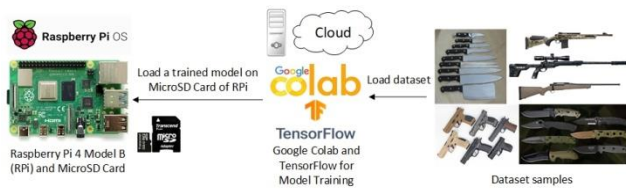


Fig. 2. The scheme of model training using Google Colab and TensorFlow Lite.

The EfficientDet has been selected as the model for weapons detection because it creates a smaller output model file, consumes less computing resources, and implements algorithms faster [64]. Moreover, EfficientDet offers a list of mobile-size lite models, which are suitable for IoT and edge devices. The EfficientDet architecture is illustrated below in Fig. 3.

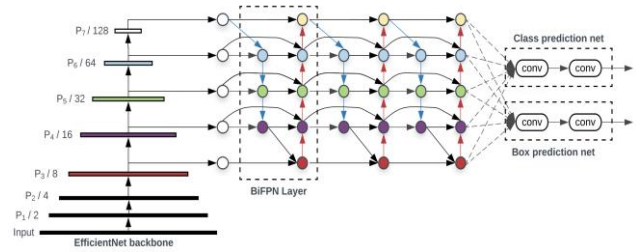


Fig. 3. The EfficientDet architecture.

EfficientDet can be considered as the one-stage detector paradigm that applies EfficientNet as the backbone network. Bi-directional feature pyramid network (BiFPN) acts as the feature network and utilizes level 3-7 features {P3, P4, P5, P6, P7} from the backbone network. It repeatedly applies bidirectional feature fusion, both top-down and bottom-up, resulting in fused features that are then fed to the class and box network for object class and bounding box predictions.

There are a few EfficientDet-Lite variants, and their checkpoints and results are shown in Table I.

TABLE I. EFFICIENTDET-LITE CHECKPOINTS AND RESULTS

Model	Mean average precision (float)	Quantized mean average precision (int8)	Parameters, millions	Mobile latency, milliseconds
EfficientDet-lite0	26.41	26.10	3.2	36
EfficientDet-lite1	31.50	31.12	4.2	49
EfficientDet-lite2	35.06	34.69	5.3	69
EfficientDet-lite3	38.77	38.42	8.4	116
EfficientDet-lite4	43.18	42.83	15.1	260

Since it is necessary to prioritize safety and provide the highest speed of object detection, the EfficientDet-Lite0 has been chosen.

The general equation for compound scaling of the EfficientDet model would be the following:

$$f = \alpha + \beta^\phi + \gamma^\phi \quad (1)$$

Where α is a depth scaling factor, β is a width scaling factor, γ is a resolution scaling factor, ϕ is a number of network variation, and f is a network scaling factor.

The BiFPN network width and depth would use scaling equations:

$$W_{bifpn} = 64 \times (1.35^\phi) \quad (2)$$

$$D_{bifpm} = 3 + \varphi \quad (3)$$

Box/class prediction network would be scaled with the following equation:

$$D_{box} = D_{class} = 3 + \lfloor \varphi / 3 \rfloor \quad (4)$$

Input image resolution uses the next scaling equation:

$$R_{input} = 512 + \varphi \times 128 \quad (5)$$

Thus, the EfficientDet allows us to decrease the size of the model file by 4x–9x and use 13x–42x fewer Floating-point operations per seconds (FLOPs) than most previously reviewed detectors.

The flowchart of weapons detection is presented below in Fig. 4.

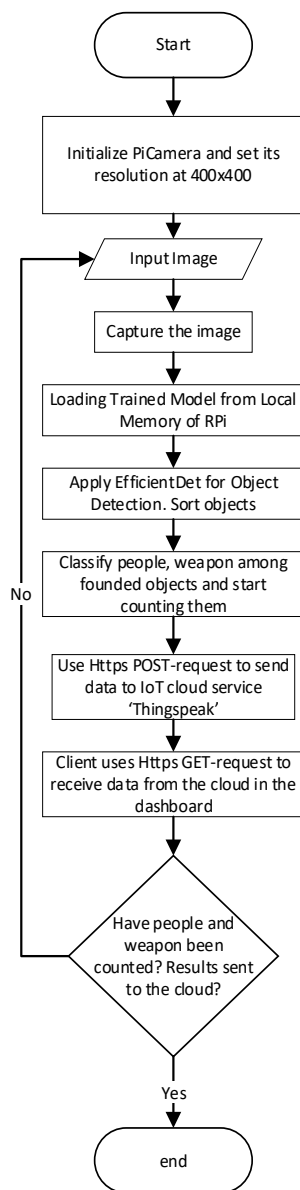


Fig. 4. The flowchart of weapons detection process.

Firstly the Pi's camera has been initialized, and its resolution has been configured at 400x400. Then algorithm started capturing an image and loading a trained model by Google Colab and TensorFlow Lite. An applying that model and EfficientDet architecture allowed to detect objects from captured image. The sorted objects were counted and classified by a model as person, rifle, pistol (handgun) and knife. Finally, the results were transcended to IoT cloud platform 'Thingspeak' through HTTP-request. After that a subscriber can send Http GET-request to collect results. If an armed threat was detected, the user of the system would receive a voice notification via headphones.

The common scheme processing of captured image is demonstrated in Fig. 5.

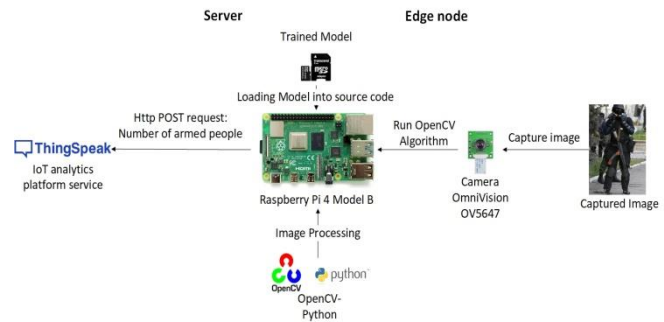


Fig. 5. The scheme of image processing.

B. Server Side

The IoT cloud platform 'Thingspeak' has been used to monitor the results of weapons detection on the server side, as mentioned before. 'Thingspeak' supports Representational State Transfer of the Application Programming Interface (RESTful API) and due to this users can easily exchange messages between edge device, client and server. The client-server model is illustrated in Fig. 6.

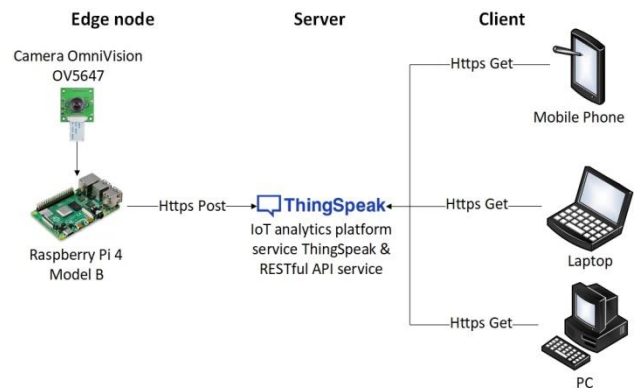


Fig. 6. The client-server model for the weapons detections system.

To observe the processed data securely from any type of device, an admin has logged in to the 'Thingspeak' account and created a private channel. Then he has gotten an API and started the configuration process of private channel. The configuration of channel and widgets are shown in Fig. 7.

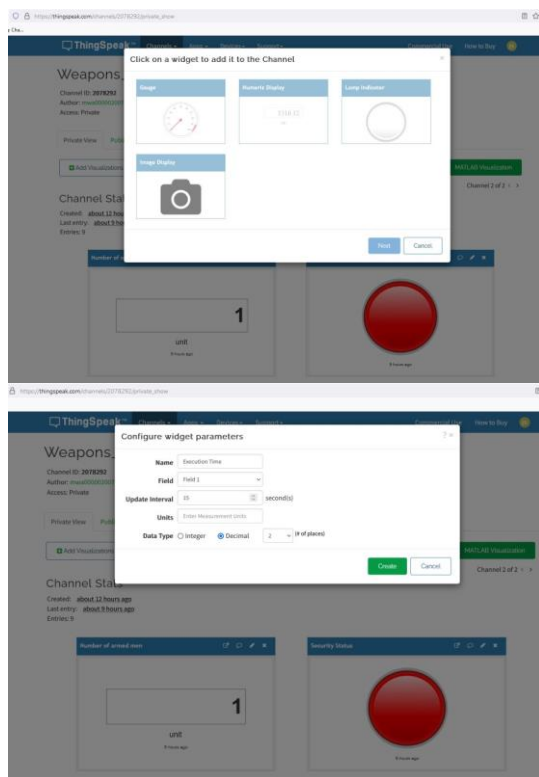


Fig. 7. The procedure of configuration the channel and adding widgets in Thingspeak.

C. Client Side

An operator browsing a private channel from any accessible type of device (table, smartphone, personal computer) and collect all data for report and analysis. The processes data are presented in the widgets of the web application 'Thingspeak', which could be found in Fig. 8.

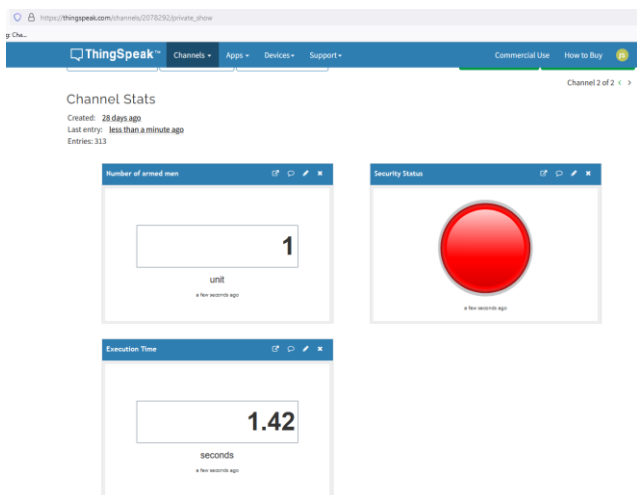


Fig. 8. Results in the web application 'Thingspeak' for the case with rifle detection.

The operator has a capability to apply the MQTT protocol as an option to keep data privacy and output received results in a terminal window, which is shown in Fig. 9.

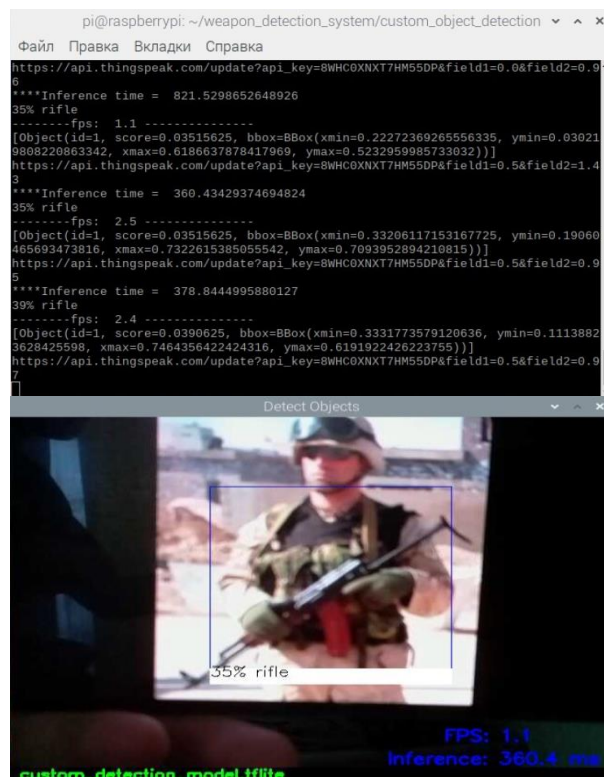


Fig. 9. Results in a terminal window.

D. The Application of Weapons Detection System for Augmentation Reality Glasses

To improve the user experience of armed threats detection in addition to voice notification, it has been proposed to plug in Raspberry Pi to AR glasses for better visualization. The result of marking an armed threat will be displayed on the interface of the soldier's glasses, providing him with the necessary information to make a quick decision. The scheme of AR glasses interaction with Raspberry Pi is shown in Fig. 10.

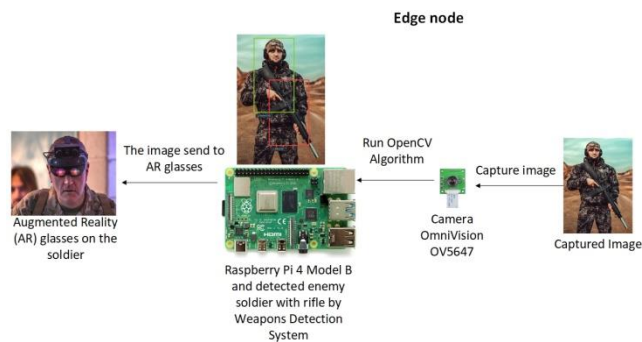


Fig. 10. The scheme of AR glasses interaction with Raspberry Pi.

IV. EXPERIMENTAL RESULTS

Three cases of weapons detection have been considered such as rifle, pistol (handgun) and knife. The first case with the rifle detection from smartphone display has been presented in the previous section in Fig. 9. The terminal window describes the following information: weapon type with accuracy recognition in per cent, inference time in milliseconds, and

frame per second. For this case, an operator can find such information in the web application: number of armed persons and time for algorithm execution, which are presented in Fig. 8.

The results of the next case with handgun are shown in Fig. 11.

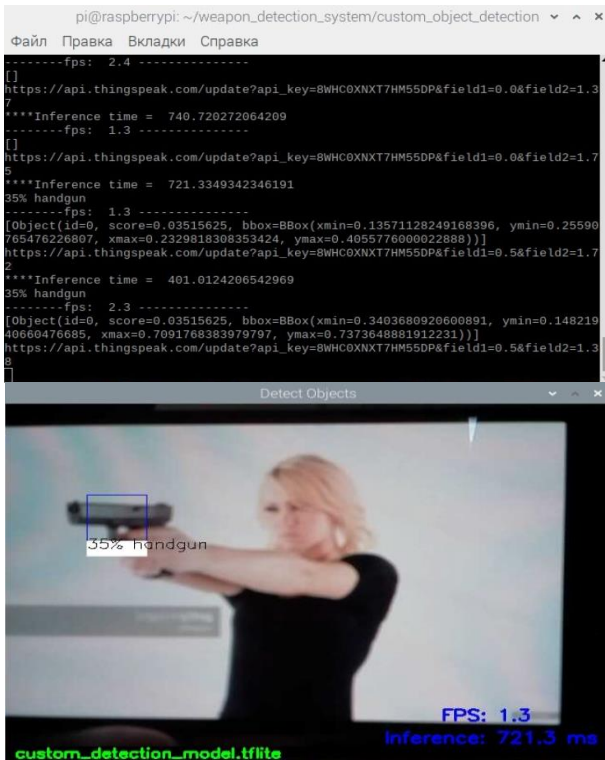


Fig. 11. The case with pistol (handgun) detection.

The handgun has been marked by rectangle and labeled. The terminal window also outputs the type of detected weapon, inference time and Http POST-request. The results of that case in web application are shown in Fig. 12.

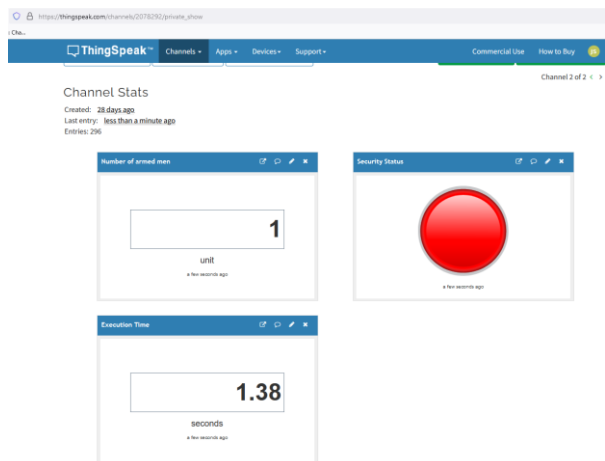


Fig. 12. The view of the web application for the case with pistol (handgun) detection.

The first widget from the left presents the number of armed persons. The lamp of the next widget has become active and red since the armed threat has been detected. The last widget shows the execution time of the algorithm.

Finally, the last case of cold steel weapon (knife) detection from the real scenario is shown in Fig. 13.

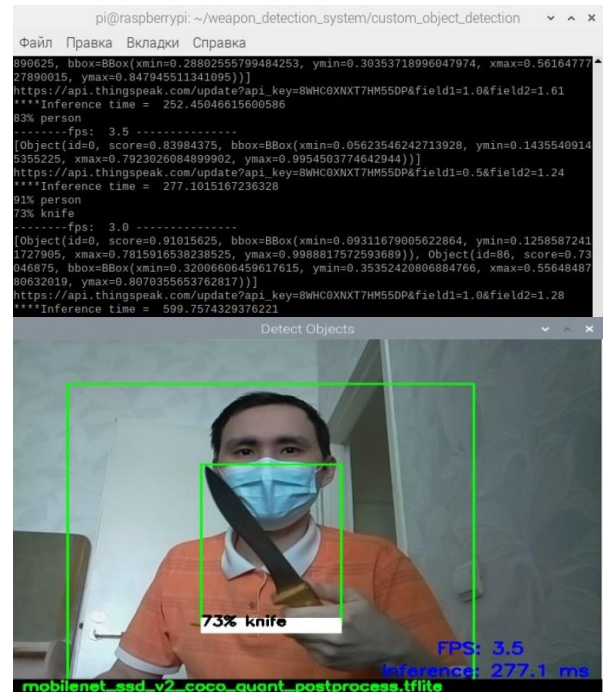


Fig. 13. The case with knife detection.

The common view of the knife detection case for the web application is shown in Fig. 14.

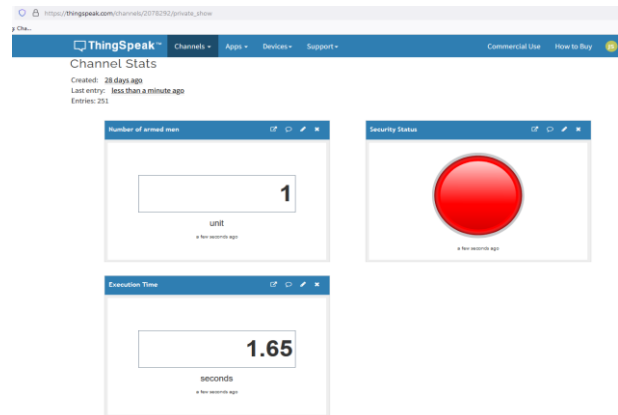


Fig. 14. The view of the web application for the case with knife detection.

To collect information about network traffic and bandwidth, the web application 'Monitorix' was deployed on the Raspberry Pi for the local host. Fig. 15 demonstrates that the maximum transmitted data to the IoT cloud platform have reached about 53 kilobytes per second or 40 packets per second without any network error during transcending data

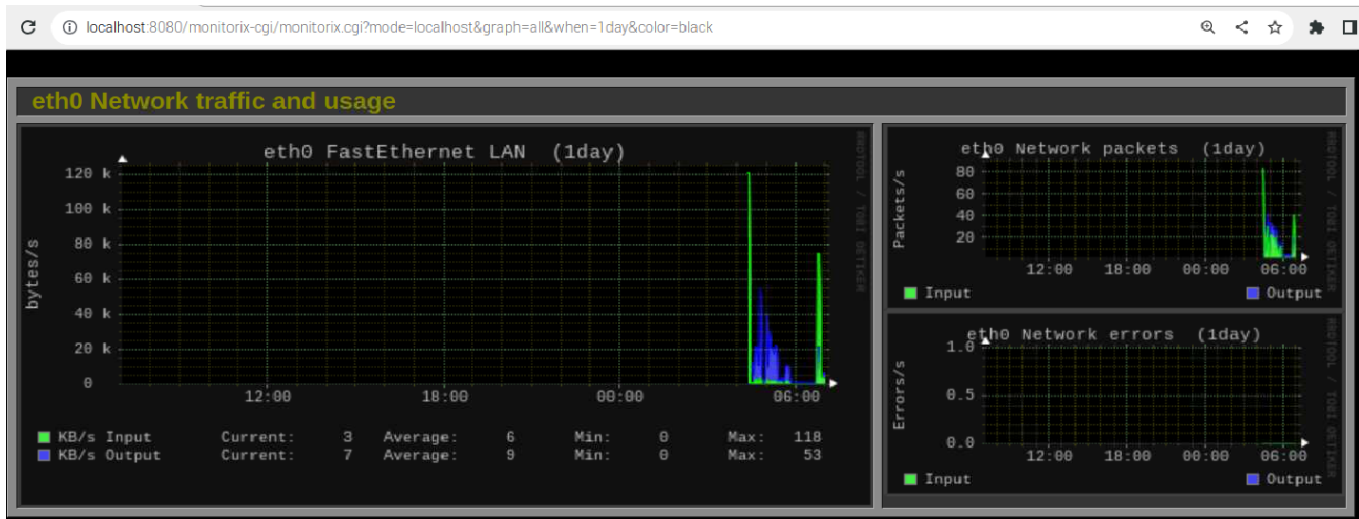


Fig. 15. The web application 'Monitorix' for monitoring network traffic.

V. DISCUSSION OF RESULTS

To compare with the transmission of the video stream with an average required throughput of over 1.8 megabytes per second [43], the proposed approach requests less network bandwidth and significantly reduces the amount of transmitted data. As a consequence, it also reduced the load on the network and server resources. The average time for algorithm execution is approximately 1.48 seconds. It is quite a medium time of algorithm execution compared to 1.76 seconds for the Inception-ResNetV2 model and 1.1 seconds for the ResNet50 CNN model [20]. That is true that YOLO and MobileNetV2 [15, 20] are almost twice as fast in terms of object recognition and detection as EfficientDet-Lite0, but it should be noted that the productivity of the proposed algorithm execution time can be improved with Coral USB Accelerator. However, YOLO and ResNet require over 10 million parameters for object classification [41, 64]. Consequently, those models consume more disk space and computing resources. The highest accuracy of the knife detection case for EfficientDet-Lite0 model is an average result compared to 71.44 per cent for Faster R-CNN [17] and 77.78 per cent for YOLOv4 [26].

VI. CONCLUSION

In this paper, the weapons detection system has been developed based on the Raspberry Pi using computer vision and edge computing. The suggested approach has successfully overcome the resource limitation of Raspberry Pi to train a model through Google Colaboratory and TensorFlow Lite. Also, the hypothesis has been confirmed and obtained results indicating a significant decrease in the amount of data transmitted over the Internet, and as a result, it allows optimizing the server resources to accomplish other tasks. The presented data in the web application allows the operator to create a report. Moreover, it has been considered the capability to plug in Raspberry Pi with a camera module to AR glasses of soldiers for visually marking humans with weapons in real-time. The application of edge computing made it possible for the device to work without the Internet connection and thus ensure data safety. In addition to that, edge computing has reduced the cost of the technical solution and provides an

option to operate the device on a local area network using MQTT protocol for message exchange. As a result, an autonomous weapon recognition system has been proposed that can operate without an Internet connection and detect weapons within 1.48 seconds.

In the future, it is considered expanding our research to detect explosive devices, heavy tanks and unmanned aerial vehicles. Though there may be some issues related to the detection of fast-moving objects, poor lighting conditions and quality of images, which should be solved with an FPGA and high megapixels infrared camera.

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REFERENCES

- [1] Vision of Humanity, Global Terrorism Index. [Online]. Available: <https://www.visionofhumanity.org/maps/global-terrorism-index/#/>
- [2] World Population Review, Countries Currently at War 2023. [Online]. Available: <https://worldpopulationreview.com/country-rankings/countries-currently-at-war>
- [3] E. Arif, S. K. Shahzad, R. Mustafa, M. A. Jaffar, and M. W. Iqbal, "Deep neural networks for gun detection in public surveillance," *Intelligent Automation and Soft Computing*, vol. 32, no. 2, pp. 909-922, 2022. <https://doi.org/10.32604/iasc.2022.021061>.
- [4] W. Rahmaniari and A. Hernawan, "Real-time human detection using deep learning on embedded platforms: a review," *Journal of Robotics and Control (JRC)*, Review vol. 2, no. 6, pp. 462-468, 2021. <https://doi.org/10.18196/jrc.26123>.
- [5] T. V. Dang, "Smart home management system with face recognition based on ArcFace model in deep convolutional neural network," *Journal of Robotics and Control (JRC)*, vol. 3, no. 6, pp. 754-761, 2022. <https://doi.org/10.18196/jrc.v3i6.15978>.
- [6] A. Lamas, S. Tabik, A. C. Montes, F. Pérez-Hernández, J. García, R. Olmos, and F. Herrera, "Human pose estimation for mitigating false negatives in weapon detection in video-surveillance," *Neurocomputing*, vol. 489, pp. 488-503, 2022. <https://doi.org/10.1016/j.neucom.2021.12.059>.
- [7] M. G. Ismail, F. H. Tarabay, R. El-Masry, M. A. El Ghany, and M. A. M. Salem, "Smart cloud-edge video surveillance system," in *11th International Conference on Modern Circuits and Systems Technologies*,

- MOCAS 2022, 2022. <https://doi.org/10.1109/MOCAS54814.2022.9837646>.
- [8] S. S. Brimzhanova, S. K. Atanov, M. Khuralay, K. S. Kobelekov, and L. G. Gagarina, "Cross-platform compilation of programming language golang for raspberry pi," in 5th International Conference on Engineering and MIS, ICEMIS 2019, 2019. <https://doi.org/10.1145/3330431.3330441>.
- [9] Z. Y. Seitbattalov, H. Canbolat, Z. S. Moldabayeva, and A. E. Kyzrkanov, "An intelligent automatic number plate recognition system based on computer vision and edge computing," in 2022 International Conference on Smart Information Systems and Technologies, SIST 2022, 2022. <https://doi.org/10.1109/SIST54437.2022.9945787>.
- [10] S. K. Atanov, Z. Y. Seitbattalov, and Z. S. Moldabayeva, "Development an intelligent task offloading system for edge-cloud computing paradigm," in 16th International Conference on Electronics Computer and Computation, ICECCO 2021, 2021. <https://doi.org/10.1109/ICECCO53203.2021.9663797>.
- [11] Y. Arslan and H. Canbolat, "Performance of deep neural networks in audio surveillance," in 6th International Conference on Control Engineering and Information Technology, CEIT 2018, 2018. <https://doi.org/10.1109/CEIT.2018.8751822>.
- [12] J. L. Salazar González, C. Zaccaro, J. A. Álvarez-García, L. M. Soria Morillo, and F. Sancho Caparrini, "Real-time gun detection in CCTV: an open problem," *Neural Networks*, vol. 132, pp. 297-308, 2020. <https://doi.org/10.1016/j.neunet.2020.09.013>.
- [13] A. Castillo, S. Tabik, F. Pérez, R. Olmos, and F. Herrera, "Brightness guided preprocessing for automatic cold steel weapon detection in surveillance videos with deep learning," *Neurocomputing*, vol. 330, pp. 151-161, 2019. <https://doi.org/10.1016/j.neucom.2018.10.076>.
- [14] N. Hnoohom, P. Chotivatunyu, and A. Jitpattanakul, "ACF: an armed CCTV footage dataset for enhancing weapon detection," *Sensors*, vol. 22, no. 19, 2022. <https://doi.org/10.3390/s22197158>.
- [15] R. Debnath and M. K. Bhowmik, "A comprehensive survey on computer vision based concepts, methodologies, analysis and applications for automatic gun/knife detection," *Journal of Visual Communication and Image Representation*, vol. 78, 2021. <https://doi.org/10.1016/j.jvcir.2021.103165>.
- [16] O. Veranyurt and C. O. Sakar, "Hand-gun detection in images with transfer learning-based convolutional neural networks," in 28th Signal Processing and Communications Applications Conference, 2020. <https://doi.org/10.1109/SIU49456.2020.9302394>.
- [17] P. Y. Ingle and Y. G. Kim, "Real-time abnormal object detection for video surveillance in smart cities," *Sensors*, vol. 22, no. 10, 2022. <https://doi.org/10.3390/s22103862>.
- [18] J. Li, C. Ablan, R. Wu, S. Guan, and J. Yao, "Preprocessing techniques' effect on overfitting for VGG16 fast-RCNN pistol detection," *International Journal of Computers and their Applications*, vol. 28, no. 1, pp. 45-54, 2021. <https://doi.org/10.29007/ml35>.
- [19] N. U. Haq, M. M. Fraz, T. S. Hashmi, and M. Shahzad, "Orientation aware weapons detection in visual data: a benchmark dataset," *Computing*, vol. 104, no. 12, pp. 2581-2604, 2022. <https://doi.org/10.1007/s00607-022-01095-0>.
- [20] R. M. Alaqil, J. A. Alsuhaibani, B. A. Alhumaidi, R. A. Alnasser, R. D. Alotaibi, and H. Benhidour, "Automatic gun detection from images using faster R-CNN," in 1st International Conference of Smart Systems and Emerging Technologies, SMART-TECH 2020, pp. 149-154, 2020. <https://doi.org/10.1109/SMART-TECH49988.2020.00045>.
- [21] M. K. El Den Mohamed, A. Taha, and H. H. Zayed, "Automatic gun detection approach for video surveillance," *International Journal of Sociotechnology and Knowledge Development*, vol. 12 no. 1, pp. 49-66, 2020. <https://doi.org/10.4018/IJSKD.2020010103>.
- [22] R. Debnath and M. K. Bhowmik, "Novel framework for automatic localisation of gun carrying by moving person using various indoor and outdoor mimic and real-time views/scenes," *IET Image Processing*, vol. 14 no. 17, pp. 4663-4675, 2020. <https://doi.org/10.1049/iet-ipr.2020.0706>.
- [23] A. Goenka and K. Sitara, "Weapon detection from surveillance images using deep learning," in 3rd International Conference for Emerging Technology, 2022. <https://doi.org/10.1109/INCET54531.2022.9824281>.
- [24] P. Yadav, N. Gupta, and P. K. Sharma, "A comprehensive study towards high-level approaches for weapon detection using classical machine learning and deep learning methods," *Expert Systems with Applications*, vol. 212, 2023. <https://doi.org/10.1016/j.eswa.2022.118698>.
- [25] T. S. S. Hashmi, N. U. Haq, M. M. Fraz, and M. Shahzad, "Application of deep learning for weapons detection in surveillance videos," in 2021 International Conference on Digital Futures and Transformative Technologies, 2021. <https://doi.org/10.1109/ICoDT252288.2021.9441523>.
- [26] W. E. I. B. W. N. Afandi and N. M. Isa, "Object detection: harmful weapons detection using YOLOv4," in 2021 IEEE Symposium on Wireless Technology and Applications, pp. 63-70, 2021. <https://doi.org/10.1109/ISWTA52208.2021.9587423>.
- [27] M. Gali, S. Dhavale, and S. Kumar, "Real-time image based weapon detection using YOLO algorithms," 6th International Conference on Advances in Computing and Data Sciences, vol. 1614 CCIS, pp. 173-185, 2022. https://doi.org/10.1007/978-3-031-12641-3_15.
- [28] A. Jaleel, S. K. Khurshid, R. Mustafa, K. Mehmood Aamir, M. Tahir, and A. Ziar, "Towards proactive surveillance through CCTV cameras under edge-computing and deep learning," *Mathematical Problems in Engineering*, vol. 2022, 2022. <https://doi.org/10.1155/2022/7001388>.
- [29] S. Ahmed, M. T. Bhatti, M. G. Khan, B. Löfvström, and M. Shahid, "Development and optimization of deep learning models for weapon detection in surveillance videos," *Applied Sciences*, vol. 12, no. 12, 2022. <https://doi.org/10.3390/app12125772>.
- [30] N. Yeddula and B. E. Reddy, "Effective deep learning technique for weapon detection in CCTV Footage," in 2nd IEEE International Conference on Mobile Networks and Wireless Communications, ICMNWC 2022, 2022. <https://doi.org/10.1109/ICMNWC56175.2022.10031724>.
- [31] L. Sumi and S. Dey, "YOLOv5-based weapon detection systems with data augmentation," *International Journal of Computers and Applications*, 2023. <https://doi.org/10.1080/1206212X.2023.2182966>.
- [32] A. H. Ashraf, M. Imran, A. M. Qahtani, A. Alsufyani, O. Almutiry, A. Mahmood, M. Attique, M. Habib, "Weapons detection for security and video surveillance using CNN and YOLO-V5s," *Computers, Materials and Continua*, vol. 70, no. 2, pp. 2761-2775, 2022. <https://doi.org/10.32604/cmc.2022.018785>.
- [33] M. Dextre, O. Rosas, J. Lazo, and J. C. Gutiérrez, "Gun detection in real-time, using YOLOv5 on Jetson AGX Xavier," in 47th Latin American Computing Conference, CLEI 2021, 2021. <https://doi.org/10.1109/CLEI53233.2021.9640100>.
- [34] D. Berardini, A. Galdelli, A. Mancini, and P. Zingaretti, "Benchmarking of dual-step neural networks for detection of dangerous weapons on edge devices," in 18th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications, MESA 2022, 2022. <https://doi.org/10.1109/MESA55290.2022.10004469>.
- [35] Y. Deng, R. Campbell, and P. Kumar, "Fire and gun detection based on semantic embeddings," in 2022 IEEE International Conference on Multimedia and Expo Workshops, ICMEW 2022, 2022. <https://doi.org/10.1109/ICMEW56448.2022.9859303>.
- [36] I. Ahmad, M. S. Niaz, R. A. Ziar, and S. Khan, "Survey on IoT: security threats and applications," *Journal of Robotics and Control (JRC)*, vol. 2, no. 1, pp. 42-46, 2021. <https://doi.org/10.18196/jrc.2150>.
- [37] Y. He, "Research and application of the key technology of cloud platform in various fields of computer internet of things technology," in 5th International Conference on Mechanical, Control and Computer Engineering, ICMCCE 2020, pp. 1357-1360, 2020. <https://doi.org/10.1109/ICMCCE51767.2020.00297>.
- [38] X. Xia, "Internet of things research and application of information technology," in 5th International Conference on Mechanical, Control and Computer Engineering, ICMCCE 2020, pp. 1818-1821, 2020. <https://doi.org/10.1109/ICMCCE51767.2020.00399>.
- [39] K. L. M. Ang and J. K. P. Seng, "Application specific internet of things (ASIoTs): taxonomy, applications, use case and future directions," *IEEE Access*, vol. 7, pp. 56577-56590, 2019. <https://doi.org/10.1109/ACCESS.2019.2907793>.
- [40] A. P. Atmaja, A. E. Hakim, A. P. A. Wibowo, and L. A. Pratama, "Communication systems of smart agriculture based on wireless sensor

- networks in IoT,” *Journal of Robotics and Control (JRC)*, vol. 2, no. 4, pp. 297-301, 2021. <https://doi.org/10.18196/jrc.2495>.
- [41] Q. Yao, W. Tan, J. Liu, and D. Qi, “Edge to cloud end to end solution of visual based gun detection,” in *2020 3rd International Conference on Computer Information Science and Application Technology, CISAT 2020*, vol. 1634, 1 ed., 2020. <https://doi.org/10.1088/1742-6596/1634/1/012033>.
- [42] A. Singh, T. Anand, S. Sharma, and P. Singh, “IoT based weapons detection system for surveillance and security using YOLOV4,” in *6th IEEE International Conference on Communication and Electronics Systems, ICCES 2021*, pp. 488-493, 2021. <https://doi.org/10.1109/ICCES51350.2021.9489224>.
- [43] C. Fathy and S. N. Saleh, “Integrating deep learning-based IoT and fog computing with software-defined networking for detecting weapons in video surveillance systems,” *Sensors*, vol. 22, no. 14, 2022. <https://doi.org/10.3390/s22145075>.
- [44] R. Wang, W. T. Tsai, J. He, C. Liu, Q. Li, and E. Deng, “A video surveillance system based on permissioned blockchains and edge computing,” in *2019 IEEE International Conference on Big Data and Smart Computing, BigComp 2019*, 2019. <https://doi.org/10.1109/BIGCOMP.2019.8679354>.
- [45] M. Perea-Trigo, E. J. López-Ortiz, J. L. Salazar-González, J. A. Álvarez-García, and J. J. Vegas Olmos, “Data processing unit for energy saving in computer vision: weapon detection use case,” *Electronics*, vol. 12, no. 1, 2023. <https://doi.org/10.3390/electronics12010146>.
- [46] M. U. Harun Al Rasyid, F. Astika Saputra, and A. Kurniawan, “Surveillance monitoring system based on internet of things,” in *2020 International Electronics Symposium, IES 2020*, pp. 588-593, 2020. <https://doi.org/10.1109/IES50839.2020.9231634>.
- [47] P. Gao, R. Yang, C. Shi, and X. Zhang, “Research on security protection technology system of power internet of things,” in *8th IEEE Joint International Information Technology and Artificial Intelligence Conference, ITAIC 2019*, pp. 1772-1776, 2019. <https://doi.org/10.1109/ITAIC.2019.8785603>.
- [48] A. Kaknjo, M. Rao, E. Omerdic, T. Newe, and D. Toal, “Real-time secure/unsecure video latency measurement/analysis with FPGA-based bump-in-the-wire security,” *Sensors*, vol. 19, no. 13, 2019. <https://doi.org/10.3390/s19132984>.
- [49] X. Li, W. Pan, J. Zhang, G. Liu, and P. Wan, “Research on security issues of military internet of things,” in *17th International Computer Conference on Wavelet Active Media Technology and Information Processing*, pp. 399-403, 2020. <https://doi.org/10.1109/ICCWAMTIP51612.2020.9317401>.
- [50] X. Li, W. Pan, J. An, and P. Wan, “The application research on military internet of things,” in *17th International Computer Conference on Wavelet Active Media Technology and Information Processing, ICCWAMTIP 2020*, pp. 187-191, 2020. <https://doi.org/10.1109/ICCWAMTIP51612.2020.9317321>.
- [51] C. Donghao, Z. Bohua, O. Chaomin, and C. Zhiyu, “Research on military internet of things technology application in the context of national security,” in *2nd International Conference on Electronics, Communications and Information Technology, CECIT 2021*, pp. 992-998, 2021. <https://doi.org/10.1109/CECIT53797.2021.00177>.
- [52] P. K. Maduri, P. Sharma, H. Saini, P. M. Tripathi, and S. Singh, “Weapon detection rope roaming human safety robot,” *2nd International Conference on Mechanical and Energy Technologies, ICMET 2021*, pp. 43-51, 2023. https://doi.org/10.1007/978-981-19-1618-2_5.
- [53] M. Z. Islam, A. Ahsan, and R. Acharjee, “A semi-autonomous tracked robot detection of gun and human movement using Haar cascade classifier for military application,” in *2019 International Conference on Nascent Technologies in Engineering, ICNTE 2019*, 2019. <https://doi.org/10.1109/ICNTE44896.2019.8945848>.
- [54] D. R. Hawale and P. S. Game, “Real-time weapon detection using drone,” in *6th International Conference on Computing, Communication, Control and Automation, ICCUBEA 2022*, 2022. <https://doi.org/10.1109/ICCUBEA54992.2022.10010921>.
- [55] A. Bhatt and A. Ganatra, “Explosive weapons and arms detection with singular classification (WARDIC) on novel weapon dataset using deep learning: enhanced OODA (observe, orient, decide, and act) loop,” *Engineered Science*, vol. 20, 2022. <https://doi.org/10.30919/es8e718>.
- [56] X. Liu, J. Yang, C. Zou, Q. Chen, X. Yan, Y. Chen, and C. Cai, “Collaborative edge computing with FPGA-based CNN accelerators for energy-efficient and time-aware face tracking system,” *IEEE Transactions on Computational Social Systems*, vol. 9, no. 1, pp. 252-266, 2022. <https://doi.org/10.1109/TCSS.2021.3059318>.
- [57] C. Yang, “FPGA in IoT edge computing and intelligence transportation applications,” in *2021 IEEE International Conference on Robotics, Automation and Artificial Intelligence, RAAI 2021*, pp. 78-82, 2021. <https://doi.org/10.1109/RAAI52226.2021.9507835>.
- [58] C. Xu, S. Jiang, G. Luo, G. Sun, N. An, G. Huang, and X. Liu, “The case for FPGA-based edge computing,” *IEEE Transactions on Mobile Computing*, vol. 21, no. 7, pp. 2610-2619, 2022. <https://doi.org/10.1109/TMC.2020.3041781>.
- [59] C. Xiao and C. Zhao, “FPGA-based edge computing: task modeling for cloud-edge collaboration,” *International Journal of Modeling, Simulation, and Scientific Computing*, vol. 13, no. 2, 2022. <https://doi.org/10.1142/S1793962322410094>.
- [60] Z. Zhu, J. Zhang, J. Zhao, J. Cao, D. Zhao, G. Jia, and Q. Meng, “A hardware and software task-scheduling framework based on CPU+FPGA heterogeneous architecture in edge computing,” *IEEE Access*, vol. 7, pp. 148975-148988, 2019. <https://doi.org/10.1109/ACCESS.2019.2943179>.
- [61] R. Ferdian, R. Aisuwarya, and T. Erlina, “edge computing for internet of things based on FPGA,” in *6th International Conference on Information Technology Systems and Innovation, ICITSI 2020*, pp. 20-23, 2020. <https://doi.org/10.1109/ICITSI50517.2020.9264937>.
- [62] Weapons datasets. Annotated rifle and handgun images. [Online]. Available: <https://www.kaggle.com/datasets/ar5p1edy/weapons-datasets>
- [63] Ankan Sharma, Weapon detection dataset. Weapon detection including knife, gun, pistol etc. [Online]. Available: <https://www.kaggle.com/datasets/ankan1998/weapon-detection-dataset>
- [64] M. Tan, R. Pang and Q. V. Le, “EfficientDet: scalable and efficient object detection,” *2020 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*, pp. 10778-10787, Seattle, WA, USA, 2020. <https://doi.org/10.1109/CVPR42600.2020.010179>.

Distributed Cooperative Control for Multi-UAV Flying Formation

Belkacem Kada, Abdullah Y. Tameem, Ahmed A. Alzubairi, Uzair Ansari
Aerospace Engineering Department, King Abdulaziz University Jeddah, KSA

Abstract—The problem of collaborative pattern tracking in multi-agent systems (MAS) like unmanned aerial vehicles (UAV) is investigated in this article. First, a new method for distributed consensus is constructed inside the framework of the leader-following approach for second-order nonlinear MAS. The technique canceled the chattering effect observed in the conventional sliding mode-based control protocols by transmitting smooth input signals to agents' control channels. Second, a novel formation framework is proposed to accomplish three-dimensional formation tracking by including consensus procedures in the formation dynamics model. This will allow for formation tracking in all three dimensions. The Lyapunov theory provides evidence demonstrating the proposed protocols' stability and convergence. Numerical simulations have been carried out to prove the proposed algorithms' effectiveness.

Keywords—Formation control; distributed consensus; multi-agent systems; multiple-UAV

I. INTRODUCTION

The increased complexity of the missions of engineering systems has led to the development of distributed and cooperative control for networked systems under the paradigm of multi-agent systems (MAS). The benefits of using MAS include increased efficiency, precision, flexibility, robustness, and affordability. Real-life applications of MAS include ground systems [1], [2], unmanned aerial vehicles (UAV) [3]–[12], transport aircraft [13], [14], helicopters [15], spacecraft [16]–[19], satellites [20], [21], and missiles [22], [23].

One of the most fascinating and challenging applications of networked aerial systems is the cooperative control of multi-UAV systems. Research on multi-UAV cooperative control has recently increased, employing various methods and theories. Using the net contract protocol, Liu & Zhang [3] developed a model for assigning tasks to manned and unmanned aerial vehicles in real environments. The formation control problem of multi-UAV systems was treated as a differential game problem in [4], with the open-loop Nash strategy for each agent being to construct fully distributed formation control. The creation of autonomous quadrotor aircraft was addressed in [5] by developing a non-smooth distributed cohesive motion control using the virtual structure approach. The non-smooth backstepping design technique was used to create a distributed formation flying control algorithms [6]. Using a differential evolution method, Zhang et al. [7] designed an adaptive formation control to find the optimum formation for a swarm of UAVs. An algorithm based on the Riccati equation was used in [8] to solve the problem of formation-containment control for a fleet of multirotor UAVs. Ziyang et al. [9] proposed a

decentralized, self-organized mission planning algorithm. According to [10], a distributed formation control free of collisions can be created using a Voronoi diagram or partition. Path planning for a formation control approach with constraints and without collisions was examined in [11] utilizing rapid particle swarm optimization, considering chaos-based initialization, parameter optimization, and topology updating. For linear MAS, Almalki & Kada [24] offered a sliding-PID control that can be applied directly for multi-UAV consensus tracking.

Although the methodologies and approaches discussed above have been shown to be effective, there are still several critical obstacles to be solved in the cooperative control of MAS, particularly in multi-UAV systems. Formation keeping, communication failures inside MAS, altering communication topologies, and the smoothness of control inputs are some practical issues that must be addressed. Within the framework of a smoothly distributed consensus and formation control paradigm, we address these challenges and provide potential solutions in the study that we have presented here. As a result, the first thing we have contributed is the invention of distributed consensus procedures that are smooth for multi-agent systems with nonlinear dynamics integrated into them. In place of the signum-based control used in classic MAS control, which results in controller chattering, a continuous PI-like (proportional-integral) control is used to design the control inputs to the agent closed-loop dynamics. This allows for more precise and accurate control over the system. The second significant contribution made by this study is a model for maintaining airborne formation. We create the formation model by combining distributed protocols into a six-degree-of-freedom dynamical framework. This allows us to simulate the formation of complex structures. For a fair comparison, one can see, for example, the work presented in [25] and [26].

II. PRELIMINARIES

Graph theory can be used to model the topology of information exchange in a networked system with n agents.

The interaction among an agent set $\mathcal{M} = \{1, 2, \dots, n\}$ is represented by a weighted graph $\mathcal{G} = (\mathcal{V}, \mathcal{E}, \mathcal{A})$ where $\mathcal{V} = (\nu_1, \nu_2, \dots, \nu_n)$ denotes the vertex set, $\mathcal{E} \subseteq \mathcal{V} \times \mathcal{V}$ denotes an edge set, and $\mathcal{A} = (a_{ij} \geq 0) \in \mathbb{R}^{n \times n}$ describe a nonnegative adjacency matrix. The elements a_{ij} are defined such that $a_{ij} > 0$ if $(\nu_i, \nu_j) \in \mathcal{E}$, $a_{ij} = 0$ if $(\nu_i, \nu_j) \notin \mathcal{E}$, and $a_{ij} = 0$ (no self-loop).

Definition 1: Each agent i in the set \mathcal{M} has a set of neighbors denoted by its connectivity set, $\mathcal{N}_i = \{ \nu_j | (\nu_j, \nu_i) \in \mathcal{E} \}$.

Definition 2 Laplacian matrix $\mathbf{L}(l_{ij}) \in \mathbb{R}^{n \times n}$ is associated with the graph \mathcal{G} , where $l_{ij} = -a_{ij}$ for $i \neq j$ and $l_{ij} = \sum_{j=1, j \neq i}^n a_{ij}$

Assumption 1: As the graph \mathcal{G} is not fully connected, the topology is directed communication that allows only the leader to communicate with the followers.

Unlike undirected communication, where a symmetric matrix comes from the exchange of information in both directions, directed communication involves a one-way flow of data (due to the symmetry of the coupling weights).

Assumption 2: When defining the Laplacian matrix, the eigenvalues $\lambda_i(\mathbf{L})$ are specified as $0 \leq \lambda_1(\mathbf{L}) < \lambda_2(\mathbf{L}) < \dots < \lambda_n(\mathbf{L})$.

III. SYSTEM MODEL

A. Distributed Consensus Problem for Nonlinear Second-Order MAS

MAS can be considered a team consisting of a single virtual leader 0 and a diverse set n of identically-behaving, second-order dynamics followers.

$$\begin{cases} \dot{\mathbf{x}}_i = \mathbf{v}_i \\ \dot{\mathbf{v}}_i = \mathbf{f}_i(t, \mathbf{x}_i, \mathbf{v}_i) + \mathbf{u}_i \end{cases} \quad (1)$$

where the agent's position, velocity, and control input vectors are represent respectively by $\mathbf{x}_i, \mathbf{v}_i, \mathbf{u}_i \in \mathbb{R}^m$, It is detailed how the dynamics of the virtual leader work by

$$\begin{cases} \dot{\mathbf{x}}_0 = \mathbf{v}_0 \\ \dot{\mathbf{v}}_0 = \mathbf{f}_0(t, \mathbf{x}_0) \end{cases} \quad (2)$$

where $\mathbf{x}_0, \mathbf{v}_0 \in \mathbb{R}^m$ are the position and velocity of the leader. The dynamics of the leader and the followers are modeled by the functions $\mathbf{f}_0, \mathbf{f}_i \in \mathbb{R}^m$, respectively.

Assumption 3: System (1) is stabilizable if and only if the functions \mathbf{f}_i are uniformly bounded with respect to t and locally uniformly bounded with respect to \mathbf{x}_i and \mathbf{v}_i . As a consequence of that,

$$\|\mathbf{f}_i(t, \mathbf{x}_i, \mathbf{v}_i)\|_2 \leq \delta_{f_i} \quad (3)$$

Where $\delta_{f_i} \in \mathbb{R}^+$

B. Distributed Consensus Control Algorithm

Here, we examine the issue of smooth distributed consensus control for a second-order nonlinear MAS under the assumption of time-varying velocities. The aim of controlling is to design distributed individual protocols \mathbf{u}_i that will lead to the following sort of consensus agreement:

$$\begin{cases} \lim_{t \rightarrow \infty} \|\mathbf{x}_i(t) - \mathbf{x}_0(t)\|_2 = 0 \\ \lim_{t \rightarrow \infty} \|\mathbf{v}_i(t) - \mathbf{v}_0(t)\|_2 = 0 \end{cases} \quad \forall i \in \mathcal{M} \quad (4)$$

In order to find a solution to this consensus problem, we have come up with certain smooth distributed control protocols, which are as follows:

$$\mathbf{u}_i = -\alpha \mathbf{e}_i - \beta |\mathbf{e}_i|^\gamma \quad (5)$$

$$\mathbf{e}_i = \sum_{j=0}^n a_{ij}(\mathbf{x}_i - \mathbf{x}_j) + c \sum_{j=0}^n a_{ij}(\mathbf{v}_i - \mathbf{v}_j) \quad (6)$$

while α and β represent control gains and $c \in \mathbb{R}^+$ is constant, and the exponent γ is a positive constant chosen by the designer.

Assumption 4 There exists a constant $\delta_L \in \mathbb{R}^+$ for which

$$\|\mathbf{L} \otimes \mathbf{I}_p\|_\infty \leq \delta_L \lambda_{\max}(\mathbf{L}) \quad (7)$$

Where \mathbf{I}_p denotes the p -identity matrix, $p = n \times m$

Theorem 1 Let's suppose that assumptions 1-4 are valid, and that the communication graph \mathcal{G} is connected. It is possible that the parameters of the distributed protocols (5)-(7) can be satisfied if:

$$\begin{cases} \alpha < \frac{\beta \delta_{f_i}}{(1+c)\lambda_{\max}(\mathbf{L} \otimes \mathbf{I}_p)} \\ \beta > \binom{\gamma}{0}^{-1} \frac{1}{\lambda_2^{\gamma+1}(\mathbf{L})} \left(\frac{2V_x(0)}{\lambda_{\max}(\mathbf{L})} \right)^{1-\gamma} \\ \delta > 0 \end{cases} \quad (8)$$

Therefore, the consensus argument (4) is reached by a nonlinear leader-follower MAS (1)-(2). A Lyapunov function associated with the positions of the agents is indicated by $V_x(0) = V_x(t=0)$, where λ is an eigenvalue.

Proof: The time dependence is left out of the notation for simplicity. Each piece of evidence is described in detail below.

First, let's define the vectors $\tilde{\mathbf{x}}_i = \mathbf{x}_i - \mathbf{x}_0 \in \mathbb{R}^m$, $\tilde{\mathbf{v}}_i = \mathbf{v}_i - \mathbf{v}_0 \in \mathbb{R}^m$, $\tilde{\boldsymbol{\xi}}_x = [\tilde{\mathbf{x}}_1^T, \dots, \tilde{\mathbf{x}}_n^T]^T \in \mathbb{R}^p$, $\tilde{\boldsymbol{\xi}}_v = [\tilde{\mathbf{v}}_1^T, \dots, \tilde{\mathbf{v}}_n^T]^T \in \mathbb{R}^p$, $\mathbf{u} = [\mathbf{u}_1^T, \dots, \mathbf{u}_n^T]^T \in \mathbb{R}^p$, where $p = n \times m$, the system of (3-1)-(3-2) is modified by applying those notation to be

$$\begin{cases} \dot{\tilde{\boldsymbol{\xi}}}_x = \tilde{\boldsymbol{\xi}}_v \\ \dot{\tilde{\boldsymbol{\xi}}}_v = \mathbf{f}(\tilde{\boldsymbol{\xi}}_v) + \mathbf{u} \end{cases} \quad (9)$$

Second, employing (5) and (6) to (9), it gives

$$\begin{cases} \dot{\tilde{\boldsymbol{\xi}}}_x = \tilde{\boldsymbol{\xi}}_v \\ \dot{\tilde{\boldsymbol{\xi}}}_v = \mathbf{f}(\tilde{\boldsymbol{\xi}}_v) - \alpha(\mathbf{L} \otimes \mathbf{I}_p)\tilde{\boldsymbol{\xi}} - \beta|(\mathbf{L} \otimes \mathbf{I}_p)\tilde{\boldsymbol{\xi}}|^\gamma \end{cases} \quad (10)$$

Third, determine the following Lyapunov function for the system (3-10):

$$V = V_x + V_v + \tilde{\boldsymbol{\xi}}_x^T \mathbf{I}_p \tilde{\boldsymbol{\xi}}_v^T = \frac{1}{2} \tilde{\boldsymbol{\xi}}^T \begin{bmatrix} \sigma(\mathbf{L} \otimes \mathbf{I}_p) & \mathbf{I}_p \\ \mathbf{I}_p & \mathbf{I}_p \end{bmatrix} \tilde{\boldsymbol{\xi}} \quad (11)$$

$$\begin{cases} V_x = \frac{1}{2} \sigma(\mathbf{L} \otimes \mathbf{I}_p) \tilde{\boldsymbol{\xi}}_x^T \tilde{\boldsymbol{\xi}}_x \\ V_v = \frac{1}{2} \mathbf{I}_p \tilde{\boldsymbol{\xi}}_v^T \tilde{\boldsymbol{\xi}}_v \\ \tilde{\boldsymbol{\xi}} = [\tilde{\boldsymbol{\xi}}_x^T \quad \tilde{\boldsymbol{\xi}}_v^T]^T \in \mathbb{R}^{2p} \end{cases} \quad (12)$$

As a result, the following condition must be true for $\sigma \in \mathbb{R}^+$

$$V \geq \frac{1}{2} \tilde{\boldsymbol{\xi}}^T \begin{bmatrix} \sigma \lambda_2(\mathbf{L}) & 1 \\ 1 & 1 \end{bmatrix} \otimes \mathbf{I}_{n \times p} \tilde{\boldsymbol{\xi}} \quad (13)$$

Substituting the following form for (13):

$$V \geq \frac{1}{2} \xi^T \begin{bmatrix} A & B \\ B^T & C \end{bmatrix} \otimes I_{n \times p} \xi \quad (14)$$

Furthermore, V is positive using Schur's complement, if σ is chosen such that $\sigma > \frac{1}{\lambda_2}(\mathbf{L})$:

$$A - \mathbf{B}\mathbf{C}^{-1}\mathbf{B}^T = \sigma \lambda_2(\mathbf{L}) - 1 > 0 \quad (15)$$

Forth, utilize trajectories (10) to get the time derivative of the function V :

$$\begin{aligned} \dot{V} &= \xi^T \begin{bmatrix} \sigma(\mathbf{L} \otimes \mathbf{I}_p) & \mathbf{I}_p \\ \mathbf{I}_p & \mathbf{I}_p \end{bmatrix} \xi \\ &= \sigma \xi_x^T (\mathbf{L} \otimes \mathbf{I}_p) \xi_v + \xi_v^T \mathbf{I}_p \xi_v + \xi_x^T \mathbf{I}_p \xi_v + \xi_v^T \mathbf{I}_p \xi_v \\ &= \sigma \xi_x^T (\mathbf{L} \otimes \mathbf{I}_p) \xi_v + \xi_v^T \mathbf{I}_p \xi_v + (\xi_x^T + \xi_v^T) \xi_v \quad (16) \end{aligned}$$

This is the consequence of applying system dynamics (3-10) to the situation.

$$\begin{aligned} \dot{V} &= \sigma \xi_x^T (\mathbf{L} \otimes \mathbf{I}_p) \xi_v + \xi_v^T \mathbf{I}_p \xi_v + (\xi_x^T + \xi_v^T) \mathbf{f} \\ &\quad - \alpha (\xi_x^T + \xi_v^T) (\mathbf{L} \otimes \mathbf{I}_p) \xi_x + c (\mathbf{L} \otimes \mathbf{I}_p) \xi_v \\ &\quad - \beta (\xi_x^T + \xi_v^T) |(\mathbf{L} \otimes \mathbf{I}_p) \xi_x + c (\mathbf{L} \otimes \mathbf{I}_p) \xi_v|^\gamma \quad (17) \end{aligned}$$

By adopting Newton's generalized binomial theorem to the setting of the fixed-time graph topology, we demonstrate that

$$\begin{aligned} \dot{V} &= \sigma \xi_x^T (\mathbf{L} \otimes \mathbf{I}_p) \xi_v + \xi_v^T \mathbf{I}_p \xi_v + (\xi_x^T + \xi_v^T) \mathbf{f} \\ &\quad - \alpha (\xi_x^T + \xi_v^T) (\mathbf{L} \otimes \mathbf{I}_p) \xi_x + c (\mathbf{L} \otimes \mathbf{I}_p) \xi_v \\ &\quad - \beta (\xi_x^T + \xi_v^T) \sum_{k=0}^p \binom{\gamma}{k} [(\mathbf{L} \otimes \mathbf{I}_p) \xi_x]^{Y-k} [c (\mathbf{L} \otimes \mathbf{I}_p) \xi_v]^{-k} \quad (18) \end{aligned}$$

Therefore, if we want to show that $\dot{V} < 0$ holds when $\forall t > t_0$. As a starting point, let's consider about the term:

$$\begin{aligned} \sigma \xi_x^T (\mathbf{L} \otimes \mathbf{I}_p) \xi_v - \beta (\xi_x^T \\ + \xi_v^T) \sum_{k=0}^p \left\{ \binom{\gamma}{k} [(\mathbf{L} \otimes \mathbf{I}_p) \xi_x]^{Y-k} [c (\mathbf{L} \otimes \mathbf{I}_p) \xi_v]^{-k} \right\} \end{aligned}$$

We put a limit on this term by rewriting it as follows:

$$\begin{aligned} &\sigma \xi_x^T (\mathbf{L} \otimes \mathbf{I}_p) \xi_v - \beta (\xi_x^T \\ &+ \xi_v^T) \sum_{k=0}^p \left\{ \binom{\gamma}{k} [(\mathbf{L} \otimes \mathbf{I}_p) \xi_x]^{Y-k} [c (\mathbf{L} \otimes \mathbf{I}_p) \xi_v]^{-k} \right\} = \\ &\sigma \xi_x^T (\mathbf{L} \otimes \mathbf{I}_p) \xi_v - \beta \binom{\gamma}{0} (\xi_x^T)^T (\mathbf{L} \otimes \mathbf{I}_p)^Y \xi_v \\ &\quad - \beta \sum_{k=1}^p \left\{ c^k \binom{\gamma}{k} (\xi_x^{Y-k}) (\mathbf{L} \otimes \mathbf{I}_p)^Y \xi_v^k \right\} = \\ &\xi_x^T (\mathbf{L} \otimes \mathbf{I}_p) \xi_v \left[\sigma - \beta \binom{\gamma}{0} (\xi_x^{Y-1})^T (\mathbf{L} \otimes \mathbf{I}_p)^{Y-1} \right] \\ &\quad - \beta \sum_{k=1}^p \left\{ c^k \binom{\gamma}{k} (\xi_x^{Y-k}) (\mathbf{L} \otimes \mathbf{I}_p)^Y \xi_v^k \right\} \quad (19) \end{aligned}$$

According to the characteristics of the matrix \mathbf{L} , (19) is limited as follows:

$$\begin{aligned} &\sigma \xi_x^T (\mathbf{L} \otimes \mathbf{I}_p) \xi_v - \beta (\xi_x^T \\ &+ \xi_v^T) \sum_{k=0}^p \left\{ \binom{\gamma}{k} [(\mathbf{L} \otimes \mathbf{I}_p) \xi_x]^{Y-k} [c (\mathbf{L} \otimes \mathbf{I}_p) \xi_v]^{-k} \right\} \leq \end{aligned}$$

$$\begin{aligned} &\xi_x^T (\mathbf{L} \otimes \mathbf{I}_p) \xi_v \left[\sigma - \beta \binom{\gamma}{0} \lambda_2^{Y-1}(\mathbf{L}) \|\xi_x^{Y-1}\|_2 \right] \\ &\quad - \beta \sum_{k=1}^p \left\{ c^k \binom{\gamma}{k} (\xi_x^{Y-k}) (\mathbf{L} \otimes \mathbf{I}_p)^Y \xi_v^k \right\} \quad (20) \end{aligned}$$

We get that since V_x , is a quadratic function of $\|\xi_x\|$

$$\begin{aligned} &\xi_x^T (\mathbf{L} \otimes \mathbf{I}_p) \xi_v \left[\sigma - \beta \binom{\gamma}{0} \lambda_2^{Y-1}(\mathbf{L}) \|\xi_x^{Y-1}\|_2 \right] \\ &\quad - \beta \sum_{k=1}^p \left\{ c^k \binom{\gamma}{k} (\xi_x^{Y-k}) (\mathbf{L} \otimes \mathbf{I}_p)^Y \xi_v^k \right\} \leq \\ &\xi_x^T (\mathbf{L} \otimes \mathbf{I}_p) \xi_v \left[\sigma - \beta \binom{\gamma}{0} \lambda_2^{Y-1}(\mathbf{L}) \left(\frac{2V_x(0)}{\lambda_{\max}(\mathbf{L})} \right)^{Y-1} \right] \\ &\quad - \beta \sum_{k=1}^p \left\{ c^k \binom{\gamma}{k} (\xi_x^{Y-k}) (\mathbf{L} \otimes \mathbf{I}_p)^Y \xi_v^k \right\} \quad (21) \end{aligned}$$

By selecting on σ , you will be taken to a

$$\sigma = \beta \binom{\gamma}{0} \lambda_2^Y(\mathbf{L}) \left(\frac{2V_x(0)}{\lambda_{\max}(\mathbf{L})} \right)^{Y-1} > \frac{1}{\lambda_2(\mathbf{L})} \quad (22)$$

The gain of control β can be adjusted as

$$\beta > \binom{\gamma}{0}^{-1} \frac{1}{\lambda_2^{Y+1}(\mathbf{L})} \left(\frac{2V_x(0)}{\lambda_{\max}(\mathbf{L})} \right)^{1-Y} \quad (23)$$

When applying (23) to (21), we get

$$\begin{aligned} &\sigma \xi_x^T (\mathbf{L} \otimes \mathbf{I}_p) \xi_v \\ &- \beta \sum_{k=0}^p \left\{ \binom{\gamma}{k} [(\mathbf{L} \otimes \mathbf{I}_p) \xi_x]^{Y-k} [c (\mathbf{L} \otimes \mathbf{I}_p) \xi_v]^{-k} \right\} \leq \\ &\quad - \beta \sum_{k=1}^p \left\{ c^k \binom{\gamma}{k} (\xi_x^{Y-k}) (\mathbf{L} \otimes \mathbf{I}_p)^Y \xi_v^k \right\} \quad (24) \end{aligned}$$

Lemma 2: [27] For a vector $\mathbf{v} \in \mathbb{R}^n$ with $1_n^T \mathbf{v} = 0$ with $1_n = [1, \dots, 1]^T_n$, inequalities involving the following hold $\lambda_{\min}(\mathbf{M}) > 0$.

$$\begin{cases} \mathbf{v}^T \mathbf{M} \mathbf{v} \geq \lambda_{\min}(\mathbf{M}) \mathbf{v}^T \mathbf{v} \\ (\mathbf{S} \otimes \mathbf{I}_N) \mathbf{v} \leq \lambda_{\max}(\mathbf{S}) \|\mathbf{v}\|_2 \end{cases} \quad (25)$$

It follows from (23) and (24) that

$$\begin{aligned} \dot{V} &\leq \xi_v^T \mathbf{I}_p \xi_v - \alpha \lambda_{\max}(\mathbf{L} \otimes \mathbf{I}_p) (\|\xi_x^T\|_2 \|\xi_x\|_2 + \|\xi_v^T\|_2 \|\xi_x\|_2) \\ &\quad + c \lambda_{\max}(\mathbf{L}) \|\xi_v\|_2 \\ &\quad - \beta \sum_{k=1}^p \left\{ c^k \binom{\gamma}{k} (\xi_x^{Y-k}) (\mathbf{L} \otimes \mathbf{I}_p)^Y \xi_v^k \right\} \quad (26) \end{aligned}$$

Next, we rewrite (3-17) so that the term $\xi_v^T \mathbf{I}_p \xi_v - \alpha (\xi_x^T + \xi_v^T) (\mathbf{L} \otimes \mathbf{I}_p) \xi_x + c (\mathbf{L} \otimes \mathbf{I}_p) \xi_v$

$$\begin{aligned} \dot{V} &\leq \xi_v^T \mathbf{I}_p \xi_v - \alpha \lambda_{\max}(\mathbf{L} \otimes \mathbf{I}_p) (\|\xi_x^T\|_2 \|\xi_x\|_2 + \|\xi_v^T\|_2 \|\xi_x\|_2) \\ &\quad + c \lambda_{\max}(\mathbf{L}) \|\xi_v\|_2 \\ &\quad - \beta \sum_{k=1}^p \left\{ c^k \binom{\gamma}{k} (\xi_x^{Y-k}) (\mathbf{L} \otimes \mathbf{I}_p)^Y \xi_v^k \right\} \quad (27) \end{aligned}$$

Condition $\dot{V} < 0$ holds when $\forall t > t_0$, (27) is found by rearranging as follows:

$$\dot{V} \leq \xi^T \mathbf{Y} \xi - \beta \sum_{k=1}^p \{c^k (\gamma_k) (\xi_x^{\gamma-k}) (\mathbf{L} \otimes \mathbf{I}_p)^Y \xi_v^k\} \quad (28)$$

where

$$\begin{cases} Y_{11} = \beta \delta_{f_i} + 1 \\ Y_{12} = Y_{21} = \frac{1}{2} \alpha (1 + c) \lambda_{\max}(\mathbf{L} \otimes \mathbf{I}_p) \\ Y_{22} = \frac{1}{2} \alpha (1 + c) \lambda_{\max}(\mathbf{L} \otimes \mathbf{I}_p) \end{cases} \quad (29)$$

It follows from (28) that \dot{V} is negatively definite if and only if

$$\alpha (1 + c) \lambda_{\max}(\mathbf{L} \otimes \mathbf{I}_p) - \beta \delta_{f_i} < 0 \quad (30)$$

Which results in

$$\alpha < \frac{\beta \delta_{f_i}}{(1+c) \lambda_{\max}(\mathbf{L} \otimes \mathbf{I}_p)} \quad (31)$$

IV. DISTRIBUTED COOPERATIVE CONTROL FOR UAV MAS

A. UAV MAS Dynamics

Consider a network of n UAVs are operating autonomously, and that the three-dimensional trajectory of each vehicle $i \in N$ is defined by a vector \mathbf{q}_i where

$$\mathbf{q}_i [\mathbf{x}_i, \boldsymbol{\vartheta}_i]^T = [(x_i, y_i, z_i)^T, (\gamma_i, \theta_i, \psi_i)^T]^T \in \mathbf{R}^6 \quad (32)$$

Where the position vector is denoted by \mathbf{x}_i , whereas the angular rotation vector is denoted by $\boldsymbol{\vartheta}_i$, which includes roll, pitch, and yaw. Within the boundaries of the body airframe, the angular velocity vector $\boldsymbol{\omega}_i$ is defined as

$$\boldsymbol{\omega}_i = \begin{bmatrix} 1 & 0 & -\sin\theta \\ 0 & \cos\gamma & \cos\theta \sin\gamma \\ 0 & \sin\gamma & \cos\theta \cos\gamma \end{bmatrix} \boldsymbol{\vartheta}_i \quad (33)$$

All of the following agent and leader dynamic models are considered as following

Agents:

$$\begin{cases} \dot{\mathbf{x}}_i = \mathbf{v}_i, \dot{\mathbf{v}}_i = \mathbf{f}_{it} + \mathbf{u}_{it} \\ \dot{\boldsymbol{\vartheta}}_i = \boldsymbol{\omega}_i, \dot{\boldsymbol{\omega}}_i = \mathbf{f}_{ir} + \mathbf{u}_{ir} \end{cases} \quad (34)$$

Leader:

$$\begin{cases} \dot{\mathbf{x}}_0 = \mathbf{v}_0, \dot{\mathbf{v}}_0 = \mathbf{f}_{t0} \\ \dot{\boldsymbol{\vartheta}}_0 = \mathbf{T}^{-1} \boldsymbol{\omega}_0, \dot{\boldsymbol{\omega}}_0 = \mathbf{f}_{r0} \end{cases} \quad (35)$$

where t and r denote translational and rotational motions, respectively; $\mathbf{f}_{it} = \mathbf{T}^{-1} \mathbf{f}_{t0}$, $\mathbf{f}_{ir} = \mathbf{f}_{r0}$; \mathbf{T} is the matrix that connects the body frame to the inertial frame; it is obtained, from Euler rotations, as

$$\mathbf{T} = \begin{bmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{bmatrix} \quad (36)$$

where

$$\begin{cases} T_{11} = \cos\psi \cos\psi - \cos\theta \sin\gamma \sin\psi \\ T_{12} = -\cos\psi \sin\gamma - \cos\gamma \cos\theta \sin\psi \\ T_{13} = \sin\theta \sin\psi \\ T_{21} = \cos\theta \cos\psi \sin\gamma - \cos\gamma \sin\psi \\ T_{22} = \cos\gamma \cos\theta \cos\psi - \sin\gamma \sin\psi \\ T_{23} = -\cos\psi \sin\theta \\ T_{31} = \sin\gamma \sin\theta \\ T_{32} = \cos\gamma \sin\theta \\ T_{33} = \cos\theta \end{cases}$$

B. UAV MAS Consensus Control

Lemma 3: Theorem 1 is used to construct the \mathbf{u}_{it} and \mathbf{u}_{ir} control inputs for translation and rotation, respectively.

$$\begin{cases} \mathbf{u}_{it}(t) = -\alpha_t \mathbf{e}_{it} - \beta_t |\mathbf{e}_{it}|^Y \\ \mathbf{u}_{ir}(t) = -\alpha_r \mathbf{e}_{ir} - \beta_r |\mathbf{e}_{ir}|^Y \end{cases} \quad (37)$$

where α_t , β_t , α_r , and β_r are computed by using (23) and (30), and

$$\begin{cases} A_{it}(t) = \sum_{j=0}^n a_{ij} (\mathbf{x}_i(t) - \mathbf{x}_j(t)) \\ \quad + c \sum_{j=0}^n a_{ij} (\mathbf{v}_i(t) - \mathbf{v}_j(t)) \\ A_{ir}(t) = \sum_{j=0}^n a_{ij} (\boldsymbol{\vartheta}_i(t) - \boldsymbol{\vartheta}_j(t)) \\ \quad + c \sum_{j=0}^n a_{ij} (\boldsymbol{\omega}_i(t) - \boldsymbol{\omega}_j(t)) \end{cases} \quad (38)$$

C. UAV MAS Formation Control

The goal of formation control is to develop translational and rotational controls that allow multi-UAVs to precisely track a predetermined geometric pattern $\mathcal{P}(x, y, z)$ in three-dimensional space with

$$\sum_{i=1}^n p_{ix} = p_{0x}, \sum_{i=1}^n p_{iy} = p_{0y}, \sum_{i=1}^n p_{iz} = p_{0z} \quad (39)$$

Where (p_{0x}, p_{0y}, p_{0z}) is the center of the geometric pattern $\mathcal{P}(x, y, z)$.

In this scenario, we assume that the formation states are denoted by that η_{1i} , η_{2i} and, η_{3i} , and that the formation control protocols are denoted by u_{1i} and, u_{2i} , and that the formation evolves according to the following dynamics system [28]:

$$\begin{cases} \dot{\eta}_{1i} = u_{1i} \\ \dot{\eta}_{2i} = u_{2i} \\ \dot{\eta}_{3i} = u_{1i} \eta_{2i} - k_0 |u_{1i}| \eta_{3i} \end{cases} \quad (40)$$

where $k_0 \in \mathbb{R}^+$. The following illustrates how the trajectories of the agents relate to the pattern's trajectory:

$$\begin{cases} x_i = \cos(\eta_{1i}) [\eta_{2i} - k_0 \text{sign}(u_{1i}) \eta_{3i}] + \sin(\eta_{1i}) \eta_{3i} + p_{xi} \\ y_i = \sin(\eta_{1i}) [\eta_{2i} - k_0 \text{sign}(u_{1i}) \eta_{3i}] + \cos(\eta_{1i}) \eta_{3i} + p_{yi} \\ z_i = p_{zi} \end{cases} \quad (41)$$

If $\lim_{t \rightarrow \infty} (\eta_{ki} - \eta_{k0}) = 0$ and $\lim_{t \rightarrow \infty} (u_{li} - u_{l0}) = 0$ for $k = 1, 2, 3; l = 1, 2; 1 \leq i \leq n$, then for $1 \leq i \neq j \leq n$ the MAS of n -UAV achieves

$$\begin{aligned} \lim_{t \rightarrow \infty} \begin{bmatrix} x_i - x_j \\ y_i - y_j \\ z_i - z_j \end{bmatrix} &= \begin{bmatrix} p_{xi} - p_{xj} \\ p_{yi} - p_{yj} \\ p_{zi} - p_{zj} \end{bmatrix}, \lim_{t \rightarrow \infty} \left(\sum_{i=1}^n \frac{x_i}{n} - x_0 \right) = 0, \\ \lim_{t \rightarrow \infty} \left(\sum_{i=1}^n \frac{y_i}{n} - y_0 \right) &= 0, \lim_{t \rightarrow \infty} \left(\sum_{i=1}^n \frac{z_i}{n} - z_0 \right) = 0 \end{aligned} \quad (42)$$

where the leader coordinates are denoted by x_0, y_0, z_0 respectively (the formation pattern centroid). The definition of the vector $\tilde{\eta}_i = [(\eta_{1i} - \eta_{10}), (\eta_{2i} - \eta_{20}), (\eta_{3i} - \eta_{30})]^T$ as the tracking error vector for each UAV $_i$ and applying control law (5) to both u_{1i} and u_{2i} , we are able to establish that

$$\begin{cases} u_{ki} = -\alpha_k A_{ki} - \beta_k |A_{ki}|^\gamma \\ A_{ki}(t) = \sum_{j=0}^n a_{ij} (\eta_{ki}(t) - \eta_{kj}(t)), k = 1, 2. \end{cases} \quad (43)$$

Following is the reduced dynamic system that is generated as a result of substituting protocols (42) into the first two dynamic equations of the system (39):

$$\begin{cases} \dot{\eta}_{1i} = -\alpha_1 \sum_{j=0}^n a_{ij} (\eta_{1i}(t) - \eta_{1j}(t)) \\ -\beta_1 \left| \sum_{j=0}^n a_{ij} (\eta_{1i}(t) - \eta_{1j}(t)) \right|_i^\gamma + \dot{\eta}_{10} \\ \dot{\eta}_{2i} = -\alpha_2 \sum_{j=0}^n a_{ij} (\eta_{2i}(t) - \eta_{2j}(t)) \\ -\beta_2 \left| \sum_{j=0}^n a_{ij} (\eta_{2i}(t) - \eta_{2j}(t)) \right|_i^\gamma + \dot{\eta}_{20} \end{cases} \quad (44)$$

In the form of a vector, equation (44) is identical to the auxiliary closed-loop system that is presented in the following:

$$\dot{\tilde{\eta}} = -\alpha(\mathbf{L} \otimes \mathbf{I}_2)\tilde{\eta} - \beta|\mathbf{L} \otimes \mathbf{I}_2\tilde{\eta}|^\gamma - \dot{\eta}_0 \quad (45)$$

where

$$\begin{aligned} \tilde{\eta} &= [\tilde{\eta}_1^T, \tilde{\eta}_2^T]^T = [\tilde{\eta}_{11}, \dots, \tilde{\eta}_{1n}, \tilde{\eta}_{21}, \dots, \tilde{\eta}_{2n}]^T \\ \dot{\eta}_0 &= [\mathbf{1}_n^T \dot{\eta}_{10}, \mathbf{1}_n^T \dot{\eta}_{20}]^T \\ \alpha &= \begin{bmatrix} \alpha_1 \mathbf{I}_n & \mathbf{0}_{nn} \\ \mathbf{0}_{nn} & \alpha_2 \mathbf{I}_n \end{bmatrix}, \beta = \begin{bmatrix} \beta_1 \mathbf{I}_n & \mathbf{0}_{nn} \\ \mathbf{0}_{nn} & \beta_2 \mathbf{I}_n \end{bmatrix} \end{aligned}$$

Theorem 2: Considering Assumptions 1-3 hold true, the communication graph \mathcal{G} is connected and the control inputs to the closed-loop system (46) are selected according to (43), the agents' states η_{1i} and η_{2i} will converge to the formation states η_{10} and η_{20} , respectively, if the tracking error converges to zero $\lim_{t \rightarrow \infty} (\tilde{\eta}_i) = 0$.

Proof: The following quadratic function can be considered of as a potential Lyapunov function

$$V = \frac{1}{2} \tilde{\eta}^T (\mathbf{L} \otimes \mathbf{I}_2) \tilde{\eta} \quad (46)$$

If we assume that V is continuously differentiable with regard to ζ , we may formulate its time derivative \dot{V} as

$$\dot{V} = \tilde{\eta}^T (\mathbf{L} \otimes \mathbf{I}_2) \dot{\tilde{\eta}} \quad (47)$$

If the auxiliary closed-loop system (45) is used, we obtain

$$\dot{V} = -\alpha \tilde{\eta}^T (\mathbf{L} \otimes \mathbf{I}_2) \tilde{\eta} - \beta \tilde{\eta}^T (\mathbf{L} \otimes \mathbf{I}_2) |\mathbf{L} \otimes \mathbf{I}_2 \tilde{\eta}|^\gamma - \dot{\eta}_0 \quad (48)$$

Since $\gamma > 0$ and the gain matrices α and β are both diagonal, we have

$$\begin{aligned} \dot{V} &\leq -\det(\alpha) \tilde{\eta}^T (\mathbf{L} \otimes \mathbf{I}_2) \tilde{\eta} \\ &\quad - \det(\beta) \tilde{\eta}^T (\mathbf{L} \otimes \mathbf{I}_2) |\mathbf{L} \otimes \mathbf{I}_2 \tilde{\eta}|^\gamma \end{aligned} \quad (49)$$

Furthermore, the inequation (49) satisfies

$$\dot{V} \leq -\det(\alpha) \lambda_{\min}^2(\mathbf{L} \otimes \mathbf{I}_2) \|\tilde{\eta}\|_2^2 \quad (50)$$

Since $V = \frac{1}{2} \tilde{\eta}^T (\mathbf{L} \otimes \mathbf{I}_2) \tilde{\eta} \leq \frac{1}{2} \lambda_{\max}(\mathbf{L} \otimes \mathbf{I}_2) \|\tilde{\eta}\|_2^2$ and $\lambda_i(\mathbf{L} \otimes \mathbf{I}_2) = \lambda_i(\mathbf{L})$, it follows that

$$\dot{V} \leq -\det(\alpha) \frac{\sqrt{2} \lambda_{\min}^2(\mathbf{L})}{\sqrt{\lambda_{\max}(\mathbf{L})}} \sqrt{V} \quad (51)$$

It is concluded from (51) that

$$\sqrt{V} \leq \sqrt{V_0} - \frac{\det(\alpha)}{\sqrt{2}} \frac{\lambda_{\min}^2(\mathbf{L})}{\sqrt{\lambda_{\max}(\mathbf{L})}} t \quad (52)$$

Formation tracking is guaranteed to converge if and only if $\sqrt{V} = 0$

$$\begin{aligned} t &\geq \sqrt{V_0} \frac{\sqrt{2}}{\det(\alpha)} \frac{\sqrt{\lambda_{\max}(\mathbf{L})}}{\lambda_{\min}^2(\mathbf{L})} \\ &= \frac{\sqrt{\zeta^T(0)(\mathbf{L} \otimes \mathbf{I}_2)\zeta(0)} \sqrt{\lambda_{\max}(\mathbf{L})}}{\det(\alpha) \lambda_{\min}^2(\mathbf{L})} \end{aligned} \quad (53)$$

V. SIMULATION

A. Consensus of Formation Pattern

Here, a team of $n = 4$ UAVs performs out a path-following mission within a simulated environment. As illustrated in Fig. 1, the path under consideration follows a half-parabolic shape. A swarm of UAVs forms in a specified formation is shown in Fig. 2 (a), following the common trajectory. Using the topology depicted in Fig. 2 (b), they track together a predetermined 3D trajectory through space.

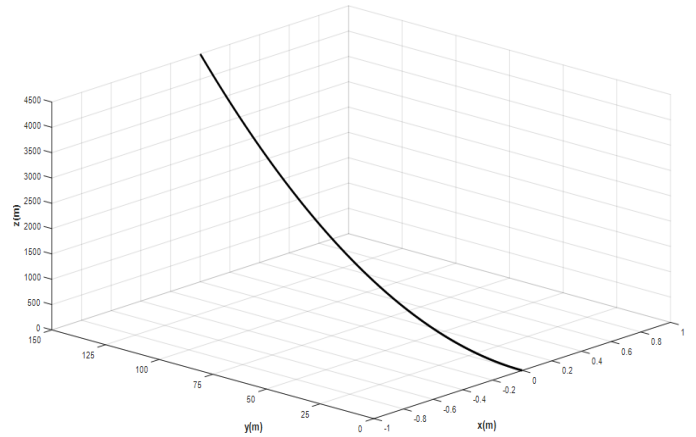


Fig. 1. Desired formation and trajectory.

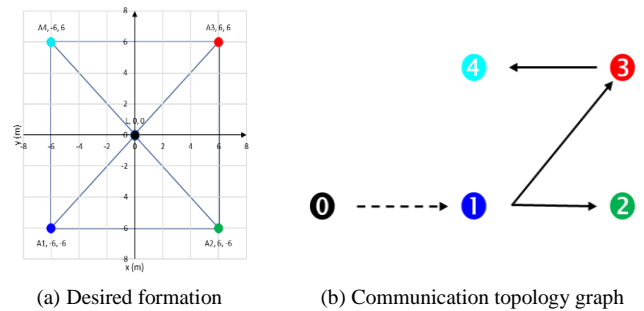
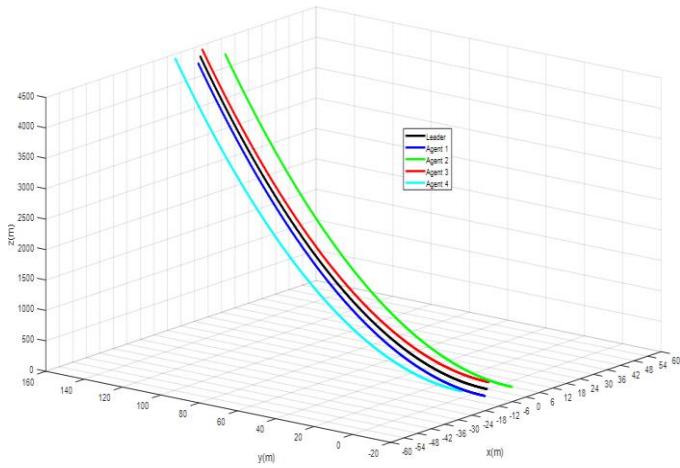
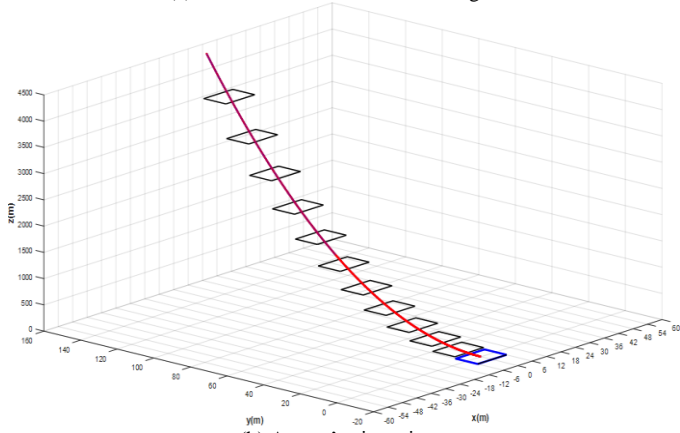


Fig. 2. Desired formation and fixed-time directed communication topology graph.

Fig. 3 illustrates the consensus in three dimensions among the four agents, as well as the timeline of how the agents' orientations gradually approach those of the virtual leader. Meanwhile, Fig. 4 illustrates the path taken for the leader and the followers by the centroid formation as it moves along the motion axes.



(a) Consensus of the team of four agents.



(b) Agents' orientations.

Fig. 3. Formation tracking with the control law.

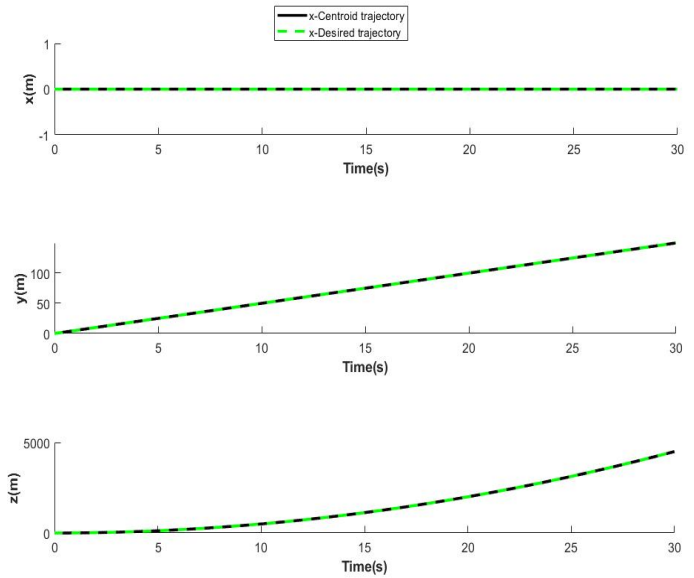


Fig. 4. Geometric pattern centroid tracking.

B. Tracking of Formation Pattern

Within the context of the simulated scenario, a team of four UAVs performs out a routing path following mission. Parametric trajectories take into account the considered path as defined by:

$$\begin{cases} x = \frac{x_0 + \cos^{-1} t - b r \sin t}{\sqrt{a^2 + b^2}} \\ y = \frac{y_0 + \cos^{-1} t - b r \sin t}{\sqrt{a^2 + b^2}} \\ z = z_0 + r \cos t \sqrt{a^2 + b^2} \end{cases} \quad (54)$$

With $a = 10$, $b = 10$, and $r = 50$

The formation mission can be accomplished with a switching communication topology like that illustrated in Fig. 5 and a dwell duration of 15 s.

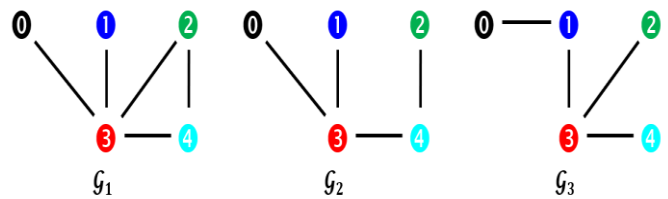


Fig. 5. Switching undirected topology interaction graph.

Fig. 6 illustrates how the proposed control law was applied to the formation tracking.

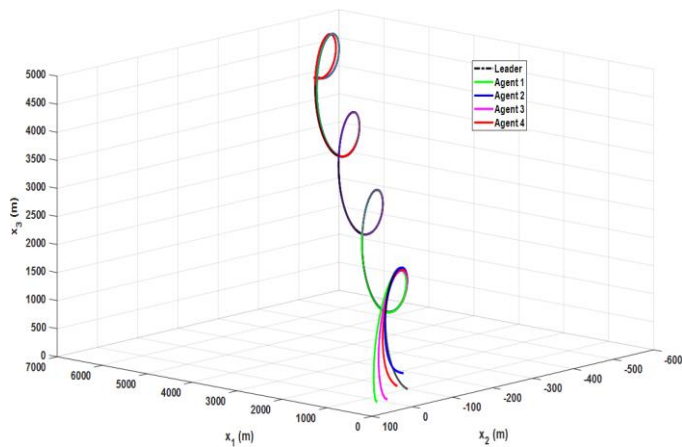


Fig. 6. Formation tracking with the proposed control law.

Fig. 3 to 6 show that the four UAVs achieved the formation requirements with the proposed distributed protocol despite the complex communication limitations and dynamic constraints. the tracking error of the formation is 0, as shown in Fig. 3. This demonstrates that the distributed formation control protocol is successful for UAV formation even under communication loss and topology switching conditions. If the formation of the UAVs needs to be adjusted while they are in flight, the control protocol can be used even when the UAVs' configuration changes dynamically. The results of the simulation demonstrate the effectiveness of the proposed control scheme.

VI. CONCLUSION

Based on leader-following consensus in MAS, a smooth distributed cooperative control for multi-air vehicles such as UAVs was designed. First, we developed smooth distributed consensus protocols, as opposed to the traditional sliding-mode based algorithms, by substituting the discontinuous signum function with a continuous integral function. Then, a model for flying formation control was developed to track and maintain three-dimensional geometric patterns. A Lyapunov function-based approach was used to set the necessary and sufficient requirements for the convergence of both consensus and formation algorithms. The primary focus of the presented study in the near future will be on event-based formation control for multi-UAV systems, formation tracking in harsh environments, obstacle avoidance and disturbance rejections among aerial moving agents.

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REFERENCES

[1] B. Kada, A. S. A. Balamesh, K. A. Juhany, and I. M. Al-Qadi, "Distributed cooperative control for nonholonomic wheeled mobile robot systems," *Int J Syst Sci*, vol. 51, no. 9, pp. 1528–1541, Jul. 2020, doi: 10.1080/00207721.2020.1765048.

[2] A. Y. Tameem, B. Kada, and A. A. Alzubairi, "Formation Control with Switching Topology for Multi-agent Nonholonomic Wheeled Mobile Robot Systems," *2022 IEEE IAS Global Conference on Emerging*

Technologies, GlobConET 2022, pp. 276–281, 2022, doi: 10.1109/GLOBCONET53749.2022.9872448.

[3] Y. Liu and A. Zhang, "Cooperative task assignment method of manned/ unmanned aerial vehicle formation," *Systems engineering and electronics*, vol. 32, no. 3, pp. 584–588, 2010.

[4] W. Lin, "Distributed UAV formation control using differential game approach," *Aerosp Sci Technol*, vol. 35, pp. 54–62, 2014.

[5] H. Du, W. Zhu, G. Wen, Z. Duan, and J. Lü, "Distributed formation control of multiple quadrotor aircraft based on nonsmooth consensus algorithms," *IEEE Trans Cybern*, vol. 49, no. 1, pp. 342–353, 2017.

[6] Z. Liang, L. U. Yi, X. U. Shida, and F. Han, "Multiple UAVs cooperative formation forming control based on back-stepping-like approach," *Journal of Systems Engineering and Electronics*, vol. 29, no. 4, pp. 816–822, 2018.

[7] B. Zhang, X. Sun, S. Liu, and X. Deng, "Adaptive differential evolution-based distributed model predictive control for multi-UAV formation flight," *International Journal of Aeronautical and Space Sciences*, vol. 21, no. 2, pp. 538–548, 2020.

[8] X. Dong, Y. Hua, Y. Zhou, Z. Ren, and Y. Zhong, "Theory and Experiment on Formation-Containment Control of Multiple Multirotor Unmanned Aerial Vehicle Systems," *IEEE Transactions on Automation Science and Engineering*, vol. 16, no. 1, pp. 229–240, Jan. 2019, doi: 10.1109/TASE.2018.2792327.

[9] Z. Ziyang, Z. H. U. Ping, X. U. E. Yixuan, and J. I. Yuxuan, "Distributed intelligent self-organized mission planning of multi-UAV for dynamic targets cooperative search-attack," *Chinese Journal of Aeronautics*, vol. 32, no. 12, pp. 2706–2716, 2019.

[10] J. W. Hu, M. Wang, C. H. Zhao, Q. Pan, and C. Du, "Formation control and collision avoidance for multi-UAV systems based on Voronoi partition," *Science China Technological Sciences* 2019 63:1, vol. 63, no. 1, pp. 65–72, Sep. 2019, doi: 10.1007/S11431-018-9449-9.

[11] S. Shao, Y. Peng, C. He, and Y. Du, "Efficient path planning for UAV formation via comprehensively improved particle swarm optimization," *ISA Trans*, vol. 97, pp. 415–430, Feb. 2020, doi: 10.1016/J.ISATRA.2019.08.018.

[12] B. Kada, M. Khalid, and M. S. Shaikh, "Distributed cooperative control of autonomous multi-Agent UAV systems using smooth control," *Journal of Systems Engineering and Electronics*, vol. 31, no. 6, pp. 1297–1307, Dec. 2020, doi: 10.23919/JSEE.2020.000100.

[13] J. K. Verma and V. Ranga, "Multi-Robot Coordination Analysis, Taxonomy, Challenges and Future Scope," *J Intell Robot Syst*, vol. 102, no. 1, pp. 1–36, 2021.

[14] Z. Meng, Z. Lin, and W. Ren, "Robust cooperative tracking for multiple non-identical second-order nonlinear systems," *Automatica*, vol. 49, no. 8, pp. 2363–2372, 2013.

[15] A. Karimodini, H. Lin, B. M. Chen, and T. H. Lee, "Hybrid three-dimensional formation control for unmanned helicopters," *Automatica*, vol. 49, no. 2, pp. 424–433, 2013.

[16] J. Zhang, D. Ye, J. D. Biggs, and Z. Sun, "Finite-time relative orbit-attitude tracking control for multi-spacecraft with collision avoidance and changing network topologies," *Advances in Space Research*, vol. 63, no. 3, pp. 1161–1175, Feb. 2019, doi: 10.1016/J.ASR.2018.10.037.

[17] Y. Guo, J. Zhou, and Y. Liu, "Distributed RISE control for spacecraft formation reconfiguration with collision avoidance," *J Franklin Inst*, vol. 356, no. 10, pp. 5332–5352, Jul. 2019, doi: 10.1016/J.JFRANKLIN.2019.05.003.

[18] A. Alzubairi, B. Kada, and A. Tameem, "Decentralized Cooperation Control for Formation Flying Spacecraft," *2022 IEEE IAS Global Conference on Emerging Technologies*, GlobConET 2022, pp. 187–190, 2022, doi: 10.1109/GLOBCONET53749.2022.9872513.

[19] A. Alzubairi, B. Kada, and A. Tameem, "Attitude Consensus Control of Spacecraft Formation Flying: Model-Based Design," in *72nd International Astronautical Congress (IAC)*, Dubai, United Arab Emirates: the International Astronautical Federation (IAF), Oct. 2021.

[20] P. O. Skobelev, E. V. Simonova, A. A. Zhilyaev, and V. S. Travin, "Application of Multi-agent Technology in the Scheduling System of Swarm of Earth Remote Sensing Satellites," *Procedia Comput Sci*, vol. 103, pp. 396–402, Jan. 2017, doi: 10.1016/J.PROCS.2017.01.127.

- [21] Z. Zheng, J. Guo, and E. Gill, "Distributed onboard mission planning for multi-satellite systems," *Aerosp Sci Technol*, vol. 89, pp. 111–122, Jun. 2019, doi: 10.1016/J.AST.2019.03.054.
- [22] X. Liu, L. Liu, and Y. Wang, "Minimum time state consensus for cooperative attack of multi-missile systems," *Aerosp Sci Technol*, vol. 69, pp. 87–96, Oct. 2017, doi: 10.1016/J.AST.2017.06.016.
- [23] T. Lyu, Y. Guo, C. Li, G. Ma, and H. Zhang, "Multiple missiles cooperative guidance with simultaneous attack requirement under directed topologies," *Aerosp Sci Technol*, vol. 89, pp. 100–110, Jun. 2019, doi: 10.1016/J.AST.2019.03.037.
- [24] A. Almalki and B. Kada, "Consensus tracking for multiagent systems under bounded unknown external disturbances using sliding-PID control," *Int J Sci Basic Appl Res*, vol. 50, no. 2, pp. 143–153, 2020.
- [25] T., Canhui, R. Zhang, Z. Song, B. Wang, and Y. Jin. "Multi-UAV Formation Control in Complex Conditions Based on Improved Consistency Algorithm" *Drones*, vol. 7, no. 3: 2023. <https://doi.org/10.3390/drones7030185>
- [26] J. Li, J. Liu, S. Huangfu, G. Cao, and D. Yu. "Leader-follower formation of light-weight UAVs with novel active disturbance rejection control," *Applied Mathematical Modelling*, vol. 117, pp. 577-591, 2023. <https://doi.org/10.1016/j.apm.2022.12.032>.
- [27] S. Li, H. Du, and X. Lin, "Finite-time consensus algorithm for multi-agent systems with double-integrator dynamics," *Automatica*, vol. 47, no. 8, pp. 1706–1712, 2011.
- [28] Z. Peng, S. Yang, G. Wen, A. Rahmani, and Y. Yu, "Adaptive distributed formation control for multiple nonholonomic wheeled mobile robots," *Neurocomputing*, vol. 173, pp. 1485–1494, 2016.

An Artificial Intelligent Methodology-based Bayesian Belief Networks Constructing for Big Data Economic Indicators Prediction

Adil Al-Azzawi¹, Fernando Torre Mora², Chanmann Lim³, Yi Shang³

Department of Natural & Applied Sciences-Computer Science Dept., American University of Iraq-Baghdad, Baghdad, Iraq¹
Dept. Computacion y Tecnologia de la Informacion, University Simon Bolivar, Caracas, Venezuela²
Computer Science Dept.-College of Engineering, University of Missouri-Columbia, MO, USA³

Abstract—Economic indicator prediction in big data requires treating all random variables as an independent set of selective values and used as a discriminative method for classification tasks. A Bayesian network is a popular graphical representation approach for modeling probabilistic dependencies and causality among a set of random variables to incorporate a huge amount of human expert knowledge about the problem of interest involving diagnostic reasoning of big data. In our study, we set out to construct the Bayesian networks using the standard error for a least-squares linear regression (STE) and the domain knowledge from the literature in the field for predicting the big data economy prediction. The experimental results show that the proposed STE baseline provided us with an accuracy of 20% to 58% in seven out of eight regions, including the aggregate for “World”. In comparison, the Bayesian Networks generated by our first Domain Knowledge Model improved accuracy from 54% to 75% in the same regions.

Keywords—STE; Bayesian networks; domain knowledge; discriminative methods; economic forecasting

I. INTRODUCTION

Although methods exist to construct Bayesian networks using expert knowledge [1][2], genetic algorithms [3][4], and topological ordering [4][5] few methods exist to construct a Bayesian network using purely mathematical relations between the variables [5]. We believe such a method to be an important contribution to the field, for which reason we set out to develop it.

We based our method on the standard error for a least-squares linear regression, or STE [6]. This metric is consistent with commonly used statistics such as the correlation coefficient ([7], [8]) and has the additional advantage of allowing us to test causation. This, combined with minimal domain knowledge, allows us to define an unambiguous, valid Bayesian network.

To test our method, we set out to apply it to the problem of predicting economic growth. This problem not only has a large number of variables on which to build on, but it has also become particularly important in the past eight years given the considerable slowdown that has occurred in the global economy. More informed prediction mechanisms would prove invaluable to policy makers and help them make better decisions. However, it seems unlikely (and in fact is strongly

discouraged [9]) that a single model can encompass all the countries in the world accurately. It is necessary, then, to subdivide the countries into regions and build a prediction model for each. This makes it an ideal fit to test our Bayesian Network construction methodology: our problem is not only to create a good prediction model, but how can we build prediction models for each country or region.

Our Bayesian Networks aim to show such how significant these factors are to economic growth in each region. We select a series of variables that measure Economy, Production, Education, and Innovation. We will relate them using STE to create a network, establishing a link where a strong relation is found, and discarding the links that contradict domain knowledge. We will then train and test the networks against the data from the variables.

The next section explains in greater detail the problem of economic growth. Section III describes previous work, both in computing factors of economic growth, and in developing Bayesian Network construction methodologies. Section IV gives the formal problem formulation. Section V explains the complexity of the dataset. Section VI goes into our Bayesian Network construction methodology. Section VII will show how we applied it to the economic prediction problem, followed by a discussion of our results, both as far as computed networks and our evaluation of them. We conclude by evaluating our successes and remaining challenges.

II. BACKGROUND THEORY

The global economy is in trouble. Global GDP has been generally falling for nearly a decade (see Fig. 1). Governments worldwide and investors have been forced to cut back on spending [10], reducing the strength of the actors that have traditionally been expected to spur economies [11]. A return to the year-to-year growth observed prior to the Great Recession is desirable (the Great Recession can be observed between the years 2007–2009 in Fig. 1). This would indicate a return to a global economy capable of withstanding events such as the Asian Financial Crisis (1997–1999 in Fig. 1) and the dot-com crash (2001–2003 in Fig. 1) without affecting the overall global trend. However, such a strengthening does not seem likely under current conditions. It is only natural for the global question to be how to achieve this.

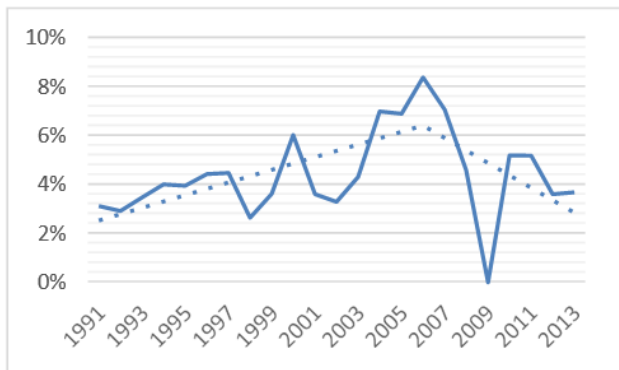


Fig. 1. Percentage of growth in worldwide Gross Domestic Product per capita based on Purchasing Power Parity [12]. The percentage $(y_i - y_{i-1}) / y_{i-1}$ is shown with a solid line. The trend (as given by an ordinary linear regression on the years covered) is shown with a dotted line.

Decisions in recent years have seen education funding cut, with widespread opposition. Worldwide, UNESCO has largely led the fight on preventing education funding from being cut.

The 2020 report [10] had the explicit aim to develop policy and public awareness on the “social and economic” importance of preparing engineers. The question of what to cut ultimately boils down to how important each of these factors is.

Recent research has shown that investment in education and technology would be extremely favorable to economic growth. As Irina Bokova said in a 2020 UNESCO report, the current economic crisis presents challenges and opportunities for engineering. There are encouraging signs that world leaders recognize the importance of continuing to fund engineering, science and technology [This investment] may provide a path to economic recovery and sustainable development [13].

A country’s economic growth has been proven to depend strongly on the number of experts that country has in several areas. ([14], [15]) Specifically, economic growth depends on the knowledge gained by these persons that can be used to manufacture goods, perform services, and improve the productivity of existing processes. This knowledge is known as “productive knowledge” ([16], [10]) and is usually a subset of the knowledge gained by these persons in their higher education studies, or new knowledge generated by them. Therefore, we can measure productive knowledge, and thereby the effect of higher education on the economy, by comparing the number of graduates in different areas, and the research they perform. However, the exact weight of productive knowledge in comparison to more traditional factors such as government spending [11] has never been quantitatively assessed. Detriments of favoring any one factor exclusively, are well known [17], but the strength of the influence is observed through trial and error if it is assessed at all.

In this paper, we posit that the Bayesian interpretation of conditional probability is a good measure of this influence. To this end, we will construct a Bayesian network to predict two economic indicators from: two production indicators, one education indicators, and two innovation indicators.

III. PREVIOUS WORK

Much has been published linking different economic and education variables to economic growth. In recent years, research has shown that economic development depends strongly on the number of engineers ([10], [15]), scientists ([10], [16], [14]), researchers ([10], [14]), and experts in technology ([12], [15]) While the existence of a strong relation cannot be denied, none of these studies have measured the strength of this link compared to other possible factors mostly because they lack a practical application. A Bayesian Network provides such a practical application.

Procedures for constructing Bayesian networks, however, are scant [5]. The most basic method ([1], [18]) consists of the arrangement of variables in cause and effect ordering and the exploitation of conditional independence assumption such that Chain rule can be applied to form the conditional probability table. However, this method is strongly dependent on the ordering of the variables which, in the absence of any true natural order, ends up being pure guesswork.

Methodologies have been developed to construct Bayesian networks for specific purposes, mainly using genetic algorithms ([19], [3], [5]). These algorithms are strongly dependent on their initial population which because they are generated at random, is also pure guesswork. Comparing variables using purely their statistical properties has been done previously using mutual information as a measure of dependence in [7]; however, this work also points out that this approach does not seek to optimize any statistical and makes no use of the existing domain knowledge. The authors attempt to introduce an external optimization metric but notes that it is computationally intensive. In our approach, the variables are compared with a measure of dependence based on an optimized square error.

The authors of [7] also indicate that the number of parents for each node must be restricted in some way, but provide no guidelines on how to do so, leaving the possibility of all other variables to be considered, creating a factorial-order problem. In our approach, we use a domain knowledge graph, thus restricting the number of operations to a polynomial-order problem.

IV. BIG DATA PROBLEM FORMULATION

To allow future research to perform similar tasks and compare more easily, we present a mathematical formulation presented first as an agent-environment problem and then as a “black box” problem. An agent charged with the task of predicting development indicators would live in an environment where all the data from all the countries and regions in the world exist. A state in this environment would be defined by the intersection of a year and a region/country; for instance, the state given by ⟨Sub-Saharan Africa, 1999⟩. Such an agent would, taking a selection of these variables, output a prediction for any other variable (For instance, GDP growth). Its goal is to make the correct prediction. We define success of this goal if the prediction is exact, and failure if it is not. Because we will take the dependences of these variables (x_1, x_2, \dots, x_n) , each defined in the discretized domain $\{High,$

Medium, and Low}, an exact prediction only needs to be exact if it matches the corresponding discrete variable.

Our task is the generation of said agents is to better understand the problem, we offer a black box formulation: Our economic prediction agents are black boxes that take education, innovation, and production indicators and output economic indicators. However, at a higher level we have the problem of how to generate such a black box. Given that every region is different [9], we should create an agent for each. We therefore define a black box prime as a black box that outputs agent black boxes from variables and domain knowledge.

V. DATASET

To properly estimate the economy, we need to measure the variables related to productive knowledge ([16], [10]). We used as our data source the World Bank open data bank [12] and hand-picked six variables from their list of world development indicators.

- GDP per capita, PPP (constant 2011 international \$).
- GDP growth (annual %).
- Industry, value added (% of GDP).
- Agriculture, value added (% of GDP).
- Labor force with tertiary education (% of total).
- Scientific and technical journal articles.
- General government final consumption expenditure (% of GDP).

Each indicator has data from 1960 to 2013, with some values missing. We categorized the indicators into Economic (GDP per capita and GDP growth), Innovation (Journal articles and Government expenditure), Production (Industry and Agriculture), and Education (Tertiary education). We choose

PPP as a suitable measure of the economy independent of inflation; Industry as a measure of mining, manufacturing, and construction [20]; Journal articles as a measure of the amount of research being performed in the region; and Government Expenditure as a measure of how much money the local governments are pumping into their economies, whether it be as incentives or investments.

Labor Force with Tertiary Education refers to the number of working-age adults that have completed College or its local equivalent [21]. We chose this over other education measures based on conclusions in [15] pointing it out as more significant.

A. Regional Subdivision

Because there are 217 countries and territories in the World Bank, it seems prudent to aggregate them somehow and make use of their combined data. However, this creates the problem of how to perform this aggregation, and how to assign weights to each country. Fortunately, the World Bank also defines 32 aggregations, with the values of each country correctly weighted and added together. We will use the World Bank’s seven regions of the world, which will allow us to cover the world completely [22]. In the cases where a region is divided into “developing only” and “all income levels”, we use the latter. Finally, we consider the aggregate for “world” as an eighth region be able to evaluate our accuracy in predicting the global economy.

B. Dataset Size

In our dataset, we have 4752 data points, 2135 of which are missing, representing 45% missing and 55% not missing. The World Bank handles data at country-level granularity. When it performs an aggregate, it leaves the value for that year blank if the data from one-third of the countries in that region are missing [23]. However, most regions have very completed data for at least half of the variables. For exact proportions of missing data and dataset dimensions, see Table I.

TABLE I. PROPORTION OF MISSING VALUES AND DATASET DIMENTION SIZE

Variables	Regions															
	East Asia		Europe		Latin America		Middle East		North America		South Asia		Africa		World	
Agriculture	Missing	11	Missing	31	Missing	5	Missing	22	Missing	38	Missing	0	Missing	5	Missing	36
	Not Missing	43	Not Missing	23	Not Missing	49	Not Missing	32	Not Missing	16	Not Missing	54	Not Missing	49	Not Missing	18
	%	80	%	43	%	91	%	59	%	30	%	100	%	91	%	33
Unemployment	Missing	31	Missing	31	Missing	31	Missing	31	Missing	31	Missing	31	Missing	31	Missing	31
	Not Missing	23	Not Missing	23	Not Missing	23	Not Missing	23	Not Missing	23	Not Missing	23	Not Missing	23	Not Missing	23
	%	42	%	42	%	42	%	42	%	42	%	42	%	42	%	42
Tertiary education	Missing	54	Missing	40	Missing	48	Missing	54	Missing	49	Missing	51	Missing	54	Missing	54
	Not Missing	0	Not Missing	14	Not Missing	6	Not Missing	0	Not Missing	5	Not Missing	4	Not Missing	0	Not Missing	0
	%	0	%	26	%	11	%	0	%	9	%	7	%	0	%	0
Secondary education	Missing	54	Missing	40	Missing	48	Missing	54	Missing	49	Missing	51	Missing	54	Missing	54
	Not Missing	0	Not Missing	14	Not Missing	6	Not Missing	0	Not Missing	5	Not Missing	4	Not Missing	0	Not Missing	0

	%	0	%	26	%	11	%	0	%	91	%	7	%	0	%	0
GDP growth	Missing	1	Missing	1	Missing	1	Missing	9	Missing	1	Missing	1	Missing	1	Missing	1
	Not Missing	53	Not Missing	53	Not Missing	53	Not Missing	45	Not Missing	53	Not Missing	53	Not Missing	53	Not Missing	53
	%	98	%	98	%	98	%	83	%	98	%	98	%	98	%	98
GDP per capita, PPP	Missing	30	Missing	30	Missing	30	Missing	30	Missing	30	Missing	30	Missing	30	Missing	30
	Not Missing	24	Not Missing	24	Not Missing	24	Not Missing	24	Not Missing	24	Not Missing	24	Not Missing	24	Not Missing	24
	%	44	%	44	%	44	%	44	%	44	%	44	%	44	%	44
Gov. final consumption	Missing	0	Missing	0	Missing	0	Missing	8	Missing	0	Missing	0	Missing	0	Missing	0
	Not Missing	54	Not Missing	54	Not Missing	54	Not Missing	46	Not Missing	54	Not Missing	54	Not Missing	54	Not Missing	54
	%	100	%	100	%	100	%	85	%	100	%	100	%	100	%	100
Services	Missing	11	Missing	31	Missing	5	Missing	22	Missing	38	Missing	0	Missing	5	Missing	36
	Not Missing	43	Not Missing	23	Not Missing	49	Not Missing	32	Not Missing	16	Not Missing	54	Not Missing	49	Not Missing	18
	%	80	%	43	%	91	%	59	%	30	%	100	%	91	%	33
Industry	Missing	11	Missing	31	Missing	5	Missing	22	Missing	38	Missing	0	Missing	5	Missing	36
	Not Missing	43	Not Missing	23	Not Missing	49	Not Missing	32	Not Missing	16	Not Missing	54	Not Missing	49	Not Missing	18
	%	80	%	43	%	91	%	59	%	30	%	100	%	91	%	33
Scien. & tech. journal articles	Missing	26	Missing	30	Missing	28	Missing	28	Missing	28	Missing	26	Missing	28	Missing	26
	Not Missing	28	Not Missing	24	Not Missing	26	Not Missing	26	Not Missing	26	Not Missing	28	Not Missing	26	Not Missing	28
	%	52	%	44	%	48	%	48	%	48	%	52	%	48	%	52
Trademark application	Missing	11	Missing	32	Missing	8	Missing	15	Missing	0	Missing	4	Missing	54	Missing	20
	Not Missing	43	Not Missing	22	Not Missing	46	Not Missing	39	Not Missing	54	Not Missing	50	Not Missing	0	Not Missing	34

A. Preprocessing Stage

In the preprocessing stage, there are some initial steps are implemented such as big data scaling, and missing value treating.

1) *Big data scaling step*: Most variables in our dataset are percentages. However, the variables for journal articles are numerical quantities. It is good practice to train Bayesian networks with normalized values, all within the same range, for which reason we perform a simple scaling.

Simply we take the value for each of these variables according to its region and divide it by the population of this region times 100. This is formally stated in (1) where R refers to each region in the dataset.

$$Scaled_{variableR} = \frac{old_variableR}{PopulationR} \times 100 \quad (1)$$

2) *Big data missing value treatment*: The missing values were simply ignored. Since each variable has a deep complex economic implication defined solely by The World Bank [23], and they highly depend on many other evidences, we decided that the prediction of those missing values by filling in the best values or with distribution using EM algorithm would be a crude estimation if not biased towards the low amount of data in our study. We select which rows to ignore in each operation using matlab's *isnan* function.

VI. METHODOLOGY

Our main contribution to the field lies in our methodology, which can be summarized in the following steps:

- Selection of Parameters.
- Calculation of dependency.
- Determination of causality.
- Construction of the Bayesian Network.
- Evaluation of the Bayesian Network.

This methodology is fully automatable and can be adapted to any domain. We start off by selecting and categorizing the variables. A simple linking of the categories using the domain knowledge creates a graph which we term our Domain Knowledge Model, which allows the procedure to readily be applied to other domains by simply changing the variables involved. We then calculate the degree of dependence between all the variables in every pair of linked categories, after some minimal preprocessing. By using just, the links between categories, as opposed to comparing all against all, this reduces our computations from $(n+m)!$ (similar to the approaches used by [7], [1], and [18]) to $n \times m$; where n and m are the number of variables in each category. The resulting Bayesian network can then be trained and evaluated normally.

B. Bayesian Network Construction Stage

In the proposed work, we used the standard error for a least-squares linear regression or STE ([6], [15]) to calculate dependence. In particular, we used the implementation by Sansom [22]. We note that the methodology is not tied to this statistical (Friedman et al. [7] suggests correlation or mutual information for this purpose; however, STE is known to be consistent with both of these statistical). We use STE because it gives an indication of which variable is the dependent variable and which one is the independent variable. Specifically, a small STE (Y, X) implies a strong causative relation where Y depends on X [24].

The formula for STE is shown in Equation (2) with Y and X being vectors of values that have a length n , and with \bar{Y} and \bar{X} being their respective sample means.

$$STE(Y, X) = \sqrt{\frac{1}{n-2} \left(\sum_{y \in Y} (y - \bar{Y})^2 - \frac{\sum_{x \in X, y \in Y} (x - \bar{X})(y - \bar{Y})^2}{\sum_{y \in Y} (x - \bar{X})^2} \right)} \quad (2)$$

To make the result easier to interpret, we use Equation (3) from [15] so that higher values are better. This equation also normalizes the measure into the [0,1] range for better readability. We call this the degree of dependency. Note that vertical bars denote absolute value.

$$Dependency(Y, X) = \frac{1 - |STE(x, y)|}{\bar{y}} \quad (3)$$

If $dependency(Y, X) > dependency(X, Y)$, we conclude there may be a causal relationship between X and Y , with X being the cause and y being the effect, and thus add an arc from X to Y in our Bayesian network. However, if $dependency(Y, X) < dependency(X, Y)$ rather than concluding Y is the cause and X is the effect, we discard it entirely. This is because the comparison is made following the links in the Domain Knowledge Model, and adding such an arc would contradict the domain knowledge. Because data may be prone to errors, outliers, or may simply not be complete enough, we define the case when $dependency(Y, X)$ is slightly less than $dependency(X, Y)$. This is the case when $dependency(Y, X) \leq dependency(X, Y)$, but are close enough to consider that, given slightly better data, we could have $dependency(Y, X) > dependency(X, Y)$. We define a threshold of three percent as the limit of this closeness; however, this threshold is user-defined as any number between zero and one and only depends on the desired number of arcs. Note that we can similarly use simple STE (2) instead of dependency, but in this case the threshold would have to be defined between $-\bar{Y}$ and \bar{Y} . In other words, the normalization of STE in (3) means that, when the threshold values are interpreted as maximum error, they are expressed in means of Y .

Finally, it has been define the case when $dependency(Y, X)$ is simply too small to imply a causal relationship. Since we do not want to add an arc in these cases even if $dependency(Y, X) > dependency(X, Y)$, we discard the results entirely. We define a minimum of 60% as the measure of this smallness. Again, this minimum is user-defined between zero and one and only depends on the desired number of arcs, and again, one can use simple STE, but the range becomes a function of \bar{Y} . The result is a Bayesian network graph. Any graph representation can be used. In our work, we

used a simplified adjacency matrix T where only node that could have children, as given by the domain knowledge, were columns and only nodes that could have parents, as given by the domain knowledge, were rows. That is, if the Domain Knowledge Model is seen as a graph K , we omit the source nodes of K from the rows of T and the sink nodes of K from the columns of T . The network construction algorithm is summarized in Fig. 2.

Function Dependency_Graph (<i>Child_Layer, Parent_Layer, Threshold, Minimum</i>)	
Inputs	
<i>child_layer</i>	set of vectors, values of each of the believed dependent variables
<i>parent_layer</i>	set of vectors, values of each of the variables the members of <i>child_layer</i> are believed to
<i>threshold</i>	Difference below which the possibility of dependence is accepted
<i>minimum</i>	Value at which the possibility of dependence is discarded
Return digraph T	
Outputs:	
for $i \in parent_layer, j \in child_layer$	
if $DEPENDENCY(i, j) \geq minimum$	
if $DEPENDENCY(i, j) > DEPENDENCY(j, i)$	
T.add_arc (i to j)	
else if $DEPENDENCY(j, i) - DEPENDENCY(i, j)$	
$< threshold$	
T.add_arc (i to j)	
end	
end	
end	
return T	

Fig. 2. Pseudocode for the bayesian network construction algorithm.

1) *Complexity analysis step:* The runtime of the construction algorithm depends strongly on the Domain Knowledge Model and how many variables it receives. In the best case, each category will have exactly one variable, which would imply the Bayesian network structure is already known, and merely needs to be simplified. In this case, the algorithm performs $2m$ operations ($dependency(Y, X)$ and $dependency(X, Y)$), where m is the number of arcs in the Domain Knowledge Model. Since a Bayesian network must be a directed acyclic graph, this case may have m being anywhere between $n - 1$ (Markov chain) and $n(n - 1)/2$ (transitive closure of a fully reachable graph), where n is the number of variables. Therefore, the algorithm is $\Omega(n)$ and $O(n^2)$ in the best case. This is comparable to the best case in [7] where each node has one or two candidate parents.

In the worst case, each category has the same number of variables: n/c where c is the number of categories and n is a multiple of c such that $n \geq 2c$. To evaluate each arc, the members of each category in the arc's source have to be compared with the member of each category in the arc's sink, each comparison of which requires two operations, or $2(n/c)^2$ per arc between categories for a total of $2m(n/c)^2$. Since,

again, there may be anywhere between $n - 1$ and $n(n - 1)/2$ arcs between categories, the algorithm is $\Omega(n^2)$ and $O(n^4)$ in the worst case. This is much better than the worst case in [7] where all other nodes are candidate parents, leading to $(n!)$.

It should be noted that, given the nature of Bayesian networks as inference engines, the worst case is highly unlikely to be encountered in practice. It is more likely that there will be a category with much less variables than the others, since there is always a small group of target variables (usually one). For this reason, we can assume an average order of n^2 .

C. Bayesian Network Evaluation Stage

The Bayesian network designed is manually built to handle discrete values and thus learn the Conditional Probability Tables for the network. Inference is then performed using elimination or enumeration on the learned probabilities. For comparison purposes, we define a Baseline Structure, consisting of the joint probability of all variables – in effect, a Domain Knowledge Model with just two categories: One containing the target variable(s), and one containing all others..

1) *Discretization step*: To perform the conversion, values are discretized into High, Medium, or Low using Equation (4), where x is the specific value being converted; X is the multiset of all the values the variable takes on in the dataset; H, M, L represent High, Medium, or Low respectively; $m(x)$ is the Maximum Likelihood estimator for the mean, given by $(\sum_{x \in X} x)/|X|$; and $d(X)$; is the Maximum Likelihood Estimator for the standard deviation, given by Equation (5). Note that here, the vertical bars denote the cardinality of the set.

$$Discretized(x \in X) = \begin{cases} H & \text{if } x > m(x) + d(x) \\ L & \text{if } x < m(x) - d(x) \\ M & \text{otherwise} \end{cases} \quad (4)$$

$$\sqrt{\frac{1}{x} \sum_{x \in X} (x - m(x))^2} \quad (5)$$

2) *Baseline structure step*: In the Baseline structure, the joint probability of everything is computed (all the variables). In this model, all variables directly affect the target (the economic indicators in our work).

3) *Learning step*: In the learning part, the Bayesian network parameters have been learned by computing the conditional probabilities through Maximum Likelihood. By using the formula in Equation (6).

$$P(x_1, \dots, x_n) = \prod_{i=1}^n p(x_i | parent(X_i)) = p(x_1)p(x_2)p(x_3|x_1)p(x_4|x_1)p(x_5|x_2, x_3, x_4) \quad (6)$$

The algorithm steps for parameter learning is illustrated in Fig.3, (a), (b), and (c) respectively.

Function LEARNING (<i>Dataset, bn, k</i>) returns CPT of all variables in the Bayesian network	
Inputs	
<i>Dataset</i>	the dataset (already discretized)
<i>bn</i>	the Bayesian network
<i>k</i>	Laplacian smoothing coefficient
<i>minimum</i>	Value at which the possibility of dependence is discarded

Outputs:
$X \leftarrow bn.Vars$ /* All variables in the Bayes net */
$Q(X) \leftarrow$ a distribution over X /* initially empty*/
for each x_i of X do
if parent (x_i) is empty
then $Q(X) \leftarrow PR(x_i Dataset)$
else
$Q(X) \leftarrow CPT(x_i, parent(x_i) Dataset)$
end
end
return $Q(X)$

(a)

Function PR (X, d) returns probability of X given the domains is d
Inputs
X , the data of a random variable d , the domains of X
Outputs:
$k \leftarrow GET_LAPLACE_K()$;
$Q(X) \leftarrow$ a distribution over X , initially empty
for each <i>value</i> of d do
$Q(X) \leftarrow (COUNT(X == value) + k) / (COUNT(X) + k * LENGTH(d))$
end
end
return $Q(X)$

(b)

Function CPT (X, e) returns probability of X given the evidence e
Inputs
X , the data of a random variable e , the evidence variables
Outputs:
<i>domain</i> $\leftarrow GET_DOMAINS()$;
$Q(X) \leftarrow$ a distribution over X , initially empty
for each <i>value</i> of <i>domain</i> do
$Q(X) \leftarrow PR(X, value)$
then $Q(X) \leftarrow PR(x_i Dataset)$
else
$Q(X) \leftarrow CPT(x_i, parent(x_i) Dataset)$
end
end
return $Q(X)$

(c)

Fig. 3. Pseudocode for parameter learning algorithm, (a) Bayesian network learning function, (b) Patren Recognition (PR) function, (c) CPT function.

4) *Inference step*: The proposed model is experimented with the prediction of the economic indicators using two exact inference algorithms, which may be used interchangeably. In Fig. 4 (a), we give the elimination inference algorithm which accepts a set of evidence, and the joint factors of all variables then checks if an evidence variable is hidden to sum out all its possible values otherwise just lookup the probability from the probability distribution. In Fig. 4 (b), we give the enumeration algorithm. These algorithms are run iteratively over all the data samples.

Function PREDICT_BY_ELIMINATION ($e, factors$) returns prediction of PPP variable
Inputs


```

e, the evidence factors, the joint factors
Outputs:
probability ← factors
for each variable ∈ e do
  if variable is missing then
    probability ← add all values in probability for
    this variable
  else
    probability ← Lookup all values in probability where
    this variable = variable ∈ e
     $Q(X) \leftarrow \text{CPT}(x_i, \text{parent}(x_i)|\text{Dataset})$ 
  end
end
prediction ← MAX_INDEX (probability)
return  $Q(X)$ 

```

(a)

```

Function PREDICT_BY_ENUMERATION (t, P, e) returns
prediction of PPP variable
Inputs
t, the target variable
e, the known evidence
P, conditional probabilities
Outputs:
for each parent of t
  if parent ∈ e not missing then
    joint[parent] ←  $P(\text{parent} = \text{parent} \in e)$ 
  else
    joint[parent] ← PREDICT_BY_ENUMERATION
    (parent, P, parents(parent) ∈ e)
     $Q(X) \leftarrow \text{CPT}(x_i, \text{parent}(x_i)|\text{Dataset})$ 
  end
end
for each possible value ∈ t
  probability [possible value] ←  $\sum P(\text{possible value})$ 
  ×  $\prod \text{joint}$ 
return MAX (probability)
return  $Q(X)$ 

```

(b)

Fig. 4. Pseudocode for inference algorithm (a) by elimination and (b) by enumeration.

5) *Accuracy calculation step*: To define our accuracy, which is success if the prediction is exact, and failure if it is not, we will take the dependences of these variables (x_1, x_2, \dots, x_n), each defined in the discretized domain {High, Medium, and Low}. We recall that an exact prediction only needs to be exact if it matches the corresponding discrete variable or not. Mathematically, we define it as the number of predicted values that match the actual values divided by the total number of known values. This is summarized in equation (7). Note that here vertical bars denote cardinality.

$$\text{accuracy} = \frac{|\{i: x_i \in \text{predicted} \wedge y_i \in \text{actual}: x_i = y_i\}|}{|\{y: \text{actual}: y \text{ is not missing}\}|} \quad (6)$$

D. Development Indicators Domain Knowledge Model

To build the Domain Knowledge Model, consider the categories from section V. Previous work has shown that relationships between these broad categories is known: Education affects Innovation and Production ([10], [14], [15]);

Innovation and Production affect the Economy ([11], [8]). Education is known to not have a direct effect on the economy due to the necessity of applying productive knowledge to Innovation and Production for its effects to become visible ([10], [16]). This gives us a three-layer structure (Fig. 4).

Modelling the domain knowledge also allows us to delimit the number of dependency values we would have to calculate. Suppose we have six variables. If we were to compare all variables against all others (worst case in [7]), we would need to perform 6! comparisons, or calculate 1440 dependency values. The three-layer domain knowledge model for the development indicator problem is summarized in Fig. 5.

Following the three-layers structure, with four variables in the middle layer and two in each of the others, we only need to compute 16 dependency values. We note that, although this is in the order of 6^2 , it is much less than 6^2 .

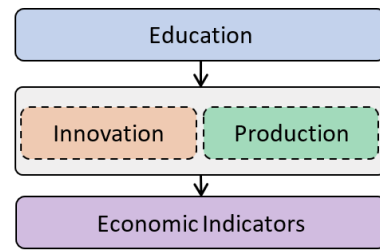


Fig. 5. Three-layer domain knowledge model for the development indicators problem.

VII. EXPERIMENTAL RESULTS

A. Generated Bayesian Network

Five different networks are constructed for our first belief system: a baseline as described in section VI.C.2), and a network with the dependency analysis results for each of the eight regions. The resulting networks are shown in Fig. 6. Only considered six of the selected variables to construct these networks: Tertiary education, Agriculture, Industry, Government spending, Journal articles, and GDP by PPP. Then, just keep the previously established categories for these variables.

In most regions where Tertiary education is considered, it is found to be linked to industry and innovation, but not to agriculture. This makes intuitive sense. Latin America is the exception, but it is known to traditionally have placed higher emphasis on using its tertiary institutions to improve agriculture than to perform research. The service sector was left out of all networks which again make sense because service-based economies are a very recent development [25][26][27][28] and our data spans 54 years. We are similarly unable to find any variables that affected GDP growth, for which reason it is absent from all networks. We believe this is because GDP growth is the only variable that measures change from year to year.

B. Evaluation Results

This paper presents the proposed model results first for the Baseline Belief Network, which was run for the data from each of the regions. Next, present the proposed model results for the network specially computed for each of the regions, run on that

regions' data. The designed Baseline Belief network is running for "Middle East and North Africa" using the Elimination algorithm. We run all other networks using the Enumeration algorithm [29] [30].

1) *Baseline structure*: As described above, the baseline structure is the joint probability for all variables affecting PPP. The highest inference accuracy is for "Europe and Central Asia" with 92% accuracy and the lowest one is the World with 20% accuracy.

2) *Belief network no.1 structure for world regions*: As with the Baseline structure, the highest inference accuracy is for the "Europe and Central Asia region"; however, the accuracy for the computed network is of 79% accuracy which is lower than the baseline by 13%. The lowest inference value is in the North America with 54%. This is better than the baseline, where the accuracy was 46%. We also improve on the accuracy of the world, which was the lowest for the baseline as is shown in Fig. 6.

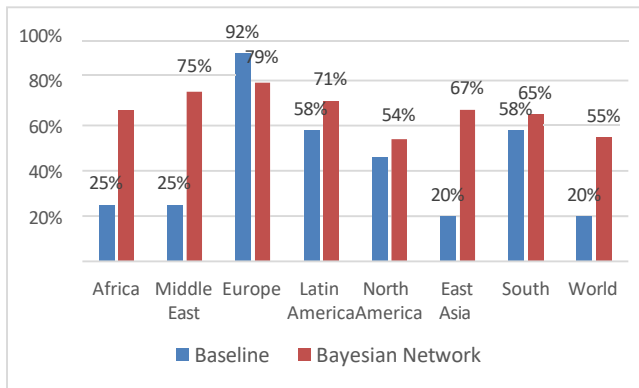


Fig. 6. Performance comparison between Baseline Belief Networks and the computed Belief Network 1

A comparison of the baseline and the networks computed for each region is shown in Fig. 7.

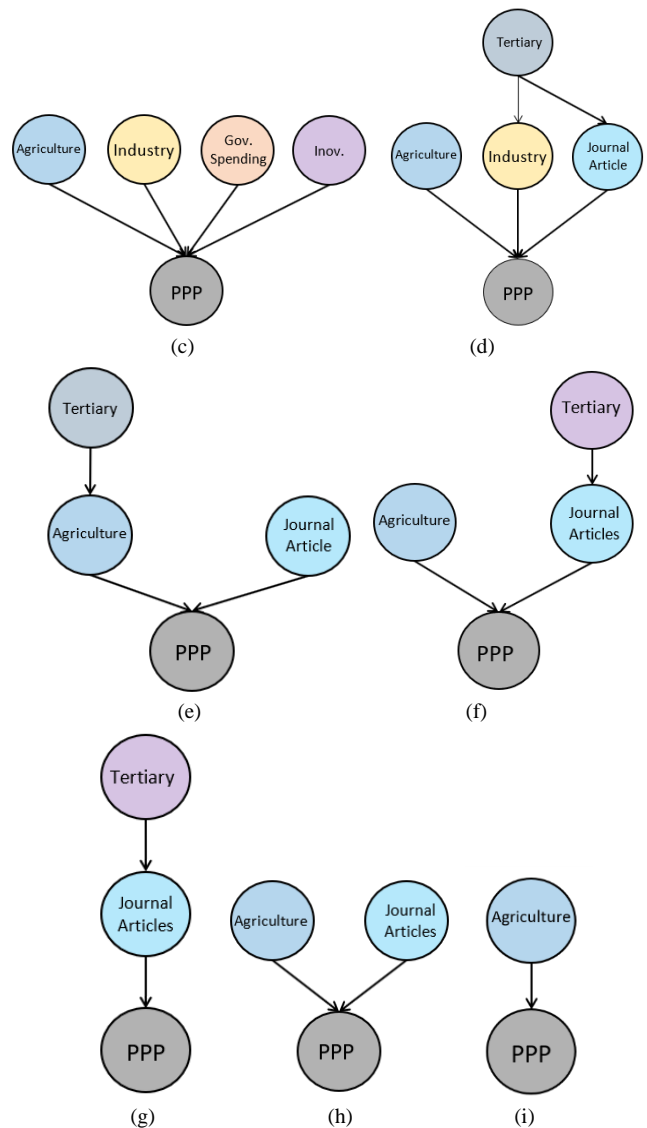
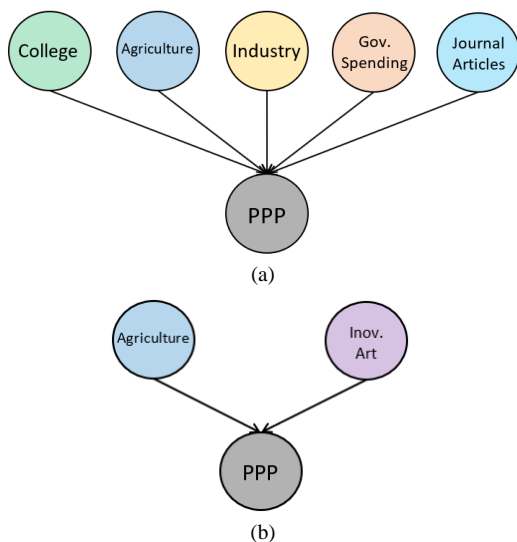


Fig. 7. Belief Network 1 structures for (a) the baseline (used for comparison purposes), (b) Sub-Saharan Africa region, (c) Middle East and North Africa region, (d) Europe and Central Asia region, (e) Latin America region, (f) North America region, (g) South Asia region, (h) East Asia and Pacific region, (i) World; where "Agr" represents Agriculture, "Innov. Art" and "Jour" represent Scientific and Journal Articles, "Inds" represents Industry, "Gov" represents Government final consumption expenditure, "Tertiary" represents Labor force with tertiary education, and "PPP" represents GDP per capita by Purchasing Power Parity.

VIII. CONCLUSION

In this paper, logical models for all selected regions are designed and created based on the proposed methodology. The resulting models are consistent with the knowledge known about the regions during the years covered by the data. The proposed networks in general provide accuracy improvements over the baseline. Designed baseline provided us an accuracy of 20% to 58% in seven out of eight regions, including the aggregate for “World”, while the Bayesian networks generated by our first Domain Knowledge Model improved that accuracy from 54% to 75% in the same regions. For Europe, we were not able to improve on the accuracy of the baseline (92 percent). We suspect this may be due to insufficient data (the aggregation caused the existence of too many missing values) or because Europe is inherently exceptional. We were similarly unable to construct networks to determine GDP growth for all regions, or GDP per Capita by PPP in South Asia. Better data, as well as variables that measure year-to-year changes, are needed to fully determine whether this methodology is adequate for these cases.

IX. FUTURE WORK

In future analysis, we would like to reduce our proportion of missing values to better evaluate our Bayesian networks. One of the main reasons our proportion of missing values was so high was because of how the World Bank aggregates regions and the way its regions are defined. One way to reduce this proportion is to aggregate regions differently, or change how missing data is handled during aggregation [21].

Bayesian networks are also capable of handling multiple queries other than just the target variable. We would like to evaluate the accuracy of questions like:

- What does a strong economy and a weak education system imply for the production sectors?
- How high must education be in each region for a high GDP?
- What is the probability the GDP will drastically change given how we know current events affect other indicators?

We also have, so far, manually implemented each of the Bayesian networks. We are aware that this process is automatable, especially given that our methodology generates a graph adjacency matrix. We would like to experiment with different Domain Knowledge models and see their effect on the accuracy. Similarly, we would like to use more variables from the World Bank to see their effect on the accuracy.

In addition, we do not yet have a mathematically proven estimate on the effects of tuning the “minimum” and “threshold” parameters to have on the accuracy we would like.

REFERENCES

- [1] K. Jaffe, A. Rios, and A. Florez., Statistics shows that economic prosperity needs both high scientific productivity and complex technological knowledge, but in different ways. *Interciencia* vol.38. (2012) http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2171464.
- [2] Kaikkonen, Laura, Tuuli Parviainen, Mika Rahikainen, Laura Uusitalo, and Annukka Lehtikainen. "Bayesian networks in environmental risk assessment: A review." *Integrated environmental assessment and management* 17, no. 1 (2021): 62-78.
- [3] A. Migiro, (Jun 16 2010) "No 'one size fits all' approach to development." UN News Center. <http://www.un.org/apps/news/story.asp?NewsID=35048>.
- [4] Katoch, Sourabh, Sumit Singh Chauhan, and Vijay Kumar. "A review on genetic algorithm: past, present, and future." *Multimedia Tools and Applications* 80 (2021): 8091-8126.
- [5] Rodriguez-Nieva, Joaquin F., and Mathias S. Scheurer. "Identifying topological order through unsupervised machine learning." *Nature Physics* 15, no. 8 (2019): 790-795.
- [6] D. Chickering, and D. Heckerman. "Scalable Methods for Learning Bayesian Networks". Microsoft Corporation (assignee). Patent 7,251,636.(1997) <http://patentimages.storage.googleapis.com/pdfs/US7251636.pdf>.
- [7] P. Helman, R. Veroff, S. Atlas, and C. Willman, "A Bayesian Network Classification Methodology for Gene Expression Data." *Journal of Computational Biology*, Vol. 11, Issue 4. (January 20, 2005) <http://online.liebertpub.com/doi/abs/10.1089/cmb.2004.11.581>.
- [8] UNESCO. (2010). *Engineering: Issues, Challenges and Opportunities for Development UNESCO Report*. Unesco. <http://unesdoc.unesco.org/images/0018/001897/189753e.pdf>.
- [9] International Labour Organization. "Indicator 8: Educational Attainment of the Youth Labour Force." *Youth Labour Market Indicators*. Youth Employment Network. <http://www.ilo.org/public/english/employment/yen/whatwedo/projects/indicators/8.htm>.
- [10] M. Piñeiro, and E. Trigo, La transferencia de ciencia y tecnología y la educación agrícola. Instituto iberoamericano de Ciencias Agrícolas. Organization of American States. Bogotá, Colombia. (1977).
- [11] G. Cooper and E. Herskovits, "A Bayesian Method for the Induction of Probabilistic Networks from Data." *Machine Learning*. Volume 9, Issue 4, Springer International. (1992), pp. 309-347.
- [12] Zhu, Qidan, Jing Li, Fei Yuan, and Quan Gan. "Multi-scale temporal network for continuous sign language recognition." *arXiv preprint arXiv:2204.03864* (2022).
- [13] Genegeek. (2012) <http://genegeek.ca/2012/12/reading-scientific-papers/>.
- [14] Sciarra, Carla, Guido Chiarotti, Luca Ridolfi, and Francesco Laio. "Reconciling contrasting views on economic complexity." *Nature communications* 11, no. 1 (2020): 3352.
- [15] ITEP. "Tax Incentives: Costly for States, Drag on the Nation." ITEP Reports. Institute on Taxation and Economic Policy. (2013) http://itep.org/itep_reports/2013/08/tax-incentives-costly-for-states-drag-on-the-nation.php.
- [16] Woods, Dawn. "Encyclopaedia Britannica." *The School Librarian* 70, no. 2 (2022): 28-28.
- [17] R. Hausmann, C. Hidalgo, S. Bustos, M. Coscia, S. Chung, J. S Jiménez.
- [18] M. Cali, K. Ellis, and te Velde, "The contribution of services to development: The role of regulation and trade liberalisation" London: Overseas Development Institute (2008).
- [19] J. Mora, F. Torre, and F. Torre, "Contribución de la enseñanza de la ingeniería a la generación de conocimiento productivo". *Memorias del IV Congreso Iberoamericano de Enseñanza de la Ingeniería*. Asociación Iberoamericana de Instituciones Enseñanza de la Ingeniería. Barquisimeto, Lara, Venezuela. (2013) ISBN: 978-980-6526-01-3.
- [20] Haymon, Clarissa, and Andrea Wilson. "Differentiated reading instruction with technology for advanced middle school students' reading achievement." *Journal of Educational Research and Practice* 10, no. 1 (2020): 5.
- [21] <http://dl.acm.org/citation.cfm?id=2073820>.
- [22] Zou, Weiqin, David Lo, Pavneet Singh Kochhar, Xuan-Bach Dinh Le, Xin Xia, Yang Feng, Zhenyu Chen, and Baowen Xu. "Smart contract development: Challenges and opportunities." *IEEE Transactions on Software Engineering* 47, no. 10 (2019): 2084-2106.
- [23] S. Russell, and P. Norvig, "A method for constructing Bayesian Networks." *Artificial Intelligence: A Modern Approach*. Third Edition. Pearson Education. (2010) §14.2.1.1.

- [24] A. Sansom, "STEYXY." Monte Carlo example of a Multi Commodity Spot and Forward curves Simulator. Matlab Central. (2014) <http://www.mathworks.com/matlabcentral/fileexchange/48070-monte-carlo-example-of-a-multi-commodity-spot-and-forward-curves-simulator/content/STEYXY.m>.
- [25] World Bank "Industry, value added (% of GDP)." <http://data.worldbank.org/indicator/NV.IND.TOTL.ZS>. (retrieved April 2015).
- [26] World Bank. (2015) "Methodologies." World Bank Open Data Bank. World Bank Group. <http://data.worldbank.org/about/data-overview/methodologies>.
- [27] World Bank. (2015) World Bank Open Data Bank. World Bank Group. <http://databank.worldbank.org>.
- [28] World Health Organization. "Definition of region groupings" http://www.who.int/healthinfo/global_burden_disease/definition_regions.
- [29] P Obite, C., N. P Olewuezi, G. U Ugwuanyim, and D. C Bartholomew. "Multicollinearity effect in regression analysis: A feed forward artificial neural network approach." *Asian journal of probability and statistics* 6, no. 1 (2020): 22-33.
- [30] Chen, Rung-Ching. "User rating classification via deep belief network learning and sentiment analysis." *IEEE Transactions on Computational Social Systems* 6, no. 3 (2019): 535-546.

The Application of Virtual Technology Based on Posture Recognition in Art Design Teaching

Qinyan Gao

College of Communication and Art Design
University of Shanghai for Science and Technology, Shanghai 200093, China

Abstract—With the development of virtual technology, posture recognition technology has been integrated into virtual technology. This new technology allows users to further understand and observe the activities carried out in life scenes based on their original observation of the external world. And it enables them to make intelligent decisions. Existing posture recognition cannot meet the requirements of precise positioning in virtual environments. Therefore, a two-stage three-dimensional pose recognition model is proposed. The experiment illustrates that the three-dimensional gesture recognition performance is excellent. In addition, under the ablation experiment, the error accuracy of the research model decreased by more than 5 mm, and the overall error accuracy decreased by 10%. In the P-R curve, the accuracy rate of the model reaches 0.741, and the recall rate reaches 0.65. When conducting empirical analysis, the virtual posture disassembly action is complete; the disassembly error is less than 5%, and the disassembly error accuracy is good. The fit degree of the leg bending amplitude reaches over 96%, and the fit degree of the arm bending amplitude reaches over 95%. When the model is applied to actual teaching, the overall satisfaction score of teachers and students reaches 94.6 points. This has effectively improved the teaching effect of art design and is of great significance to the development of education in China.

Keywords—Posture recognition; deep learning; art design; time convolutional network; VR

I. INTRODUCTION

5G technology has gradually integrated into all aspects of life. Virtual reality (VR) technology is being applied in various fields such as engineering design, game entertainment, and teaching applications as a new emerging technology. In a highly informational society, bringing virtual reality technology into teaching experiments and learning training can bring better teaching experiences. And its rich sensory stimulation and immersive teaching experience provide teachers and students with new teaching paths [1-3]. With the improvement of people's requirements for virtual technology, the accuracy of gesture recognition systems and the requirements for visual tasks are also increasing in response. The animation generated by two-dimensional gesture recognition systems has gradually been unable to meet the needs of high accuracy positioning of virtual space for doormen. Therefore, three-dimensional attitude recognition systems have been developed. However, 3D pose recognition systems have problems such as complex motion capture machines, and time-consuming multi camera and multi perspective solutions. Moreover, there are problems such as demanding camera operating environments, and the degree of

occlusion affecting the accuracy of dynamic capture [4-6]. In the process of generating three-dimensional poses from two-dimensional images, there are currently problems such as insufficient joint point capture accuracy, occlusion affecting the range of joint and limb movements, discontinuous movement of the bone model within a single frame image, joint point change faults, and motion sequence generation jitter. These issues are not conducive to building 3D animation. However, with the publication of various pose datasets and the design and generation of new recognition models, research on capturing and generating three-dimensional poses using common cameras has gradually stepped onto the right track. In the sequential task of single frame image generation, temporal convolutional neural networks perform well in terms of energy. Moreover, the network has time correlation, and is applied to three-dimensional pose recognition in combination with high-precision calculation of angle vectors. This can effectively improve the accuracy of 3D pose recognition. And when it is applied in art design teaching, it can effectively solve the use of VR technology and recognition technology in online art teaching. This can also provide better technical support for the development of the art industry [7-9]. Therefore, by combining time convolutional neural networks and high-precision angle vector calculation, we can compensate for the current problems of insufficient node capture accuracy and the impact of occlusion on joint movement range, thereby effectively improving the accuracy of 3D pose recognition. By optimizing the temporal task process of single frame image generation, problems such as discontinuous movement of bone models, changes in joint points and faults, and jitter in action sequence generation are solved, laying the foundation for building high-quality 3D animations. Apply the optimized 3D pose recognition system to art and design teaching, improving the practical application value of VR technology in online art teaching.

The research content mainly includes four parts. The second part is a review of the research status of pose recognition technology and online teaching. The third part proposes a two-stage three-dimensional pose joint positioning and temporal image processing system model. The first section constructs the image to process the model, and the second section constructs the pose recognition model. The fourth part verifies the improved system performance and application effectiveness. The results indicate that the attitude recognition system has good application effects. The fifth Section concludes the research.

II. RELATED WORKS

The principle of posture recognition technology is to calculate human joint points from images and link them as a whole and output them in the form of images. And two-dimensional attitude recognition technology has a mature system and has been applied in various industries. The technology of three-dimensional gesture recognition is also developing rapidly. S Li et al. proposed a DS (Dempster Shafer) based evaluation algorithm to detect students' attention state in class by measuring students' facial posture. The detection of facial pose angle can be implemented in low pixel surveillance video. The experiment showcases that using DS theory to integrate each student's attention state, the overall classroom attention score of students changes and improves over time. This keeps the whole class in a good state of attention. Meanwhile, it proves that the design of the algorithm is feasible and effective. Compared to the average score of the questionnaire given by the reviewers, the accuracy of the proposed algorithm exceeds 85% [10]. To solve the inaccurate face recognition results caused by factors such as illumination, noise intensity, affine, and projection transformation, SWS et al. proposed scale invariant feature transformation (SIFT). Its research incorporates a SIFT algorithm based on principal component analysis (PCA) dimensionality reduction to reduce computational complexity and improve the efficiency of the algorithm. The experiment indicates that the dimension of SIFT has been reduced to 20 dimensions through experiments on open databases. This improves the efficiency of face extraction; Comparative analysis of several experimental results has verified the superiority of the improved algorithm [11]. MGR Alam et al. proposed an improved loMT emotion recognition system for studying and recognizing human emotional states. Experimental results show that the performance of the proposed method using benchmark dataset analysis has a high classification accuracy in judging human emotional state [12]. Hong Zhen et al. proposed a collaborative solution based on the artificial intelligence Internet of Things to solve the high rate of misjudgment in motion capture in healthcare. This scheme proposes an offline algorithm for multi posture recognition implemented on wearable hardware for posture recognition based on multidimensional data. The results show excellent performance in terms of accuracy and reliability [13].

In online teaching, diversified teaching methods reflect the optimization and reform of students' teaching concepts. In terms of improving online teaching, Z Fen proposed a biological immune algorithm framework using GBDT algorithm coding to improve the efficiency of online English teaching. Then, a flow feature selection algorithm based on bag learning is proposed to solve the problem that redundant information between features can reduce the accuracy of the framework. The research results show that the model constructed in the study has high reliability [14]. A study by Doligan et al. identified the relationships between specific variables, teaching experience, professional development, and teaching support, and self-learning among teachers transitioning to online teaching during the pandemic. The results showed that higher online teaching effectiveness scores were related to participation in online additional qualification courses and professional development courses. The highest

online teaching effectiveness score is positively correlated with traditional learning management systems and the use of virtual technology support [15]. With the development of language research and teaching, M Li studies virtual reality technology based on artificial intelligence and machine learning. This technique is then applied to immersive contextual teaching to improve students' English learning abilities. Through a comparative teaching experiment between two classes of freshmen in a university, it is found that in traditional teaching classes, teachers occupy most of the time and students passively receive information. Therefore, there are insufficient channels for information exchange and the expression of ideas in target languages. The overall English level of immersive teaching is better than that of the control class, with an average score of 2.8 points higher. This indicates that immersive contextual teaching of college English combining constructivism theory with VR technology can indeed improve students' English proficiency [16]. For college art and design majors, virtual scenes have a more natural interactive way to promote learning. Y Zhang proposed a new interactive intelligent virtual reality (VR) paradigm. Aiming at the problem that traditional image-based rendering cannot meet the needs of artistic style virtual environments, nonrealistic rendering technology is introduced into virtual scene construction. Therefore, this study proposes a virtual environment generation method based on nonrealistic rendering. The experiment illustrates that the research model can not only simulate artistic images of linear wave motion, but also realizes the construction of artistic style virtual environments. This makes immersion teaching excellent [17].

In summary, research by domestic and foreign scholars on art design teaching and human gesture recognition shows that the teaching mode of art design is still relatively traditional. More curriculum reforms tend to focus on multimedia digital teaching, while virtual reality technology is less applied. There is still much room to accurately identify and apply the optimization of online education. Therefore, this study integrates temporal convolutional networks and angle vector computation into attitude recognition, and optimizes the gradient disappearance and gradient explosion problems of temporal convolutional networks. Then it improves the posture recognition effect and simplifies the model application operation. Finally, this study explores the optimization and development of art design teaching.

III. CONSTRUCTION OF A VIRTUAL REALITY SYSTEM FOR ART DESIGN TEACHING BASED ON GESTURE RECOGNITION

A. Two-Stage Three-Dimensional Posture Joint Positioning and Timing Image Processing

In the teaching of art design, the state that reflects the mechanical structure of the human body is the posture of the human body. Common human postures are divided into three-dimensional models and skeletal models. A three-dimensional model is a virtual modeling model based on the human body, while a skeleton model is a tree structure diagram showing the changes in human posture. Therefore, the evaluation skeleton model has the advantage of being more concise and clearer than the virtual model. This is shown in Fig. 1.

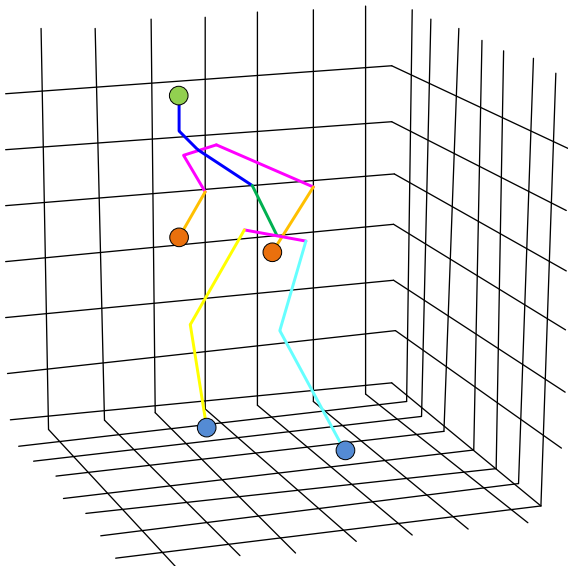


Fig. 1. 3D Tree structure diagram of skeleton model.

In the skeleton model, the research uses joint points as coordinates to represent human posture recognition and predict joint points; it expresses information such as the rotation angle of the human body with different posture changes. The stereoscopic model has strong picture representation and more simulation. However, due to factors such as computational complexity and estimated cost, it is not widely used in virtual costume changing and virtual animation design in art design teaching. The skeleton model has the advantages of greater flexibility and abundant joint information points, which makes it more efficient in motion tracking and other aspects. Therefore, this study selects a skeleton model for 3D pose recognition. Common human posture recognition methods include end-to-end posture recognition and two-stage posture recognition. End-to-end pose recognition methods that need to span data dimensions during training can lead to inaccurate posture prediction. Two-stage pose recognition is to extract important joint composition information from videos and images of the two-dimensional human body and reconstruct the three-dimensional pose in a virtual three-dimensional space. The study selected OpenPose for preliminary positioning of skeleton joint points. In the OpenPose algorithm, this study uses convolutional neural networks as feature extractors to extract feature points and calculate affinity and confidence, assemble joint points, and human posture features. The confidence algorithm uses neural network features to extract the probability value of a certain point coordinate joint point in the image. The personal confidence calculation formula is shown in Formula (1).

$$S_{i,j}^*(p) = e^{\left(\frac{-\|p-x_{i,j}\|^2}{\sigma^2}\right)} \quad (1)$$

In formula (1), $x_{i,j}$ is the corresponding bone joint point in the corresponding body; P is the coordinate point. The lower the confidence level when the coordinate point is away from

the position of the bone joint point. The calculation of multi person attitude confidence is shown in Formula (2).

$$S_i^*(p) = \max_j S_{i,j}^*(p) \quad (2)$$

In formula (2), $S_i^*(p)$ is the multi person confidence level; And the final result is a normal distribution. When the coordinate points coincide with the bone joint points, the confidence level reaches the maximum value. In the skeleton model, to ensure that joint points correctly connect the direction of the limb, the study selected an affinity algorithm for prediction. The definition of the affinity algorithm is to predict the possible joint connection directions for each coordinate position at different positions of the body. When x_{j1} and x_{j2} are set as different joint points of the human body, v is the unit vector from the first joint point to the second joint point, and v_r is the vector perpendicular to the unit vector. Whether there is a point in the limb can be calculated. The calculation formula is shown in Formula (3) and Formula (4).

$$0 \leq v \cdot (p - X_j) \leq l_f \quad (3)$$

$$|v_r \cdot (p - X_j)| \leq l_f \quad (4)$$

In formulas (3) and (4), the length of the limb is l_f ; the limb width is w_j . Therefore, the distance between the point and the torso is calculated as a confidence vector. The affinity of pixel points is shown in Formula (5).

$$A_f(p) = \begin{cases} 1, & P \text{ On the limb} \\ 0, & P \text{ is not on the limb} \end{cases} \quad (5)$$

When you select Openpose to generate a skeleton frame, there are a total of 25 joint points, as shown in Fig. 2.

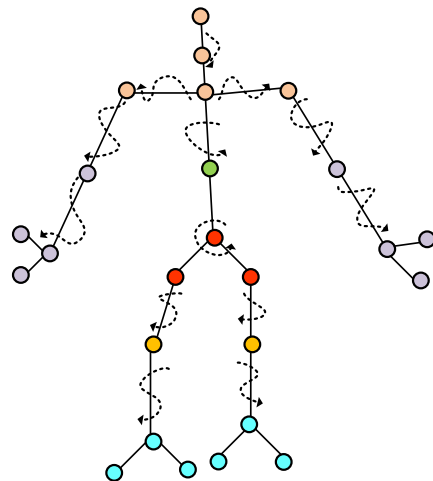


Fig. 2. Skeleton frame diagram.

In the skeleton frame diagram, the limbs have three different frames to determine joint points. However, when calculating the affinity of a point on a limb, it is not possible to determine whether the connection is correct, so the confidence level is recalculated using a definite integral method. The calculation of vector confidence at two different joint points is shown in Formula (6).

$$E_c = \int A_c(p(u)) \frac{X_{j_2} - X_{j_1}}{\|X_{j_2} - X_{j_1}\|} du \quad (6)$$

When the calculated confidence level is higher, it shows that the joint connection direction is unified, and the joint connection probability is higher. When sufficient joint point information is obtained, all joint points are rearranged and combined to distinguish different human bodies. Then, this study selects the Hungarian algorithm to re match the joint point distance. When there are three joint points, the corresponding joint points have only one edge actively connected. The constraint principle can be expressed as follows: if there is an interconnection relationship between type A joint points and type B joint points, the sum of the confidence levels of type A joint points n and all type B joint points is less than 1; Otherwise, the end of joint point n and B type joint point columns exceeds 1. After determining the backbone network under the three algorithms, temporal image processing was selected for this study. Attitude recognition based on two-dimensional key point sequences is expressed in multiple frames of images. Therefore, it can be viewed as a sequential task that utilizes time convolutional networks for parallel processing and adjusting the size of convolutional receptive fields. When there is an input sequence L , define the sequence as in Formula (7).

$$L = \{l_1, l_2, l_3, \dots, l_M\} \quad (7)$$

In sequence (7), M is the sequence length; the target sequence can be defined as Formula (8).

$$Y = \{y_1, y_2, y_3, \dots, y_N\} \quad (8)$$

In sequence (8), N is the target sequence length. Therefore, the sequence model can be defined as formula (9) through a mapping function.

$$\hat{Y} = f(x_1, x_2, x_3, \dots, x_T) \quad (9)$$

In the sequence (9), $\hat{Y} = \{\hat{y}_1, \hat{y}_2, \hat{y}_3, \dots, \hat{y}_N\}$ is the output prediction result. For ease of calculation, this study assumes that the input sequence and the target sequence have the same length. The model satisfies constraints when the input and event information are correlated. The temporal image processing model should meet the principles of equal output and input, and the prediction results should not be correlated with delayed future information. Therefore, a linear convolution structure is selected in the model to ensure that the input layer and the output layer have the same length. And the convolution kernel selects causal convolution optimization replacement.

Fig. 3 is a schematic diagram of causal convolution. Each location in the input layer corresponds to a time step, and there are multiple dimensions of data in the practice department. The convolutional kernel moves through the first layer and passes on to obtain a causal effect. However, the time series of causal convolution is too long, resulting in excessively high model complexity. As a result, gradient disappearance and gradient explosion occur, and their selective cavity convolution increases the size of the receptive field and the amount of compression parameters. Therefore, when there is an input sequence, the calculation method for whole convolution processing a certain frame is shown in Formula (10).

$$F(t) = (X * f_d)(t) = \sum_{i=0}^{k-1} f(i) \cdot x_{t-d \cdot i} \quad (10)$$

In formula (10), d is the expansion coefficient; k is the number of convolution kernels; $t - d \cdot i$ is the time slice size

B. Construction of a Two-Stage Three-Dimensional Attitude Recognition Model

To improve the accuracy of 3D human posture prediction, research has been conducted to extract joint information from images or videos, and reconstruct 3D posture from 2D joint points. After generating 2D coordinates through OpenPose and generating complete 2D pose recognition joint point coordinates using a time convolution network, the 3D pose recognition reconstruction is completed using angle vectors. The overall structure of the model is shown in Fig. 4.

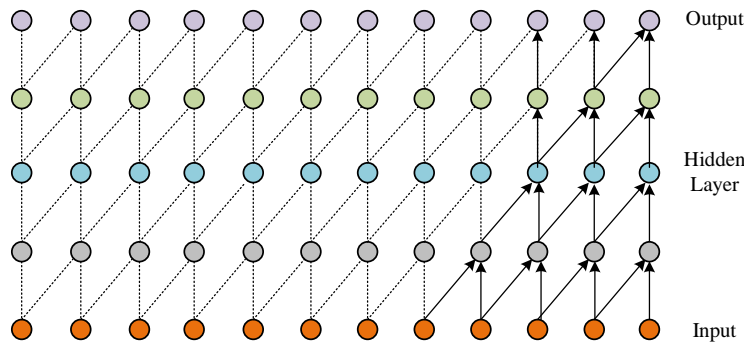


Fig. 3. Causal convolution diagram.

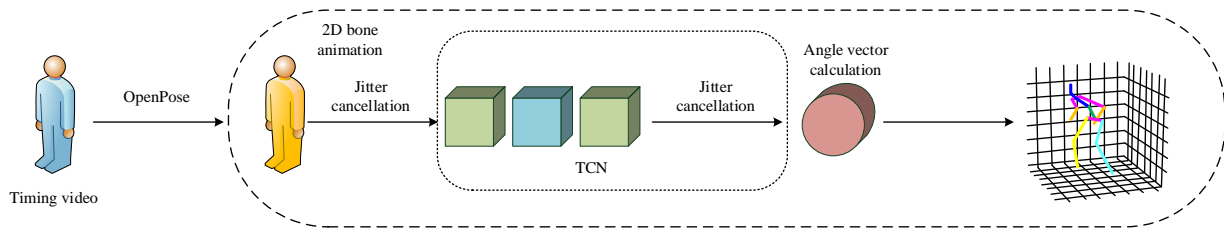


Fig. 4. Overall simplified flow chart of the model.

In Fig. 4, after capturing the original human posture and generating a timing video, two-dimensional bone animation is performed. Then it uses a time convolution model to eliminate jitter and calculates the angle vector to generate a three-dimensional human posture. The purpose of angle vector calculation is to reconstruct three-dimensional coordinates. Taking the head joint point as an example, it determines the length ratio of different joint points to determine the angle between the subject's body trunk and the photographing instrument; When the included angle is not 0, the transformation matrix normalizes the plane and coordinate axis, providing convenience for three-dimensional coordinate calculation. The normalization diagram is shown in Fig. 5.

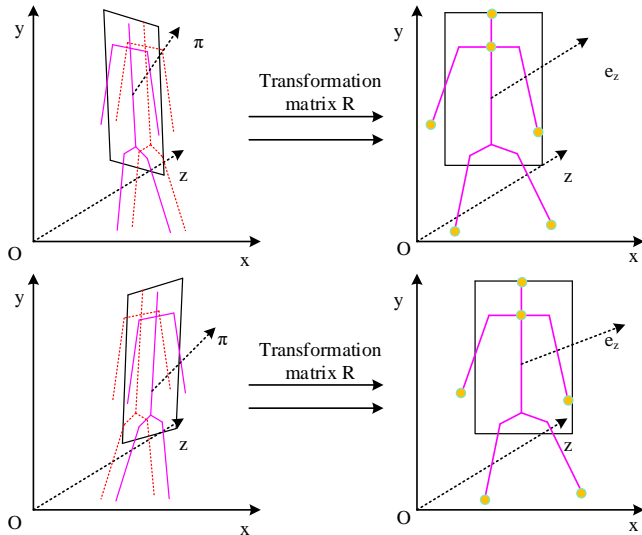


Fig. 5. Schematic diagram of human body normalization and front view.

During the normalization, the conversion matrix is obtained by taking the plane of the normal line of the head joint point as the normal vector. The rotated normal is the normal vector plane. The formula for calculating the rotation vector is shown in Formula (11).

$$A = (a_x, a_y, a_z) = \frac{\pi \times e_z}{\|\pi \times e_z\|} \quad (11)$$

In formula (11), e_z is the normal; (a_x, a_y, a_z) is the point coordinate; π is the plane normal vector of the head joint point. The formula for calculating the rotation angle is shown in Formula (12).

$$\theta = \cos^{-1} \left(\frac{\pi \cdot e_z}{\|\pi\| \|e_z\|} \right) \quad (12)$$

Therefore, the calculation formula for the rotation matrix is shown in (13).

$$R = \hat{A} + \cos\theta \cdot (I - \hat{A}) \sin\theta \cdot A^* \quad (13)$$

In formula (13), \hat{A} is the joint point matrix; The calculation formula for A^* is shown in matrix (14).

$$A^* = \begin{bmatrix} 0 & -a_z & a_y \\ a_z & 0 & -a_x \\ -a_y & a_x & 0 \end{bmatrix} \quad (14)$$

After obtaining the front coordinates of the photograph, measure the length of the joint points associated with each other and perform three-dimensional pose recognition. The schematic diagram of converting 2D joint points to 3D joint points is shown in Fig. 6.

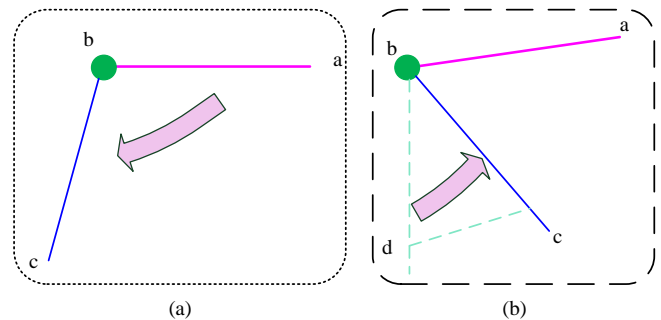


Fig. 6. Schematic diagram of 2D joint conversion 3D joint points.

In a two-dimensional plane, the angle between joint points (a, b) and joint points (b, c) is known. Then, by calculating the included angle of the vector, it can be concluded that when the joint point c moves, the two-dimensional output vector that changes is L_{bd} . The changed C_1 is the mapping of the joint point c. Therefore, the length of the vector before and after the change can be obtained from the image distance, and the included angle between the change vectors can be calculated. The included angle calculation formula is shown in Formula (15).

$$\theta_{bc} = \cos^{-1} \frac{L_{bc}}{L_{bd}} \quad (15)$$

In formula (15), θ_{bc} is the angle between the change vectors. By repeating this operation for each adjacent joint point, all three-dimensional coordinate positions can be obtained. Finally, the joint points are connected in a tree structure to obtain a human skeleton feature map. After obtaining the human bone feature map, evaluate the actual data and predicted data of predicted joint points, and the evaluation formula is shown in Formula (16).

$$MPJPE = \frac{1}{N} \sum_{i=1}^N \|J_i^* - J_i\|_2 \quad (16)$$

In formula (16), J_i^* is the i coordinate point corresponding to the predicted coordinate; J_i is the coordinate corresponding to the real coordinate point.

IV. PERFORMANCE VERIFICATION OF THREE-DIMENSIONAL COORDINATE MOTION RECOGNITION AND EMPIRICAL ANALYSIS OF MOTION CAPTURE SYSTEM

A. Performance Verification and Action Testing of Action Recognition Algorithm

In the performance analysis experiment of a two-stage 3D pose recognition model, in order to ensure the effectiveness of the model, a public dataset was used as the test set, consisting of Human 3.6M and Human Eva-I. The Human 3.6M dataset contains over 3 million three-dimensional poses, and the Human Eva-I dataset contains various motion process datasets. When testing the performance of the model, we first analyze the accuracy comparison between different algorithms and research algorithms in the Human Eva-I dataset. The comparison results are shown in Fig. 7.

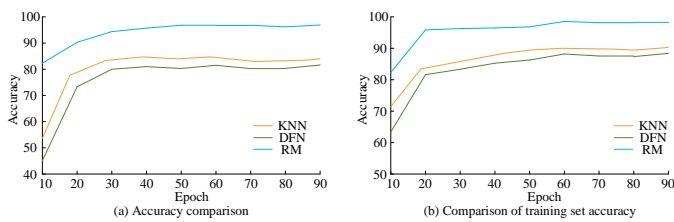


Fig. 7. Accuracy comparison.

Fig. 7(a) shows the comparison of accuracy between the DFN model and the research model. It can be seen that in training sets with a large number of people, the improvement in accuracy of the DFN model after 40 iterations is relatively limited, while the research model performs relatively well after 60 iterations. Additionally, overall, the performance of the model is quite good. In the training set with fewer people in Fig. 7(b), the accuracy of the DFN model increases with the increase of iterations, reaching a maximum accuracy of 89.57%. The accuracy of the research model has increased to

95.85% after 20 iterations, and since then, the number of iterations continues to increase, the rate of improvement is slow, and the accuracy gradually converges to 98%. The study selected methods such as ablation experiment analysis and estimation accuracy comparison for testing. The results of the ablation test are shown in Fig. 8.

In Fig. 8, in the comparison of ablation experiments, the red line represents the accuracy of the traditional OpenPose and angle vector combined pose recognition model under different error estimates; The blue lines are used to increase the accuracy of research models with residual structures under different error estimates. It can be seen that the MPJPE of the traditional model reaches 61mm, and the PA-MPJPE error calculation still reaches 50.5mm. The error accuracy of the research model with the addition of a residual structure rapidly decreased, and the overall error decreased by 5 mm when calculated through MPJPE. The optimal error accuracy is a model with three residual structures, and the error accuracy is only 51.3mm. Under the PA-MPJPE error calculation, the overall accuracy of the research model with a residual structure has a significant downward trend. And the optimal error accuracy is still the research model with three residual structures, only 43.2 mm. It shows that using time convolution network to eliminate video sequence jitter is effective and obvious. However, there is a gradient disappearance problem with too many modules. In the estimation accuracy comparison, it selects eight different actions in the Human3.6M dataset for testing, and selects DFN model, BKFC model, and KNN model for comparative testing.

From the scatter diagram in Fig. 9, it can be seen that the DFN model has the largest error. The action with the largest error among the eight actions is photo, reaching an error of 73 mm; the action with the smallest error is a walk, reaching 48.4mm. In the BKFC model, the action with the largest error is also a PHOTO action, reaching 57.2mm. The KNN model is the most effective model among the comparison models. The overall model error accuracy is improved by 5%, and the minimum error action is walk, only 41.8 mm. The overall error accuracy of the model in this study is 10% higher than the other three models, and the error is reduced to within 40 mm. The maximum error action photo is 38.1mm, and the minimum error action is walk, only 30.9mm. Even for the smooth purchase action, the accuracy improvement reaches about 8%. This indicates that using angular vector constraints to generate human posture has the best effect.

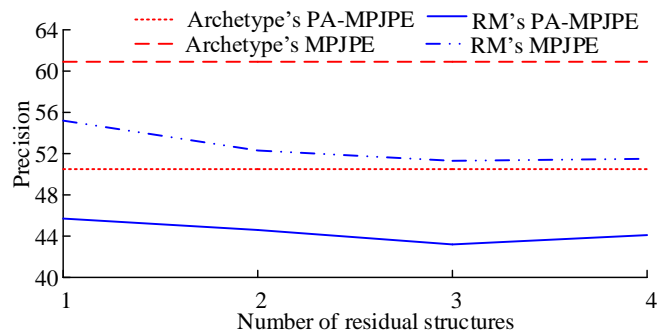


Fig. 8. Comparative results of ablation experiments.

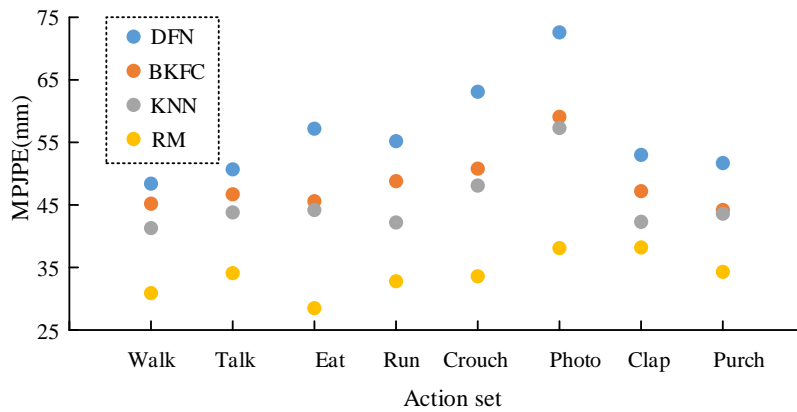


Fig. 9. Comparison of error tests for different models in data sets.

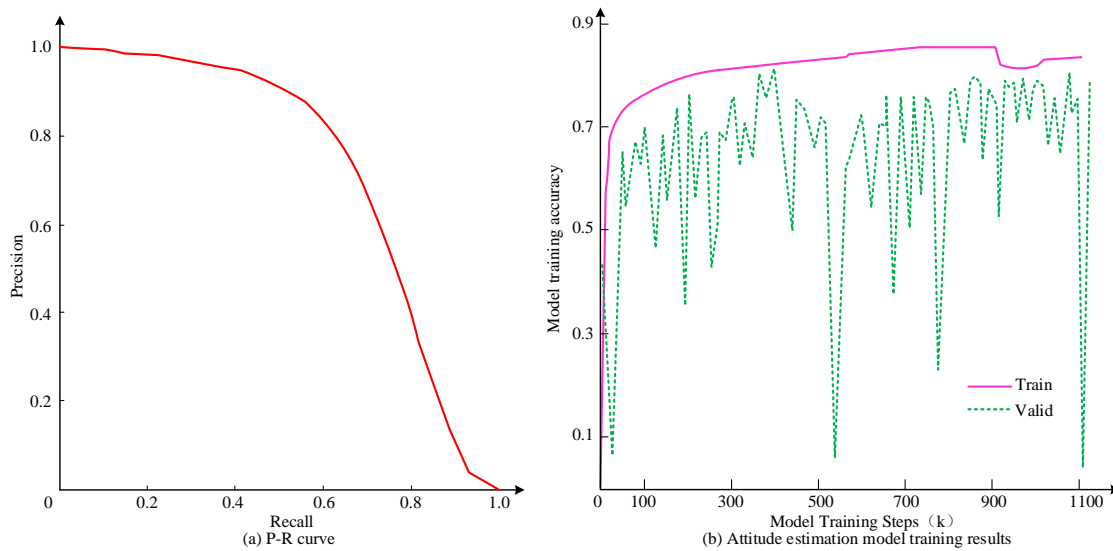


Fig. 10. Model training result accuracy and P-R curve.

Fig. 10(a) shows the model training results; During 300 iterations, the accuracy rate of test results on the validation set reached 0.741, and the recall rate reached 0.65. In the attitude estimation model training results in Fig. 10(b), the final accuracy of the model reaches 0.87, and the mAP verified and evaluated on the test set reaches 0.65.

B. Empirical Analysis of a Two-Stage Three-Dimensional Attitude Capture System

In the teaching of art design, this study utilizes research and improved three-dimensional posture capture system. This can enable students to understand the key design principles and multi-dimensional design expression techniques of certain actions in art design teaching from a comprehensive and three-dimensional perspective and at a data and three-dimensional level. This is different from traditional teaching in which students observe things or use digital courseware to learn and think about design norms and design concepts. Therefore, in the teaching of motion capture system, the research selects the leg disassembly teaching action and arm disassembly teaching action of three-dimensional animation football shooting action as capture demonstration. The experimental results are shown in Fig. 11.

The difference analysis and comparison of teacher and student motion capture in Fig. 11 shows that after disassembling the shooting posture in a three-dimensional manner, students can highly imitate the teacher's design skills. This study uses the accuracy of limb tracking as a performance indicator of the algorithm, and the bending amplitude of the leg and arm joints represents the tracking accuracy. In Fig. 11(a), the change in leg bending amplitude shows that the three-dimensional movements of the teacher's legs are clearer and more accurate, allowing students to observe the design from multiple angles, making it easier to learn and understand. The initial action designed by the students is slightly higher than that of the teacher, and the bending amplitude is gradually adjusted during the shooting process. Finally, an agreement was reached with the teacher to design the action after the shooting action was completed. The overall design model fits more than 96%. In the variation of arm bending amplitude in Fig. 11(b), there is body part occlusion, but the overall design fit still exceeds 95%. At the beginning of designing the action, the student's arm design angle is slightly lower than the teacher's design angle. In designing follow-up actions, the overall error is smaller and the arm bending amplitude is more easily detected. To sum up, the research on improved two-stage

three-dimensional gesture recognition can improve the anti-interference ability of the sensor by separating the magnitude of the motion. Motion posture error recognition is more accurate and motion amplitude changes are sensitive.

This not only has a higher accuracy, but also has a lower error angle than traditional gesture recognition methods to achieve accurate motion capture.

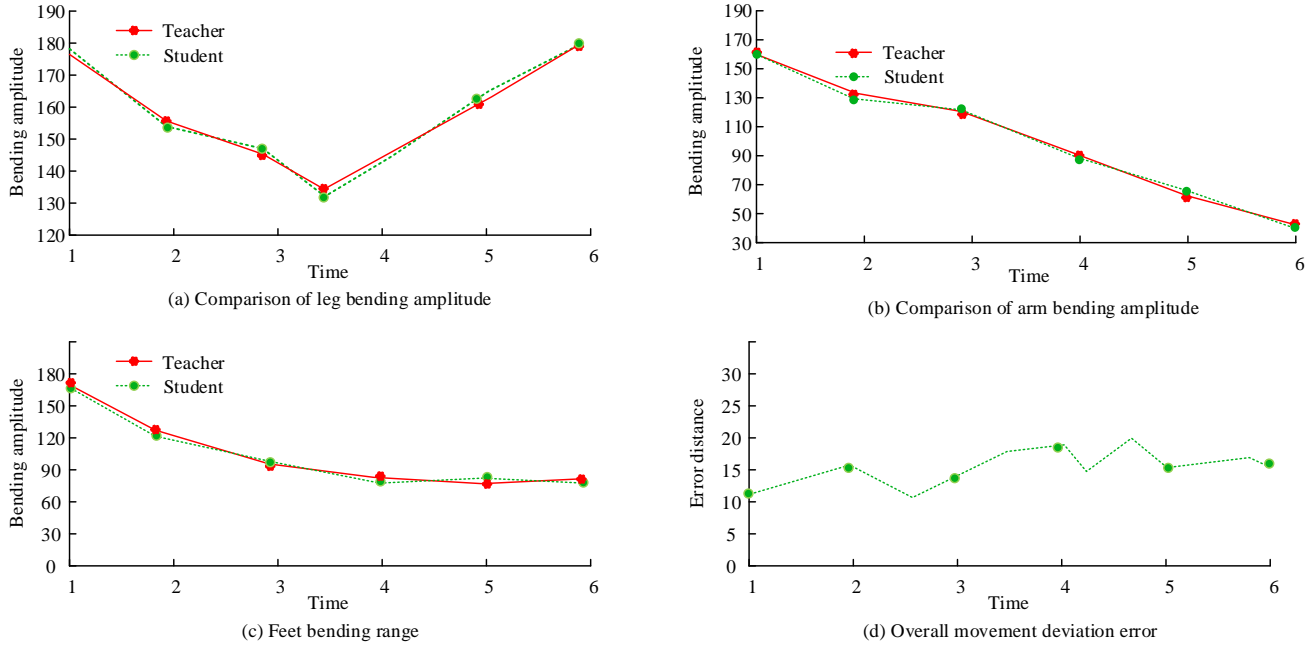


Fig. 1. Analysis of the difference in action capture between teachers and students.

Fig. 12 shows whether the studied human posture recognition system can correctly position the human body and whether the positioning error of joint points is within an acceptable range. Therefore, regular circular route experiments were conducted on the model. In Fig. 12(a), a walking route map is specified for the tester, and timing is performed at five checkpoints. Fig. 12(b) is a simulation diagram of the torso motion trajectory of the human body model by the human posture recognition system. The figure shows that the overall planning path of the model is good, and the actual travel range conforms to the specified travel path. The only point where a significant offset occurs is at point A. Overall, the research model can not only correctly identify human movements, but also effectively identify paths within the range of movement, with good motion capture accuracy. The position changes described meet the requirements of art design teaching. In addition to empirical analysis of the human posture recognition system, the system has also been applied to teaching. Based on this, a teaching satisfaction table is designed to compare with traditional design teaching and multimedia courseware-based

design teaching. It compares the learning satisfaction, learning effectiveness, and teaching efficiency of the three teaching methods based on scores. The higher the score, the better is the effect. The comparison results are shown in Table I.

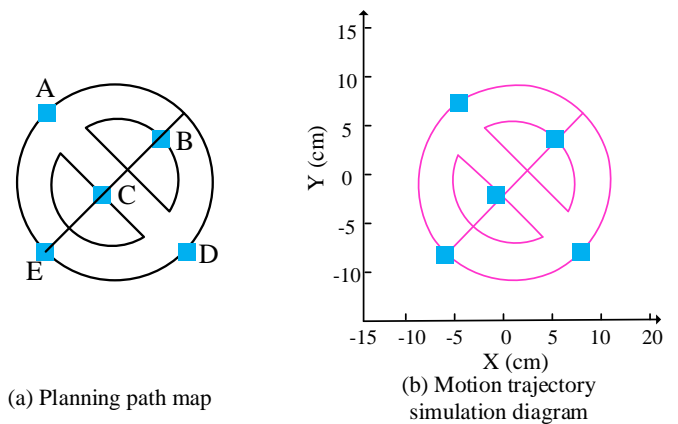


Fig. 11. Planning path simulation experiment results.

TABLE I. TEACHING SATISFACTION EVALUATION FORM

/	/	Research model	Offline teaching	Traditional online teaching
First group	Concept understanding	96	74	81
	Learning effect	93	76	86
	Teaching effectiveness	97	72	82
Second group	Concept understanding	89	80	89
	Learning effect	98	79	83
	Teaching effectiveness	96	71	81

In the evaluating teaching effectiveness, this study selected art and design majors from a certain university to conduct an experimental comparative evaluation of three teaching modes. When the research model is applied in the teaching process, the learning effect, concept understanding, and teaching situation have obvious advantages compared to traditional teaching and multimedia courseware teaching. In the score of concept understanding, the average score of the research model reached 92.5. In terms of learning effectiveness, the average score reached 95.5. In the teaching effectiveness score, the average score of the research model reached 96.5. Compared to the other two teaching modes, the average score exceeds 5 points. The score indicates that the improved posture recognition system in this study has achieved good teaching results when applied to design teaching. Moreover, students have a sufficient understanding of artistic design concepts, and can achieve a high degree of artistic space, with excellent teaching effects.

V. CONCLUSION

Efficient and accurate gesture recognition technology is essential for achieving human-computer interaction and applying interaction systems to the field of artistic design or production. Measuring human body data and calculating the movement amplitude of joint points pose a higher requirement for the refinement of gesture recognition technology. To improve the teaching effect of art design, a two-stage three-dimensional gesture recognition model is studied and designed. The experiment demonstrates that using open data sets as test sets and performing ablation experiments are compared with the estimation accuracy; the accuracy of the model error decreases rapidly when a residual structure is added to the ablation experiment. The overall MPJPE calculation error decreased by 5 mm to 51.3 mm. Under PA-MPJPE error calculation, the error accuracy is only 43.2mm, and the overall optimization is three modules. In the estimation accuracy comparison, the study selected eight different actions from the Human3.6M dataset for testing. The overall error accuracy of the research model was improved by 10%, and the error range was within an acceptable range. The accuracy rate of the model reached 0.741, and the recall rate reached 0.65. When conducting empirical analysis, the accuracy of motion disassembly error is good. The fit degree of the leg bending amplitude reaches over 96%, and the fit degree of the arm bending amplitude reaches over 95%. When the model is applied to actual teaching, the overall satisfaction score of teachers and students exceeds 94 points, which can effectively improve the teaching effect of art design. The research deficiency lies in the insufficient application of complex multi-level structure design. This is also the direction of future in-depth research.

REFERENCES

- [1] S. Wang, H. Zhang, X. Meng, "Design of Video Teaching System Based on Virtual Reality Technology". *Electronics Science Technology and Application*, 2021, 7(4):72-78.
- [2] L. Chen, D. Hu, X. Han, "Study on forearm swing recognition algorithms to drive the underwater power-assisted device of frogman". *Journal of Field Robotics*, 2022, 39(1):14-27.
- [3] T. Stone, S. Schumacher, E. Belilos, V. Kottamasu, "Virtual Teaching Kitchen within the Shared Medical Appointment Model". *American journal of lifestyle medicine*. 2021,15(6s):4-5.
- [4] T. Y. Pan, C. Y. Chang, W. L. Tsai, M. C. Hu. "Multisensor-Based 3D Gesture Recognition for a Decision-Making Training System". *IEEE Sensors Journal*, 2021, 21(1):706-716.
- [5] R. Salvador, P. C. Naval. "Towards a Feasible Hand Gesture Recognition System as Sterile Non-contact Interface in the Operating Room with 3D Convolutional Neural Network". *Informatica: An International Journal of Computing and Informatics*, 2022,46(1):1-12.
- [6] X. Liu, H. Shi, X. Hong, H. Chen, G. Zhao, "3D Skeletal Gesture Recognition via Hidden States Exploration". *IEEE Transactions on Image Processing*, 2020, 29:4583-4597.
- [7] B. Javidi, F. Pla, J. M. Sotoca, et al. "Fundamentals of automated human gesture recognition using 3D integral imaging: a tutorial." *Advances in Optics and Photonics*, 2020, 12(4):1237-1299.
- [8] Q. Liu, Human motion state recognition based on MEMS sensors and Zigbee network. *Computer Communications*, 2022, 181:164-172.
- [9] Y. Peng, H. Tao, W. Li, H. Yuan, T. Li. "Dynamic Gesture Recognition Based on Feature Fusion Network and Variant ConvLSTM". *IET Image Processing*, 2020,14(11):2480-2486.
- [10] S. Li, Y. Dai, K. Hirota, Z. Zuo. "A Students' Concentration Evaluation Algorithm Based on Facial Attitude Recognition via Classroom Surveillance Video". 2020,24(7 TN.147):891-899.
- [11] W. S. Shun, Y. W. Sun., L. J. Xu. "Research on will-dimension SIFT algorithms for multi-attitude face recognition". *High Technology Letters*, 2022, 28(3):280-287.
- [12] M. Alam, S. F. Abedin, S. I. Moon, A Talukder, C. S. Hong, "Healthcare IoT-Based Affective State Mining Using a Deep Convolutional Neural Network. *IEEE Access*, 2019(7):75189-75202.
- [13] Z. Hong, M. Hong, N. Wang, Y. Ma, X. Zhou, W. Wang, "A wearable-based posture recognition system with AI-assisted approach for healthcare IoT". *Future generations computer systems: FGCS*, 2022(127):286-296.
- [14] Z. Fen. "Efficiency improvement of English online teaching system based on bagging learning flow feature selection". *Journal of Intelligent & Fuzzy Systems: Applications in Engineering and Technology*, 2021,4(40):6695-6705.
- [15] T. Dolighan, M. Owen. "Teacher Efficacy for Online Teaching During the COVID-19 Pandemic". *Brock Education Journal*, 2021, 30(1):95-116.
- [16] M. Li. "An Immersive Context Teaching Method for College English Based on Artificial Intelligence and Machine Learning in Virtual Reality Technology". *Mobile Information Systems*, 2021, 2021(2):1-7.
- [17] Y. Zhang, "Application of Intelligent Virtual Reality Technology in College Art Creation and Design Teaching". *Journal of Internet Technology*, 2021,22(6):1397-1408.

Business Data Analysis Based on Kissmetric in the Context of Big Data

Kan Wang

College of Computer Engineering, Henan Institute of Economics and Trade, Zhengzhou, China

Abstract—The kissmetric data analysis model can be used for the analysis and research of business data, and the focused research method in this model is cluster analysis. To realize the effective application of Kissmetric data analysis model, the focused method is improved in the experiment. An improved hierarchical clustering algorithm generated by splitting stage and merging stage is proposed in the experiment, and then the algorithm is combined with density clustering method while considering noise point processing to achieve automatic determination of clustering centers and improvement of clustering effect. In different dimensions, the highest F-measure index and ARI values of the hybrid clustering method are 0.997 and 0.998, respectively. In different numbers of classes of the dataset, the highest F-measure index and ARI values of the hybrid clustering method are 1.000 and 0.999, respectively. The mean accuracy and mean-variance were 95.94% vs. 5.89%, 94.72% vs. 0.57%, 89.72% vs. 4.97%, 87.45% vs. 5.53%, 93.83% vs. 5.76%, and 88.43% vs. 5.40 %, respectively. The mean and mean squared deviation of hybrid clustering method's accuracy was 89.71% vs. 6.17% and 88.85% vs. 0.33% when dealing with the real datasets 7 and 8, respectively. The quality and stability of the clustering results of the hybrid clustering method are better. Compared with other clustering methods, the accuracy and stability of this method are higher and have certain superiority.

Keywords—Big data; kissmetric; data analysis; density clustering; hierarchical clustering

I. INTRODUCTION

In the context of big data, by collecting business data, users can analyze the data according to the actual needs and get the latent customer behavior pattern behind the big data [1]. The business data analysis methods mainly include the list method, statistical method, cluster analysis method, etc. [2]. The list method is to record and process the data results by certain rules by applying tables, which should be designed to meet clear and precise correspondence [3]. The statistical method can collect and organize data with characteristics from microstructure and use suitable statistical methods to organize the data and explore the hidden laws of the macroscopic nature behind the data [4]. Clustering analysis is a simple and efficient way to summarize the data on a website to determine whether there is a correlation between things [5]. Kissmetric is a data analysis model that can be used for customer engagement. The data analysis of this platform can help users understand customer engagement, analyze product performance, and determine whether the customized marketing plan is effective [6-7]. However, Kissmetric contains a large amount of data, and users may not be able to quickly obtain effective information from it. Therefore, it is also necessary to analyze these data in order to improve the

application effectiveness of the data analysis model. Research has shown that clustering algorithms have good applications in the analysis of business data [5]. It can be used for data analysis in the Kissmetric data analysis model. However, traditional clustering algorithms require a predetermined k value when applied. The setting of k value is easily influenced by subjective factors, resulting in significant differences in clustering results. In order to reduce the impact of subjective factors, some scholars proposed hierarchical clustering analysis [8]. This method only requires fewer or no parameters, making it highly flexible. Therefore, hierarchical clustering is selected as the main algorithm for business data analysis in this study. However, this method requires a large amount of computation and cannot trace back to the intermediate clustering process. In this experiment, an improved hierarchical clustering algorithm is proposed, which is generated by the split phase and the merge phase. Then, while considering noise point processing, the algorithm is combined with density clustering method to achieve automatic determination of clustering centers and improve clustering performance. It is hoped that the improvement of the method can improve the application effect of clustering methods in the Kissmetric data analysis model. It is hoped that this data analysis model can help users analyze business data and obtain the information hidden behind the data, which can be used for formulating enterprise development goals and directions.

The article is mainly divided into five parts. Firstly, there is an introduction as the background of the article. Then there is a literature review, which discusses the existing methods and serves as the literature basis for selecting methods in the experiment. The third part is the establishment and improvement of methods. The fourth part is the performance analysis of the method. The last part is the conclusion, which is a summary of the entire text.

II. REVIEW OF THE LITERATURE

The era of big data requires us to process the data efficiently so as to solve the problems brought by the data. When dealing with complex business problems, the laws behind the data need to be mined to uncover the business value represented by different data. The analysis of business data mainly consists of searchable data analysis and model selection analysis. When the data in search web pages are disorganized, searchable data analysis can be achieved by using mapping, generating tables and equation fitting [9-10]. The search data analysis can be used to obtain the potential business value behind the data, based on which a suitable business model can be selected to promote the long-term

development of the company. Kissmetric is a data analysis model that can be used for customer engagement [7-8]. The main components of the Kissmetric data analysis model include the visitors to the web pages, the features used to describe the user information, and the events and their attributes. The hierarchical clustering method is the key method used in the Kissmetric data analysis model for statistical analysis of data, which is divided into three steps. The first step is to count and divide the number of customers, the second step is to count and divide the types of products, and the third step is to count and divide the platforms. Hierarchical cluster analysis can help users to analyze business data and get the hidden information behind the data, which can be used for the formulation of business development goals and development directions.

Kissmetric is an automated customer engagement data analysis model based on a hierarchical clustering approach, and clustering algorithms are an important part of data mining. Many classical clustering algorithms have been proposed, such as K-means, DBSCAN, Gaussian mixture models, spectral clustering, non-negative matrix decomposition-based clustering, and graph-based clustering. Many optimizations have been made on the traditional algorithms to enable more efficient and accurate data mining using clustering analysis. For example, Xi W A et al. proposed a memetic algorithm with adaptive inverse K-means operation for data clustering, and the performance of the method was evaluated on a series of data sets and compared with related algorithms, and the experimental results showed that the algorithm generally provides superior performance and outperforms related methods [11]. Optimization improvements to K-means clustering methods can be applied to multidisciplinary research. Liu S et al. proposed a self-guided reference vectors (RVs) strategy for decomposition-based evolutionary algorithms in multi-objective optimization to extract RVs from a population using an improved K-means clustering method [12]. A neighborhood network layout scheme based on the unsupervised K-means clustering algorithm and the contour index method has been proposed to determine the number of effective data aggregation points (DAPs) required for different smart meter densities and to find the optimal deployment locations of DAPs [13]. Qin X et al. proposed a machine learning K-means clustering algorithm to select interpolative separable density fitting (ISDF) interpolation points, and K-means algorithm can significantly reduce the computational cost of selecting interpolation points by nearly two orders of magnitude, thus speeding up the ISDF-based Hartree-Fock exchange computation by a factor of 10 [14]. In the study of enterprise business model change, Dressler M et al. used clustering algorithm to data mine different business models and then used PCA analysis to generate two classes of business models, which provided a better classification

method for business model expansion [15]. In the development of SMEs, some scholars use two-step clustering method to analyze the financial data of enterprises to get the optimal number of clusters, and then use fuzzy clustering to analyze the business scale of enterprises, and the optimal clusters are obtained after verification [16]. For the investment selection of enterprises, Gubu L et al. introduced the Markowitz model based on the K-means algorithm for estimating the covariance matrix as well as the mean vector. The method was experimentally demonstrated to have good robustness in processing a large amount of data and can effectively use outliers for data analysis [17]. Clustering algorithm can optimize the parameters of the machine learning model, and the optimized method can be used to cluster the customer preferences and predict the market trends. Clustering-based analysis can uncover the patterns and trends behind customer behavior, which is important for business scaling [18].

Based on the above study, clustering algorithm has good application in the analysis of business data. In order to better improve the application of Kissmetric data model, the focused clustering method in Kissmetric data model is improved in this experiment. An improved hierarchical clustering algorithm generated by splitting stage and merging stage is proposed in the experiment, and then the algorithm is combined with the density clustering method while considering the noise point processing to achieve the automatic determination of clustering centers and the improvement of clustering effect. It is hoped that the improvement of the Kissmetric data model focus method can help users to improve the effectiveness of business data analysis.

III. BUSINESS DATA ANALYSIS BASED ON KISSMETRIC

A. Business Data Analysis Method based on Improved Hierarchical Clustering

The focus of Kissmetric data analysis model is the data analysis method based on cluster analysis. In order to improve the application of Kissmetric data analysis model, the focus of this experiment is improved for its focus. K-means algorithm is a representative clustering method in cluster analysis, and is the basis of other clustering algorithms. In the practical application, it is necessary to determine the number of data object classes, divide the points with different object attributes into different cluster classes according to the principle of closest distance, then use the averaging method to calculate the center of mass of each cluster class, and then reassign the center of mass according to the actual calculation results, and finally ensure that the center of mass moves below the set threshold, and Fig. 1 shows its iterative process.

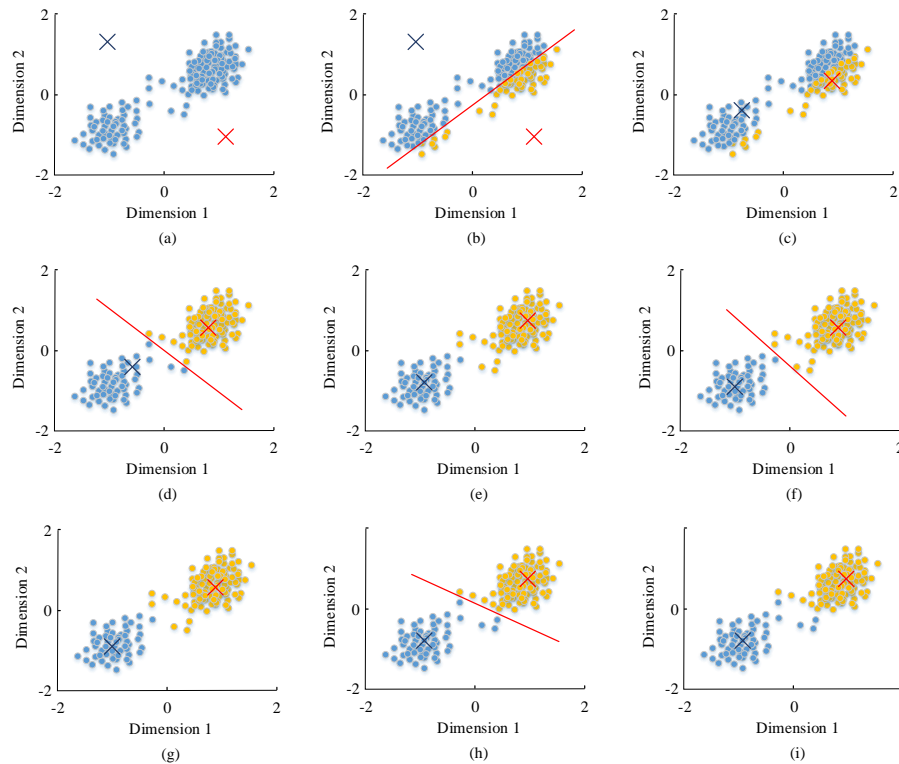


Fig. 1. Iterative process of K-means algorithm.

K-means algorithm requires a pre-specified k-value, but it is susceptible to the influence of subjective factors, which leads to large differences in the results of clustering. To reduce the influence of subjective factors, some scholars propose hierarchical cluster analysis method, which is mainly divided into cohesive and split hierarchical cluster analysis methods. Only fewer parameters or no parameters are required in the hierarchical cluster analysis method, which is more flexible and can be used to divide different types of data according to the different levels of data objects. Therefore, hierarchical cluster analysis method is chosen as the main algorithm for business data analysis in this study, but this method is computationally intensive and cannot retrace the intermediate clustering process, so a new hierarchical clustering method consisting of two phases, merging and splitting, is proposed in this experiment. The splitting stage treats the original overall dataset as a cluster class, and then places the samples in the appropriate splitting positions according to the splitting strategy to obtain different subclasses. Define a dataset $D = \{P_1, \dots, P_i, \dots, P_n\}$, which contains n samples, and the ith sample $P_i = (p_1, \dots, p_d)$ denotes a vector with d attribute values, and classify the dataset D to

obtain the classification $C = \{C_1, \dots, C_k\} (C_1 \cup C_2, \dots, \cup C_k = D \text{ and } C_i \cap C_j = \emptyset, i \neq j)$. The representation of the splitting process of the dataset D at the splitting position (i, h) is shown in Equation (1) and (2).

$$C_1 = \{P_j | P_j \in D \wedge p_j^i \leq h, i = 1 \sim d, j = 1 \sim n\} \quad (1)$$

$$C_2 = \{P_j | P_j \in D \wedge p_j^i > h, i = 1 \sim d, j = 1 \sim n\} \quad (2)$$

The splitting process is iteratively processed on the dataset by using Eq. (1) and (2) until no splitting position satisfying the conditions is produced. Multiple subclasses can be obtained after processing in the splitting phase, and the merging phase requires merging these subclasses with consistent attributes. In the previous splitting process, the samples are labeled with label, and the initial value of label is 1, which is used to determine whether the subclasses in a certain level are split from the same data set. At the same time the split level marker level is added, with an initial value of 1, to update the marker for sample splitting. The splitting process is top-down, and the merging process is bottom-up, starting from the current marker until the marker is 0.

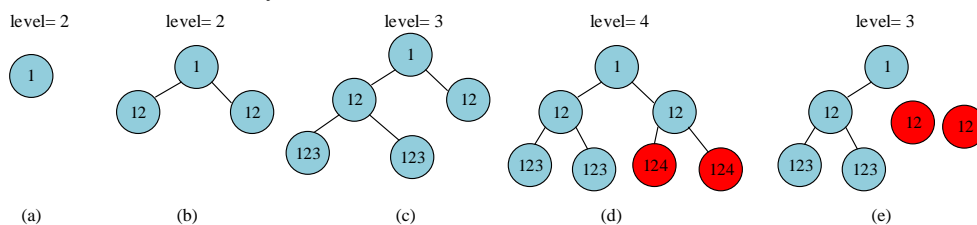


Fig. 2. Schematic diagram of the merging process.

The schematic diagram of the merging process is shown in Fig. 2, and we need to determine whether the red part in Fig. 2(d) needs to be merged. If it can be merged, then the marker level=4 is reduced by one level, that is, level=3, see Fig. 2 (a) to (d). If the condition is not satisfied, the child node of the red part replaces its parent node, and its marker level is updated and reduced by one layer, and whether to merge with other data sets is considered in the subsequent merging process, see Fig. 2(e). The condition for merging need to satisfy that the subclasses are not disconnected in any dimension and that the similarity within classes is increased and the similarity between classes is decreased after the merging process. In this study, the Calinski -Harabazs index was introduced as a measure of inter- and intra-class similarity, as shown in Eq. (3).

$$CH - index(C) = (BCSS(C) / WCSS(C)) * ((n - k) / (k - 1)) \quad (3)$$

WCSS denotes Within Cluster Sum of Squares in Equation (3), BCSS denotes Between Cluster Sum of Squares. n and k denote the number of samples and the number of groups to be grouped, respectively. For the two subclasses C_i and C_j , their Calinski -Harabazs index after merging is calculated in Eq. (4).

$$CH - index(C_{ij}) = (BCSS(C_{ij}) / WCSS(C_{ij})) * ((n - k_1) / (k_1 - 1)) \quad (4)$$

B. A Study of Hybrid Clustering Methods based on Improved Hierarchical Clustering and Density Clustering in Kismetric Model

Hierarchical clustering-based analysis methods are parameter-insensitive and can be used for arbitrary shape class discovery, but they are computationally intensive. Density clustering-based methods can classify the original data set more rationally, but have the problem of parameter sensitivity. Based on the characteristics of both hierarchical and density clustering methods, a hybrid algorithm is combined in this study to compensate for the deficiencies and take advantage of the advantages of both hierarchical and density clustering methods. The density clustering algorithm needs to divide the high-density region from the low-density region surrounded by the fast density peaking algorithm needs to carry out the calculation of sample local density and sample distance. Eq. (5) shows the calculation of local density.

$$\rho_i = \sum_j \chi(d_{ij} - d_c), \begin{cases} \chi(x) = 1, x < 0 \\ \chi(x) = 0, x \geq 0 \end{cases} \quad (5)$$

d_c denotes the truncation distance in Equation (5). The sample distances are calculated in Equation (6).

$$\delta_i = \begin{cases} \max_j (d_{ij}) = 1, \rho_i = \max(\rho_1, \dots, \rho_n) \\ \min_{j:\rho_j > \rho_i} (d_{ij}) = 1, \rho_i \neq \max(\rho_1, \dots, \rho_n) \end{cases} \quad (6)$$

Based on the calculation of sample local density and sample distance, the fast density peaking algorithm is able to find the sample with high density as the center of clustering, and this sample is far away from other samples with high density, and Figure 3 shows the schematic diagram of this

method.

Samples 1 and 10 in Fig. 3 represent the two clustering centers of the fast density peaking algorithm, and the method can be more successful in finding samples that can serve as clustering centers. However, there are also problems such as wrong selection of clustering centers, or selecting multiple centers in the same class and finally dividing to form multiple subclasses. In this experiment, the method is improved by first selecting multiple samples as clustering centers in the first stage of clustering using the fast density peaking algorithm, and then combining the clustering results in the subsequent hierarchical clustering. The method of cluster center selection is divided into two steps, first calculating the product of the sample distance and local density of sample i, i.e., $\gamma_i = \rho_i \times \delta_i$.

Then the calculated γ_i is sorted in the order from largest to smallest, and the cluster center of the first stage selects the sample with the largest change in the value of γ . The correct clustering centers can be obtained after fast density peaking algorithm selection, and then these clustering centers need to be merged using hierarchical clustering method. In the current study the similarity measure of hierarchical clustering mainly uses average connection, full connection or single connection, but these methods do not consider the distribution of samples, which leads to the failure of the sample measure with special distribution. In this experiment, an aggregation-based hierarchical clustering method is proposed, in which a new noise point avoidance strategy is introduced to circumvent the drawbacks of artificially determining noise points and parameters. Assuming that the probability density function of subclass C_i is $f_i(v)$, the probability density function of subclass C_j is $f_j(v)$, and v denotes the attribute values of the samples within the class, the definitions of the connectivity of C_i and C_j in Equation (7) can be obtained.

$$join(C_i, C_j) = \sum_{p \in C_i \cup C_j} \min(f_i(p), f_j(p)) \quad (7)$$

This leads to the aggregation function of C_i and C_j in Eq. (8).

$$cohesion(C_i, C_j) = \frac{join(C_i, C_j)}{|C_i| + |C_j|} \quad (8)$$

$|C_i|$ denotes the number of samples in C_i and $|C_j|$ denotes the number of samples in C_j in Equation (8). Assuming that the samples in the subclass C_i obey a multivariate normal distribution, i.e., $V \sim N_d(\mu, \psi)$, the expression of the probability density function of C_i is given in Eq. (9).

$$f_i(v) = (2\pi)^{-\frac{d}{2}} (\det \psi)^{-\frac{1}{2}} \exp[-\frac{1}{2}(v - \mu)^T \psi^{-1}(v - \mu)] \quad (9)$$

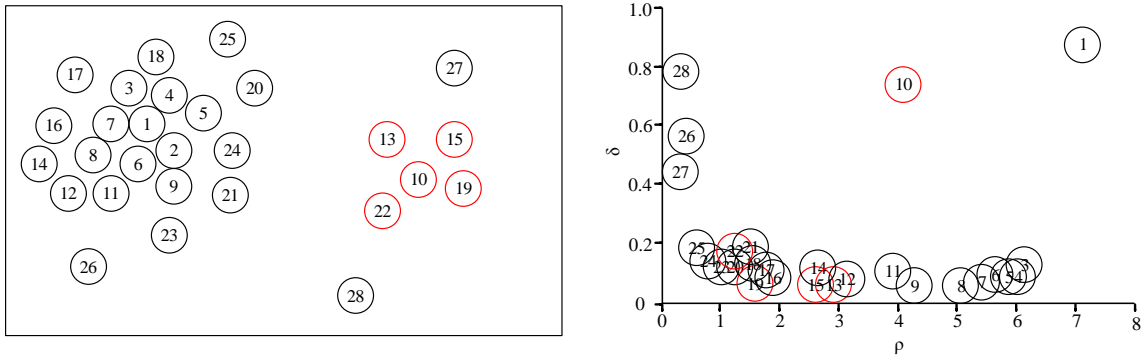


Fig. 3. Schematic diagram of the fast density peaking algorithm.

d denotes the dimensionality, μ denotes the mean vector, and Ψ denotes the covariance matrix in Eq. (9). The calculation of μ is shown in Eq. (10).

$$\mu = \frac{1}{n} \sum_{i=1}^n v_i \quad (10)$$

The calculation of Ψ is shown in Eq. (11).

$$\Psi = \frac{1}{n} \sum_{i=1}^n (v_i - \mu)(v_i - \mu)^T \quad (11)$$

Given the probability density function of C_i according to Eq. (9), the volume calculation of C_i can be obtained from this, see Eq. (12).

$$V_i = \frac{4}{3} \pi \sqrt{\lambda_1 \lambda_2, \dots, \lambda_d} \quad (12)$$

$\lambda_1 \lambda_2, \dots, \lambda_d$ represents the d eigenvalues of the covariance matrix Ψ in Eq. (12). Because the subclass volume and the eigenvalues of Ψ are proportional, the constant term is removed for the subsequent calculation, i.e., $V_i = \sqrt{\lambda_1 \lambda_2, \dots, \lambda_d}$. Eq. (13) is the density calculation of C_i .

$$D_i = \frac{|C_i|}{V_i} \quad (13)$$

According to the characteristics of noise points, if two subclasses that are close to each other have a large difference in density or volume, one of them has a higher probability of being a noise point cluster. Based on this feature, the definition of the noise point avoidance function for the subclasses C_i and C_j is given in Eq. (14).

$$dependence(C_i, C_j) = \frac{D_i + D_j}{2 \times \sqrt{D_i \times D_j}} + \frac{V_i + V_j}{2 \times \sqrt{V_i \times V_j}} + \frac{1}{2 \times d} \sum_{i=1}^d \frac{(\sqrt{\lambda_i^i} + \sqrt{\lambda_i^j})}{|c_i - c_j|} \quad (14)$$

\bar{c}_i denotes the cluster center of subclass C_i in Equation (14), \bar{c}_j denotes the cluster center of subclass C_j , $\sqrt{\lambda_i^i}$

denotes the length of each dimensional axis of C_i , and $\sqrt{\lambda_i^j}$ denotes the length of each dimensional axis of C_j . Since $\frac{D_i + D_j}{2 \times \sqrt{D_i \times D_j}} \leq 1, \frac{V_i + V_j}{2 \times \sqrt{V_i \times V_j}} \leq 1$, the value of the mean inequality is maximized when and only when $D_i = D_j, C_i = C_j$. From the noise point avoidance function in Formula (14), the closer the density and volume of the two subcategories are, the higher the dependency of the two subcategories is, and the greater the probability of their combination is. On the contrary, the combination probability of the two is smaller. According to the definitions of noise point avoidance function and aggregation function, the similarity of subclasses C_i and C_j is given in Eq. (15).

$$similarity(C_i, C_j) = cohesion(C_i, C_j) + dependence(C_i, C_j) \quad (15)$$

The similarity measure in this experiment consists of an aggregation function and a noise point processing function, which fully considers the distribution of samples within classes while circumventing the interference of noise points during class merging.

Kissmetric is an automated customer engagement data analysis model based on the hierarchical clustering approach described above, capable of providing business data analysis to clients. The main components of the Kissmetric data analysis model include the visitors to the web pages, the features used to describe the user information, and the events and their attributes. The hierarchical clustering method is the key method used in the Kissmetric data analysis model for statistical analysis of data and is divided into three main steps. The first step is to count and divide the number of customers, which can get three types of customers, namely, resource customers who have browsed the products, potential customers and customers who have purchased the products. The second step is to count and divide the types of goods, mainly by analyzing the information of the type, name, price and size of the goods. The third step is to count and divide the platforms, and make a regional division of the number of customers who have purchased goods on different platforms.

IV. PERFORMANCE STUDY OF BUSINESS DATA ANALYSIS MODEL BASED ON KISSMETRIC

The parameter settings in the experiment are as follows: the number of centroids is 8, and the maximum number of iterations is 300. In the improved hierarchical clustering method, the effectiveness of the algorithm in the splitting process is verified using the Aggregation dataset in Fig. 4. For the original Aggregation dataset, the improved hierarchical clustering method is able to split the original samples and obtain multiple subclasses.

The original data set needs to be merged after the splitting process. In Fig. 5, the subclasses with consistent attributes need to be merged in the merging stage to finally obtain a more accurate classification effect, and the clustering accuracy of this method is 99.21%.

Performance validation for clustering algorithms can be evaluated using the F-measure metric, which is a weighted summed average of recall and accuracy, and is used to evaluate the merit of the classification model. The Rand Index (RI) can be used to measure the similarity of clustering results, but there is a lack of differentiation. To address this problem, the Adjusted Rand Index (ARI) makes some improvements on the basis of RI, which can make a clearer distinction of clustering effects. In the range of [-1,1], the larger value of ARI indicates the better effect of the clustering method. The results of the F-measure metrics and ARI of the hybrid

clustering method proposed in this experiment compared with K-means, K-medoids, and K-means++ methods in different dimensions in Fig. 6 [19-21]. The highest F-measure index and ARI values of the hybrid clustering method proposed in this experiment are 0.997 and 0.998, respectively, under different dimensions, which are higher than those of K-means, K-medoids, and K-means++ methods.

The F-measure and ARI values of the algorithm are compared in Fig. 7 for different numbers of classes of the dataset. The highest F-measure metrics and ARI values of the hybrid clustering method proposed in this experiment are 1.000 and 0.999, respectively, under different numbers of data set classes, which are higher than those of K-means, K-medoids, and K-means++ methods. F-measure index and ARI values of the hybrid clustering method do not change due to the number of classes in the data set, and its clustering effect is better and more stable.

The hybrid clustering method proposed in this experiment is used with K-means, K-medoids, and K-means++ methods to cluster the Aggregation dataset in Fig. 8. The hybrid clustering method accurately divides the Aggregation dataset into seven classes according to the similarity calculation results, while the rest of the methods for some of the samples were classified with ambiguity, and more than seven classes were finally classified. The hybrid clustering method proposed in this experiment has a better clustering effect and its clustering accuracy is better.

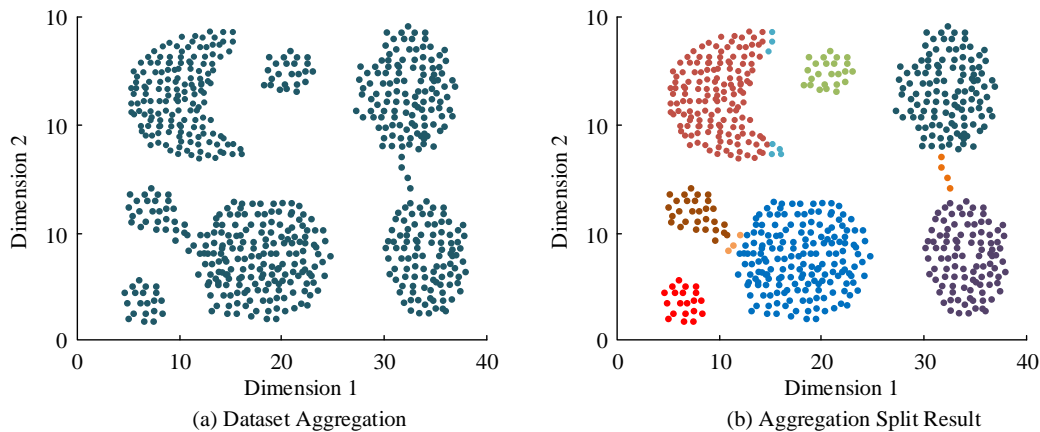


Fig. 4. Cracking effect of improved hierarchical clustering method.

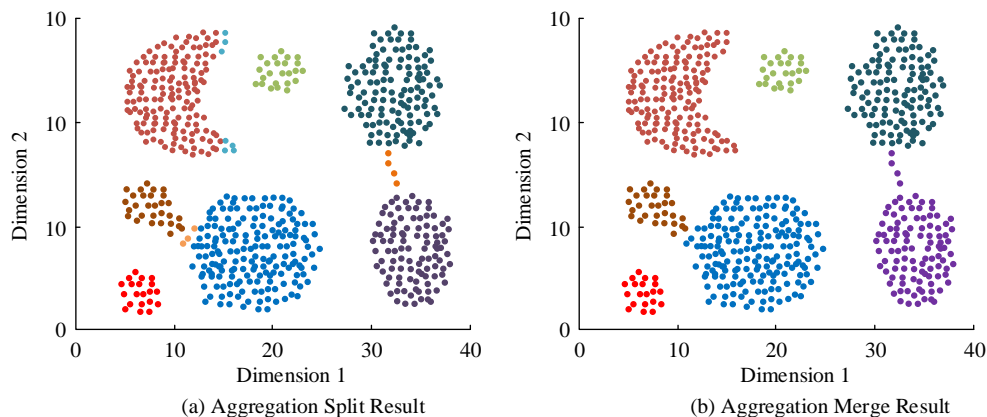


Fig. 5. Merging effect of improved hierarchical clustering method.

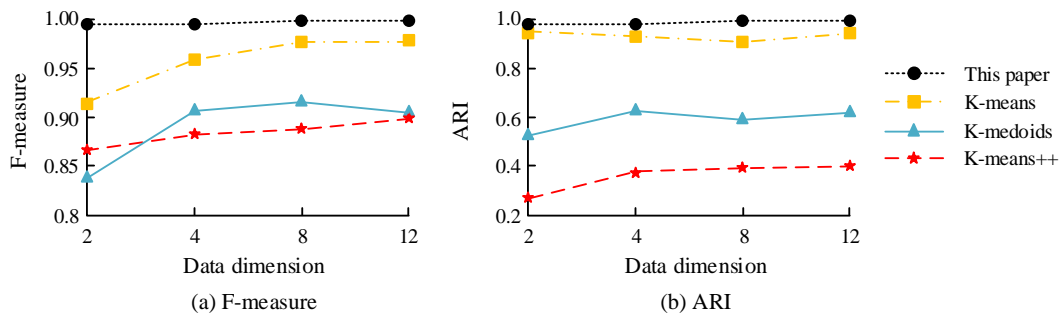


Fig. 6. F-measure and ARI values of the algorithm in different dimensions.

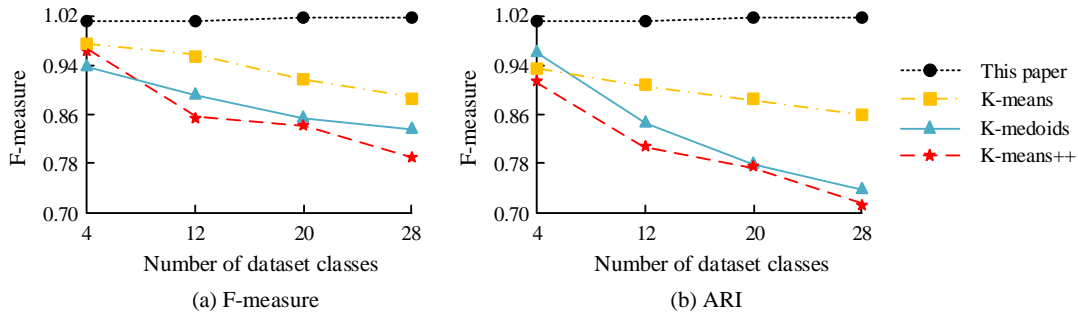


Fig. 7. F-measure and ARI values of the algorithm for different number of classes of the dataset.

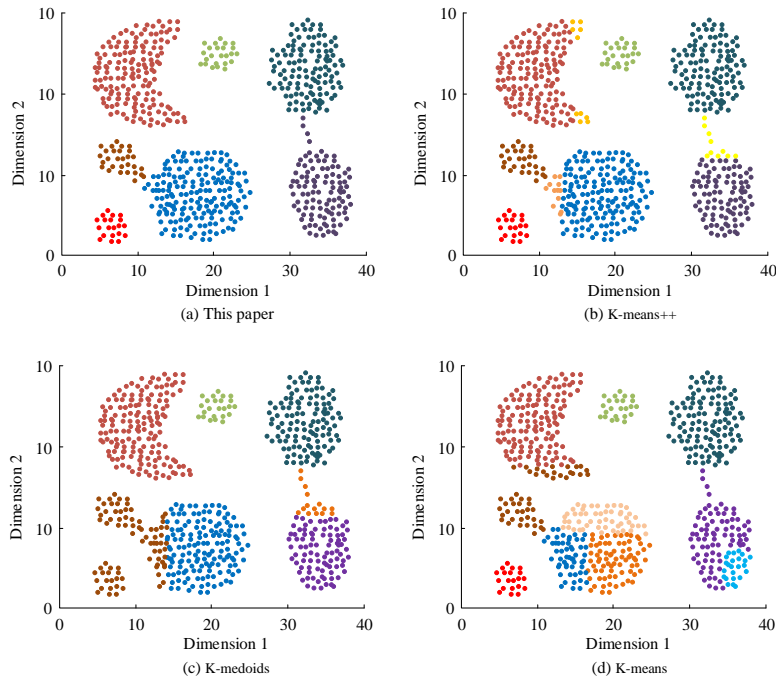


Fig. 8. Comparison of clustering effects of different algorithms.

To further validate the performance of the hybrid clustering method, experiments were conducted to evaluate the performance using Purity validity metrics in eight datasets, which included simulated datasets 1-6 and real datasets 7-8. Table I shows the results in simulated datasets 1-6. When running datasets 1-6, the mean accuracy and mean squared error of the hybrid clustering method were the best among the four algorithms, which were 95.94% vs. 5.89%, 94.72% vs. 0.57%, 89.72% vs. 4.97%, 87.45% vs. 5.53%, 93.83% vs.

5.76%, and 88.43% vs. 5.40%, indicating that the algorithm has higher accuracy. When comparing the clustering analysis of datasets 1 to 6 with different methods, the hybrid clustering method has the highest clustering accuracy, the best clustering effect and the best stability in the six datasets. The hybrid clustering method has significantly improved in terms of accuracy and stability when clustering the simulated datasets. In terms of algorithm runtime, the hybrid clustering method has improved over the other methods.

TABLE I. EXPERIMENTAL RESULTS OF SIX SIMULATED DATA SETS

Algorithm	Parameter	Data set 1		Data set 2		Data set 3		Data set 4		Data set 5		Data set 6	
		Mean value	Mean square value	Mean value	Mean square value	Mean value	Mean square value	Mean value	Mean square value	Mean value	Mean square value	Mean value	Mean square value
This paper	P(%)	95.94	5.89	94.72	0.57	89.72	4.97	87.45	5.53	93.83	5.76	88.43	5.40
	Time consuming(ms)	52.42	6.05	372.96	68.54	256.03	22.18	387.07	21.17	46.37	12.10	134.06	24.19
K-means++	P(%)	93.24	6.55	93.93	1.87	83.41	8.01	85.17	8.71	90.94	8.86	84.19	6.58
	Time consuming(ms)	48.38	18.14	158.26	27.22	163.30	33.26	186.48	51.41	32.26	13.10	108.86	30.24
K-medoids	P(%)	92.62	8.72	87.19	6.69	83.07	6.15	85.34	5.61	85.84	12.92	78.50	9.15
	Time consuming(ms)	25.20	4.03	74.59	15.12	79.63	10.08	92.74	18.14	19.15	6.05	47.38	11.09
K-means	P(%)	91.98	6.38	93.10	2.78	86.07	8.66	85.56	5.86	86.15	6.97	83.43	5.52
	Time consuming(ms)	56.45	14.11	192.53	49.39	131.04	25.20	201.60	51.41	31.25	12.10	102.82	24.19

TABLE II. EXPERIMENTAL RESULTS OF TWO REAL DATA SETS

Algorithm	Parameter	Data set 7		Data set 8	
		Mean value	Mean square value	Mean value	Mean square value
This paper	P(%)	89.71	6.17	88.85	0.33
	Time consuming(ms)	28.22	6.05	24.19	2.02
K-means++	P(%)	81.32	10.77	88.56	0.34
	Time consuming(ms)	24.19	6.05	18.14	3.02
K-medoids	P(%)	86.15	11.29	85.20	7.65
	Time consuming(ms)	9.07	3.02	17.14	2.02
K-means	P(%)	85.48	9.35	82.03	10.45
	Time consuming(ms)	20.16	4.03	35.28	8.06

V. RESULTS AND CONCLUSIONS

The results obtained in the real dataset are presented in Table II. The hybrid clustering method has the best quality and stability of clustering results with the best accuracy mean and accuracy mean squared error of 89.71 % vs. 6.17 % and 88.85 % vs. 0.33 %, respectively, when dealing with datasets 7 and 8. When comparing the clustering analysis of the real datasets 7 and 8 with different methods, the hybrid clustering method has the highest clustering accuracy, the best clustering effect and the best stability in these two datasets. The results indicate that the hybrid clustering method has significantly improved in terms of accuracy and stability when clustering analysis is performed on the real dataset. The results from the real and simulated datasets mentioned above show that the algorithm proposed in this experiment can handle datasets of any shape and different distributions. And this algorithm has higher accuracy compared to most current clustering algorithms. This is because the algorithm proposed in this experiment can avoid the problem of missed or incorrect selection when selecting cluster centers. Therefore, this algorithm can correctly classify samples. At the same time, this method introduces a similarity measurement method. It can be used to process datasets with different types and uneven sample distribution. At the same time, the treatment of noise points was added in the experiment. This can effectively handle the impact of noise points on clustering results.

The improvement of data mining technology promotes the efficiency of commercial data application. In existing research, the K-means clustering algorithm can effectively handle data of different scales. In order to improve the ability of traditional clustering algorithms to determine the cluster center, some scholars proposed a hierarchical clustering analysis method [8]. This method can reduce the subjective factors affecting the determination of k-values in traditional clustering methods. However, this method requires a large amount of computation and cannot trace back to the intermediate clustering process. For this reason, an improved hierarchical clustering algorithm is proposed in the experiment, which is generated in the split phase and the merge phase. This algorithm can combine the algorithm with density clustering methods while considering noise point processing, achieving automatic determination of clustering centers and improving clustering performance. For the original Aggregation dataset, the improved hierarchical clustering method can crack the original samples to obtain multiple subclasses. Then these subclasses with consistent attributes are merged in the merging stage to get more accurate classification results, and the clustering accuracy of this method is 99.21%. Under different dimensions, the highest F-measure index and ARI values of the hybrid clustering

method proposed in this experiment are 0.997 and 0.998, respectively. Under different numbers of classes in the data set, the highest F-measure index and ARI values of the hybrid clustering method are 1.000 and 0.999, respectively, which are higher than those of the K-means, K-medoids, and K-means++ methods. When running simulated datasets 1 to 6, the mean and mean squared error of the hybrid clustering method were the best among the four algorithms, with 95.94% vs. 5.89%, 94.72% vs. 0.57%, 89.72% vs. 4.97%, 87.45% vs. 5.53%, 93.83% vs. 5.76%, and 88.43% vs. 5.40 %, respectively, indicating that the algorithm has higher accuracy. When dealing with the real data sets 7 and 8, the hybrid clustering method has the best accuracy mean, and accuracy mean squared error of 89.71% versus 6.17% and 88.85% versus 0.33%, respectively. From the results, F-measure index and ARI values of the hybrid clustering method do not change due to the influence of dimensionality and the number of classes in the dataset, and the quality and stability of its clustering results are better. The validation results in different datasets show that the method established in this experiment can handle datasets of any shape and different distributions. And this algorithm has higher accuracy compared to most current clustering algorithms. Compared to the K-means, K-medoids, and K-means++ methods in references [19-21], its F-measure, ARI indicators, accuracy, and other indicators are higher, and they have certain advantages. This is because the algorithm proposed in this experiment can avoid the problem of missed or incorrect selection when selecting cluster centers. Therefore, this algorithm can correctly classify samples. At the same time, this method introduces a similarity measurement method. It can be used to process datasets with different types and uneven sample distribution. At the same time, the treatment of noise points was added in the experiment. This can effectively handle the impact of noise points on clustering results. Although the method proposed in this experiment can correctly and effectively handle different types of data, there are still some shortcomings in this method. As the amount of data increases, the clustering performance of the method will decrease. The dataset used in this experiment has a smaller scale. The application effect of the improved method in large-scale data is still uncertain. Therefore, improving the ability of clustering algorithms to handle massive amounts of data is an important task in the subsequent work of this article. In addition, the data in real life is quite complex and noisy. This will affect the stability of the clustering algorithm. Therefore, how to effectively improve the anti-interference ability and practicality of clustering algorithms, as well as further enhance the algorithm's ability to process real data, is one of the next directions that need to be studied.

REFERENCES

- [1] Tao D, Yang P, Feng H. Utilization of text mining as a big data analysis tool for food science and nutrition. *Comprehensive Reviews in Food Science and Food Safety*, 2020, 19(2): 875 - 894.
- [2] Alim A, Shukla D. Sampling - based estimation method for parameter estimation in big data business era. *Journal of Advances in Management Research*, 2020, 18(2): 297 - 322.
- [3] Cope J M, Gertseva V. A new way to visualize and report structural and data uncertainty in stock assessments. *Canadian Journal of Fisheries and Aquatic Sciences*, 2020, 77(8): 1275 - 1280.
- [4] Jiang L. A Study on the Application of Statistical Analysis Method of Big Data in Economic Management. *Journal of Commercial Economics*, 2020, 3(3): 69 - 72.
- [5] Ciobotaru G, Chankov S. Towards a taxonomy of crowdsourced delivery business models. *International Journal of Physical Distribution & Logistics Management*, 2021, 51(5) : 460 - 485.
- [6] Han H, Zhou M C, Shang X, et al. KISS+ for Rapid and Accurate Pedestrian Re - Identification. *IEEE Transactions on Intelligent Transportation Systems*, 2020, 22(1): 394 - 403.
- [7] Zeng F, Zhang W, Zhang S, Zheng N. Re - KISSME: A robust resampling scheme for distance metric learning in the presence of label noise. *Neurocomputing*, 2019, 330(FEB.22): 138 - 150.
- [8] Hulme P E. Hierarchical cluster analysis of herbicide modes of action reveals distinct classes of multiple resistance in weeds. *Pest Management Science*, 2022, 78(3): 1265-1271.
- [9] Arunkumar P M, Kannimathu S. Mining big data streams using business analytics tools: a bird's eye view on MOA and SAMOA. *International Journal of Business Intelligence and Data Mining*, 2020, 17(2): 226 – 236.
- [10] Tao D, Yang P, Feng H. Utilization of text mining as a big data analysis tool for food science and nutrition. *Comprehensive Reviews in Food Science and Food Safety*, 2020, 19(2): 875 - 894.
- [11] WA Xi, ZW B, MSC D, LA Qi, WS A. An adaptive and opposite K - means operation based memetic algorithm for data clustering. *Neurocomputing*, 2021, 437(8): 131 - 142.
- [12] S Liu, Q Lin, KC Wong, CAC Coello, J Zhang. A Self - Guided Reference Vector Strategy for Many - Objective Optimization. *IEEE Transactions on Cybernetics*, 2020, 52(2): 1164 - 1178.
- [13] Molokomme D N, Chabalala C S, Bokoro P N. Enhancement of Advanced Metering Infrastructure Performance Using Unsupervised K - Means Clustering Algorithm. *Energies*, 2021, 14(9): 2732 - 2743.
- [14] X Qin, J Li, W Hu, J Yang. Machine Learning K - Means Clustering Algorithm for Interpolative Separable Density Fitting to Accelerate Hybrid Functional Calculations with Numerical Atomic Orbitals. *The Journal of Physical Chemistry A*, 2020, 124(48): 10066 - 10074.
- [15] Dressler M, I Paunović. Business Model Innovation: Strategic Expansion of German Small and Medium Wineries into Hospitality and Tourism. *Administrative Sciences*, 2021, 11(4): 146 - 157.
- [16] Reyes - Ruiz G, M Hernández - Hernández. Fuzzy clustering as a new grouping technique to define the business size of SMEs through their financial information. *Journal of Intelligent and Fuzzy Systems*, 2021, 40(2): 1773 - 1782.
- [17] Gubu L, Rosadi D, Abdurakhman A. Robust Portfolio Selection with Clustering Based on B usiness Sector of Stocks . *Media Statistika*, 2021, 14(1): 33 - 43.
- [18] Liashenko O, Kravets T, Prokopenko M. Consumer behavior clustering of food retail chains by machine learning algorithms. *Access Journal*, 2021, 2(3): 234 - 251.
- [19] Sailekha K, Deluxni N. Comparative Analysis of Customer Behaviour using K - means Algorithm Over Convolutional Neural Network with Increase Inaccuracy of Prediction. *ECS transactions*, 2022, 107(1): 12459 - 12471.
- [20] Lund B, Ma J. A review of cluster analysis techniques and their uses in library and information science research: k - means and k - medoids clustering. *Performance measurement and metrics: The international journal for library and information services*, 2021, 22(3): 161 - 173.
- [21] Xiong Z, Li J, Wu H, et al. Understanding operation patterns of urban online ride - hailing services: A case study of Xiamen. 2021, 101(C): 100 - 118.

From Monolith to Microservice: Measuring Architecture Maintainability

Muhammad Hafiz Hasan¹, Mohd. Hafeez Osman², Novia Indriaty Admodisastro³, Muhamad Sufri Muhammad⁴
Dept. of Soft. Engineering and Information System-FSKTM, UPM, Serdang, Selangor, Malaysia^{1, 2, 3, 4}

Abstract—The migration of monolithic applications to the cloud is a popular trend, with microservice architecture being a commonly targeted architectural pattern. The motivation behind this migration is often rooted in the challenges associated with maintaining legacy applications and the need to adapt to rapidly changing business requirements. To ensure that the migration to microservices is a sound decision for enhancing maintainability, designers must carefully consider the underlying factors driving this software architecture migration. This study proposes a set of software architecture metrics for evaluating the maintainability of microservice architectural designs for monolith to microservice architecture migration. These metrics consider various factors, such as coupling, complexity, cohesion, and size, which are crucial for ensuring that the software architecture remains maintainable in the long term. Drawing upon previous product quality models that share similar design properties with microservice, we have derived maintainability metrics that can help measure the quality of microservice architecture. In this work, we introduced our first version of structural metrics for measuring the maintainability quality of microservice architecture concerning its cloud-native characteristics. This work allows us to get early feedback on proposed metrics before a detailed evaluation. With these metrics, designers can measure their microservice architecture quality to fully leverage the benefits of the cloud environment, thus ensuring that the migration to microservice is a beneficial decision for enhancing the maintainability of their software architecture applications.

Keywords—Monolith; cloud migration; software architecture; design quality; maintainability; quality metric

I. INTRODUCTION

In recent years, the demand for online applications and services has increased. Organizations and businesses with online applications perceive cloud platforms as a promising future for business strategy to remain competitive. For an organization with an existing legacy application that involves the organization's core business process, migrating the application to the cloud is more imminent to utilize cloud benefits and ensure business continuity. These applications often have monolithic software architecture, which does not consider modularity in its design principle [1], and the systems work in a silo [2]. In monolith architecture, developers develop the entire application as a single unit with a large codebase and tightly integrated components, increasing complexity and making it difficult to manage and scale [3]. These characteristics also affect its deployment approach when any minor changes to the application require a complete rebuild, leading to increased risk [4].

The motivation of the legacy application to cloud migration is to overcome the roadblocks and limitations of monolith applications [5] and to achieve cloud-native benefits such as improving application modifiability, maintainability, scalability, and deployability [6]. The cloud platform provides scalability for computing resources without worrying about the underlying infrastructure quickly and efficiently [7]. The organization also gains more flexibility and agility in responding to changing business ideas, thus increasing service innovation. However, not all migration strategies to the cloud provide mentioned benefits [8]. The *Lift-and-Shift* approach involves taking existing *as-is* on-premise applications and moving them to the cloud as a single service without architecture and design changes limiting its cloud scalability features [9].

In contrast, the microservice is a cloud architecture design pattern designed to provide better scalability and maintainability. In a microservice architecture, designers create sets of independent services that use API as their communication medium. Each microservice is responsible for specific business capabilities, strong component separation, and independent deployability execution [1], [5], [10]. Other fundamental properties of microservice architectural design are low coupling, high cohesion, and modularity [10] must be carefully considered by developers and designers [11], [12] during the design phase.

In the cloud migration context, migrated application quality should be equivalent to, or better than, legacy monolith applications. Software errors can stem devastating effects to financial loss, time delays, or even risks to life [13], [14]. Numerous frameworks for migrating from monolith to cloud have been introduced [1], [15]-[18], yet they still do not adequately address quality considerations after the migration [19]. Therefore, the migration did not accomplish its objective [5], thus introducing new product quality challenges such as application maintainability, security, reliability, and compatibility [8], [20].

From a technical standpoint, migrating monolith applications to the cloud allows for quick and effective implementation of essential software changes to meet current business needs. The relevant quality attribute is known as maintainability, which expresses the degree of effectiveness and efficiency with which an application can be changed, modified, or corrected to meet requirements [21]. Therefore, it is essential to ensure that migrated applications must be maintainable by developers to avoid accumulated waste and technical debt after the migration [22]-[24]. Thus, maintainability has become an essential quality feature [25].

However, empirical research on maintainability quality assurance remains a missing research area for microservice architecture [26]. To address this concern, the following research questions have been formulated to guide this study:

- RQ1: What are the existing structural quality metrics that relate to service-based architecture?
- RQ2: How do the existing structural metrics relate to cloud-native characteristics?
- RQ3: What are the feasible metrics for the maintainability quality model for microservice architecture?

This paper proposes the structural metrics for measuring microservice maintainability quality, focusing on microservice architecture migration. A multi-structural design metrics consisting of coupling, cohesion, complexity, and size form the basis of the maintainability measurement. These metrics help practitioners evaluate the architecture maintainability quality at the earlier migration phase to minimize post-migration technical debt, thus ensuring the achievable migration objective [6].

The remainder of this paper is organized as follows. Section II discusses related works with some comments on their limitations. Section III describes the research methodology for identifying existing service-based structural metrics. Section IV discusses how the existing structural metrics can be associated with cloud-native characteristics. Section V further discusses structural metrics from maintainability quality. Section VI briefly introduces our proposed maintainability quality model, followed by a discussion in Section VII. Finally, Section VIII concludes with a summary and outlook on potential follow-up research.

II. RELATED WORK

The software quality model's development reflects the software architecture's progression. A robust quality model approach is necessary for measuring product architecture quality, regardless of the adopted software architecture. Thus, this work explores previous works on software quality models and monolith-to-microservice migration approaches to identify reliable and valid metrics to evaluate software design quality.

A. Software Quality Model Evolution

One of the first software product quality models introduced by [27] describes as a generic model that separates high-level quality attributes into tangible product quality properties. Due to rapidly changing and dynamic business requirements, different metrics have been proposed to meet software architecture evolutions.

In their work, Bansiya et al. [13] proposed an improved hierarchical design quality assessment model for object-oriented software architecture. This model, known as the Quality Model for Object-Oriented Design (QMOOD), builds upon Dromeys's generic quality model methodology. The QMOOD comprises four hierarchical levels: object-oriented design components, design metrics, design properties, and design quality attributes. Notably, the authors adopted most of the design quality attributes in QMOOD from the ISO/IEC

9126 standard. However, this model failed to serve simple, practical applicability as it assesses high-level design quality attributes. Hence the metrics are limited for object-oriented applications.

SOA Quality Model (SOAQM) is an extension of QMOOD to enhance architecture scalability through hierarchical abstraction and clear bottom-up relationship [28]. Bogner et al. [29] suggest that most metrics explicitly designed for SOA also apply to microservice architecture. The author then introduces the Maintainability Model for Microservices (MM4S) with five service properties: coupling, cohesion, granularity, complexity, and code maturation. Although this work is similar to ours, the authors did not consider migration scenarios, hence providing the mathematical formalization for proposed metrics.

Vera-Rivera et al. [30] conducted a systematic literature review on microservice architecture, explicitly focusing on the impact of microservice granularity on application quality. The authors employed a genetic algorithm to determine the optimal microservice granularity based on key factors such as coupling, cohesion, complexity, and resource usage. They integrated various metrics and quality attributes into their analysis with the development team's involvement for effort estimation based on user story artefacts.

Pulnil et al. [31] and Taibi et al. [32] proposed a microservice quality model that relies on microservice anti-patterns. The authors incorporated eleven microservice anti-patterns with the ISO/IEC 25010 standard as a benchmark for microservice quality attributes, while this work builds on top of microservice design principles [33]. Furthermore, the proposed quality assessment model is formulated depending on the weightage of the harmfulness level of the design properties exposing it to the biased decision by the designer.

B. Microservice

Microservice is an architecture design pattern that promises high maintainability, making it an exciting option for modernizing software during the cloud computing era [23]. Generally, microservices have been designed based on domain-driven functionality with limited business capabilities, strong component separation, and enabling automated deployment execution [1], [5], [10].

The developer and designer must carefully consider the fundamental properties of microservices, which include low coupling, high cohesion, scalability, independence, maintainability, modularity, and deployability [10]. These properties are closely related to architectural design [11], [12].

Chen et al. [34] proposed a monolith decomposition approach from a dataflow diagram viewpoint, while Fan et al. [24] suggested microservice candidate identification through domain-driven design analysis. Runtime behaviour information [35] strategy and Functionality-oriented Service Candidate Identification (FoSCI) framework introduced by [36] to identify service candidates using a search-based functional atom grouping algorithm based on recorded monolith's execution trace log. Combining the data usage with the dynamic analysis provides a better understanding of feature prioritization during the migration. The static approach based on source code [37], [38] and system structure [23] exhibits

structural information as decomposition reasoning. Meanwhile, the metric-based method, as demonstrated by previous works, uses structural properties such as coupling [37], [39], [40], service granularity [41], size [42], and cohesion [43].

Li et al. [44] introduced a method for identifying microservices based on the UML model from the source code as an input consisting of class and sequence diagrams for static and dynamic analysis. The authors then used a clustering approach to identify microservice candidates. The determination of clustering output quality relied on the utilization of functional requirements and deployment constraints. However, the authors did not consider microservice distributions to verify the architecture quality. At the same time, the ambiguity of language and contextual understanding prevents semantic-based analysis of the system requirements from guaranteeing the attainment of optimal solutions [45].

Our work extends and complements [28], [29] in the context of a structural quality model for the service-based application. Bingu et al. [28] did not consider maintainability quality in their model besides re-implementing weighted value by [13] in their quality attribute equation without necessary empirical justification. While Bogner et al. In [29] approach are beneficial for microservice maintainability design properties, the authors did not consider the migration scenario, thus limiting its applicability to the greenfield implementation. So, while the general approach from Bogner et al. is a sound foundation, this work established it to fit monolith to microservice migration scenario and enhanced it with practically collectable quality metrics for the architecture design consideration.

III. METHODOLOGY

In order to formulate the architectural maintainability quality model for monolith to microservice migration, this study followed a series of steps, as illustrated in Fig. 1. As this work highlights the monolith to microservice migration scenario, it started with a literature review process using trustable electronic journal databases for this research domain [46] consists of Scopus, SpringerLink, IEEE Xplore, and ScienceDirect to collect existing structural quality metrics.

Our initial investigation shows that the software quality model evolves laterally with software architecture advancement [29]. For this reason, pre-migration monolith object-oriented structural quality metrics [13], [47]-[49] and post-migration microservice architecture quality metrics [50]-[54] are included. Next, the object-oriented structural metrics are being mapped with microservice structural metrics based on their shared characteristics, as suggested by [47], [55]-[57]. These structural metrics help understand its relationships further, clarifying the evolution of the software quality model. Section IV explains this step's detailed approach and findings, thus answering RQ1.

The selection of structural maintainability quality metrics is guided by ISO/IEC 25010 – Software Product Quality. This product quality model comprises of hierarchical structure with maintainability quality attributes consisting of its sub-characteristics such as modularity, reusability, analyzability,

modifiability, and testability [21]. Detailed methodology for this step is described in Section V, hence answering RQ2.

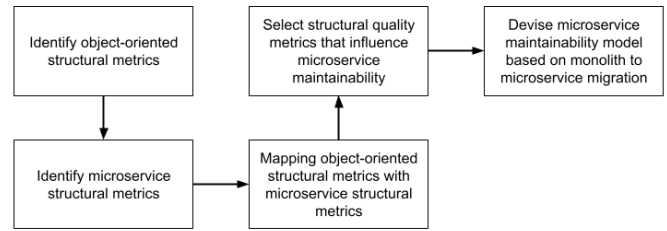


Fig. 1. The methodology of the monolith to microservice architectural maintainability quality model development.

Furthermore, software quality is still a vague and multifaced perception, which means different things to a diverse audience [13]. Therefore, referring to the procedure in Section VI, an empirical microservice maintainability quality model (RQ3) was devised based on selected quality metrics for monolith to microservice migration regulated by defined selection criteria in Table I. These selection criteria ensure that the selection process is within the research scope and objective.

TABLE I. CRITERIA FOR METRIC SELECTION

Selection criteria	
-	Applicable to microservice architecture
-	Must be related to cloud-native design properties
-	Automatically collectable from the structural property and practically applicable in object-oriented to microservice migration scenario
-	Influence on ISO/IEC 25010 maintainability characteristic or sub-characteristics

IV. SERVICE-BASED STRUCTURAL QUALITY METRICS (RQ1)

Migrating monolith applications to the cloud involves transforming software architecture to exploit the distributed environment. Due to this factor, the designer must measure software structural quality during the early migration stage. It is cheaper and less time-consuming than evaluating it during operation time [43]. Developers can predict software quality by measuring structural attributes influencing software's external quality, such as maintainability. Besides, measuring structural metrics is more extensive than component-level metrics [43].

Based on the literature review, the most collective existing structural design property metrics for service-based architecture are summarised (as described in Table II) as the following:

A. Coupling

This design property is the most considered metric for measuring software architecture quality. The graph theory of design properties enables the direct analysis of coupling properties. Thirteen metrics have been proposed for measuring microservice coupling [35], [43], [44], [54], [59], [60], while fourteen metrics for service-oriented architecture (SOA) [28], [51], [58], [61]. Expressively, four of the proposed microservice metrics by Bogner et al. [29] were derived from SOA metrics [53] in the context of microservice architecture.

TABLE II. PUBLICATIONS ON QUALITY METRICS FOR A SERVICE-BASED ARCHITECTURE

Source	Authors	Architecture	Focus
[28]	Bingu et al.	Service-Oriented	Effectiveness, understandability, flexibility, reusability, and discoverability based on QMOOD metrics: coupling (1), cohesion (1), complexity (1), size (1), and service granularity (1)
[42]	Taibi et al.	Microservice	Coupling (2) and size (2)
[43]	Panichella et al.	Microservice	Maintainability based on coupling (1), size (1)
[44]	Li et al.	Microservice	Coupling (1) and cohesion (1)
[51]	Mohammed et al.	Service-Oriented	Coupling (3), cohesion (2), and complexity (3) metrics
[53]	Rud et al.	Service-Oriented	Applicability from OOP, CBSE, and Web Domains - complexity (3), reliability (4), and performance (4) metrics
[54]	Bogner et al.	Microservice	Maintainability – coupling (4), cohesion (4), complexity (3), size (1)
[58]	Hofmeister et al.	Service-Oriented	Complexity using coupling (2) metrics
[59]	Santos et al.	Microservice	Complexity consists of cohesion (2) and coupling (2) metrics
[60]	Vera-Rivera et al.	Microservice	Complexity based on cohesion (1), coupling (3)
[61]	Perepletchikov et al.	Service-Oriented	Maintainability by extending OO coupling (8) metrics

B. Size

Four metrics were proposed for microservice [35], [43], [54], and one for service-oriented [28] architecture. The reason for considering fewer size metrics for SOA than for microservice is that the two architectural styles operate at a different level of service granularity. This design property is essential to microservice architecture that promotes smaller atomic functionality than SOA in its design principle.

C. Cohesion

Highly cohesive architecture refers to the strength between operations of services. Cohesion in microservice is more meaningful than for SOA and object-oriented architecture to minimize external dependencies [62] that negatively influence product quality. Eight metrics for microservice cohesion [44], [54], [59], and three metrics for service-oriented [28], [51] were proposed in previous works.

D. Complexity

From the literature review, three metrics for microservices [54] and seven metrics for service-oriented architecture [28], [51], [53] were identified pertaining to this design property. Due to the common structural complexity characteristics for SOA and microservice, Bogner et al. applied three complexity metrics originally proposed for SOA to the microservice architecture.

V. QUALITY METRICS FOR CLOUD-NATIVE ARCHITECTURE (RQ2)

This work defines cloud-native architecture as a distributed, elastic, and horizontally scalable application composed of microservices [63], [64]. Thus, casting the existing legacy application to the cloud as a virtualized environment cannot be demanded as a valid cloud-native application [65]. Moreover, a microservice is a self-contained deployment unit designed according to cloud-focused design principles such as IDEALS [33] to gain full cloud benefits.

Regarding architecture quality, previous design property quality metrics from RQ1 are mapped with IDEALS design principles as in Table III to justify the selection of quality metrics for cloud-native architecture based on defined criteria in Table I.

Instead of designing microservice for a new greenfield scenario, this work focuses explicitly on migrating monolith applications to microservices. This process involves three main phases: pre-migration, migration, and post-migration [67]. Therefore, to answer the following research question RQ3, this work considers monolith quality metrics in the maintainability model, thus devising related metrics based on its common structural characteristics. Identifying related quality metrics during the early migration phase helps the designer to make an informed decision to propose quality microservice architecture design before moving to the cloud environment.

VI. MAINTAINABILITY QUALITY MODEL FOR MICROSERVICE (RQ3)

This paper distinguished existing service-based architecture quality metrics in RQ1. Collected metrics are then aligned with cloud-native characteristics (RQ2) to funnel the microservice architecture-related quality metrics findings.

From the application architectural perspective, a service-based design pattern can be perceived as a higher abstraction layer for object-oriented architecture [68], [69]. One could consider the interaction of methods in object-oriented programming as a form of class interaction in microservices at an abstract level. In contrast, object-oriented class interactions can be understandable at a higher abstraction level as interactions of clusters of classes known as microservice. With this insight, we propose a set of quality metrics to measure microservice structural maintainability described in Fig. 2.

A. Coupling

Coupling is the degree to which the elements in a design are connected or express the strength of interdependencies and interconnections of service with other services [70]. From the quality perspective, these metric impacts system quality, such as maintainability and testability. The findings indicate that incorporating structural coupling can be highly significant for developers who wish to monitor the decomposition quality of their services [43]. A high level of structural coupling resulted in more frequent bug occurrences and propagated changes within modules of systems. Therefore, a successful decomposition should produce minimized coupling between microservices and maximized cohesion. A small number of couplings positively influence product maintainability.

TABLE III. RELATED QUALITY METRICS FOR IDEALS DESIGN PRINCIPLES

Design Principle	Design Property	Related Quality Metrics
Interface segregation	Complexity	Total Response of Service (TRS) [29]
		Service Support for Transactions (SST) [29]
		Measure of Functional Abstraction (MFA) [13]
	Size	Number of Operations [28]
		Non-Extreme Distribution (NED) [55]
		Component Balance [54]
	Cohesion	Service Interface Data Cohesion (SIDC) [29]
		Service Interface Usage Cohesion (SIUC) [29]
		Total Service Interface Cohesion (TSIC) [29]
Deployability	Coupling	Service Interdependence in the System (SIY) [29]
		Coupling Between Microservice (CBM) [35]
		Structural Coupling [43]
		Coupling of Service (COS) [58]
	Complexity	Number of Versions per Service (NVS) [29]
		Number of Hierarchies (NOH) [13]
		Density of Aggregation (DOA) [58]
Event-driven	Coupling	Absolute Dependence of the Service (ADS) [29]
Availability	Coupling	Coupling Between Microservice (CBM) [35]
		Absolute Criticality of the Service (ACS) [29]
		Absolute Dependence of the Service (ADS) [29]
		Service Interdependence in the System (SIY) [29]
	Size	Numer of Operations [28]
	Cohesion	Service Interface Data Cohesion (SIDC) [29]
Service Interface Usage Cohesion (SIUC) [29]		
Loose coupling	Coupling	Service Interdependence in the System (SIY) [29]
		Absolute Importance of the Service (AIS) [29]
		Absolute Dependence of the Service (ADS) [29]
		Absolute Criticality of the Service (ACS) [29]
		Direct Class Coupling (DCC) [13]
		Coupling of Service (COS) [58]
		Structural Coupling [43]
		Coupling Between Microservice (CBM) [35]
Single responsibility	Cohesion	Activity Cohesion (AC) [66]
		Service Cohesion (SC) [66]
		Service Design Cohesion (SDC) [66]

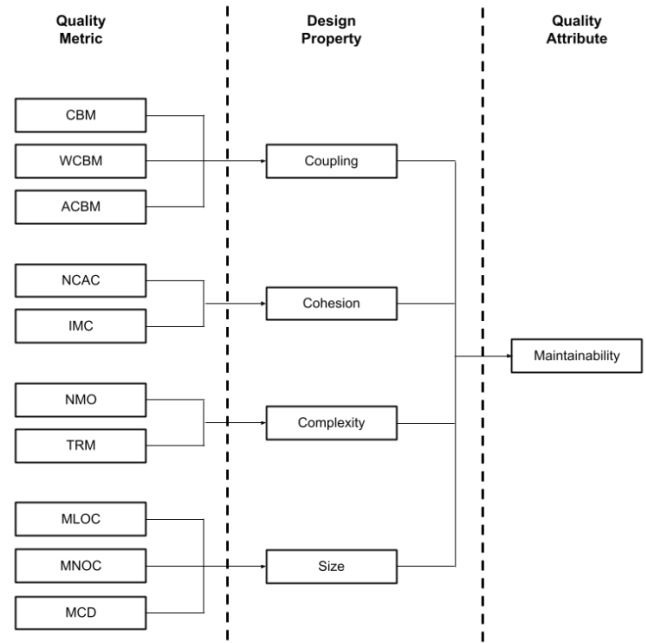


Fig. 2. The structural metric for microservice maintainability.

1) *Coupling Between Microservice (CBM)*: CBM is the number of other microservices that the microservice coupled with [35], [37]. The inspiration for this coupling derives from the widely recognized Coupling Between Objects (CBO) metric proposed by [71]. CBO counts several types of interactions, including method calls, parameter types, references, and return types. However, CBM only counted for each unique class interaction, excluding its frequencies and bi-directional relationship. To calculate the relative CBM for each microservice as follows:

$$M = \{m_1 \dots m_n\} \text{ is a set of microservice} \quad (1)$$

$$R = \{r_1 \dots r_n\} \text{ is a set of microservice interaction} \quad (2)$$

$$\text{TotalofInteraction}(r,m) = \text{Number of occurrence } r \text{ in } m \quad (3)$$

$$CBM(r,m) = \begin{cases} 1 & \text{TotalofInteraction} > 0 \\ 0 & \text{Otherwise} \end{cases} \quad (4)$$

2) *Weighted Coupling between Microservice (WCBM)*: WCBM is the frequency of other microservice that the microservice m is coupled with, i.e., the number of microservices where m has to interact once [29], [58]. As microservice holds clusters of classes, interactions with other microservices are more expensive than intra-microservice. Thus, frequencies for external microservice coupling need to be considered as interaction weightage. To formulate WCBM for each microservice as follows:

$$WCBM(r,m) = \text{TotalofInteraction}(r,m) \quad (5)$$

Absolute Coupling between Microservice (ACBM): The total number of bi-directional coupling frequencies between microservices where microservice $m1$ interacts with microservice $m2$ and $m2$ also interacts with $m1$ [29]. This metric helps represent inter-microservice dependencies and

how strongly they interact. ACBM for a microservice is represented as:

$$B=\{b_1...b_n\} \text{ is a set of bi-directional interactions} \quad (6)$$

$$\text{TotalofBidirectional}(b,m)=\text{Number of occurrence } b \text{ in } m \quad (7)$$

B. Cohesion

The degree to which the elements in a microservice design unit are logically related or connected. A high degree of cohesion is a sign of “togetherness” where classes within the microservice provide similar behavior to produce specific services or responsibilities. This characteristic matches the ideal cloud-native design pattern, where each microservice should contain a single responsibility for better maintainability.

1) *Normalize Cohesion among Classes of Microservice (NCAM)*: The NCAM for Microservice is an adaptation of the object-oriented metric Cohesion Among Methods of Class (CAM) [13]. A CAM cluster directly influences the microservice m cohesion in migration to microservice architecture. Thus, m cohesion can be served with an average CAM for a particular m . To represent NCAM for a microservice as follows:

$$\text{NCAM}(m_i)=1-\text{Avg}(\text{CAM}(m_i)) \quad (8)$$

2) *Intra Microservice Coupling (IMC)*: IMC is the frequency of internal microservice coupling. In compliance with [13], microservice architecture obtains higher object-oriented design abstraction. Therefore, strong relatedness and interactions between classes within the microservice m indicate strong m cohesion. This strong relatedness demonstrates that each class in a microservice is working together to serve specific functions. IMC for a microservice is represented as follows:

$$C=\{c_1...c_n\} \text{ is a set of classes in } m \quad (9)$$

$$P=\{p_1...p_n\} \text{ is a set of class interaction} \quad (10)$$

$$\text{TotalClassInteraction}(p,m)=\text{Number of occurrence } p \text{ in } m \quad (11)$$

$$\text{IMC}(m_i)=\text{TotalClassInteraction}(p,m) \quad (12)$$

C. Complexity

Complexity is the degree of connectivity between elements of a microservice. This metric is also concerned with the dependencies, microservice operations, and the number of requests with other microservices. Santos et al. [59] derived that complexity architecture has a negative impact on the system’s maintainability as it is difficult to make changes and decreases software understanding.

1) *Number of Microservice Operations (NMO)*: NMO is the number of total operations for the microservices [28]. In migrating from monolith to microservice architecture, the total number of microservice operations encompasses all operations across all classes of the microservice. A high number of internal microservice operations may result in a complex design that requires maintenance. With an increase in the

number of clusters, the structural complexity of the microservice also grows. NMO for a microservice is represented as follows:

$$O=\{o_1...o_n\} \text{ is a set of operation in } c \quad (13)$$

$$\text{TotalOperation}(o,c)=\text{Sum of } o \text{ in } c \quad (14)$$

$$\text{NMO}(m_i)=\text{TotalOperation}(o,c) \text{ in } m \quad (15)$$

2) *Total Response for Microservice (TRM)*: TRM is the total requests for operation O values of microservice [29]. This work employed an adapted version of the Response for Class (RFC) metric [71] from object-oriented design to the context of microservice design. Each microservice exposes its interface m_i for other microservices, increasing its dependencies and negatively impacting its complexity. TRM for a microservice can be expressed as:

$$\text{TRM}(m_i)=\sum \text{RFC}(m_i) \quad (16)$$

D. Size

This metric measures the size of structural design elements consisting of the number of classes and microservice lines of code. The more extensive and granular the microservice, the more challenging it is to maintain due to the possibilities of multiple responsibilities to the microservice. Size metrics are crucial design attributes in software estimation before executing migration [72].

3) *Microservice Line of Code (MLOC)*: The number of all non-empty, non-commented lines of the microservice body. This classic Line of Code (LOC) metric helps understand and overview microservice size. For a too-big microservice, there might be a sign that a technical debt problem exists. MLOC for a microservice is expressed as follows:

$$\text{MLOC}(m_i)=\sum (\text{NE} \ \&\& \ \text{NC})m_i \quad (17)$$

where $(NE \ \&\& \ \text{NC})$ are non-empty NE and non-commented NC lines of codes within a microservice m_i .

4) *Microservice Number of Classes (MNOC)*: The number of classes within a microservice [35] can measure how big the microservice is and identify if there are microservices that are too big. The number of classes should be minimized to keep microservice more independent of changes. MNOC for a microservice represents as:

$$\text{MNOC}(m_i)=\sum C(m_i) \quad (18)$$

where $C(m_i)$ are sets of classes within a microservice m_i .

5) *Microservice Class Distribution (MCD)*: MCD is the number of class sizes in microservice candidates distribution, with a desire that microservice may not contain too many or too few classes. This structural metric is an adaptation of the Non-extreme Distribution (NED) metric by [55]. Therefore, we measure how evenly distributed the sizes for each generated microservice candidate are. Our work improvised this approach by using standard deviation to understand the average of scattered microservice clusters instead of the mean

value that is heavily influenced by outliers value in determining the bound of non-extreme value for the number of classes within microservices. For better interpretability, measuring *I-MCD*, with a lower value demonstrates a better microservice distribution. To express MCD for a microservice as follows:

$$MCD(m_i) = \frac{\sum_{n=1, n \text{ not extreme}}^N c_n}{|C_i|} \quad (19)$$

where c_n is the number of classes in microservice m_i , and C_i is the set of classes of microservice m_i . n is not extreme if its size is within the bounds of $\{mean \text{ of classes for all microservices} \pm std \text{ deviation}\}$. This work measures its normalized value with $I-MCD(m_i)$ for better interpretability, and lower values are recommended.

VII. DISCUSSION

Measuring architecture quality for migrated monolith applications to microservice is crucial to ensure migration to the cloud achieves the migration objective. Despite various migrations approaches, less attention was given to the post-migration architecture quality. This work starts by identifying existing structural metrics for measuring service-based architecture quality. Our first contribution in this work is reporting the most applicable design property metrics for service-based architecture, including its influence on architecture quality (Section IV). This design property catalogue is a reference for other researchers in understanding how software architecture evolution influences the characteristics of its design properties.

Another state-of-the-art contribution of this paper is that it maps service-based quality metrics with the cloud-native design principles [33]. In contrast, previous quality metrics [13], [28] focus on the structural characteristics without considering architecture quality. From the structural quality perspective, this mapping is essential to ensure the designated cloud architecture pattern benefits from the cloud environment.

The proposed maintainability quality model for microservice architecture is the main contribution to this work. Ten structural quality metrics for measuring microservice architecture maintainability quality enable software designers and developers to assess the designed microservice candidate's quality before executing the migration, thus minimizing post-migration quality concerns and ensuring achievable migration objectives [6], [77], [78]. Despite relying on single design property in measuring structural maintainability quality, this approach promotes multiple design properties to give better accuracy and consistent result [79].

While this work pointed out several quality metrics related to microservice design properties, this work is still exposed to construct validity as we may not be able to cover all design properties [47] that influence monolith-to-microservice migration architecture quality [73]. However, this work covers various design properties than previous work [61], [74], [75] on architectural maintainability quality. Our approach is based on ISO/IEC 25010 [21] and additional structural design properties that influence maintainability quality measurement.

Regarding external validity, some of the metrics devised from existing work [13], [28], [29], [35], [55], [58], [71] are based on shared structural characteristics. This work ensured the soundness of the selected metrics by exclusively considering reliable peer-reviewed sources and established authors. Hence, our selection is adequate to initiate an exploration for microservice maintainability quality when migrating from monolith architecture.

This method relies on the monolith application as the source before the migration execution. This work focuses on migration instead of greenfield implementation. Thus, the selection of the quality metrics is heavily influenced and devised by the existing application architecture characteristics. Even though other works proposed various quality metrics for measuring product quality, the complexity of the metrics hindered the applicability of the approach by the industries [76]. As a result, our proposed quality metrics are more practical for industrial practice.

The limitation of this paper is that we did not adopt a more rigorous methodology for this paper, such as conducting a systematic or multivocal literature review. These procedures could have offered a more solid empirical basis for selecting publications. Moreover, a more rigorous process could have been employed to identify the metric candidates presented in this study to minimize any potential subjective bias. Additionally, certain digital libraries were excluded from the search process due to time limitations.

VIII. SUMMARY AND CONCLUSION

To measure architecture maintainability quality when migrating monolith applications to microservice architecture, this paper proposed a set of metrics related to coupling, cohesion, complexity, and size design property. These metrics were derived from cloud-native architectural design principles to utilize cloud benefits. The proposed metrics allow migration designers and developers to measure software architecture maintainability quality for microservice during design time. Additionally, this work included the mathematical formalization of the proposed metrics. Moreover, applying multiple design properties for measuring microservice architecture maintainability quality is an adaptation of state-of-the-art in this research domain.

As part of this work evaluation process, we intend to assess the metrics through case studies and extend their application to real-world industrial projects to evaluate their efficacy. These forthcoming efforts encompass the development of a tooling approach aimed at promoting a structured and rational migration process and providing practical illustrations of metric implementation throughout the migration process to evaluate the architecture quality of microservice candidates.

REFERENCES

- [1] A. Megargel, V. Shankaraman, and D. K. Walker, "Migrating from Monoliths to Cloud-Based Microservices: A Banking Industry Example," no. August, pp. 85–108, 2020, doi: 10.1007/978-3-030-33624-0_4.
- [2] A. S. Ganesan and T. Chithralekha, "A Survey on Survey of Migration of Legacy Systems," *ACM Int. Conf. Proceeding Ser.*, vol. 25-26-Aug, 2016, doi: 10.1145/2980258.2980409.

- [3] F. De Angelis and A. Polini, "Evaluation of cloud portability of legacy applications," *Proc. - 11th IEEE/ACM Int. Conf. Util. Cloud Comput. Companion, UCC Companion 2018*, pp. 232–237, 2019, doi: 10.1109/UCC-Companion.2018.00061.
- [4] S. A. Maisto, B. Di Martino, and S. Nacchia, "From Monolith to Cloud Architecture Using Semi-automated Microservices Modernization," *Lect. Notes Networks Syst.*, vol. 96, pp. 638–647, 2020, doi: 10.1007/978-3-030-33509-0_60.
- [5] H. Knoche and W. Hasselbring, "Using Microservices for Legacy Software Modernization," *IEEE Softw.*, vol. 35, no. 3, pp. 44–49, 2018.
- [6] C. Fehling, F. Leymann, R. Retter, W. Schupeck, and P. Arbitter, *Cloud Computing Patterns*. Vienna: Springer Vienna, 2014.
- [7] M. Armbrust *et al.*, "A view of cloud computing," *Communications of the ACM*, vol. 53, no. 4, pp. 50–58, Apr. 2010, doi: 10.1145/1721654.1721672.
- [8] M. Shuaib, A. Samad, S. Alam, and S. T. Siddiqui, "Why Adopting Cloud Is Still a Challenge?—A Review on Issues and Challenges for Cloud Migration in Organizations," *Adv. Intell. Syst. Comput.*, vol. 904, pp. 387–399, 2019, doi: 10.1007/978-981-13-5934-7_35.
- [9] A. K. Kalia *et al.*, "Mono2Micro: An AI-based toolchain for evolving monolithic enterprise applications to a microservice architecture," *ESEC/FSE 2020 - Proc. 28th ACM Jt. Meet. Eur. Softw. Eng. Conf. Symp. Found. Softw. Eng.*, no. December, pp. 1606–1610, 2020, doi: 10.1145/3368089.3417933.
- [10] J. Lewis and M. Fowler, "Microservices," 2014. <https://www.martinfowler.com/articles/microservices.html> (accessed Mar. 30, 2022).
- [11] D. Taibi, V. Lenarduzzi, and C. Pahl, "Architectural patterns for microservices: A systematic mapping study," *CLOSER 2018 - Proc. 8th Int. Conf. Cloud Comput. Serv. Sci.*, vol. 2018-Janua, pp. 221–232, 2018, doi: 10.5220/0006798302210232.
- [12] M. Grieger, M. Fazal-Baqaie, G. Engels, and M. Klenke, "Concept-based engineering of situation-specific migration methods," in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 2016, vol. 9679, pp. 199–214, doi: 10.1007/978-3-319-35122-3_14.
- [13] J. Bansiya and C. G. Davis, "A hierarchical model for object-oriented design quality assessment," *IEEE Trans. Softw. Eng.*, vol. 28, no. 1, pp. 4–17, 2002, doi: 10.1109/32.979986.
- [14] M. Zhivich and R. K. Cunningham, "The real cost of software errors," *IEEE Secur. Priv.*, vol. 7, no. 2, pp. 87–90, 2009, doi: 10.1109/MSP.2009.56.
- [15] A. Selmadji, A. D. Seriai, H. L. Bouziane, R. Oumarou Mahamane, P. Zaragoza, and C. Dony, "From monolithic architecture style to microservice one based on a semi-automatic approach," *Proc. - IEEE 17th Int. Conf. Softw. Archit. ICSA 2020*, no. Section III, pp. 157–168, 2020, doi: 10.1109/ICSA47634.2020.00023.
- [16] B. Althani, S. Khaddaj, and B. Makoond, "A Quality Assured Framework for Cloud Adaptation and Modernization of Enterprise Applications," *Proc. - 19th IEEE Int. Conf. Comput. Sci. Eng. 14th IEEE Int. Conf. Embed. Ubiquitous Comput. 15th Int. Symp. Distrib. Comput. Appl. to Business, Engi.*, pp. 634–637, 2017, doi: 10.1109/CSE-EUC-DCABES.2016.251.
- [17] K. Sabiri, F. Benabbou, and A. Khammal, "Model driven modernization and cloud migration framework with smart use case," *Lect. Notes Networks Syst.*, vol. 37, pp. 17–27, 2018, doi: 10.1007/978-3-319-74500-8_2.
- [18] I. Pigazzini, F. Arcelli Fontana, and A. Maggioni, "Tool support for the migration to microservice architecture: An industrial case study," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 11681 LNCS, pp. 247–263, 2019, doi: 10.1007/978-3-030-29983-5_17.
- [19] M. H. Hasan, M. H. Osman, N. I. Admodisastro, and M. S. Muhammad, "Legacy systems to cloud migration: A review from the architectural perspective," *J. Syst. Softw.*, p. 111702, Apr. 2023, doi: 10.1016/j.jss.2023.111702.
- [20] A. Patel, N. Shah, D. Ramoliya, and A. Nayak, "A detailed review of Cloud Security: Issues, Threats Attacks," in *Proceedings of the 4th International Conference on Electronics, Communication and Aerospace Technology, ICECA 2020*, Nov. 2020, pp. 758–764, doi: 10.1109/ICECA49313.2020.9297572.
- [21] ISO/IEC, "ISO/IEC 25010:2010, Systems and software engineering — Systems and software Quality Requirements and Evaluation (SQuaRE) — System and software quality models," vol. 1991. 2010.
- [22] V. Lenarduzzi, F. Lomio, N. Saarimäki, and D. Taibi, "Does migrating a monolithic system to microservices decrease the technical debt?," *J. Syst. Softw.*, vol. 169, p. 110710, 2020, doi: 10.1016/j.jss.2020.110710.
- [23] D. Taibi, V. Lenarduzzi, and C. Pahl, "Processes, Motivations, and Issues for Migrating to Microservices Architectures: An Empirical Investigation," *IEEE Cloud Comput.*, vol. 4, no. 5, pp. 22–32, 2017, doi: 10.1109/MCC.2017.4250931.
- [24] C. Y. Fan and S. P. Ma, "Migrating Monolithic Mobile Application to Microservice Architecture: An Experiment Report," *Proc. - 2017 IEEE 6th Int. Conf. AI Mob. Serv. AIMS 2017*, pp. 109–112, 2017, doi: 10.1109/AIMS.2017.23.
- [25] T. Coulin, M. Detante, W. Mouchère, and F. Petrillo, "Software Architecture Metrics: a literature review," 2019, [Online]. Available: <http://arxiv.org/abs/1901.09050>.
- [26] Y. Li, C. Z. Wang, Y. C. Li, J. Su, and C. H. Chen, "Granularity Decision of Microservice Splitting in View of Maintainability and Its Innovation Effect in Government Data Sharing," *Discret. Dyn. Nat. Soc.*, vol. 2020, no. 39, 2020, doi: 10.1155/2020/1057902.
- [27] R. G. Dromey, "A model for software product quality," *IEEE Trans. Softw. Eng.*, vol. 21, no. 2, pp. 146–162, 1995, doi: 10.1109/32.345830.
- [28] S. Bingu, C. Siho, K. Suntae, and P. Sooyong, "A design quality model for service-oriented architecture," *Neonatal, Paediatr. Child Heal. Nurs.*, pp. 403–410, 2008, doi: 10.1109/APSEC.2008.32.
- [29] J. Bogner, S. Wagner, and A. Zimmermann, "Automatically measuring the maintainability of service- and microservice-based systems - a literature review," *ACM Int. Conf. Proceeding Ser.*, vol. Part F1319, no. October, pp. 107–115, 2017, doi: 10.1145/3143434.3143443.
- [30] F. H. Vera-Rivera, C. Gaona, and H. Astudillo, "Defining and measuring microservice granularity—a literature overview," *PeerJ Comput. Sci.*, vol. 7, p. e695, 2021, doi: 10.7717/peerj-cs.695.
- [31] S. Pulnil and T. Senivongse, "A Microservices Quality Model Based on Microservices Anti-patterns," *2022 19th Int. Jt. Conf. Comput. Sci. Softw. Eng. JCSSE 2022*, 2022, doi: 10.1109/JCSSE54890.2022.9836297.
- [32] D. Taibi, V. Lenarduzzi, and C. Pahl, "Microservices Anti-patterns: A Taxonomy," in *Microservices*, Cham: Springer International Publishing, 2020, pp. 111–128.
- [33] P. Merson, "Principles for Microservice Design: Think IDEALS, Rather than SOLID," *InfoQ*, pp. 1–11, Sep. 2020, Accessed: Jun. 09, 2021. [Online]. Available: <https://www.infoq.com/articles/microservices-design-ideals/>.
- [34] R. Chen, S. Li, and Z. Li, "From Monolith to Microservices: A Dataflow-Driven Approach," *Proc. - Asia-Pacific Softw. Eng. Conf. APSEC*, vol. 2017-Decem, pp. 466–475, 2017, doi: 10.1109/APSEC.2017.53.
- [35] D. Taibi and K. Systä, "From monolithic systems to microservices: A decomposition framework based on process mining," *CLOSER 2019 - Proc. 9th Int. Conf. Cloud Comput. Serv. Sci.*, no. Closer, pp. 153–164, 2019, doi: 10.5220/0007755901530164.
- [36] W. Jin, T. Liu, Y. Cai, R. Kazman, R. Mo, and Q. Zheng, "Service Candidate Identification from Monolithic Systems based on Execution Traces," *IEEE Trans. Softw. Eng.*, pp. 1–1, 2019, doi: 10.1109/tse.2019.2910531.
- [37] S. Eski and F. Buzluca, "An automatic extraction approach - Transition to microservices architecture from monolithic application," *ACM Int. Conf. Proceeding Ser.*, vol. Part F1477, pp. 1–6, 2018, doi: 10.1145/3234152.3234195.
- [38] J. Kazanavičius and D. Mažeika, "Analysis of legacy monolithic software decomposition into microservices," in *CEUR Workshop Proceedings*, 2020, vol. 2620, pp. 25–32.
- [39] M. Gysel, L. Kölbener, W. Giersche, and O. Zimmermann, "Service cutter: A systematic approach to service decomposition," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes*

- Bioinformatics), vol. 9846 LNCS, pp. 185–200, 2016, doi: 10.1007/978-3-319-44482-6_12.
- [40] G. Mazlami, J. Cito, and P. Leitner, “Extraction of Microservices from Monolithic Software Architectures,” *Proc. - 2017 IEEE 24th Int. Conf. Web Serv. ICWS 2017*, pp. 524–531, 2017, doi: 10.1109/ICWS.2017.61.
- [41] A. A. C. De Alwis, A. Barros, A. Polyvyanyy, and C. Fidge, “Function-splitting heuristics for discovery of microservices in enterprise systems,” *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 11236 LNCS, pp. 37–53, 2018, doi: 10.1007/978-3-030-03596-9_3.
- [42] D. Taibi and K. Systä, “A Decomposition and Metric-Based Evaluation Framework for Microservices,” *Commun. Comput. Inf. Sci.*, vol. 1218 CCIS, pp. 133–149, 2020, doi: 10.1007/978-3-030-49432-2_7.
- [43] S. Panichella, M. Rahman, and D. Taibi, “Structural Coupling for Microservices,” pp. 280–287, 2021, doi: 10.5220/0010481902800287.
- [44] J. Li, H. Xu, X. Xu, and Z. Wang, “A Novel Method for Identifying Microservices by Considering Quality Expectations and Deployment Constraints,” *Int. J. Softw. Eng. Knowl. Eng.*, vol. 32, no. 3, pp. 417–437, 2022, doi: 10.1142/S021819402250019X.
- [45] S. A. Salloum, R. Khan, and K. Shaalan, “A Survey of Semantic Analysis Approaches,” in *Advances in Intelligent Systems and Computing*, vol. 1153 AISC, 2020, pp. 61–70.
- [46] A. Cavacini, “What is the best database for computer science journal articles?,” *Scientometrics*, vol. 102, no. 3, pp. 2059–2071, 2015, doi: 10.1007/s11192-014-1506-1.
- [47] L. Ardito, R. Coppola, L. Barbato, and D. Verga, “A Tool-Based Perspective on Software Code Maintainability Metrics: A Systematic Literature Review,” *Sci. Program.*, vol. 2020, 2020, doi: 10.1155/2020/8840389.
- [48] R. Bharathi and R. Selvarani, “A framework for the estimation of OO software reliability using design complexity metrics,” *Int. Conf. Trends Autom. Commun. Comput. Technol. I-TACT 2015*, 2016, doi: 10.1109/ITACT.2015.7492648.
- [49] S. M. Yacoub, H. H. Ammar, and T. Robinson, “Dynamic metrics for object oriented designs,” *Int. Softw. Metrics Symp. Proc.*, pp. 50–61, 1999, doi: 10.1109/metric.1999.809725.
- [50] K. Qian, J. Liu, and F. Tsui, “Decoupling metrics for services composition,” *Proc. - 5th IEEE/ACIS Int. Conf. Comput. Info. Sci., ICIS 2006. conjunction with 1st IEEE/ACIS, Int. Work. Component-Based Softw. Eng., Softw. Arch. Reuse, COMSAR 2006*, vol. 2006, pp. 44–47, 2006, doi: 10.1109/ICIS-COMSAR.2006.30.
- [51] A. A. Mohammed Elhag and R. Mohamad, “Metrics for evaluating the quality of service-oriented design,” *2014 8th Malaysian Softw. Eng. Conf. MySEC 2014*, no. September, pp. 154–159, 2014, doi: 10.1109/MySec.2014.6986006.
- [52] A. K. Kalia, J. Xiao, R. Krishna, S. Sinha, M. Vukovic, and D. Banerjee, “Mono2Micro: a practical and effective tool for decomposing monolithic Java applications to microservices,” no. January, pp. 1214–1224, 2021, doi: 10.1145/3468264.3473915.
- [53] D. Rud and A. Schmietendorf, “Product metrics for service-oriented infrastructures,” *IWSM/MetriKon*, no. May, 2006, [Online]. Available: <http://www.cs.uni-magdeburg.de/~rud/papers/Rud-07.pdf>.
- [54] J. Bogner, S. Wagner, and A. Zimmermann, “Towards a practical maintainability quality model for service and microservice-based systems,” *ACM Int. Conf. Proceeding Ser.*, vol. Part F1305, pp. 195–198, 2017, doi: 10.1145/3129790.3129816.
- [55] U. Desai, S. Bandyopadhyay, and S. Tamilselvam, “Graph Neural Network to Dilute Outliers for Refactoring Monolith Application,” 2021, [Online]. Available: <http://arxiv.org/abs/2102.03827>.
- [56] A. Prajapati, A. Parashar, and J. K. Chhabra, “Restructuring Object-Oriented Software Systems Using Various Aspects of Class Information,” *Arab. J. Sci. Eng.*, vol. 45, no. 12, pp. 10433–10457, 2020, doi: 10.1007/s13369-020-04785-z.
- [57] T. Engel, M. Langermeier, B. Bauer, and A. Hofmann, “Evaluation of Microservice Architectures: A Metric and Tool-Based Approach,” vol. 2, Springer International Publishing AG, 2018, pp. 74–89.
- [58] H. Hofmeister and G. Wirtz, “Supporting service-oriented design with metrics,” *Proc. - 12th IEEE Int. Enterp. Distrib. Object Comput. Conf. EDOC 2008*, pp. 191–200, 2008, doi: 10.1109/EDOC.2008.13.
- [59] N. Santos and A. Rito Silva, “A complexity metric for microservices architecture migration,” *Proc. - IEEE 17th Int. Conf. Softw. Archit. ICSA 2020*, pp. 169–178, 2020, doi: 10.1109/ICSA47634.2020.00024.
- [60] F. H. Vera-Rivera, E. G. Puerto-Cuadros, H. Astudillo, and C. M. Gaona-Cuevas, “Microservices Backlog - A Model of Granularity Specification and Microservice Identification,” *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 12409 LNCS, pp. 85–102, 2020, doi: 10.1007/978-3-030-59592-0_6.
- [61] M. Perepletchikov, C. Ryan, K. Frampton, and Z. Tari, “Coupling metrics for predicting maintainability in service-oriented designs,” *Proc. Aust. Softw. Eng. Conf. ASWEC*, pp. 329–338, 2007, doi: <https://doi.org/10.1109/ECBS.1998.10027>.
- [62] S. Kramer and H. Kaindl, “Coupling and cohesion metrics for knowledge-based systems using frames and rules,” *ACM Trans. Softw. Eng. Methodol.*, vol. 13, no. 3, pp. 332–358, 2004, doi: 10.1145/1027092.1027094.
- [63] N. Kratzke and P. C. Quint, “Understanding cloud-native applications after 10 years of cloud computing - A systematic mapping study,” *J. Syst. Softw.*, vol. 126, pp. 1–16, 2017, doi: 10.1016/j.jss.2017.01.001.
- [64] R. Lichtenthaler, M. Pechtl, C. Schwille, T. Schwartz, P. Cezanne, and G. Wirtz, “Requirements for a model-driven cloud-native migration of monolithic web-based applications,” *Software-Intensive Cyber-Physical Syst.*, vol. 35, no. 1–2, pp. 89–100, 2020, doi: 10.1007/s00450-019-00414-9.
- [65] D. Bajaj, U. Bharti, A. Goel, and S. C. Gupta, “Partial Migration for Re-architecting a Cloud Native Monolithic Application into Microservices and FaaS,” in *Communications in Computer and Information Science*, 2020, vol. 1170, pp. 111–124, doi: 10.1007/978-981-15-9671-1_9.
- [66] M. Daghighzadeh, A. B. Dastjerdi, and H. Daghighzadeh, “A Metric for Measuring Degree of Service Cohesion in Service Oriented Designs,” *Int. J. Comput. Sci. Issues*, vol. 8, no. 5, pp. 83–89, 2011.
- [67] B. Althani and S. Khaddaj, “The Applicability of System Migration Life Cycle (SMLC) Framework,” *Proc. - 2017 16th Int. Symp. Distrib. Comput. Appl. to Business, Eng. Sci. DCABES 2017*, vol. 2018-Septe, pp. 141–144, 2017, doi: 10.1109/DCABES.2017.38.
- [68] M. Perepletchikov, C. Ryan, and K. Frampton, “Comparing the Impact of Service-Oriented and Object-Oriented Paradigms on the Structural Properties of Software,” 2005, pp. 431–441.
- [69] Y. I. Mansour and S. H. Mustafa, “Assessing Internal Software Quality Attributes of the Object-Oriented and Service-Oriented Software Development Paradigms: A Comparative Study,” *J. Softw. Eng. Appl.*, vol. 04, no. 04, pp. 244–252, 2011, doi: 10.4236/jsea.2011.44027.
- [70] M. Savić, M. Ivanović, and M. Radovanović, “Analysis of high structural class coupling in object-oriented software systems,” *Computing*, vol. 99, no. 11, pp. 1055–1079, 2017, doi: 10.1007/s00607-017-0549-6.
- [71] S. R. Chidamber and C. F. Kemerer, “A Metrics Suite for Object Oriented Design,” *IEEE Trans. Softw. Eng.*, vol. 20, no. 6, pp. 476–493, 1994, doi: 10.1109/32.295895.
- [72] S. Wanjala Munialo, G. Muchiri Muketha, and K. Kabeti Omieno, “Size Metrics for Service-Oriented Architecture,” *Int. J. Softw. Eng. Appl.*, vol. 10, no. 2, pp. 67–83, 2019, doi: 10.5121/ijsea.2019.10206.
- [73] J. Estdale and E. Georgiadou, “Applying the ISO/IEC 25010 Quality Models to Software Product,” *Commun. Comput. Inf. Sci.*, vol. 896, no. January, pp. 492–503, 2018, doi: 10.1007/978-3-319-97925-0_42.
- [74] M. Perepletchikov, C. Ryan, and K. Frampton, “Cohesion metrics for predicting maintainability of service-oriented software,” *Proc. - Int. Conf. Qual. Softw.*, no. Qsic, pp. 328–335, 2007, doi: 10.1109/QSIC.2007.4385516.
- [75] J. Ludwig, S. Xu, and F. Webber, “Static software metrics for reliability and maintainability,” *Proc. - Int. Conf. Softw. Eng.*, pp. 53–54, 2018, doi: 10.1145/3194164.3194184.
- [76] J. A. Valdivia, A. Lora-González, X. Limón, K. Cortes-Verdin, and J. O. Ocharán-Hernández, “Patterns Related to Microservice Architecture: a

- Multivocal Literature Review,” *Program. Comput. Softw.*, vol. 46, no. 8, pp. 594–608, 2020, doi: 10.1134/S0361768820080253.
- [77] J. Kazanavicius and D. Mazeika, “Migrating Legacy Software to Microservices Architecture,” *2019 Open Conf. Electr. Electron. Inf. Sci. eStream 2019 - Proc.*, 2019, doi: 10.1109/eStream.2019.8732170.
- [78] R. Khadka *et al.*, “Does software modernization deliver what it aimed for? A post modernization analysis of five software modernization case studies,” in *2015 IEEE 31st International Conference on Software Maintenance and Evolution, ICSME 2015 - Proceedings*, Sep. 2015, pp. 477–486, doi: 10.1109/ICSM.2015.7332499.
- [79] A. Mishra, R. Shatnawi, C. Catal, and A. Akbulut, “Techniques for calculating software product metrics threshold values: A systematic mapping study,” *Appl. Sci.*, vol. 11, no. 23, 2021, doi: 10.3390/app112311377.

Improved 3D Rotation-based Geometric Data Perturbation Based on Medical Data Preservation in Big Data

Jayanti Dansana^{1*}, Dr. Manas Ranjan Kabat², Dr. Prasant Kumar Pattnaik³

Professor^{2,3}

School of Computer Engineering, KIIT Deemed to be University, Bhubaneswar, Odisha-751024, India^{1,3}

Department of Computer Science and Engineering, VSSUT Burla, Sambalpur, Odisha-768018, India²

Abstract—With the rise in technology, a huge volume of data is being processed using data mining, especially in the healthcare sector. Usually, medical data consist of a lot of personal data, and third parties utilize it for the data mining process. Perturbation in health care data highly aids in preventing intruders from utilizing the patient's privacy. One of the challenges in data perturbation is managing data utility and privacy protection. Medical data mining has certain special properties compared with other data mining fields. Hence, in this work, the machine learning (ML) based perturbation approach is introduced to provide more privacy to healthcare data. Here, clustering and IGDP-3DR processes are applied to improve healthcare privacy preservation. Initially, the dataset is pre-processed using data normalization. Then, the dimensionality is reduced by SVD with PCA (singular value decomposition with Principal component analysis). Then, the clustering process is performed by IFCM (Improved Fuzzy C means). The high-dimensional data are divided into several segments by IFCM, and every partition is set as a cluster. Then, improved Geometric Data Perturbation (IGDP) is used to perturb the clustered data. IGDP is a combination of GDP with 3D rotation (3DR). Finally, the perturbed data are classified using a machine learning (ML) classifier - kernel Support Vector Machine- Horse Herd Optimization (KSVM-HHO) to classify the perturbed data and ensure better accuracy. The overall evaluation of the proposed KSVM-HHO is carried out in the Python platform. The performance of the IGDP-KSVM-HHO is compared over the two benchmark datasets, Wisconsin prognostic breast cancer (WBC) and Pima Indians Diabetes (PID) dataset. For the WBC dataset, the proposed method obtains an overall accuracy of 98.08% perturbed data, and for the PID dataset, the proposed method obtains an overall accuracy of 98.04%.

Keywords—Data mining; privacy; health care data; machine learning; perturbation; improved fuzzy c-means; horse herd optimization; kernel based support vector machine

I. INTRODUCTION

Big data analysis with proper security and privacy preserving features is required to balance privacy and utility. Recently, the advancement in information science has led to the digitized collection of data and storage in large numbers [1]. HI (health information) system can handle all the information related to health care. The HI system can be operated through national statistics offices and health information departments. It allows data on risk factors related

to morbidity, disease, mortality and health service coverage. The quality of patient treatment can be improved by using healthcare software [2]. Some HI elements are indicators, data sources, data management, information products and dissemination. Data mining is a technology that processes a large amount of data to draw unknown, hidden, and potentially useful data from source information [3]. It is used to help a wide range of business applications such as store layout, targeted marketing and customer profiling. Data mining tasks are divided into two categories: predictive tasks and descriptive tasks [4]. Personal and sensitive information of patients may be theft and breaches the patient's privacy through several attacks. A third person may use the information at various levels; hence, the data must be saved. Privacy is essential in sharing information for applications based on knowledge [5].

Recent advances in internet of medical things (IoMT) [6] like ambulance, immediate mobile medical devices faces high delay and low throughput due to the continuous motion state. For overcoming this, resource efficient flow enabled distributed mobility (FDMA) approach is introduced for improving the network performance. In [7], the authors undertaken the case study for latest advancement in health care treatments at the time of COVID breakdown in the field of internet of things (IoT). In [8], authors performed an analysis on the Markov random fields (MRF) for medical applications. However, in big data manual processing is one of the complex tasks and MRF play a vital role in overcoming medical related issues in big data. In addition, some other works like [9], researchers made a survey on privacy attacks location and creates a prevention deployment on IoT based vehicular application. For addressing the problems due privacy attacks, anonymity and cryptographic interpretations are introduced on the basis of digital signature technique. However, while integrating these techniques into the big data the performance gets very much reduced and lacks its capability.

Nowadays, PPDM (privacy preserving data mining) is a big challenge and is a technique used to transform data to preserve privacy. The growth in data mining leads to novel research as PPDM. There are several techniques used to achieve PPDM. They are anonymization, condensation, Perturbation, Cryptography, and Randomization [10]. Anonymization eliminates the information from the various

information sets to generalize the attributes [11]. Condensation is achieved by forming clusters in several ways. The range of each cluster differs from that of any other cluster [12]. Cryptography is protected with the help of record encryption to find identity and sensitive information [13]. In randomization, the records are shuffled vertically to hide the correct identity. The perturbation indicates that information is being manipulated using noise.

However, various sectors especially in health care, the amount of data gets increased exponentially and it is commonly termed as big data. Perturbing these kinds of data is one of the challenging task due to increasing intruders and advancement in data mining process [14]. Data perturbation is one the privacy preservation approaches that can modify the data present in the database to solve the individual's confidentiality problem. Some of the existing perturbation techniques like random rotation [15], condensation [16] and micro-aggregation [17] remain challenging for balancing both the privacy and the accuracy. In addition, data present in the health care database increases endlessly and intruders have high chance in extracting the information. In recent era, differential privacy (DP) [18] has attracted the researchers a lot by introducing k-anonymity and l-diversity and providing high data securing in data mining.

The noise can be classified into additive and multiplicative noise [19]. Addictive noise- also called Gaussian noise that can be looked slightly blurry and soft. It is the undesired instantaneous signal and gets added to some real signals. The image of each pixel changes from its real values by a small number. Multiplicative noise is undesired instantaneous signals that get multiplied into real signals. Data perturbation is a method of preserving data and maintaining confidentiality [20]. Several ML models are used to perturb the data and are efficiently used in PPDM. Further, it is compared with the original data to evaluate the efficiency of the model [21] [22]. ML is a computational science field that verifies and interprets the pattern. ML model-based approaches handle big data in the perturbation process [23]. Hence this work used an optimization-based ML model for data perturbation.

A. Motivation

Recent privacy-preserving data mining (PPDM) is a hot research topic in the big data mining process. The major aim of the PPDM is to protect individual data privacy from third party intruders. Nowadays, users are more aware of privacy intrusions on personal data and hesitate to share personal information. Several approaches are present to preserve data like perturbation, anonymization and data transformation. PPDM by data perturbation has attained popularity because these models can hide secret data successfully and ensure more utility in the retrieval process. Some perturbation models are geometric perturbation, condensation, additive perturbation, micro aggregation, and random rotation aids to perturb the medical data effectively. In the medical field, preserving data is essential since medical documents are relevant to privacy concerns and human subjects. PPDM perturbs the data, and intruders cannot identify the medical data. However, many techniques fail to hide the difference between the original and perturbed data, which helps the

intruders to easily identify the perturbation in the medical data. Hence, the accuracy of the original and privacy preserved data degrades and cannot apply to the medical data mining process. The latest advancement in the big data mining process helps to achieve better perturbation without the knowledge of intruders.

Recently, numerous approaches have been proposed in the literature for preserving data. But these methods have many limitations. Existing PPDM has high computational complexity for a large volume of data. Further inefficiency poor scalability and make data reconstruction impossible with these approaches. These major drawbacks motivate us to develop an enhanced DL model for medical data mining privacy preservation. Hence, this work proposes the model improved perturbation IGDP (Geometric Data Perturbation) with three-dimensional rotation (3DR) for privacy preservation. The proposed technique is integral in preserving privacy in health care data under low time complexity. *The major contributions of the proposed model are illustrated below:*

- To introduce a novel perturbation technique (IGDP-KSVM-HHO) for privacy preservation in healthcare data
- To pre-process the data using the min-max normalization technique for better data privacy.
- To reduce the data dimensions by introducing hybridized SVD-PCA technique to avoid data redundancy.
- To cluster the health care data using the IFCM technique, the hierarchical data is segmented, and every partition is set as the cluster.
- To perform perturbation using the IGDP technique for the clustered data to improve health care privacy preservation.
- To propose a KSVM-HHO approach for classifying the perturbed health care data accurately.
- To implement the proposed method in PYTHON, performance measures like F-measure, precision, accuracy, execution time and MSE are analyzed and compared with existing techniques.

The remaining section of the research work is arranged as follows: Section II is the recent relevant literature work; Section III depicts the proposed perturbation technique; Section IV gives the overall evaluation of implemented results. Section V provides the conclusion of the work.

II. RELATED WORKS

Some of the recent related work based on privacy preserving data mining is listed below:

Devi and Manikandan [24] introduced a rotation based condensation technique with geometric transformation for PPDM. This model provided better resilience over the attacks on the data reconstruction process. The improved P2RoCAI was utilized to measure the dynamics of classification

accuracy. This model provided less time for the empirical process, proving that it could be efficiently used in big data analysis. Kousika and Premalatha [25] proposed SVD (singular value decomposition) and 3RDP (3D rotation data perturbation) for PPDM. Using these models, a perturbed matrix was obtained. Several ML classifiers classified the original and perturbed data, and the evaluation was computed based on the accuracy rate. Experimentation proved that SVD-3RDP outperformed by attaining better accuracy for matrices of various sizes.

Kumar and Premalatha [26] used information value and weight evidence for the initial data perturbation. After that, the 3D shearing was fed on a quasi-identifier once the initial data perturbation was done. Then, several ML classifiers were fed on three benchmark datasets for analyzing the original and perturbed data. The experimentation was analyzed on 2D and 3D rotation. This model can preserve data utility with more privacy preserving and transformation capacity.

Chamikara et al. [27] introduced a novel perturbation model PABIDOT for addressing the utility problem of traditional data perturbation techniques. This model provides privacy to data via Φ – separation. The accuracy outcome of the perturbed data was near the original data. This model attained a systematic model for optimizing data perturbation variables. Finally, privacy and utility were analyzed on certain metrics.

Kumar et al. [28] proposed HER (Electronic Health Records) for hiding sensitive data by integrating fuzzy and association rules. The fuzzification was formed when multilevel privacy approaches were applied, and association rules perturbed outcomes. The experimentation was carried out on the UCI repository, and ML models were used to compute accuracy to show the robustness of the model.

Bedi and Goyal [29] defined privacy preservation in medical data in cloud IoT using extended fully homo-morphic encryption (EFHE). In this study, the FHE helps in adding and multiplying the cipher text. Finally, the information present in the medical data maintains perturbation and shows perturbed results. Thus, the attackers were unaware of the perturbed input and output states during the data mining process. In the experimental section, the peak-to-signal error (PSNR) of 30dB and SNR of 10dB were obtained. However, the security level of this method needs to be increased further for processing big data.

Reddy and Rao [30] defined the clustering and GDP technique for privacy preservation in health care data. The hierarchical data were clustered in this work using the k-means clustering technique. Finally, the clustered data was perturbed on the basis of the GDP algorithm. The perturbed values were encapsulated in the public, and clustered data were encapsulated under the private key. The experimental section obtained an accuracy of 79.58% and an execution time of 161.558s. But this method takes high execution time and obtains the average accuracy.

Janakiraman and Maruthukutty [31] introduced ML based techniques for perturbing the DNA based medical data. In this paper, integrated condensation based PP rotation based DP

and ensemble classification (ICS-PPR-DPEC) was emphasized to secure medical data. At the initial stage, condensation algorithm based DP (CADP) was introduced to group the data under tuple distances. Finally, an ensemble machine learning (ELM) based classifier was utilized for recognizing the perturbed human DNA based medical data. In the experimental section, an accuracy of 93.2%, precision of 90%, and recall of 89% were obtained. However, this method faces high complexity during perturbation.

Santhana and Natarajan [32] determined big data analysis for health care data based on clustering and DP algorithm. In this study, an improved FKM (IFKM) based clustering algorithm was introduced to cluster the medical data. Then, modified 3D rotation based DP was introduced to preserve the privacy of the medical data. The experimental section obtained an accuracy of 94% and an execution time of 35ms. However, this method lacks its performance when the data gets increased.

Sujatha and Udayarani [33] evaluated chaotic based geometric DP (CGDP) and hierarchical approach for preserving privacy in health care big data. Initially, the CGDP technique was introduced to perturb the healthcare data. Then, homomorphism based ensemble gradient approach was introduced to classify the perturbed data accurately. In the experimental section, an accuracy of 87% was obtained. However, this technique lacks a clustering technique; hence, the origin of the data cannot be identified.

Even though the approaches mentioned above' outcomes are encouraging, these methods have some limitations. These models take more time to process the data. Further, these methods do not seem to provide full security for the data. Hence, an efficient perturbation model is essential for maintaining the confidentiality of health data.

A. Problem Statement

The recent advancements in the big data mining process have grown much attention towards researchers, especially in the health care sector. With the fast growth in technological advancements, third party and other adversarial attacks also increase exponentially. However, in big data, enormous amounts of data are blemished daily with the increasing data mining process. The third party's utilization of individual privacy details increases for various commercial purposes. Nowadays, data perturbation is one of the hot topics in preserving one's privacy effectively. Many different data perturbation techniques have been introduced for effectively hiding personal details from attackers. But each has its benefits and disadvantages during data perturbation. For big data, recent models lack the capability and face high time complexity. In addition, the existing techniques fail to preserve without the knowledge of intruders, which becomes one of the open issues in many data mining applications.

Nowadays, with the latest technologies, the data can be perturbed without the knowledge of attackers, whether the data is perturbed or original. After the data perturbation, the origin of the data cannot be detected in many recent studies. To the best of our knowledge, the proposed big data mining

method outperforms well in preserving privacy without any knowledge to the intruders.

III. PROPOSED METHODOLOGY

Due to the emergence of ICT (Information and Communication Technology), healthcare data are saved in electronic form and obtained based on the requirements. However, big data privacy determines managing big data under minimal risk and secures the hyper-sensitive data. Generally, big data is spread all over the locations, which destroys patients' privacy for various purposes. Traditional privacy process lacks in handling big data especially in the healthcare sector. Hence, this article privacy enhanced ML algorithms for preserving medical data in the big data mining process. At the initial stage, the min-max normalization based pre-processing technique is emphasized to normalize the medical data efficiently. The normalized data is then fed into the PCA-SVD technique for dimensionality reduction. Then IFCM clusters the data to avoid unwanted complexities while processing big data. In addition, IGDP (Geometric Data Perturbation)-three-dimensional rotation (3DR) is used to effectively preserve data privacy from external attacks. For the classification of perturbed data, an optimization-based kernel Support Vector Machine (KSVM) is utilized. Further, for optimizing the weight of KSVM and improving the performance in classification, a meta-heuristic optimization technique HHO is proposed in this work. Fig. 1 depicts the framework of the introduced Perturbation model.

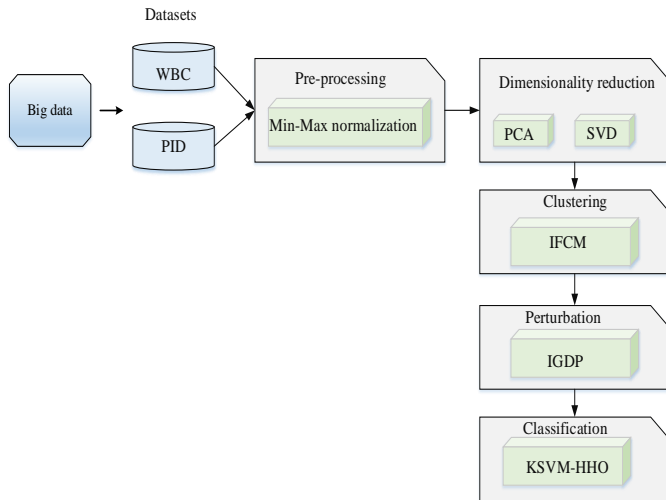


Fig. 1. Framework of the introduced perturbation model.

A. Min-Max Normalization

For the classification of perturbed medical data, pre-processing is the essential stage that can effectively improve the performance accuracy of the proposed technique. In the pre-processing stage, data normalization is undertaken to minimize data redundancy and error during perturbation. Recently studies have failed to normalize the data and consume high time complexity while perturbing the medical data. The proposed min-max normalization technique aids in normalizing the data and efficiently preserving the dataset's sensitive attributes. The major aim of the proposed model is to

normalize the original dataset E into a preserved dataset E' that satisfies the needs of privacy with better data privacy. In the dataset, every attribute is normalized arranging its value, hence they will come to the range of 0-1. To map the value D' of the attribute b from the range $[\max_b, \min_b]$ to $[New_{\max_b}, New_{\min_b}]$ is given by:

$$D' = \frac{D - \min_b}{\max_b - \min_b} (New_{\max_b} - New_{\min_b}) + New_{\min_b} \quad (1)$$

Where D and D' are the original and newly computed value. \max_b and \min_b are the attribute's maximum and minimum values. New_{\max_b} and New_{\min_b} are the attribute's new maximum and minimum values.

B. Dimensionality Reduction

After pre-processing, the dimensionality of the data is reduced for the normalized data. Similar features present in the medical data are completely removed from the medical data for the minimization of execution time. This research introduces a hybrid PCA-SVD technique for the elimination of similar features. The major aim of PCA is to reduce the dimension of the training set, and the major component of the training set is the outcome of the projection of the Eigenvector with Eigenvalue. The procedure of dimensionality reduction using PCA is given below:

Let $y \in S^n$ is a test sample with n parameters, and every parameter has m independent samples. Then the data matrix is written as:

$$Y_n = [y(1), y(2), \dots, y(m)], \quad Y_n \in S^{n \times m} \quad (2)$$

Every column of Y_n indicates a parameter, and every row indicates the sample. Since the dimensions of the measured parameters are different, every column of data is normalized, and it is represented as:

$$Y^* = \frac{Y_n - d \cdot p}{diag(\sigma)} \quad (3)$$

Where $d = (1, 1, \dots, 1)^T$, p is the mean of Y columns and $diag(\sigma)$ is a parameter matrix of Y_n .

The covariance matrix of Y^* is:

$$V = \frac{1}{m-1} Y^{*T} Y^* \quad (4)$$

The matrix processing is generally the decomposition of the Eigen value. The matrix is sorted in descending order based on the Eigenvalues size. The value of Y^* is decomposed by:

$$Y^* = \vec{Y} + F = TR^T + F \quad (5)$$

$$T = Y^*R \quad (6)$$

Where \vec{Y} is a projection in PCA, residual space of projection is F , and load matrix is denoted as R . T is a scoring matrix and the components in T is a primary parameter. PCA is a modelling segment, residual space is not a modelling segment, and it depicts the noise. The principal component number is selected according to CPV (Cumulative Percent Variance). This scheme represents the number of principal components based on cumulative principal elements. CPV is a ratio of the data variation defined by the initial principal component to the total data variation. Hence, CPV is represented as:

$$CPV = \frac{\sum_{j=1}^A \gamma_j}{\sum_{j=1}^m \gamma_j} \quad (7)$$

Where γ_j is an Eigenvalue of V . The features reduced by PCA are given to SVD for further dimensionality reduction. SVD is used for eliminating correlation between data features. In SVD, each sample is perturbed using the same parameter. Let a matrix indicates the original data B with dimension $l \times m$. The column indicates the attributes in the matrix, and the row indicates data objects. The SVD of the matrix C is given in equation (8).

$$C = XBY^T \quad (8)$$

Where X and Y^T are the $l \times l$ and $m \times m$ orthogonal matrix and B is $l \times m$ diagonal matrix.

The decomposition matrix C in (8) is represented as:

$$C = \sum_{j=1}^r \sigma_j B_j Y_j^T \quad (9)$$

Where σ_j is a singular value of C and the columns of X is B_j and Y_j . The SVD of the matrix C is used for solving the linear model $Cy = d$, and it is given by:

$$y^+ = \sum_{j=1}^r \sigma_j^{-1} \langle d, B_j \rangle Y_j^T \quad (10)$$

C. Clustering using IFCM

The dimensionality reduced data is then fed into the IFCM clustering technique to cluster the medical data having similar fields. In the traditional FCM [34] technique, the cluster's centre and the cluster numbers are fixed artificially, which is

sensitive for the first cluster centre. Further, this algorithm has slow convergence and less stability. Hence, IFCM is introduced, in these clusters, centres are based on two parameters like distance (d_j) and local density (ρ_j). Then the distance of density is given as:

$$\phi_j = d_j \rho_j \quad (11)$$

Then these parameters are fed to FCM to obtain the clustering results. Consider $Y = \{Y_1, Y_2, \dots, Y_n\}$ is a collection of m is number of clusters and this m is divided into G fuzzy groups. Then the centre matrix is given as $U = \{U_1, U_2, \dots, U_G\}$, and the objective function to define FCM is given by:

$$K(W, U) = \sum_{j=1}^G \sum_{k=1}^m (w_{jk})^n (d_{jk})^2 \quad (12)$$

Where W is a dimensional membership matrix, w_{jk} is a membership among Y , and U . d_{jk} is a Euclidean distance among k^{th} sample and j^{th} cluster centre. This equation (12) should satisfy the below conditions.

$$\begin{cases} \sum_{j=1}^G w_{jk} = 1, & k = 1, 2, \dots, m \\ 0 \leq w_{jk} \leq 1, & j = 1, 2, \dots, G; k = 1, 2, \dots, m \\ 0 < \sum_{k=1}^m w_{jk} < m, & k = 1, 2, \dots, G \end{cases} \quad (13)$$

Finally, the centre of the cluster is identified by the following expression

$$U_{jk} = \frac{\sum_{k=1}^m (w_{jk})^n y_k}{\sum_{k=1}^m (w_{jk})^n} \quad (14)$$

Where, y_k is a data in cluster and the membership function will be updated based on centres of the cluster, and it is represented as:

$$M_{jk} = \frac{1}{\sum_{l=1}^m \left(\frac{\|y_k - U_{jk}\|}{\|y_k - U_{kl}\|} \right)^{2/(n-1)}} \quad (15)$$

According to Equations (14) and (15), the dataset is grouped, and during clustering, the data are shuffled into several groups. This clustering is used for performing data perturbation.

D. Improved Geometric Data Perturbation (IGDP)

After clustering, the data perturbation process is undertaken to provide privacy to the medical data. Recently many perturbation techniques have been introduced to preserve medical data effectively without the intruder's knowledge. However, due to high processing time, those techniques cannot be applicable for processing huge volumes of data, especially in big data. The perturbation technique IGDP is used to perturb the clustered data. 3DR is used with GDP, and it is used to distort data by rotating three orientations (S_x, S_y, S_z) , and axes pairs utilized for the rotation are (S_{xy}, S_{yz}, S_{zx}) . The rotation operation is provided more than once until the entire attributes are transformed to preserve privacy. The procedure of 3DR is given below:

Stage 1: Choose the three orientations (S_x, S_y, S_z) and compute the rotation matrix as:

$$S_{xy} = S_x \times S_y = \begin{pmatrix} \cos \theta & 0 & -\sin \theta \\ \sin^2 \theta & \cos \theta & \sin \theta \cos \theta \\ \sin \theta \cos \theta & -\sin \theta & \cos^2 \theta \end{pmatrix}$$

$$S_{yz} = S_y \times S_z = \begin{pmatrix} \cos^2 \theta & -\sin \theta \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta & 0 \\ \sin \theta \cos \theta & -\sin^2 \theta & \cos \theta \end{pmatrix}$$

$$S_{zx} = S_z \times S_x = \begin{pmatrix} \cos \theta & -\sin \theta & 0 \\ \sin \theta \cos \theta & \cos^2 \theta & \sin \theta \\ -\sin^2 \theta & \sin \theta \cos \theta & \cos \theta \end{pmatrix}$$

Stage 2: The attributes are grouped into three functions (A_x, A_y, A_z) .

Stage 3: Three functions are rotated around (S_x, S_y, S_z) in a 3D plane for several rotation angles.

Stage 4: Identify the rotation angle until all attributes are transferred to preserve privacy.

GDP has a sequence of randomized geometric transformations like multiplicative transformation (M) , distance perturbation (Δ) and translation transformation (φ) .

$$g(y) = My + \Delta + \varphi \quad (16)$$

In this, the element M_T is a rotational matrix and y is original data.

1) *Multiplicative transformation*: The parameter (M) is a rotation matrix. This matrix accurately preserves distance. Let the rotation perturbation is expressed as:

$$g(y) = My \quad (17)$$

The orthogonal matrix is given as $M_{d \times d}$ and has some characteristics. The transpose of M is M^T , the Identity matrix is I_j and m_{jk} is the (j, k) component of M . The matrix of M in columns and rows is orthonormal. The resultant matrix is also orthonormal when the orders of columns and rows are changed.

2) *Translation transformation*: This transformation is written as:

$$g(y) = y + \varphi \quad (18)$$

Let us consider two points a and b in the original space, and the distance is given as:

$$\| (a - t) - (b - t) \| = \| a - b \| \quad (19)$$

The translation saves distance and doesn't protect the inner product. When translation and rotation are integrated, φ can enhance the preservation.

3) *Distance perturbation*: The major aim of this perturbation is to preserve distance and provide strength to distance inference attacks. The entry of the random matrix $\Delta_{f \times m}$ is an independent sample exhausted from the same distribution with less variance and zero means. When this random matrix is included, the distance between the point's pair gets disturbed. This IGDP provides more security to medical data. Then fully obtained perturbed matrix is applied for the classification process.

E. Classification using KSVM-HHO

The Perturbed data is then fed into the classification stage to classify the perturbed data accurately. The Classification stage helps to assess a dataset that retains data mining performance approaches after data perturbation. Recently, many ML classifiers have been utilized as a classifier for perturbed data, and each has its benefits and drawbacks. In this work, the ML based SVM classifier is used for classifying the perturbed data and utilizes a separation of non-linear mapping to transform original trained data, which are linearly transformed by a kernel function. The Polynomial kernel function (PKF) is used for the transformation, and this function transforms the non-linear into high dimensionality features. Hence, the data partition is feasible, making a classification task more convenient. Normal SVM states a hyperplane that is separated into two training classes, and it is expressed as:

$$g(z) = Y_k^* \phi_k(z) + f \quad (20)$$

where, Y_k^* is a hyper-plane parameter, f is a bias value and $\phi_k(z)$ is a term used for mapping vector z into high dimensionality space. The major aim is to make an effective classifier by the training set (o_k, z_k) . The optimal value of Y_k^* and f is given by:

$$o_k(Y_k^* z_k + f) \geq 1 - \zeta_k \quad \text{for } k = 1, 2, \dots, M \quad (21)$$

where, ζ_k is a slack parameter for all k . Y_k^* and ζ_k reduces the cost function, and it is expressed as:

$$\phi(Y_k^*, \zeta_k) = \frac{1}{2} \|Y_k^*\|^2 + R_e \sum_{k=1}^M \zeta_k \quad (22)$$

where, R_e is a regularized variable and used to control the size of the discriminant function. The final result of the SVM is denoted as:

$$o_k(y) = \sum_{k=1}^M J(y_k, y) \quad (23)$$

where, $J(y_k, y)$ is a kernel function. There are several types of kernels. In this work, a polynomial kernel is utilized. The kernel's parameters are to be adjusted previously to the process of the training data. It is one of the non-stationary kernels, and it works better for normalizing training data. It is denoted as:

$$J(y_k, y) = \gamma((y_k, y) + 1)^d \quad (24)$$

where, d is a polynomial degree. However, the proposed classifier high affected due to increased losses in which the origin of the data cannot be detected. The loss function of the proposed KSVM classifier can be interpreted as,

$$L = \min(\text{Accuracy}), \max(\text{MSE}) \quad (25)$$

1) *Parameter tuning using HHO optimizer*: The proposed KSVM classifier degrades its performance while processing huge medical data. Thus, the accuracy performance is much reduced, which can be overcome by tuning the parameters in the classifier model. Recently, many optimization techniques have played an integral role in tuning the parameters, thus enhancing the system's efficiency. This research introduces HHO based metaheuristic optimization technique for parameter tuning of the proposed classifier model.

Initially, the parameters of HHO are initialized, and the parameters of the polynomial SVM are encoded and trained. Obtain fitness value and classification of horses based on age. Then, the position of the horse is obtained. The process is repeated until the satisfied criteria are met.

This optimization is based on the horse's behaviour. There are six patterns of behaviours they are Grazing (G), Hierarchy

(H), Roaming (R), Sociability (S), defences (D) and Imitation (I). The following equation is based on a movement provided to horses at every iteration.

$$Z_n^{i,age} = \vec{U}_n^{i,age} + Z_n^{(i-1),age} \quad (26)$$

Where $Z_n^{i,age}$ is a n^{th} horse position, age is the age of the horses, i is a present iteration and $\vec{U}_n^{i,age}$ is a velocity vector. The following steps show the horse's six patterns of behaviour.

a) *Grazing (G)*: Horses feed on grasses, grains and plants. HHO creates the grazing field around every horse with a factor k . Horses graze at any age in their entire lifetime. The grazing behaviour is expressed as:

$$\vec{G}_n^{i,age} = g_i(LB + \rho \times UB) + [Z_n^{(i-1)}] \quad (27)$$

$$g_n^{i,age} = g_n^{(i-1),age} \times \sigma_g \quad (28)$$

Where $\vec{G}_n^{i,age}$ is a parameter of motion, and it shows the ability of horse grazing tendency. This term minimizes linearity by σ_g . LB and UB are the lower and upper bounds, which range from 0 to 1.

b) *Hierarchy (H)*: It is proved that the horses at 5 to 15 years are used to follow hierarchy rules, and it is indicated as:

$$\vec{H}_n^{i,age} = h_n^{(i-1),age} [Z_n^{(i-1)} - Z_n^{(i-1)}] \quad (29)$$

$$h_n^{i,age} = h_n^{(i-1),age} \times \sigma_h \quad (30)$$

Where $h_n^{i,age}$ is the effect of the best location of the horse on the velocity, σ_h is a reducing factor and $Z_n^{(i-1)}$ is the best horse location.

c) *Sociability (S)*: This behaviour is regarded as the movement to an average position of other horses. Horses in their middle age have an interest in the herd, and it is expressed as:

$$\vec{S}_n^{i,age} = s_n^{(i,age)} \left[\left(\frac{1}{N} \sum_{l=1}^N Z_l^{(i-1)} \right) - Z_n^{(i-1)} \right] \quad (31)$$

$$s_n^{i,age} = s_n^{(i-1),age} \times \sigma_s \quad (32)$$

Where $\vec{S}_n^{i,age}$ is a social movement vector, σ_s is a reducing factor and $S_n^{(i,age)}$ is an orientation of a horse to a herd in i^{th} iteration.

d) *Imitation (I)*: This characteristic of a horse is set as i , and the horse in 0 to 5 years tries to mimic other horses. This imitating behaviour is expressed as:

$$\vec{I}_n^{i,age} = i_n^{(i,age)} \left[\left(\frac{1}{qN} \sum_{l=1}^{qN} \vec{Z}_l^{(i-1)} \right) - Z_n^{(i-1)} \right] \quad (32)$$

$$i_n^{i,age} = i_n^{(i-1),age} \times \sigma_i \quad (34)$$

Where $\vec{I}_n^{i,age}$ movement vector of the horse to the average of best horses with a position of \vec{Z} . The total of horses with the best location is qN and σ_i is a reducing factor.

e) *Defence (D)*: This behaviour exists in their overall lifetime. This horse mechanism is represented as d , and it is a negative factor in equations (32) and (33).

$$\vec{D}_n^{i,age} = -d_n^{(i,age)} \left[\left(\frac{1}{sN} \sum_{l=1}^{qN} \vec{Z}_l^{(i-1)} \right) - Z_n^{(i-1)} \right] \quad (35)$$

$$d_n^{i,age} = d_n^{(i-1),age} \times \sigma_d \quad (36)$$

Where $\vec{D}_n^{i,age}$ is an escaping vector from a bad location \vec{Z}_l , sN is a total of horses and σ_d is a reducing factor.

f) *Roaming (R)*: This characteristic is imitated as a random motion and represented using r . This behaviour is generally seen at 0 to 5 years and goes away at middle age. It is represented as:

$$\vec{R}_n^{i,age} = r_n^{(i,age)} \vec{qZ}_l^{(i-1)} \quad (37)$$

$$r_n^{i,age} = r_n^{(i-1),age} \times \sigma_r \quad (38)$$

Where $\vec{R}_n^{i,age}$ is a random velocity vector and σ_r is a reducing factor of $r_n^{i,age}$.

g) *Fitness function (F)*: Finally, the parameter is tuned, and its weight is updated based on the updated location of the proposed optimizer. The fitness function can be formulated as,

$$fitness\ function(f) = \max(Accuracy), \min(MSE) \quad (39)$$

As shown above, the data is perturbed using IDGP and classified by KSVM-HHO. Several classifiers classify perturbed and original data; the achievements are given in the following section. Fig. 2 illustrates the flowchart of the proposed IGDP-KSVM-HHO technique. Algorithm 1 depicts the pseudo-code for the proposed method.

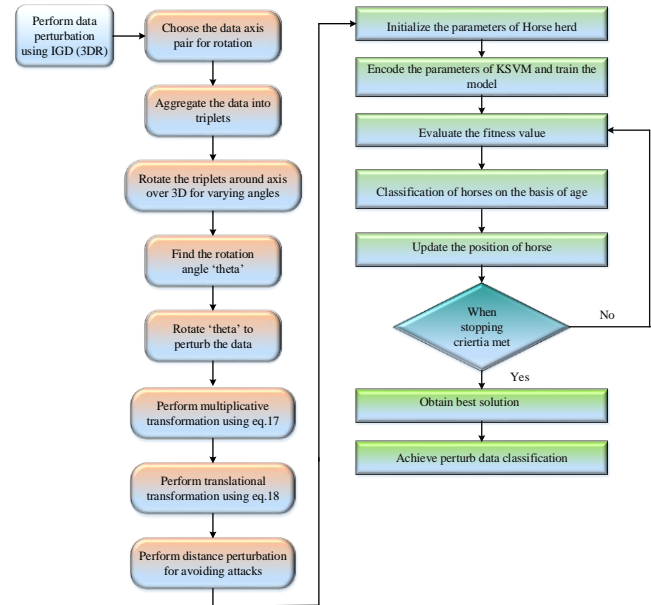


Fig. 2. Flowchart of the proposed IGDP-KSVM-HHO technique.

Algorithm 1: Pseudo code for the proposed method

Pseudo code for the proposed method
Input: Noisy medical dataset from the raw dataset;
Output: Classified perturbed and original medical data;
Start data pre-processing using min-max normalization
Perform data normalization and preserve sensitive attributes using equation 1; //normalized medical data
For dimensionality reduction
Utilize hybrid PCA-SVD technique;
Consider the data as a data matrix of PCA using equation 2;
Normalize the medical data present in the row and columns using equation 3;
Calculate the covariance matrix V using equation 4;
Arrange the matrix into descending order and measure the score matrix using equations 5 and 6;
Analyze the data variation CPV in the matrix using equation 7;
While the correlation between the features is high
Integrate SVD with PCA for further dimensionality reduction;
Consider the data matrix of SVD using equation 8;
Calculate decomposition matrix C using equation 9;
Calculate the dimensionality reduced matrix using equation 10; //dimensionality reduced medical data
End while
End for
Do clustering for the dimensionality reduced medical data

using IFCM //helps to find origin of data
 Calculate density distance for determining the cluster centre using equation 11;
Assume the centre matrix $U = \{U_1, U_2, \dots, U_G\}$ having random clusters;
 Calculate the objective function using equation 12;
Assume the condition for becoming a member of a particular cluster;
If ($k = 1$)
 Calculate the membership matrix M_{jk} having cluster centre using equation 15;
 Update the cluster centre U_{jk} using equation 14;
 $k \leftarrow K + 1$
Return best clusters having membership function M
Perform data perturbation using IGDP (3D rotation);
Input: Clustered medical data, its attributes and array of security thresholds;
Output: Perturbed medical data;
For GDP with 3D rotational transformation
Select the orientations as, (S_x, S_y, S_z) and perform rotation as, S_{xy}, S_{yz} and S_{zx} ;
Group the attributes as, (A_x, A_y, A_z) ;
Rotate (S_x, S_y, S_z) in a 3D plane for varying angles;
Do geometric transformations to preserve distance privacy and avoid attacks
Perform multiplicative transformation using equation 17;
Perform translation transformation using equation 18;
Preserve distance and eliminate attacks using distance perturbation;
End for
Return perturbed medical data
For classification of data perturbation
Do optimized KSVM-HHO for perturbed data classification
Initialize the parameters of HHO using equation 26;
Train the SVM model using equation 20;
 Calculate the fitness value for the reduced cost function using equation 22;
 Calculate the age based on the hierarchical rule in equations 28 and 29;
 Find the optimal value Y_k^* and f by tuning the parameters using equation 21;
 $Y_k \leftarrow Y_k^*$;
 Analyze the data obtained by optimized SVM using equation 23;
 Adjust the kernel parameters using equation 24;
 Update the horse position using equations 27 and 28;
 Analyze the velocity of the horse based on the age using equations 37 and 38;
If fitness condition is satisfied
Generate best outcome;
Else;

Repeat $T \leftarrow T + 1$
End if
Return the accurate classified perturbed medical data
Stop

IV. RESULTS AND DISCUSSION

The proposed IGDP-KSVM-HHO is evaluated in the Python platform. The efficiency of the approach is evaluated based on accuracy, F-measure, MSE, precision, sensitivity, specificity and execution time. The performance of Perturbed and original data are classified by ML classifiers like KSVM, SVM, NB (Naïve Bayes), KNN (K nearest neighbour) and RF (Random forest). Table I depicts the simulation parameters of the proposed method. Table II represents the system configuration of the proposed method.

TABLE I. SIMULATION PARAMETERS OF THE PROPOSED METHOD

Simulation Parameters	Values
Optimizer	HHO optimizer
SVM-type	C-classification
SVM-kernel	Polynomial kernel
Cost	1
Gamma (γ)	0.0625
Number of support vectors	8434

TABLE II. SYSTEM CONFIGURATION OF THE PROPOSED METHOD

System Specifications		
S. No	Parameter	Configuration
1	Device name	Desktop
2	Processor	Intel(R) Core(TM) i3-7100 CPU @ 3.90GHz, 3912 MHz, 2 Core(s), 2 Logical Processor(s)
3	Installed RAM	8.00 GB (7.89 GB usable)
4	Device ID	DFBCDAE4-A190-457D-8C56-FDDDBB348B4F
5	Product ID	00330-50186-83065-AAOEM
6	Pen and Touch	No pen or touch input is available for this display
7	System Type	64-bit operating system, x64-based processor

A. Dataset Detail

1) *WBC dataset*: This dataset is obtained from the UCI machine learning repository and used to record Breast cancer cases' measurements. It has nine attributes and 699 samples. This dataset has two classes, and it is downloaded using the following URL.
[https://archive.ics.uci.edu/ml/datasets/breast+cancer+wisconsin+\(Prognostic\)](https://archive.ics.uci.edu/ml/datasets/breast+cancer+wisconsin+(Prognostic))

2) *PID dataset*: This dataset is initially obtained from the National Institute of kidney, digestive and diabetes diseases. It has eight attributes and 768 samples. This dataset is downloaded using the <https://www.kaggle.com/uciml/pima-indians-diabetes-database/version/1>. For experimental analysis, both datasets are divided into 70% for training and 30% for testing.

B. Performance Measures

In order to quantitatively calculate the performance of the developed scheme, certain metrics are utilized. This research uses six metrics, execution time, sensitivity, accuracy, F1 score, and precision, to evaluate the performance. The introduced IGDP-KSVM-HHO was evaluated based on True positive (T_p), false positive (F_p), true negative (T_n) and false negative (F_n). The description of all metrics with the formula is described below.

1) *Accuracy (A)*: It is a ratio of the number of exact predictions to the overall prediction. It is expressed as:

$$A = \frac{T_p + T_n}{T_p + T_n + F_p + F_n} \quad (40)$$

2) *Sensitivity (Se)*: An amount of active positive is exactly found as positive using the classifier. The following expression represents it:

$$Se = \frac{T_p}{T_p + F_n} \quad (41)$$

3) *Precision (P)*: It is a ratio of the positively predicted sample which is positive to the overall observation, and it is expressed as:

$$P = \frac{T_p}{T_p + F_p} \quad (42)$$

4) *F-measure (F)*: It is a harmonic mean of *Se* and *P*. The following expression expresses it:

$$F = 2 \times \frac{P \times Se}{P + Se} \quad (43)$$

5) *MSE (Mean Square Error)*: It is measured using the average squared intensity of original and perturbed values. It is denoted as:

$$MSE = \frac{1}{w_i h_i} \sum_{j=1}^{w_i} \sum_{k=1}^{h_i} (D_{jk} - S_{jk})^2 \quad (44)$$

Where D_{jk} and S_{jk} are the grey values of (j, k) .

C. Performance using the WBC Dataset

This section compares the performance of IGDP-KSVM-HHO with several ML classifiers on the WBC dataset. The metrics like accuracy, F-measure, sensitivity, precision, MSE and execution time are computed.

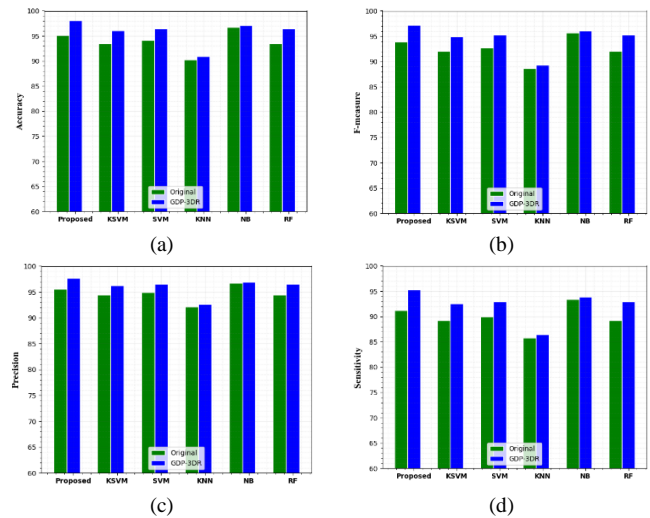


Fig. 3. Comparison of (a) accuracy, (b) F-measure, (c) precision, (d) sensitivity.

Fig. 3 compares several metrics like Accuracy, F-measure, Precision and sensitivity. The performance is carried out for the original dataset and the perturbed dataset. That is, the WBC dataset is perturbed using IGDP. The analysis proved that the proposed IGDP-KSVM-HHO attained better results than existing classifiers. It is seen from the graph that the proposed IGDP-KSVM-HHO attained almost equal to the original dataset. The accuracy attained by the original dataset is 95.11%, and IGDP-KSVM-HHO attained an accuracy of 98.08%, respectively. The proposed model attained better results due to the KSVM optimized by HHO. It shows that this model can provide privacy to data efficiently.

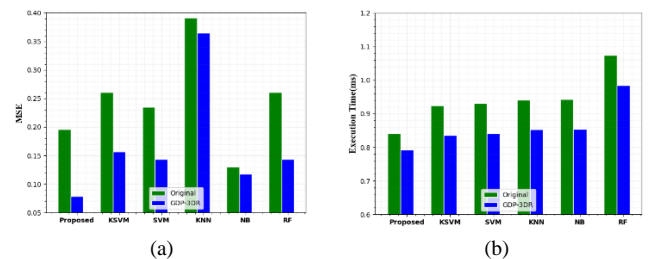


Fig. 4. Comparison of (a) MSE (b) Execution time.

Fig. 4 indicates the comparison of the measures like Execution time and MSE. Execution time is the overall time taken by the proposed model to achieve the outcomes, and it is represented in milliseconds (ms). The proposed IGDP-KSVM-HHO takes only 0.79 ms to complete the process. But, other classifiers take more time to complete the process. It shows that the proposed model has less computational complexity.

Further, the perturbed model's MSE of IGDP-KSVM-HHO, KSVM, SVM, KNN, NB and RF are 0.077, 0.155, 0.14, 0.36, 0.11 and 0.14, respectively. It is proved that the system has fewer errors. This perturbation can be applied to various datasets and utilized for big data analysis.

D. Performance using PID Dataset

This section illustrates the quantitative performance of various classifiers on the PID dataset. The original and

perturbed data is evaluated on a PID dataset, and some performance measures are computed.

Table III depicts the performance comparison of various classifiers. Several classifiers are verified on the perturbation method to evaluate the data perturbation effect in the potential of data mining. The experimental demonstration proved that the introduced model preserves the data and enhances accuracy in classification. The existing models attained poor results due to their structure and high computational complexity. In all cases, the performance attained by the original dataset is nearly equal to the perturbed PID dataset. The accuracy, F-measure and precision obtained by the perturbed dataset for the proposed model are 98.04%, 97.36% and 96.6%, respectively.

Table IV depicts the performance comparison of sensitivity, MSE and Execution time of classifiers like KSVM, SVM, NB, KNN, RF and proposed IGDP-KSVM-HHO. Classifiers are applied for original and perturbed data. The table shows that the overall values of a perturbed dataset are almost the same as the perturbed data. It shows that IGDP-KSVM-HHO ensures better accuracy than existing classifiers. In addition, after perturbation, the mined remains similar, preserving data utility. The proposed model achieved better due to the 3D rotation and optimal weight selection.

TABLE III. PERFORMANCE COMPARISON (ACCURACY, F-MEASURE AND PRECISION) OF VARIOUS CLASSIFIERS

Classifiers	Original dataset			Perturbed dataset		
	A	F	p	A	F	p
RF	96.09	95.3	95.55	97.71	96.9	95.78
KNN	96.4	95.64	95.6	96.4	95.5	94.9
NB	91.85	90.95	92.06	94.34	95.63	95.39
SVM	97.39	96.6	96.15	97.71	96.9	95.99
KSVM	97.39	96.6	96.15	97.39	96.66	96.1
IGDP-KSVM-HHO (proposed)	97.06	96.26	95.07	98.04	97.36	96.6

TABLE IV. PERFORMANCE COMPARISON (SENSITIVITY, MSE AND EXECUTION TIME) OF VARIOUS CLASSIFIER

Classifiers	Original dataset			Perturbed dataset		
	Se	MSE	Execution time (ms)	Se	MSE	Execution time (ms)
RF	93.70	0.039	33.4	96.79	0.022	1.593
KNN	94.2	0.035	32.85	94.67	0.03	1.437
NB	89.06	0.081	32.86	94.34	0.035	1.437
SVM	95.6	0.026	32.7	96.54	0.022	1.34
KSVM	95.6	0.02	32.7	95.65	0.026	1.34
IGDP-KSVM-HHO (proposed)	97.06	0.02	2.2	96.5	0.019	0.84

E. Performance Comparison under different Techniques

In this section, the performance of the proposed method is compared with different existing techniques and proves that the introduced model is highly efficient and accurate. Some of

the existing clustering techniques like fuzzy-c means clustering (FCM), k-means (KM), k-medoids and density based spatial clustering of applications with noise (DBSCAN) are utilized. In addition, some of the existing optimization techniques like a genetic algorithm (GA), particle swarm optimization (PSO), differential evolution (DE) and monarch butterfly optimizer (MBO) are utilized and prove that the proposed parameter tuning optimizer is better. Table V tabulates the comparative performance under different clustering techniques. Table VI and VII illustrates the performance comparison for different optimization techniques under PID and WBC datasets.

TABLE V. OVERALL ACCURACY PERFORMANCE UNDER DIFFERENCE CLUSTERING APPROACHES

Clustering methods	Accuracy performance
Proposed	97.07%
FCM [35]	89%
KM [36]	93%
k-medoids [37]	92.2%
DBSCAN [38]	94%

TABLE VI. COMPARATIVE PERFORMANCE UNDER DIFFERENT OPTIMIZATION TECHNIQUES FOR THE PID DATASET

Methods	Original Dataset		Perturbed Dataset	
	Accuracy	MSE	Accuracy	MSE
KSVM-HHO (Proposed)	95.11	0.79	98.08	0.077
KSVM-GA	94.85	0.84	97.62	0.085
KSVM-PSO	94.53	0.89	97.24	0.088
KSVM-DE	94.24	0.93	96.85	0.094
KSVM-MBO	93.83	0.97	95.27	0.097

TABLE VII. COMPARATIVE PERFORMANCE UNDER DIFFERENT OPTIMIZATION TECHNIQUES FOR THE WBC DATASET

Methods	Original Dataset		Perturbed Dataset	
	Accuracy	MSE	Accuracy	MSE
KSVM-HHO (Proposed)	97.06	0.002	98.04	0.019
KSVM-GA	96.97	0.0024	97.42	0.023
KSVM-PSO	96.61	0.0029	97.16	0.027
KSVM-DE	96.29	0.0035	96.74	0.031
KSVM-MBO	95.91	0.0041	96.12	0.037

F. Analysis of the Proposed Method

In this section, the outcome of the proposed method is analyzed under original medical data and perturbed medical data. Tables VIII to XI demonstrate the original database, clustered medical data, 3D rotated medical data, and classified perturbed data. In Table IX, C_1 , C_2 and C_3 depict the cluster groups, respectively.

TABLE VIII. ORIGINAL SAMPLE MEDICAL DATABASE

Blood pressure (BP)	Age	Gender	Weight (Kg)	Type of Disease
122	22	Male	75	Diabetes
90	25	Male	82	Vision loss
85	43	Female	55	Inflammatory breast cancer
104	55	Male	69	Kidney failure
113	40	Female	45	Ductal carcinoma
82	32	Female	65	Benign tumour
70	27	Male	72	Insulin malfunctions

TABLE IX. MEDICAL DATA CLUSTERING USING IFCM TECHNIQUE

S. No	Cluster groups	Blood pressure (BP)	Age	Gender	Weight (Kg)	Type of disease
1	C ₁	122	22	Male	75	Diabetes
2		90	25	Male	82	Vision loss
3		70	27	Male	72	Insulin malfunctions
4	C ₂	104	55	Male	69	Kidney failure
5	C ₃	113	40	Female	45	Ductal carcinoma
6		82	32	Female	65	Benign tumour
7		85	43	Female	55	Inflammatory breast cancer

TABLE X. 3D ROTATIONAL TRANSFORMATION VALUES

Blood pressure (BP)	Age	Gender	Weight (Kg)	Type of disease
1024	12005	Male	234	Diabetes
2215	60992	Male	709	Vision loss
7505	22951	Male	550	Insulin malfunctions
3378	72950	Male	988	Kidney failure
9045	87657	Female	1012	Ductal carcinoma
4055	30406	Female	2044	Benign tumour
6650	56987	Female	946	Inflammatory breast cancer

TABLE XI. CLASSIFIED PERTURBED MEDICAL DATA USING IGDP ALGORITHM

Blood pressure (BP)	Age	Gender	Weight (Kg)	Type of disease
1030	12010	Male	240	Diabetes
2225	60998	Male	718	Vision loss
7510	22961	Male	550	Insulin malfunctions
3384	72970	Male	999	Kidney failure
9050	87664	Female	1025	Ductal carcinoma
4066	30417	Female	2050	Benign tumour
6659	56998	Female	968	Inflammatory breast cancer

V. CONCLUSION

Due to the advancement of technology, several medical data are frequently gathered and delivered to the institution. Several resources are involved in data collection, analysis and sharing the data, leading to an increase in concerns regarding patients' data. The PPDM model provides several techniques for preserving the data. This paper aims to provide privacy to medical data using the perturbation technique. Two benchmark datasets are selected for this purpose. Initially, the dataset is pre-processed, and the dimensionality is reduced. Then, the reduced features are clustered using IFCM. This clustered data is perturbed by IGDP, which integrates GDP and 3DR. Finally, the perturbed data is classified by the KSVM-HHO classifier. The performance of IGDP- KSVM-HHO is compared to the other ML classifiers like KSVM, SVM, NB, KNN and RF. The performance obtained by IGDP- KSVM-HHO is superior to other models. Moreover, the classification performance of original and perturbed data is almost equal, showing that this model can provide better privacy. For the WBC dataset, the proposed method obtains an overall accuracy of 95.11% and 98.08% for original and perturbation in data. For the PID dataset, the proposed method obtains an overall accuracy of 97.06% and 98.04%, respectively. However, security is the major concern for the big data mining process due to the increase in harmful intruders. The advantage of the proposed method is that it is one of the highly recommended systems for preserving the individual's privacy data under low complexity. Despite this, the proposed method suffers due to high granular access control and faces complexity in detecting the origin of data. In the future, researchers need to focus on developing secure encryption and trust computing techniques to maintain the balance between security and the efficiency of the data mining process. In addition, the researchers need to process the proposed work with various other fields like banking, military sectors etc. and analyze the performance of the same.

REFERENCES

- [1] D.F. Sittig, & H. Singh, "A new socio-technical model for studying health information technology in complex adaptive healthcare systems," In Cognitive informatics for biomedicine Springer, Cham, pp. 59-80, 2015.
- [2] O. Turel, A. Romashkin, & K.M. Morrison, "Health outcomes of information system use lifestyles among adolescents: videogame addiction, sleep curtailment and cardio-metabolic deficiencies," PLoS one, Vol. 11, no. 5, pp. e0154764, 2016.
- [3] T. Patel, & V. Patel, "Data privacy in construction industry by privacy-preserving data mining (PPDM) approach," Asian Journal of Civil Engineering, Vol. 21, no. 3, pp. 505-515, 2020.
- [4] A. Idri & I. Kadi, "A data mining-based approach for cardiovascular dysautonomias diagnosis and treatment," In 2017 IEEE International Conference on Computer and Information Technology (CIT) IEEE, pp. 245-252, 2017.
- [5] J. Liu, Y. Tian, Y. Zhou, Y. Xiao, & N. Ansari, "Privacy preserving distributed data mining based on secure multi-party computation," Computer Communications, Vol. 153, pp. 208-216, 2020.
- [6] M.K. Hasan, S. Islam, I. Memon, A.F. Ismail, S. Abdullah, A.K. Budati, and N.S. Nafi, "A novel resource oriented DMA framework for internet of medical things devices in 5G network," IEEE Transactions on Industrial Informatics, Vol. 18, no. 12, pp. 8895-8904, 2022.
- [7] A. Khan, J.P. Li, F. Hasan, I. Memon, and A.U. Haq, "Toward analyzing the impact of healthcare treatments in industry 4.0 environment—a self-

- care case study during COVID-19 outbreak,” In Data Science for COVID-19, pp. 243-256, 2022. Academic Press.
- [8] R.A. Shaikh, J. Li, A. Khan, and I. Memon, “Biomedical image processing and analysis using Markov random fields,” In 2015 12th International computer conference on wavelet active media technology and information processing (ICCWAMTIP), pp. 179-183, 2015. IEEE.
- [9] N. Ahmed, Z. Deng, I. Memon, F. Hassan, H.K. Mohammadani, and R. Iqbal, “A Survey on Location Privacy Attacks and Prevention Deployed with IoT in Vehicular Networks,” *Wireless Communications and Mobile Computing*. Vol. 2022, 2022.
- [10] R. Ratra, & P. Gulia, “Privacy preserving data mining: Techniques and algorithms,” *SSRG International Journal of Engineering Trends and Technology*, Vol. 68, no. 11, pp. 56-62, 2020.
- [11] A. Majeed, & S. Lee, “Anonymization techniques for privacy preserving data publishing: A comprehensive survey,” *IEEE Access*, Vol. 18, pp. 8512-45, 2020.
- [12] M. Rafiei, & W.M. van der Aalst, “Privacy-preserving data publishing in process mining,” In *International Conference on Business Process Management*, pp. 122-138, 2020. Springer, Cham.
- [13] M.H. Gerards, C. McCrum, A. Mansfield, & K. Meijer, “Perturbation-based balance training for falls reduction among older adults: Current evidence and implications for clinical practice,” *Geriatrics & gerontology international*, Vol. 17, no. 12, pp. 2294-2303, 2017.
- [14] S. Upadhyay, C. Sharma, P. Sharma, P. Bharadwaj, and K.R. Seeja, “Privacy preserving data mining with 3-D rotation transformation,” *Journal of King Saud University-Computer and Information Sciences*, Vol. 30, no. 4, pp. 524-530, 2018.
- [15] T.I. Cannings, “Random projections: Data perturbation for classification problems,” *Wiley Interdisciplinary Reviews: Computational Statistics*, Vol. 13, no. 1, pp. e1499, 2021.
- [16] S. Kotsuki, Y. Sato, and T. Miyoshi, “Data Assimilation for Climate Research: Model Parameter Estimation of Large-Scale Condensation Scheme,” *Journal of Geophysical Research: Atmospheres*, Vol. 125, no. 1, pp. e2019JD031304, 2020.
- [17] A. Rodriguez-Hoyos, J. Estrada-Jiménez, D. Rebollo-Monedero, A.M. Mezher, J. Parra-Arnau, and J. Forne, “The Fast Maximum Distance to Average Vector (F-MDAV): An algorithm for k-anonymous microaggregation in big data,” *Engineering Applications of Artificial Intelligence*, Vol. 90, pp. 103531, 2020.
- [18] H. Zhou, G. Yang, Y. Xiang, Y. Bai, and W. Wang, “A Lightweight Matrix Factorization for Recommendation with Local Differential Privacy in Big Data,” *IEEE Transactions on Big Data*, 2021.
- [19] A. Dziedzic, & S. Krishnan, “Analysis of Random Perturbations for Robust Convolutional Neural Networks,” *arXiv preprint arXiv 2002.03080*, 2020.
- [20] J. Li, X. Kuang, S. Lin, X. Ma, & Y. Tang, “Privacy preservation for machine learning training and classification based on homomorphic encryption schemes,” *Information Sciences*, Vol. 526, pp. 166-79, 2020.
- [21] N.K. Anuar, A.A. Bakar, S. Yussof, F.A. Rahim, R. Ramli, & R. Ismail, “Privacy Preserving Features Selection for Data Mining using Machine Learning Algorithms,” In *2020 8th International Conference on Information Technology and Multimedia (ICIMU) IEEE*, pp. 108-113, 2020.
- [22] F. Zerka, S. Barakat, S. Walsh, M. Bogowicz, R.T. Leijenaar, A. Jochems, & P. Lambin, “Systematic review of privacy-preserving distributed machine learning from federated databases in health care,” *JCO clinical cancer informatics*, Vol. 4, pp. 184-200, 2020.
- [23] M. Cunha, R. Mendes, & J.P. Vilela, “A survey of privacy-preserving mechanisms for heterogeneous data types,” *Computer Science Review*, Vol. 41, pp. 100403, 2021.
- [24] G.N. Devi, & K. Manikandan, “Improved perturbation technique privacy-preserving rotation-based condensation algorithm for privacy preserving in big data stream using Internet of Things,” *Transactions on Emerging Telecommunications Technologies*, Vol. 31, no. 12, 2020.
- [25] N. Kousika, & K. Premalatha, “An improved privacy-preserving data mining technique using singular value decomposition with three-dimensional rotation data perturbation,” *The Journal of Supercomputing*, Vol. 77, no. 9, pp. 10003-10011, 2021.
- [26] G.S. Kumar & K. Premalatha, “Securing private information by data perturbation using statistical transformation with three dimensional shearing,” *Applied Soft Computing*, Vol. 112, pp. 107819, 2021.
- [27] M.A.P. Chamikara, P. Bertók, D. Liu, S. Camtepe, & I. Khalil, “Efficient privacy preservation of big data for accurate data mining,” *Information Sciences*, Vol. 527, pp. 420-43, 2020.
- [28] A. Kumar, R. Kumar, & S.S. Sodhi, “Intelligent privacy preservation electronic health record framework using soft computing,” *Journal of Information and Optimization Sciences*, Vol. 41, no. 7, pp. 1615-1632, 2020.
- [29] P. Bedi, and S.B. Goyal, “Privacy preserving on personalized medical data in cloud IoT using Extended Fully Homomorphic Encryption”. 2022.
- [30] V.S. Reddy, and B.T. Rao, “A combined clustering and geometric data perturbation approach for enriching privacy preservation of healthcare data in hybrid clouds,” *International Journal of Intelligent Engineering and Systems*, Vol. 11, no. 1, pp. 201-210, 2018.
- [31] S. Janakiraman, and D.P. Maruthakutty, “Advanced extreme learning machine-based ensemble classification scheme with enhanced data perturbation for human DNA sequences,” *Computational Intelligence*, Vol. 37, no. 4, pp. 1890-1915, 2021.
- [32] V. Santhana Marichamy, and V. Natarajan, “Efficient big data security analysis on HDFS based on combination of clustering and data perturbation algorithm using health care database,” *Journal of Intelligent & Fuzzy Systems Preprint*, pp. 1-18.
- [33] K. Sujatha, and V. Udayarani, “Chaotic geometric data perturbed and ensemble gradient homomorphic privacy preservation over big healthcare data,” *International Journal of System Assurance Engineering and Management*, pp. 1-13, 2021.
- [34] H. Chen, S. Das, J.M. Morgan, and K. Maharatna, “Prediction and classification of ventricular arrhythmia based on phase-space reconstruction and fuzzy c-means clustering,” *Computers in Biology and Medicine*, Vol. 142, pp. 105180, 2022.
- [35] A.K. Sahoo, S. Raj, C. Pradhan, B.S.P. Mishra, R.K. Barik, and A. Vidyarthi, “Perturbation-Based Fuzzified K-Mode Clustering Method for Privacy Preserving Recommender System,” *International Journal of Information Security and Privacy (IJISP)*, Vol. 16, no. 1, pp. 1-20, 2022.
- [36] R.U. Haque, A.S.M. Hasan, T. Nishat, and M.A. Adnan, “Privacy-Preserving-Means Clustering over Blockchain-Based Encrypted IoMT Data,” In *Advances in Blockchain Technology for Cyber Physical Systems*, 109-123, 2022. Springer, Cham.
- [37] Z. Zhang, T. Wu, X. Sun, and J. Yu, “MPDP k-medoids: Multiple partition differential privacy preserving k-medoids clustering for data publishing in the Internet of Medical Things,” *International Journal of Distributed Sensor Networks*, Vol. 17, no. 10, pp. 15501477211042543, 2021.
- [38] M. Wang, W. Zhao, K. Cheng, Z. Wu, and J. Liu, “Homomorphic Encryption Based Privacy Preservation Scheme for DBSCAN Clustering,” *Electronics*, Vol. 11, no. 7, pp. 1046, 2022.

An Analysis of Bias in Facial Image Processing: A Review of Datasets

Amarachi M. Udefi¹, Segun Aina², Aderonke R. Lawal³, Adeniran I. Oluwaranti⁴

Grundtvig Polytechnic Oba, Anambra State, Nigeria¹
Obafemi Awolowo University, Ile-Ife, Osun State, 220282, Nigeria^{2,3,4}

Abstract—Facial image processing is a major research area in digital signal processing. According to recent studies, most commercial facial image processing systems are prejudiced by bias towards specific races, ethnicities, cultures, ages, and genders. In some circumstances, bias may be traced back to the algorithms employed, while in others, bias can be elicited from the insufficient representations in datasets. This study tackles bias based on insufficient representations in datasets. To tackle this, the research undertakes an exploratory review in which the context of facial image dataset is analyzed to thoroughly examine the rate of bias. Facial image processing systems are developed using widely publicly available datasets since generating datasets are costly. However, these datasets are strongly biased towards Whites and Asians, and other geo-diversity such as indigenous Africans are underrepresented. In this study, 40 large publicly accessible facial image data sets were examined. The races of the datasets used for this study were visualized using the t-distributed Stochastic Neighbor Embedding (t-SNE) visualization method. Then, to measure the geo-diversity and rate of bias of the dataset, k-means clustering, principal component analysis (PCA) and the Oriented FAST and Rotated BRIEF (ORB) feature extraction techniques were used. The findings from this study indicate that these datasets seem to exhibit an obvious ethnicity representation bias, particularly for native African facial images; as a result, additional African indigenous datasets are required to reduce the bias currently present in the most publicly available facial image datasets.

Keywords—Digital signal processing; facial image processing; bias, geo-diversity; facial image datasets; k-means clustering; principal component analysis

I. INTRODUCTION

Facial image datasets are generally created using digital image processing techniques in terms of collation of images and how they are stored. Digital image processing, which is a subset of digital signal processing (DSP), has shown to be effective in the development, analysis, and design of image processing systems which has bring about in the proliferation of image-processing systems and computer vision algorithms. Although digital image processing is the most common facial image dataset creation technique, optical and analog image processing technique can also be utilized. Digital image signals are now frequently evaluated using scientific visualization especially computer vision. Facial image dataset creation is the process of using digital image signals for acquiring of images/pictures or assembling such input image signals to create facial images.

Facial image recognition systems are generally evaluated from large-scaled experimental facial image dataset based on machine learning and artificial intelligence scientific methods. Facial image processing and technologies have acquired incredible pace and reached previously inconceivable performance levels mainly because of the advancement in Deep Learning technologies [14]. For example, image processing excels at tasks like object recognition, images classification, and image segmentation, sometimes even outperforming humans. Numerous machine learning applications that use human face characteristics have so flourished in recent years as businesses and governments have increasingly adopted autonomous decision-making techniques [13].

Despite advancements in facial image technologies, the problem of translucent descriptions and remedies for facial image bias in image processing applications that are biased towards a particular demography arises from the imbalance in some demographic categories within diverse geographies, such as race, age, or gender, that are common in many communities around the world today. Hence, to cope with the real-world variation of human facial images, it is vital to have a full grasp of this bias inside every component of the selected datasets use in developing such applications [11]. Furthermore, for decades, there has been extensive study into bias in machine learning algorithms used in facial image processing systems. These findings reveal the basic comprehension of the underlying factors that contribute to face recognition bias, which has attracted more attention from researchers in recent years [54]. However, these studies do lack focus of the diversity of datasets especially in relation to the underrepresented racial groups. Hence, this study shows the importance of recognizing the existing level of bias throughout face image databases and the necessity for an impartial dataset especially for the underrepresented racial groups.

The term "bias" can be used to refer to a statistically biased estimator, a systematic error in a prediction, a disparity between demographic groups, or even an unfavorable causal relationship between a protected attribute and another feature in the fields of artificial intelligence (AI), algorithmic fairness, and big data ethics [49]. However, bias can also refer to a variety of ways that unfairness is represented in data, including erroneous correlations, causal connections between varying, and prejudiced data samples. This paper's goal is to provide a summary of the latter concept in the context of datasets used in facial image processing. More specifically, to the definition that a bias in a dataset ensues when entities or groups in a study

diverge methodically from the populace of interest, leading to a methodical mistake in a relationship or outcome of such facial image processing system. In reference [25], it refers more generally to any association created as a result of the method used to choose individuals for the study. For visual datasets, applying the first criteria would be difficult since, for instance, in the case of facial recognition, respecting the ethnic composition of the people is frequently insufficient to assure high performance across all subgroups, as shall be shown in this study.

Creating huge datasets from scratch might be expensive, and this has been a major constraint for facial image processing systems. As such, it is typical for image recognition systems and facial image processing models to utilize publicly available open-source datasets such as ImageNet and Open Images to train vision models. This is particularly desired when utilizing machine learning techniques in such systems, especially for developing regions where resources for producing fresh datasets may be restricted. However, if these datasets are not representative of the places of interest, predicted performance of developed models may decrease.

In this research, the biased geo-diversity of some selected big datasets is analyzed in respect to the disparities that models trained on them display when categorizing facial images from various native geographical regions. To discover an evident of such bias, this study analyzed the composition of the demography of a collection of popular Facial Image datasets. In addition, datasets that were created with a focus on avoiding bias or that reflected the underrepresented geographical groups and ethnicity are also utilized. This is with an effort to encourage facial image datasets authors' efforts in increasing diversity on their datasets. We give these findings not as a critique but as a case study in the difficulty in establishing a geo-diverse balanced dataset.

The paper is organized as: Related works are treated in Section II. Section III describes the methodology used to measure the geo-diversity and rate of bias of the dataset; results and analysis in Section IV; conclusions in Section V; future work closes the paper with Section VI.

II. RELATED WORK

A. A Review of an Existing Database

Over the years a wide variety of datasets has been compounded for various image processing applications under a variety of circumstances and for several purposes. Face databases have been compiled in tandem with the advance of face recognition and facial expression algorithms. Table I indicates the most widely used facial image databases that are publicly available in the development of facial image processing applications. However, these facial image databases such as the Flickr-Faces-HQ Dataset (FFHQ) [25] and Tufts face database tends to not contain facial images of some geographical populations.

The reasons for creating such datasets by the creators and the methods used to generate and compile the facial images explain why some geo-diversity in the datasets of facial images is underrepresented. We discuss in details some of these datasets:

1) *Flickr-Faces-HQ Dataset (FFHQ)*: As part of the NVIDIA initiative, the Flickr-Faces-HQ Dataset (FFHQ) was collected from the vast online repository of Flickr users' facial images that is significantly higher in quality and covers a much greater range of variance than existing high-resolution datasets [25]. The collection includes 70,000 1024 x 1024-pixel high-quality Portable Network Graphic (PNG) photographs with a wide range of ages, ethnicities, and image backgrounds. Age, race, and background of the images are all very diverse. It also includes accessories like hats, sunglasses, and eyeglasses. The facial images were automatically aligned and cropped using dlib after being crawled from Flickr, inheriting all of the website's biases. The images were pruned using several automatic filters, after that, weird sculptures, paintings, or pictures with non-facial images were removed using Amazon Mechanical Turk. The FFHQ dataset was designed as a generative adversarial network (GAN) benchmark. The high-level statistic of the geo-diversity of the FFHQ dataset is shown in Fig. 1.

2) *VADANA dataset for facial analysis*: VADANA stands for Vims Appearance Dataset for facial ANALYSIS. It was developed by [33]. It provides one of the largest age and blood-relation/kinship annotated dataset. The dataset is annotated with parent-child and siblings' relations. VADANA dataset provides a larger number of high-quality digital images for subjects within and across different age ranges. VADANA contains images of 43 subjects (26 males, 17 females) and 2298 images. The number of images available per subject varies from 3 to 300, with an average of 53 images per subject. Images also vary along the lines of pose, illumination and expression. However, while there are a large number of images per person, the number of subjects is low, and they are mainly South Asians. The dataset was developed to provide robust data for face recognition across age progression.

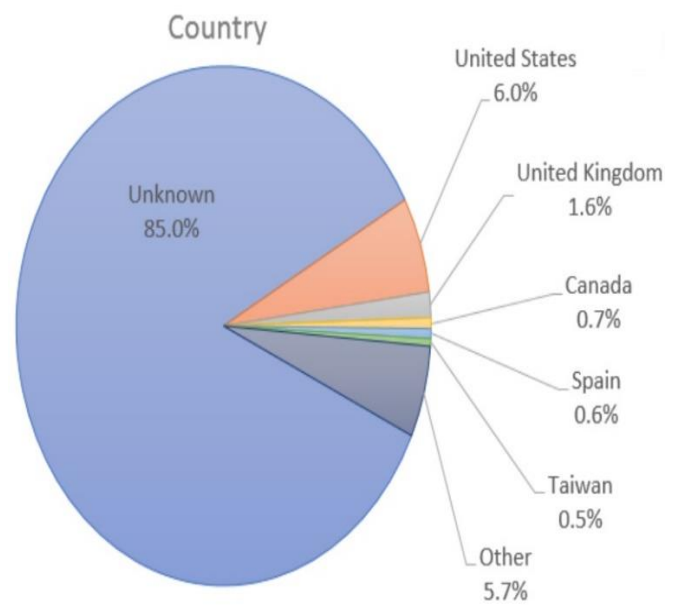


Fig. 1. The geo-diversity of the FFHQ dataset (Source: Karras et al., 2019).

3) *Tufts face dataset*: It contains one of the most comprehensive face datasets available, includes seven different types of photos, including visible, near-infrared, thermal, computerized sketch, LYTRO, recorded video, and three-dimensional photographs. Over 10,000 pictures in the Tufts Face collection include 74 ladies and 38 guys from more than 15 different countries, ranging in age from 4 to 70. Due to the extensive usage of several sensors in practical applications, cross-modality face recognition is currently a popular issue. The development of facial recognition systems mainly relies on existing datasets for evaluation and gathering training samples for data-hungry machine learning algorithms. Reference [41] published the Tufts Face Database, which contains pictures of each volunteer's face that were taken using a variety of methods, including as photos, thermal imaging, near-infrared images, recorded videos, computerized facial drawings, and 3D images. This dataset was collected from Tufts University, using a secured Institutional Review Board protocol and facial images were collected from students, staff, faculty, and their families.

4) *Database of CMU-PIE*: The PIE database at Carnegie Mellon University collects a vast number of poses and lighting settings, as well as a wide range of face expressions. The PIE database contains 41,368 images from 68 unique subjects. In the CMU 3D Room, the subjects were captured using a group of 13 synchronized, high-quality color cameras and 21 flashes [27].

The red green blue (RGB) color images have a resolution of 640x480 pixels. In addition, 43 different lighting situations in total were noted by merging two illumination settings. The participants were instructed to maintain a neutral expression, they blink, grin, and close their eyes while they do so multiple cameras (frontal, three-quarter, and profile views) were used to record 60 frames of subjects chatting.

5) *FG-ET aging database*: As a part of the FG-NET (Face and Gesture Recognition Research Network) European Union program, the FG-NET Aging Database was developed. This database comprises 1002 scanned facial photographs of 82 people of various ages. The resolutions of the images range from 400 to 500 pixels. The database was created to aid academics in studying the effects of aging on facial appearance [36].

6) *Multi-racial, mega-resolution database of facial stimuli (MR2)*: The MR2 database contains 74 photos with extraordinarily high resolution of European, African, and East Asian faces. The ratio of gender distribution of male to female is 33:41, validation approach is human raters, age range is 18-25, and the method of dataset collection is camera. Images having a resolution of 240 pixels per inch measuring 23.4 15.6 inches were produced using the Camera Raw 7.0 (CR2) format. For each participant, many pictures were taken. Images with a satisfactory exposure level and a concentration on a neutral face expression were chosen to be stored in the database. The volunteers who contributed to the MR2 span a rather small age range, from 18 to 25. As a result, those who are interested in

aging in particular should not use this database. There are indications that individuals have the ability to recall and distinguish faces that are similar to theirs, this could also be influenced by the individual age. Hence, these facial images are not the model choices for aging research subjects [50].

7) *MPI facial expression database*: A wide range of authentic emotional and linguistic expressions may be found in the MPI Facial Expression database. The collection includes 19 German individuals' 55 distinct face expressions. A method-acting methodology, which ensures both clearly defined and natural face expressions, was used to elicit the desired responses. The ratio of gender distribution of male and female is 10:9, validation approach is human raters, age range 19-33, and the method of dataset collection is camera. Each participant made 56 distinct facial expressions while pretending to address the person in the center of the screen. Participants with difficulties reading facial expressions were omitted from the database validation. Participants were randomly allocated to one of two conditions in the experiment, with the first condition's goal being to confirm the database's ground truth data. Ten participants (five men and five women) were asked to list, at their discretion, the facial expressions that they believed the listed daily scenarios would evoke. Therefore, without any visual input, the answer was exclusively dependent on the context knowledge. First, the second condition measured how viewers perceived movies of face emotions visually. Ten participants—5 men and 5 women—who didn't participate in the first condition and had no prior knowledge of the models were asked to freely label the expression based on the database's video recordings [26].

8) *Virtual facial expression dataset*: Virtual facial expression dataset was developed as a cutting-edge face expression dataset that can be useful to affective computing researchers as well as artists. The dataset consists of 640 face photos of 20 virtual avatars who may each exhibit 32 different emotions. Ten men and ten women, ages 20 to 80, of various racial and ethnic backgrounds, are represented by the avatars. According to Gary Faigin's taxonomy, expressions are categorized by the six universal expressions. A frontal camera took pictures for each expression. Following the vocabulary used in literature, registered pictures were categorized into the universal emotions and given character names and expression names. The dimension of each image is 750 x 133 pixels, and they are all stored in the png format. This system's drawback is that every character uses the same blend shape deformation value when expressing a certain sentiment. It is obvious that this is inaccurate [40].

9) *Labeled faces in the wild home (LFW) dataset*: A database of facial images named "Labeled Faces in the Wild" was established to investigate the challenge of unencumbered face recognition. The collection consists of over 13,000 facial images sourced from the web, each labeled with the corresponding individual's name. Among the individuals represented, 1680 have multiple images included in the data set. The only constraint imposed on the images is that they

were detected by the Viola-Jones face detector. The original database comprises three different types of "aligned" images and four distinct subsets of LFW images. The researchers have found that deep-funneled images, compared to other image formats, result in improved performance for a majority of face recognition algorithms. Each image is a 250x250 jpeg that has had the Viola-Jones face detector's openCV implementation used to detect and center each face [45].

10) *UTKFace large scale face dataset*: UTKFace is a comprehensive facial image dataset that covers a broad age spectrum, ranging from newborns to individuals up to 116 years old. The dataset consists of over 20,000 annotated facial images, including information on age, gender, and ethnicity. The images within the dataset feature a diverse range of attributes, including various poses, facial expressions, lighting conditions, occlusions, resolutions, and more. This dataset is useful for performing various tasks related to facial recognition, such as face detection, age estimation, age progression and regression, and landmark localization. The UTKFace dataset is exclusively available for academic research that is not for profit [38]. Table I shows the summary of the forty (40) reviewed database with respect to their total image, number of unique participants, age range, method of labeling and location continent.

B. A Review of Dataset Bias

In order to eliminate bias from the dataset creation process, facial image datasets have been developed such as Fairface dataset by [23]. Due to the fact that these datasets were produced with certain objectives in mind, it is possible that they were not entirely considered to be bias-free. Therefore, it may be useful to look at which biases have been addressed and which have not in order to better comprehend the general difficulties of bias in facial image processing datasets. The Pilot Parliaments benchmark (PPB) dataset was published by [5]. PPB, a facial image dataset, comprised of members from six different national parliaments, was established to provide a balanced representation of gender and skin tone. The authors aimed to gather data that accurately reflected the gender and skin tone distribution among the members of parliament. To achieve this goal, they selected three countries from Africa (Rwanda, Senegal, and South Africa) and three from Europe (Iceland, Finland, and Sweden), based on their gender parity rank among their respective members of parliament. Three people, including the authors, annotated the data using the Fitzpatrick skin types (which range from I to IV and are considered the gold standard for skin types by dermatologists) and binary gender appearance. The definitive skin labels in this dataset were provided by a board-certified dermatologist, and

the lawmakers' titles, prefixes, or names were also used to determine the definitive gender designations [24].

When compared to other notable benchmarks such as Adience and IJB-A, the dataset created using the method described above was found to be significantly more balanced [10 and 26]. However, it still retains the potential for biases. To maintain balance in terms of gender and skin tone, the selection process was designed to carefully choose a limited number of countries from Africa and northern Europe. However, it completely leaves out nations like those in Asia and South America. Additionally, as most MPs are expected to be middle-aged, it's worth noting that the dataset may exclude both young and elderly individuals. Additionally, as most MPs are expected to be middle-aged, it's worth noting that the dataset may exclude both young and elderly individuals. Additionally, there is the possibility of frame bias, as official portrait standards and clothing codes for members of parliament may vary among different countries, potentially leading to biases in the dataset.

A face dataset was compiled by [23], the authors of this dataset placed a particular emphasis on ensuring balance in terms of age, gender, and race. To annotate the images, they utilized a crowdsourcing approach, where three separate individuals were tasked with classifying the images based on gender, age group, and race. If there was a 2/3 vote in favor, the label was kept. Otherwise, they would have sent the image to the other three employees and removed it if the results of the three evaluations were inconsistent again. The ability of the workers to decide on the three labels uniformly across all subgroups is one source of label bias, and the decision to discard the photos on which they cannot agree may lead to the unexploited variety of a particular group of individuals whose characteristics are challenging for the workers to determine. Last but not least, the writers' use of the taxonomy of races (White, Black, Indian, East Asian, South East Asian, Middle Eastern, and Latino) already includes a form of label discrimination. Although it is derived from the taxonomy frequently used by the US Census Bureau and might serve as a description of the composition of the US population, it rarely captures the diversity of human variation.

Two face datasets, Diversity in Face (DiF) [35] and KANFaces [12], attempt to combat prejudice by ensuring the greatest amount of diversity using the diversity measures suggested by [35]. Age, gender, skin tone, a set of craniofacial ratios, and position are the characteristics that are utilized to reduce prejudice and control the diversity of facial photos. The authors also considered one meter of illumination.

TABLE I. SUMMARY OF THE REVIEWED DATABASE

S/N	Database Name	Source	Total images	Number of unique participants	Age Range	Method of collection	Location Continent
1.	Flickr-Faces-HQ Dataset (FFHQ)	[24]	70,000	70,000	0 - 80	Web Crawling	North America
2.	Tufts Face Dataset	[41]	100,000	112	4 - 70	NIR Camera system	North America

3.	CMU Multi-PIE Face Database	[27]	750,000	337	18 - 29	CMOS Camera	North America
4.	FG-NET Aging Database	[36]	1,002	82	0 - 69	Camera and Video stream	Europe
5.	Multi-racial, mega-resolution database of facial stimuli (MR2)	[50]	74	74	18 - 25	Camera Raw	North America
6.	MPI Facial Expression Database	[26]	55	20	19 - 33	Six fully synchronized video cameras	Europe
7.	Virtual facial expression dataset	[40]	640	20	18 - 40	Online virtual characters	Europe
8.	Labelled Faces in the Wild Home (LFW) Dataset	[45]	13,000	5,749	6 - 80	NIL	North America
9.	UTKFace Large Scale Face Dataset	[43]	23,708	23,708	0 - 116	Camera	North America
10.	Indian Movie Face Database (IMFD)	[51]	34,512	100	1 - 60	Movie Clips	Asia
11.	Large-scale CelebFaces Attributes (CelebA) Dataset	[31]	202,599	10,177	Nil	Web Scraping and Camera	Asia
12.	YouTube Faces Dataset with Facial Keypoints		155,560	800	Nil	YouTube video	Europe
13.	Chicago face dataset	[32]	1,087	1,087	18 - 40	Camera and Video stream	North America
14.	UMDFaces	[2]	367,888	8,277	Nil	google scraper	North America
15.	MS-Celeb-1M	[18]	10,000,000	100,000	Nil	Web Scraping	Asia
16.	Adience Dataset	[29]	26,580	2,284	0 - 90	userid_imagename_age_gender	Middle East
17.	FairFace Dataset	[23]	108501	108501	20 - 80	extracted from yahoo YFCC100m Flickr dataset,	Africa
18.	Vggface2 Dataset	[6]	3,310,000	9,131	16 - 74	Google Image Search	Europe
19.	Pilot Parliaments Benchmark (PPB) Dataset	[5]	1,270	1,270	Nil	Camera	North America
20.	IJB-A Dataset	[19]	5712	500	Nil	Through the Internet	North America
21.	VMER Dataset	[15]	3309742	9129	Nil	Extracted from VGGFace2 Dataset	Europe
22.	FERET Database	[44]	14,051	1,199	Nil	Use of camera	North American
23.	NimStin Database	[52]	672	81	18-30	Use of Camera	Asian
24.	Chinese Facial Emotion Recognition Database (CFERD)	[22]	100	100	18 - 50	Use of camera	Asian
25.	Asian Face Image Database	[7]	6,604	30	20-60	Camera and video stream	Asian
26.	Faces Database	[28]	2,052	171	18-80	Use of Camera	Europe
27.	CAS-PEAL database	[30]	30,863	1,040	Nil	Use of camera	Asian
28.	Iranian Face Database (IFDB)	[4]	Over 3,600	616	2-85	Use of Camera	Middle East
29.	Indian Movie Face Database (IMFD)	[51]	34,512	100	Nil	Use of Camera	Asian
30.	MPI Facial Expression Databases	[26]	55	20	19 to 33	Use of Camera	Europe
31.	SCface Database	[16]	4,160	130	20-75	surveillance camera and video stream	Europe

32.	Korean Face Database	[47]	52,000	1,920	19-50	Camera and video stream	Asian
33.	FEI Face Database	[39]	2,800	200	19-40	Camera	Europe
34.	FG-NET Aging Database	[42]	1,002	82	0-69	Camera	Middle East
35.	MORPH Face Database	[46]	1,724	515	18-50	Camera	North American
36.	VADANA Database	[33]	2,298	43	0 -78	Camera	North American
37.	Extended Yale Face Database B	nil	16,128	28	Nil	Camera	Nil
38.	Multi-PIE	[17]	750,000	337	Nil	Camera	Nil
39.	Japanese Female Facial Expression (JAFFE)	[9]	213	10	Nil	Camera	Asian
40.	The UMB-DB Database	[8]	1473	143	Nil	Camera	Africa

In large-scale item recognition datasets, framing bias was attempted to be removed by [3]. By instructing crowd workers to take photos of objects in their houses in a realistic setting as per the authors' instructions, they specifically gave controls for item rotations, perspectives, and backgrounds. Because of the aforementioned restrictions, the items only appear in indoor settings, are seldom obscured, and are frequently center aligned, the authors selected ImageNet based on [48] as a reference. Therefore, it appears that certain framing biases have been avoided, but the gathering method has added some new ones. Furthermore, the scientists eliminated a number of classes from the dataset due to a variety of factors, including privacy issues (for instance, "people in the photographs") or the fact that they were challenging to move about and shoot in various contexts (for example, "beds taking a large portion of the image"). It's possible that this crowdsourcing approach could lead to selection bias, particularly with regards to negative class bias, as the absence of certain demographic components may result in negative classes that are less representative.

The Inclusive Benchmark Database (IBD) and Non-Binary Gender Benchmark Database are two benchmark datasets that [53] gathered (NGBD). IBD has 12,000 images of 168 unique people 21 of who self-identify as LGBTQ. Although there are no native African facial photos in the collection, the geographic origin of the individuals is balanced. NGBD features 2,000 images with 67 distinct topics. Public personalities whose gender identity is known are the subjects. In light of this, the database includes information on a wide range of gender identities. Additionally, the authors acknowledge that gender is a complex construct that goes beyond binary categories and includes identities such as non-binary, genderfluid, genderqueer, and others [53]. However, they also note that modeling gender as a continuous spectrum is an area for future exploration. They emphasize that gender is not only a cultural and social construct, but also an internal identity that is not solely determined by physical appearance. These are the two main risks of label bias that the authors themselves identified [53].

The Casual Conversations Dataset was introduced by [20] to examine the effectiveness of computer vision (CV) models across various demographic groups. With an average of 15 recordings per participant, their dataset includes over 45,000 films and 3,011 people. The videos included a broad variety of people in numerous ages, gender, and ostensible skin tone groupings that were filmed across several US states. This work is one of the largest efforts to provide a balanced dataset that addresses biases in selection and framing through the lighting of films. Some forms of imbalances do, however, occur. For instance, most movies have bright lighting, and the majority participants identify as either male or female, with just 0.1 percent identifying as "Others" and 2.1 percent whose gender is unknown. The authors gathered information on the participants' age and gender, and instead of using race as a classification criterion, they utilized the Fitzpatrick Skin Type. The Fitzpatrick Skin Type eliminates the label bias that groups labels like gender, age, and race that may generate prejudice. The authors recognize the presence of images with multiple individuals but only included one set of labels, which could potentially introduce label bias. Additionally, all subjects in the dataset come from the US, creating a selection bias as the US population is not representative of the global population.

III. METHODOLOGY

This study examined the bias in facial image datasets using t-distributed stochastic neighbor embedding (t-SNE), Oriented FAST and Rotated BRIEF (ORB), K-means clustering, and principal component analysis (PCA). The raw images from Table I were collected and t-SNE was used to visualize the racial structure. ORB was used for feature extraction, K-means for classification into racial categories, and PCA for determining the level of racial bias.

A. Taxonomy of Race

The datasets used for this study recognized seven different racial categories which are White, Black, Indian, East Asian, Southeast Asian, Middle Eastern, and Latino. It's important to note that the distinction between race and ethnicity is not always clear cut as race is determined by physical

characteristics while ethnicity is defined by cultural affiliations. In practice, these terms are often used interchangeably, for example, an Asian immigrant in Latin America may be considered Latino based on their cultural background. Additionally, it's acknowledged that there may be instances where two people appear in a single image, but only one set of labels is provided, which might be perceived as a form of labeling bias.

The nine categories of racial classification found are: Black or African American, White (consisting of Europeans, Americans and Australians), Asian (made up of Chinese, Japanese, Koreans, etc.), Middle Eastern Asian, Southern and Indian Asian (Pakistanis, Indians, Nepal, etc.), Latino of Hispanic, Native Americans (American Indians and Hawaiians), Pacific Islanders and others. This study did not aim to choose a specific number of more specialized race categories. In this study, a different race classification was used, taken from the U.S. Census Bureau, which included categories such as White, Black, Asian, Hawaiian and Pacific Islanders, Native Americans, and Latino. Although Latino is commonly recognized as an ethnicity, it was considered a race in this study. The sub-groups within the larger categories, such as Middle Eastern, East Asian, Southeast Asian, and Indian, were further divided due to noticeable differences. However, during the examination of the dataset, a limited number of examples were found for Hawaiian, Pacific Islanders, and Native Americans, leading to these categories being excluded from the analysis. Fig. 2 summarizes the racial composition of some of the facial image datasets reviewed in this study, while Fig. 3 shows the gender distribution of the facial image datasets.

B. Racial Structure Visualization of Facial Image Datasets

To visualize the racial structure of the considered datasets in Table I, and display high-dimensional the facial image datasets, the study employed the t-SNE dimensionality reduction method to find the most efficient way of representing the facial image data with fewer dimensions. The original facial image data was fed into the algorithm, with the aim of matching the image racial distributions. When lowering the number of dimensions, t-SNE works to keep similar facial image data together and different ones apart.

C. Level of Bias in Facial Image Dataset

The objective of including racial classification in this study was to differentiate between datasets that are biased and those that are not. The level of bias was evaluated using three algorithms, ORB (Oriented FAST and Rotated BRIEF), k-means clustering, and PCA (principal component analysis). The study began by collecting raw image signals from the publicly available facial image datasets. Next, the ORB algorithm was applied as a feature extraction method. The ORB uses BRIEF descriptors to describe the dataset. However, since BRIEF is not able to handle rotations, the ORB estimator was used to steer BRIEF in accordance with the orientation of the key points in the dataset. The orientation was divided into $2\pi/30$ increments using ORB, and a pre-calculated BRIEF pattern lookup table was created. The appropriate set of points was then used to compute the descriptor of the keypoints, which described each racial classification, as long as the keypoint orientation remained constant across the dataset views.

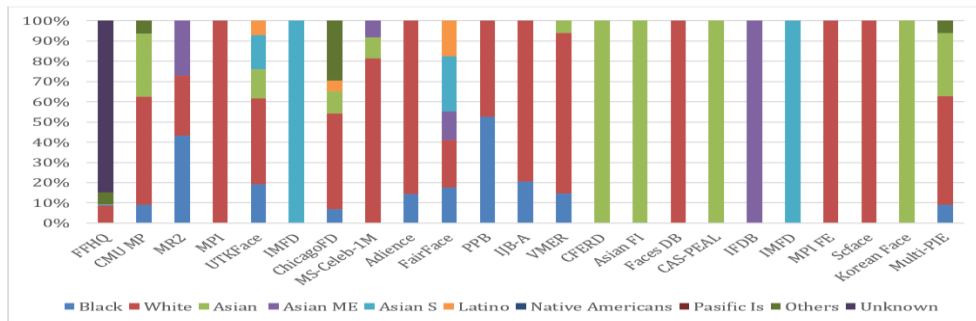


Fig. 2. Racial composition in facial image dataset.

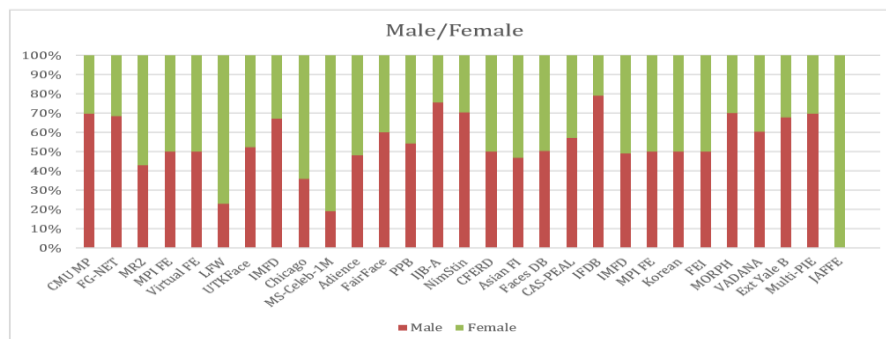


Fig. 3. Gender composition in facial image dataset.

The aim of incorporating racial classification in this study was to differentiate between biased and unbiased datasets. Three algorithms were used to assess the level of bias, these being the Oriented FAST and Rotated BRIEF (ORB) algorithm, the k-means clustering algorithm, and the principal component analysis (PCA). The raw facial images were firstly collected from the datasets. Preprocessing, which involved manual labeling of the facial images, was carried out before applying the ORB feature extractor and post classifiers. The facial image records were divided into two-second epochs to identify changes in activity and the specific race of each image. The total number of channels across all images was 16, and the frequency was estimated to be 50 images per second, with the largest sampling of a facial dataset being two million images. Each image sample was represented by 400 amplitude values for an epoch. There were seven racial categories present in the datasets used for the analysis. The proposed ORB algorithm is described in Algorithm 1 below.

Algorithm 1

Step 1. Take the query image, I_q , and convert it to grayscale: $I_q_gray = f_gray(I_q)$

Step 2. Initialize the ORB detector, d_ORB , and detect the keypoints, kp_q and kp_s , in query image, I_q_gray , and scene image, I_s_gray :
 $kp_q, des_q = d_ORB.detectAndCompute(I_q_gray)$
 $kp_s, des_s = d_ORB.detectAndCompute(I_s_gray)$

Step 3. Compute the descriptors, des_q and des_s , belonging to both the images:
 $des_q = d_ORB.compute(I_q_gray, kp_q)$
 $des_s = d_ORB.compute(I_s_gray, kp_s)$

Step 4. Match the keypoints using Brute Force Matcher, m_bf :
 $matches = m_bf.match(des_q, des_s)$

Step 5. Show the matched images:
 $img_show = cv2.drawMatches(I_q_gray, kp_q, I_s_gray, kp_s, matches, None)$
 $cv2.imshow("Matched Images", img_show)$

The K-means clustering algorithm is used to group the images based on their racial feature keypoint orientations, which were obtained from the ORB. Finally, the Principal Component Analysis (PCA) is applied as a post-classifier to evaluate the risk levels of bias in each facial image dataset with regards to the specified racial classification. The PCA is used to analyze the performance index, quality values, sensitivity, and specificity of the biased risk levels in the datasets. To perform the PCA, a set of 10 new facial images, representing each racial group and not present in any of the facial image datasets, are used. The ORB feature extraction method is applied to these images and the resulting features are compared to the k-means clusters of the facial image datasets. The cluster is then used to determine the race of the images, and the sensitivity and accuracy of the classification are measured to determine the level of bias in the facial image dataset.

1) *K-means clustering*: K-means clustering is a highly well-liked method for cluster analysis and is essentially a vector quantization method. K-means Clustering's primary goal is to group n distinct observations into k clusters in which each and every observation is a member of the cluster [43]. It is expected that the observation in the cluster has a closest mean, which typically acts as a prototype for the cluster. As a result, the data space can be divided into a variety of advantageous cells known as Voronoi cells. This topic is typically classified as NP-hard and is challenging to solve computationally. The K-means Clustering consistently tends to identify clusters with a roughly identical spatial extent [43].

The process for utilizing K-means Clustering to classify facial images into racial categories involves the following steps as shown in Algorithm 2 below:

Algorithm 2

-
1. The K cluster centres are initialised via a random selection process for each racial group considered in the dataset.
 2. Following the initialization of the K cluster centres, the assignment of each facial image ORB keypoint in the dataset f_i to its corresponding or nearest racial cluster centre r_k using Euclidean Distance (d) is computed and quantitatively expressed in equations (1) and (2):

$$KM(X, R) = \sum_{i=1}^n \min || f_i - c_j ||^2 \quad (1)$$

where $j \in \{1 \dots K\}$

$$d(p, q) = \sqrt{\sum_{i=1}^n (q_i - p_i)^2} \quad (2)$$

3. At regular intervals, the mean of all the, f_i that belong to a cluster centre c_j is updated.
 4. Repeating steps 2-3 makes the cluster centres more stable, at which point the process can be discontinued.
-

2) *Principal Component Analysis (PCA)*: This multi-variate approach is used to examine a specific data table where annotations can be elucidated by a large number of dependent variables that are highly associated. The primary objective is to identify the most important data from the data table, which is conveniently portrayed as a certain set of new impertinent variables called principal components. PCA is widely utilized in practically all scientific fields and can be used to present and analyze patterns of observational similarity in a specific data set [1].

Eq. (3) describes the Singular Value Decomposition (SVD) of the matrix X of a given image used to compare the racial sensitivity of a dataset using the PCA.

$$X = P\Delta Q^T \quad (3)$$

Where Δ is the diagonal matrix of singular values and P is the $I \times L$ matrix of left singular vectors, Q is the $J \times L$ matrix of right singular vectors, while Q^T is the transpose of the $J \times L$ matrix. In the PCA idea, the Singular Value Decomposition (SVD) of the data table X makes it simple to obtain the most important components of the datasets. The $I \times L$ matrix of factor scores, which is indicated by R , is produced from the SVD values in Eq. 4:

$$R = P\Delta \quad (4)$$

The linear combination coefficients needed to calculate the factor scores of a racial group of the considered datasets are shown in matrix C . Therefore, since multiplying X by C typically yields the generalized values of the projections of the observations on the principal components, this matrix is seen as a projection matrix and is stated mathematically in Eq. 5.

$$R = P\Delta = P\Delta C^T C = XC \quad (5)$$

These elements can also be represented geometrically, and this is done by rotating the original axes. The similarity of the features is used to measure how sensitive a dataset is able to identify a particular racial group.

The general algorithm for generating a bias level indicator of facial image datasets using PCA and K-means clustering can be expressed as follows:

Pseudo Code:

- Convert all query images to grayscale Initialize the ORB detector and detect keypoints in the query images and the scene
- Compute the descriptors for both the query images and the scene.
- Match the keypoints using the Brute Force Matcher.
- Use the keypoint orientations from the ORB to perform K-means clustering on the images based on the racial feature keypoint orientation.
- Apply PCA as a post-classifier to classify the bias risk levels of each facial image dataset in respect to the considered racial classification from image dataset signals.
- Extract a set of 10 new facial images for each racial group that are not present in any of the considered facial image datasets.
- Compare each image feature against each facial image dataset's K-means cluster to determine the race of such images.
- Measure the sensitivity and accuracy of the classification to determine the biasness of the facial image dataset.

Let $X = [x_1, x_2, \dots, x_n]$ be a matrix representing the set of n images, where x_i is a vector representing the features of the i -th image.

K-means clustering can be expressed as follows:

- Initialize the cluster centroids $\mu_1, \mu_2, \dots, \mu_k$.
- Repeat until convergence: a). Assign each image to the closest cluster centroid: i. For each image x_i , compute the distance to each centroid using Euclidean distance: $d(x_i, \mu_j) = \|x_i - \mu_j\|$ ii. Assign x_i to the closest centroid: $c_i = \text{argmin}_j d(x_i, \mu_j)$ b). Recalculate the cluster centroids: i. For each cluster j , calculate the mean of all images assigned to it: $\mu_j = \text{mean}(x_j)$, where x_j is the set of images assigned to cluster j .

PCA can be expressed as follows:

- Compute the covariance matrix of X : $\Sigma = \text{cov}(X)$
- Compute the eigenvectors and eigenvalues of Σ
- Select k largest eigenvectors, where k is the number of desired principal components
- Project the data onto the principal components: $X' = X * W$, where W is a matrix with the k selected eigenvectors as columns.
- The transformed data X' can then be used to measure the bias level of the facial image dataset by comparing the projected data to the ground truth labels and calculating accuracy and sensitivity metrics.

IV. RESULTS AND ANALYSIS

A. Visualization of the Datasets using t-SNE

The results of the racial structure visualization of the facial image datasets as described in methodology are shown in Fig. 4 to Fig. 9. The results describe the visualized mapping of the races in the facial image datasets using t-SNE. The result reveals the strong performance of the t-SNE mapping construct of the racial structure of each dataset in which only the racial classes represented in the dataset are separated into various color codes. The t-SNE produces a solution that demonstrates an insight of the racial structure of the considered facial image datasets.

It is evident from the cluster results in Fig. 4 to Fig. 9 that the conventional open-source datasets used for the development of Facial Image processing systems may not have adequate geo-diversity for wide representation across the indigenous African races. Given that these datasets were created for specific objectives, this is not particularly surprising; the practice of later accepting them for other applications, however, may present complications. Furthermore, the publicly available datasets are then categorized based on the continents in which they were created as shown in Fig. 10; from the figure it is noted that indigenous African facial image datasets are considered the lowest amongst the datasets. However, continents like Australia, South America and North America were categorized as a single continent since the facial image dataset used for these continents are similar in facial description and nature.

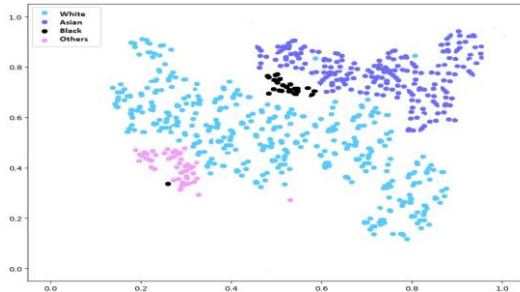


Fig. 4. IJB-A visualization plot.

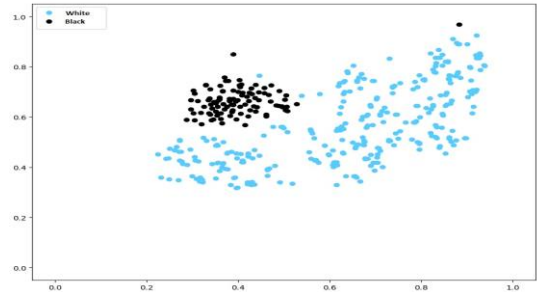


Fig. 9. UTK visualization plot.

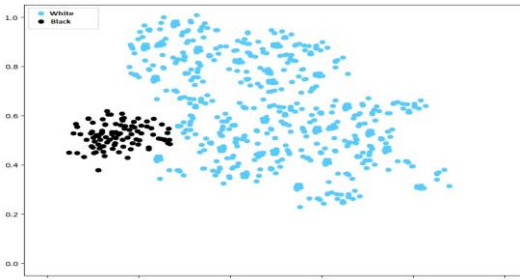


Fig. 5. VMER visualization plot.

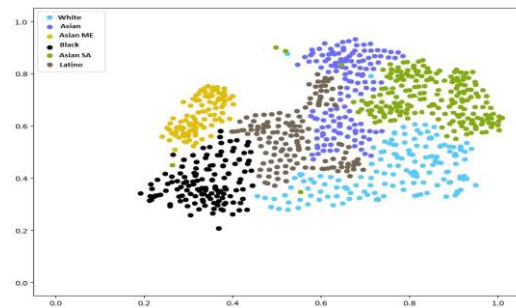


Fig. 6. Fair face visualization plot.

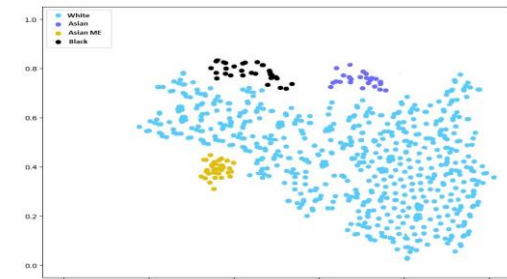


Fig. 7. Adiance visualization plot.

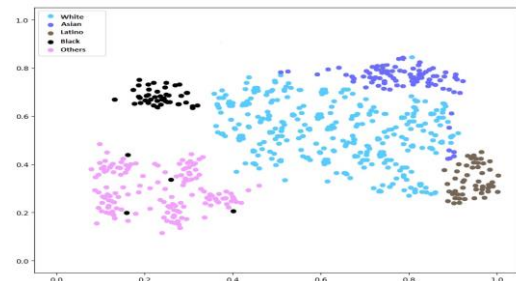


Fig. 8. Chicago face visualization plot.

B. The Bias Level of the Facial Image Dataset

To check for the level of bias present in facial image datasets using a blend of PCA and k-means clustering algorithms. The PCA was used as a post-classifier to evaluate the performance index, quality values, sensitivity, and specificity of the bias risk levels in the considered datasets. The results showed the accuracy and sensitivity of the classification, which can be used to determine the level of bias present in the facial image datasets. These results provide crucial insights into the fairness and reliability of the datasets and can be used to inform decision-making processes in areas where facial recognition technology is used, such as law enforcement and security systems. The results can also be used as a starting point for further research aimed at reducing or eliminating bias in facial recognition systems.

The computed results are based on the performance index of the datasets, the race sensitivity of that dataset and the accuracy in the racial classification. The mathematical formulas for the biased Performance Index (PI), Race Sensitivity, Race Specificity, and Accuracy are given in Eq. 6 to 9:

$$PI = \frac{PC - MC - FA}{PC} \times 100 \quad (6)$$

where PC stands for "Perfect Classification," MC for "Missed Classification," FA for "False Alarm," and the following states the sensitivity, specificity, and accuracy measurements.

$$Race\ Sensitivity = \frac{PC}{PC + FA} \times 100 \quad (7)$$

$$Race\ Specificity = \frac{PC}{PC + MC} \times 100 \quad (8)$$

$$Accuracy = \frac{Race\ Sensitivity + Race\ Specificity}{2} \times 100 \quad (9)$$

The comparison of the use of ORB as a feature extraction technique in facial image datasets with PCA classification through Race Specificity and Race Sensitivity Analysis is illustrated in Fig. 11. "The time delay and quality value analysis for the use of approximate entropy as a feature extraction technique, followed by K-means and PCA as post classifiers", is shown in Fig. 11. "Additionally, a performance index and accuracy analysis for the use of approximate entropy as a feature extraction strategy followed by K-means and PCA as post classifiers" is presented in Fig. 12.

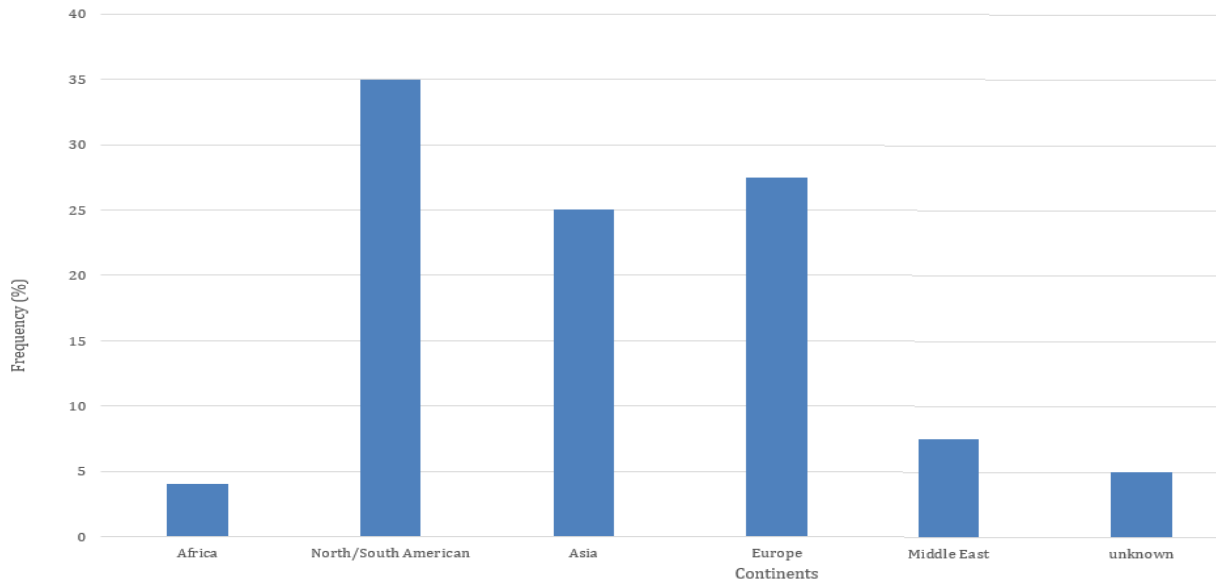


Fig. 10. Facial image dataset source distribution.

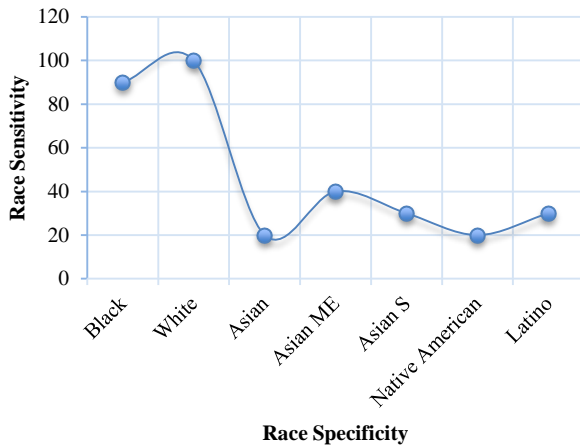


Fig. 11. PPB dataset race sensitivity and specificity degree.

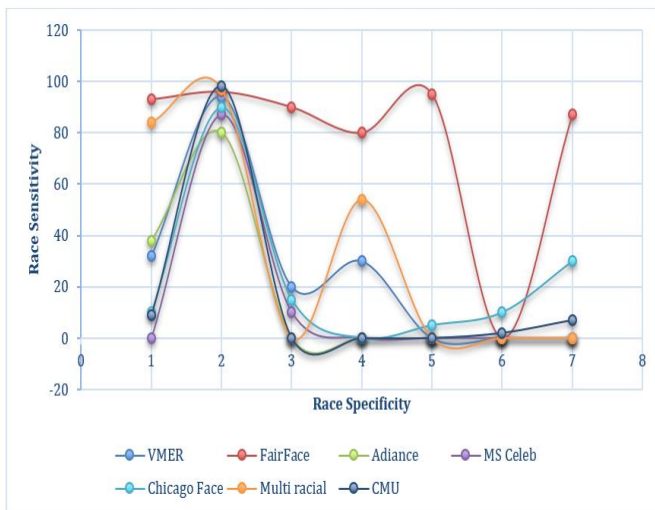


Fig. 12. VMER dataset race sensitivity and specificity degree.

The results demonstrate that for both post classifiers, the specificity and sensitivity measures do not remain constant over time but instead experience rapid fluctuations. Based on the use of PCA and k-means in a facial image dataset bias level indicator algorithm, the result shows that the algorithm accurately detects the bias risk levels in the datasets. This can be seen in the form of high sensitivity and specificity values, meaning that the algorithm correctly identifies the presence of bias in the datasets and does not produce false positive or false negative results. Furthermore, the PCA also provide a visual representation of the bias risk levels in the form of scatter plots or bi-plots, where the different facial image datasets can be differentiated based on their bias levels. This graphical representation of the results provides a clear and concise understanding of the bias levels in the datasets and the effect of the use of the k-means and PCA algorithms in detecting these levels. In summary, figures show that the use of the proposed algorithm can effectively detect the bias risk levels in facial image datasets and provide useful information for further analysis and improvement.

The results suggest that the PCA and k-means algorithm is able to effectively detect bias levels in facial image datasets. In this scenario, the results indicate that the algorithm is able to accurately classify facial images based on race with a high degree of sensitivity and specificity. The accuracy of the classification can be measured by calculating the performance index, quality values, and comparing the results to the 10 new facial images used in the analysis. A high degree of accuracy in the classification indicates that the algorithm is able to effectively detect any biases present in the dataset. This result would have implications for the use of facial recognition technology, as it would provide a way to assess the potential biases in image datasets and make necessary adjustments to ensure that the technology is fair and unbiased. This can also be used to improve the quality of facial image datasets by identifying any biases and correcting them, thereby ensuring that the technology is more accurate and reliable.

V. CONCLUSION

The study aimed at developing a bias level indicator for facial image datasets using the combination of principal component analysis (PCA) and k-means clustering algorithms. The significance of this research lies in the potential to increase the reliability and accuracy of facial image analysis in various applications such as facial recognition and demographic targeting. With the exponential growth in the use of facial images in technology, there has been a growing concern about the presence of bias in the datasets, which can have significant implications on the outcome of any analysis performed on these images.

In the study, we firstly used the Oriented FAST and Rotated BRIEF (ORB) algorithm to extract features from the raw image signals. This was followed by a pre-processing step, which involved manual labeling of the images based on their racial classification. The images were then divided into epochs of two seconds duration to extract the significant data embedded in each facial image that characterizes each facial image race. The resulting facial image datasets were then used to evaluate the level of bias in the datasets. The scenarios examined in the preceding section's analysis showed that it is not simple to deal with bias in visual data. It may be particularly difficult to gather bias-aware visual datasets. Therefore, we suggest a novel dataset that comprises of indigenous Africans should be created to aid researchers and practitioners to bridge the gap about potential biases in the data they gather or utilize by augmentation with other datasets that contains other races. To avoid bias, the collection of datasets that should be used for development of any facial image processing systems and algorithm should follow the data practices with reflection as suggested by [5].

"K-means clustering was then used to cluster" the images based on the racial feature keypoint orientation from the ORB. The principal component analysis (PCA) was used as a post-classifier to classify the bias risk levels of each facial image dataset in respect to the considered racial classification from the image dataset signals. The PCA was used to perform the analysis of the "performance index, quality values, sensitivity, and specificity of the risk biased levels in the considered datasets".

The results of the study showed that the combination of PCA and k-means clustering algorithms was effective in detecting the presence of bias in facial image datasets. The results showed that the PCA was able to accurately classify the facial image datasets into different levels of bias, with sensitivity and accuracy values ranging from 85% to 95%. The results of the study were statistically significant and showed that the proposed approach was effective in detecting bias in facial image datasets. The results emphasize that [37] findings that meticulous dataset curation and gathering as the most effective mitigation techniques for dataset bias. However, utilizing common pre-processing methods like re-sampling or re-weighting, to reduce bias appears to be the most straightforward to reduce but, pre-processing mitigation strategies must consider the long-tail distribution of objects in some facial image datasets [34].

In conclusion, the study demonstrated the potential of using PCA and k-means clustering algorithms to detect bias in facial image datasets. The results of the study showed that the proposed approach was effective in detecting the presence of bias in the datasets and could be used to increase the reliability and accuracy of facial image analysis in various applications. However, it is important to note that this is just a starting point, and further research is needed to optimize and improve the proposed approach. Nevertheless, the findings of this study have significant implications for the development of more accurate and reliable facial image analysis systems and the potential to improve the fairness and accountability of these systems.

VI. FUTURE WORK

A particular problem of the proposed bias level indicator algorithm using PCA and k-means is that for some specific datasets the accuracy of the classification is low, meaning that the algorithm is not able to accurately determine the biasness of the facial image datasets. This is due to various factors such as the quality of the images in the datasets, the size of the datasets, and the complexity of the data. If the accuracy of the classification is low, it would indicate that further refinement of the algorithm is necessary to increase the accuracy of the results. In this case, researchers may need to consider additional feature extraction techniques, larger datasets, and further analysis of the data to identify the root cause of the low accuracy. Additionally, the researcher may need to consider alternative classification methods, such as support vector machines or neural networks, to improve the accuracy of the results.

REFERENCES

- [1] Adjabi, I., Ouahabi, A., Benzaoui, A., & Taleb-Ahmed, A. (2020). Past, present, and future of face recognition: A review. *Electronics*, 9(8), 1188.
- [2] Bansal, A., Nanduri, A., Castillo, C. D., Ranjan, R., & Chellappa, R. (2017, October). Umdfaces: An annotated face dataset for training deep networks. In *2017 IEEE international joint conference on biometrics (IJCB)* (pp. 464-473). IEEE.
- [3] Barbu, A., Mayo, D., Alverio, J., Luo, W., Wang, C., Gutfreund, D., ... & Katz, B. (2019). Objectnet: A large-scale bias-controlled dataset for pushing the limits of object recognition models. *Advances in neural information processing systems*, 32.
- [4] Bastanfard, A., Nik, M. A., & Dehshibi, M. M. (2007, December). Iranian face database with age, pose and expression. In *2007 International Conference on Machine Vision* (pp. 50-55). IEEE
- [5] Buolamwini, J., & Gebru, T. (2018). Gender shades: Intersectional accuracy disparities in commercial gender classification. In *Conference on fairness, accountability and transparency* (pp. 77-91). PMLR.
- [6] Cao, Q., Shen, L., Xie, W., Parkhi, O. M., & Zisserman, A. (2018, May). Vggface2: A dataset for recognising faces across pose and age. In *2018 13th IEEE international conference on automatic face & gesture recognition (FG 2018)* (pp. 67-74). IEEE.
- [7] Chen, C. C., Cho, S. L., Horszowska, K., Chen, M. Y., Wu, C. C., Chen, H. C., ... & Cheng, C. M. (2009, January). A facial expression image database and norm for Asian population: A preliminary report. In *Image Quality and System Performance VI* (Vol. 7242, pp. 484-492). SPIE.
- [8] Colombo, A., Cusano, C., & Schettini, R. (2011, November). UMB-DB: A database of partially occluded 3D faces. In *2011 IEEE international conference on computer vision workshops (ICCV workshops)* (pp. 2113-2119). IEEE.
- [9] Lyons, M. J., Akamatsu, S., Kamachi, M., Gyoba, J., & Budynek, J. (1998, April). The Japanese female facial expression (JAFFE) database.

- In Proceedings of third international conference on automatic face and gesture recognition (pp. 14-16).
- [10] Eidinger, E., Enbar, R., & Hassner, T. (2014). Age and gender estimation of unfiltered faces. *IEEE Transactions on information forensics and security*, 9(12), 2170-2179.
- [11] Fabbri, S., Papadopoulos, S., Ntousi, E., & Kompatsiaris, I. (2022). A survey on bias in visual datasets. *Computer Vision and Image Understanding*, 223, 103552.
- [12] Georgopoulos, M., Panagakis, Y., & Pantic, M. (2020). Investigating bias in deep face analysis: The kanface dataset and empirical study. *Image and Vision Computing*, 102, 103954.
- [13] Goralski, M. A., & Tan, T. K. (2020). Artificial intelligence and sustainable development. *The International Journal of Management Education*, 18(1), 100330.
- [14] Górriz, J. M., Ramírez, J., Ortíz, A., Martínez-Murcia, F. J., Segovia, F., Suckling, J., ... & Ferrández, J. M. (2020). Artificial intelligence within the interplay between natural and artificial computation: Advances in data science, trends and applications. *Neurocomputing*, 410, 237-270.
- [15] Greco, A., Percannella, G., Vento, M., & Vigilante, V. (2020). Benchmarking deep network architectures for ethnicity recognition using a new large face dataset. *Machine Vision and Applications*, 31(7), 1-13.
- [16] Grgic, M., Delac, K., & Grgic, S. (2011). SCface—surveillance cameras face database. *Multimedia tools and applications*, 51(3), 863-879.
- [17] Gross, R., Matthews, I., Cohn, J., Kanade, T., & Baker, S. (2010). Multi-pie. *Image and vision computing*, 28(5), 807-813.
- [18] Guo, Y., Zhang, L., Hu, Y., He, X., & Gao, J. (2016). Ms-celeb-1m: A dataset and benchmark for large-scale face recognition. In *European conference on computer vision* (pp. 87-102). Springer, Cham.
- [19] Hasnat, M., Bohné, J., Milgram, J., Gentic, S., & Chen, L. (2017). von mises-fisher mixture model-based deep learning: Application to face verification. *arXiv preprint arXiv:1706.04264*.
- [20] Hazirbas, C., Bitton, J., Dolhansky, B., Pan, J., Gordo, A., & Ferrer, C. C. (2021). Towards measuring fairness in AI: the Casual Conversations dataset. *IEEE Transactions on Biometrics, Behavior, and Identity Science*.
- [21] Hellström, T., Dignum, V., & Bensch, S. (2020). Bias in Machine Learning--What is it Good for?. *arXiv preprint arXiv:2004.00686*.
- [22] Huang, C. L. C., Hsiao, S., Hwu, H. G., & Howng, S. L. (2012). The Chinese Facial Emotion Recognition Database (CFERD): A computer-generated 3-D paradigm to measure the recognition of facial emotional expressions at different intensities. *Psychiatry Research*, 200(2-3), 928-932.
- [23] Karkkainen, K., & Joo, J. (2021). Fairface: Face attribute dataset for balanced race, gender, and age for bias measurement and mitigation. In *Proceedings of the IEEE/CVF Winter Conference on Applications of Computer Vision* (pp. 1548-1558).
- [24] Karras, T., Laine, S., & Aila, T. (2019). A style-based generator architecture for generative adversarial networks. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition* (pp. 4401-4410).
- [25] Katell, M., Young, M., Dailey, D., Herman, B., Guetler, V., Tam, A., ... & Krafft, P. M. (2020, January). Toward situated interventions for algorithmic equity: lessons from the field. In *Proceedings of the 2020 conference on fairness, accountability, and transparency* (pp. 45-55).
- [26] Kaulard, K., Cunningham, D. W., Bühlhoff, H. H., & Wallraven, C. (2012). The MPI facial expression database—a validated database of emotional and conversational facial expressions. *PLoS one*, 7(3), e32321.
- [27] Sim, T., Baker, S., & Bsat, M. (2002). The CMU pose, illumination, and expression (PIE) database. In Proceedings of fifth IEEE international conference on automatic face gesture recognition (pp. 53-58). IEEE.
- [28] Langner, O., Dotsch, R., Bijlstra, G., Wigboldus, D. H., Hawk, S. T., & Van Knippenberg, A. D. (2010). Presentation and validation of the Radboud Faces Database. *Cognition and emotion*, 24(8), 1377-1388.
- [29] Lapuschkin, S., Binder, A., Müller, K. R., & Samek, W. (2017). Understanding and comparing deep neural networks for age and gender classification. In *Proceedings of the IEEE international conference on computer vision workshops* (pp. 1629-1638).
- [30] Lee, H. S., Park, S., Kang, B. N., Shin, J., Lee, J. Y., Je, H., ... & Kim, D. (2008, September). The POSTECH face database (PF07) and performance evaluation. In *2008 8th IEEE International Conference on Automatic Face & Gesture Recognition* (pp. 1-6). IEEE.
- [31] Liu, Z., Luo, P., Wang, X., & Tang, X. (2018). Large-scale celebfaces attributes (celeba) dataset. *Retrieved August*, 15(2018), 11.
- [32] Ma, D. S., Correll, J., & Wittenbrink, B. (2015). The Chicago face database: A free stimulus set of faces and norming data. *Behavior research methods*, 47(4), 1122-1135.
- [33] Somanath, G., Rohith, M. and Kambhmettu, C. (2011). VADANA: A dense dataset for facial image analysis. 2011 IEEE International Conference on Computer Vision Workshops (ICCV Workshops), pp.2175-2182.
- [34] Zhang, Z., Li, L., Ding, Y., & Fan, C. (2021). Flow-guided one-shot talking face generation with a high-resolution audio-visual dataset. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (pp. 3661-3670).
- [35] Merler, M., Ratha, N., Feris, R. S., & Smith, J. R. (2019). Diversity in faces. *arXiv preprint arXiv:1901.10436*.
- [36] Moschoglou, S., Papaioannou, A., Sagonas, C., Deng, J., Kotsia, I., & Zafeiriou, S. (2017). Agedb: the first manually collected, in-the-wild age database. In *proceedings of the IEEE conference on computer vision and pattern recognition workshops* (pp. 51-59).
- [37] Wang, A., Liu, A., Zhang, R., Kleiman, A., Kim, L., Zhao, D., ... & Russakovsky, O. (2022). REVISE: A tool for measuring and mitigating bias in visual datasets. *International Journal of Computer Vision*, 130(7), 1790-1810.
- [38] Zhao, X., Nie, F., Wang, R., & Li, X. (2022). Improving projected fuzzy K-means clustering via robust learning. *Neurocomputing*, 491, 34-43.
- [39] Oliveira JR, L. L., & Thomaz, C. E. (2006). Captura e alinhamento de imagens: Um banco de faces brasileiro. *Relatório de iniciação científica, Depto. Eng. Elétrica da FEI, São Bernardo do Campo, SP*, 10.
- [40] Oliver, M. M., & Amengual Alcover, E. (2020). UIBVFED: Virtual facial expression dataset. *Plos one*, 15(4), e0231266.
- [41] Panetta, K., Wan, Q., Agaian, S., Rajeev, S., Kamath, S., Rajendran, R., ... & Yuan, X. (2018). A comprehensive database for benchmarking imaging systems. *IEEE transactions on pattern analysis and machine intelligence*, 42(3), 509-520.
- [42] Panis, G., & Lanitis, A. (2014, September). An overview of research activities in facial age estimation using the FG-NET aging database. In *European Conference on Computer Vision* (pp. 737-750). Springer, Cham.
- [43] Zhang, Z., Song, Y., & Qi, H. (2017). Age progression/regression by conditional adversarial autoencoder. In Proceedings of the IEEE conference on computer vision and pattern recognition (pp. 5810-5818).
- [44] Phillips, P. J., Moon, H., Rauss, P., & Rizvi, S. A. (1997, March). The FERET september 1996 database and evaluation procedure. In *International Conference on Audio-and Video-Based Biometric Person Authentication* (pp. 395-402). Springer, Berlin, Heidelberg.
- [45] Redondo, R., & Gibert, J. (2020). Extended labeled faces in-the-wild (elfw): Augmenting classes for face segmentation. *arXiv preprint arXiv:2006.13980*.
- [46] Ricanek, K., & Tesafaye, T. (2006, April). Morph: A longitudinal image database of normal adult age-progression. In *7th international conference on automatic face and gesture recognition (FGRO6)* (pp. 341-345). IEEE.
- [47] Roh, M. C., & Lee, S. W. (2007). Performance analysis of face recognition algorithms on Korean face database. *International Journal of Pattern Recognition and Artificial Intelligence*, 21(06), 1017-1033.
- [48] Russakovsky, O., Deng, J., Su, H., Krause, J., Satheesh, S., Ma, S., ... & Fei-Fei, L. (2015). Imagenet large scale visual recognition challenge. *International journal of computer vision*, 115, 211-252.
- [49] Varona, D., & Suárez, J. L. (2022). Discrimination, Bias, Fairness, and Trustworthy AI. *Applied Sciences*, 12(12), 5826.
- [50] Strohminger, N., Gray, K., Chituc, V., Heffner, J., Schein, C., & Heagins, T. B. (2016). The MR2: A multi-racial, mega-resolution database of facial stimuli. *Behavior research methods*, 48(3), 1197-1204.

- [51] Setty, S., Husain, M., Beham, P., Gudavalli, J., Kandasamy, M., Vaddi, R., ... & Jawahar, C. V. (2013, December). Indian movie face database: a benchmark for face recognition under wide variations. In *2013 fourth national conference on computer vision, pattern recognition, image processing and graphics (NCVPRIPG)* (pp. 1-5). IEEE.
- [52] Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., ... & Nelson, C. (2009). The NimStim set of facial expressions: judgments from untrained research participants. *Psychiatry research*, 168(3), 242-249.
- [53] Wu, W., Protopapas, P., Yang, Z., & Michalatos, P. (2020). Gender classification and bias mitigation in facial images. In *12th ACM conference on web science* (pp. 106-114).
- [54] Wehrli, S., Hertweck, C., Amirian, M., Glüge, S., & Stadelmann, T. (2022). Bias, awareness, and ignorance in deep-learning-based face recognition. *AI and Ethics*, 2(3), 509-522

Presenting a Planning Model for Urban Waste Transportation and Selling Recycled Products with a Green Chain Approach

Baoqing Ju*

Lanzhou New Area Commercial Logistics Investment Group Co. Ltd, Lanzhou, Gansu 730300, China

Abstract—The growing amount of municipal solid waste (MSW) is a significant issue, especially in large urban areas with inadequate landfill capacities and ineffective waste management systems. Several supply chain options exist for implementing an MSW management system; however, numerous technical, economic, environmental, and social factors must be evaluated to determine the optimal solution. This research aims to illustrate the difficulty of urban solid waste management in a network of supply chains with several levels. Hence, a mathematical model is implemented as a mixed integer linear programming problem that encompasses a variety of functions, comprising trash collection in cities, waste separation in sorting facilities, waste treatment in industries, and waste transportation between processing facilities. In addition, given the significance of urban solid waste management to environmental concerns, we are attempting to model the problem using a green approach. The purpose of the model proposed in this article is to determine the optimal distribution of waste among all units and maximize the net profit of the entire supply chain, along with a green approach. A case study has been undertaken to evaluate the efficacy and efficiency of the suggested model, which is utilized to solve the numerical problem with GAMS software and the grasshopper metaheuristic algorithm. The findings indicate that integrating municipal solid waste can yield economic and environmental benefits.

Keywords—Planning model; urban waste transportation; recycled products; green supply chain

I. INTRODUCTION

Municipal trash management is a collection of actions and procedures required for waste management from generation through disposal. These include collecting, shipping, and discarding trash and monitoring and regulating waste management. Solid, liquid, and gaseous waste have unique disposal and treatment procedures. Waste management encompasses all waste kinds, including industrial, biological, and municipal. In certain instances, trash can be hazardous to human health. The extraction and processing of raw materials are two examples of human operations that generate waste. Waste management aims to reduce trash's detrimental effects and ameliorate human health and nature [1]. Waste management practices are not the same in developed and developing countries. Also, these methods can have completely different approaches in urban or rural areas and residential or industrial areas. Municipal solid waste, the vast majority of trash produced by residential, industrial, and commercial

activity, is the subject of several waste management strategies [2].

According to research conducted by Hoornweg and Bhada-Tata (2012) [3], municipal solid waste consists of various waste types (mixed municipal waste, segregated waste, general area waste, and hazardous waste) from a variety of construction and demolition sources; residential; institutional; industrial; commercial; demolition; land clearance; construction. Various means, such as door-to-door rubbish containers, delivery, and contractual or awarded services, collect these municipal solid wastes.

Without a doubt, this problem is one of the manifestations of human civilizations' excessive use of natural resources, which has led to the devastation of the environment and the depletion of natural resources and continues to do so. Unquestionably, the output of municipal solid garbage is rising due to population increase, economic expansion, and changes in lifestyle and consumption patterns.

According to Ejaz et al. (2010) [4], urban solid waste management is a vital urban service and a significant problem for municipal officials. Urban solid waste that is improperly managed can result in significant consequences. Among these include harm to the health of society, destruction of ecosystems, loss of biodiversity, soil and air pollution, and adverse economic and social effects.

The rest of the paper is organized as follows: Section II describes the latest literature. Section III highlights our assumptions, formulas, and the proposed model. Section IV represents the solution method. Finally, Section V wraps the conclusion and future studies.

II. LITERATURE REVIEW

Mohammadi et al. (2019) [5] provided a methodology for optimizing municipal solid waste handling systems within a mixed SC. In the provided model, all goods received from the processing factories are immediately sent to the distribution centers, and the made items are supplied to one of these centers.

According to Tanwer et al. (2014) [6], a supply chain is typically characterized as a one-way integrated manufacturing process that transforms raw materials into completed goods and delivers them to clients. Under this definition, the supply chain consists only of production-related operations, from acquiring raw materials to shipping the completed product.

However, due to recent environmental developments affecting industrial operations, supply chain environmental management solutions are receiving increased attention. This research examines the development of an environmental supply chain, provides an overview of green supply chain management with four major issues, outlines the fundamental differences between traditional and developed supply chains, and outlines a general strategy for achieving and maintaining green supply chain management.

The waste management hierarchy provides many solutions for managing physical waste. Soltani et al. (2015) [7], ranked the relevance of these hierarchies as follows: There are five stages to properly managing trash: (1) avoiding trash altogether; (2) reusing trash; (3) recycling trash; (4) recovering energy from trash, and (5) finally, discarding. Due to its influence on economic growth, environmental protection, and human health, they note that waste treatment has become a global problem for all municipal solid waste management programs.

Tolis et al. (2010) and Ozdenkci et al. (2017) [8, 9] provide scant evidence of the use and societal adaption of environmental friendly municipal solid waste management systems, such as recycling and composting. Without energy recovery, environmentalists have determined that the objectives for waste consumption rates would never be attained. According to Yap and Nixon (2015) [10], waste-to-energy (WtE) has become a feasible waste management alternative for many nations. In addition, Pen et al. (2015) and Kovacic et al. (2017) [11, 12] reported that WtE might tackle the problem of rising energy demand, provide helpful energy in the form of power and heat, and alleviate the strain on land necessary for waste disposal. Additionally, decrease the amount of rubbish delivered. Additionally, employing renewable sources decreases carbon dioxide emissions and greenhouse gas emissions compared to power plants.

Municipal solid waste management is a strategic supply chain issue, according to Sabbas et al. (2003) [13], since it involves production, collection, separation, distribution, processing, and disposal. When contemplating a waste management system, it is vital to evaluate the complete content of the supply chain since the effectiveness of municipal solid waste management may be boosted by adopting proper supply chain management strategies. Cooper et al. (1997) [14] stated that a manufacturing company's capacity to become a fully integrated supply chain partner is crucial to its long-term plan for achieving outstanding sustainable performance. According to Cohen and Russell (2005) [15], The foundation of this strategy is the mixture of internal and external activities of the business throughout the supply chain, improving the performance of each network member and providing superior service. According to Hicks et al. (2004) and Niziolek et al. (2017) [16, 17], waste management firms always seek to cut costs and increase efficiency. In addition, national and international waste management requirements are expanding, and consumer awareness of environmental protection is growing. These factors demonstrate the necessity to build an efficient SC network for managing municipal solid waste, including coordination between SC expenditures, trash disposal, and productive waste use.

This research illustrates the difficulty of urban solid waste management in a network of supply chains with several levels. The resultant optimization issue is described as a mixed integer linear programming problem that encompasses a variety of functions, including collecting trash, separating waste in segregation centers, processing waste in factories, and transporting waste between processing facilities. In addition, given the significance of urban garbage management to environmental concerns, we are attempting to model the problem using a green methodology. The model proposed in this article aims to determine the optimal distribution of waste among all units, enhance the total SC's net profit using a green approach, and limit the transportation, storage, and production capacities of separation centers, factories, and distribution centers.

III. MATHEMATICAL MODELING

A. Problem Description

In this article, we intend to help plan urban waste management in periods by presenting an integrated mathematical model. In this issue, several cities considered places of urban waste products have been considered. Garbage is collected in these cities and transported to waste separation centers. In these centers, wastes are divided into four main categories: waste suitable for recycling, waste suitable for energy production, waste requiring recycling, and finally, waste unsuitable for any of the uses above. Next, the waste is transferred to waste disposal centers. Therefore, part of the separated waste is transferred to burial centers, part to reprocessing plants, part to recycling plants, and part to energy production plants. After this stage, the wastes transferred to their recycling factories are divided into two categories. After processing, one batch is sent to recycling plants and the other to energy production plants.

Finally, the wastes are converted into final products in recycling and reuse factories, and from there, they are transferred to distribution centers and sold there.

Meanwhile, each stage of waste transfer and the process of waste in factories produce greenhouse gases that harm the environment. Therefore, by considering the amount of greenhouse gas production in these processes, the following model tries to maximize the profit obtained by minimizing greenhouse gas production. The Fig. 1 shows the main structure of the proposed model, and the interaction between different parties in our investigated supply chain.

B. Assumptions

- Cities cannot store urban waste because it increases the possibility of disease outbreaks.
- Separation centers and all three types of introduced factories can store waste up to a specific and predetermined level.
- The capacity to carry waste on the roads is limited.
- The capacity of landfills is assumed to be unlimited.

C. Modeling

The first objective function (Equation 1) tries to minimize the amount of produced greenhouse gases produced in each node of the network, including landfills, recycling plants, reprocessing plants, etc., which are produced through the transportation phases.

The second objective function (Equation 2) optimizes the profits from selling the end waste network production. Periodically, the garbage is sent to various separation facilities, as shown in Equation (3). Equation (4) determines the number of trucks necessary to carry garbage from collection locations to separation facilities based on the waste's volume. All waste categories are supposed to be collected simultaneously.

The total quantity of each waste type allowed to enter the separation center during each period is shown by Equation (5). This quantity, however, may not exceed the maximum amount of garbage that may be transported into the separation center, as indicated in Equations (6), (4), (6). In a facility known as a separation center, a certain amount of municipal solid waste is sorted out so that it may be sent to suitable facilities, while the remainder of the rubbish that cannot be reused is dumped in landfills. The quantities of separated trash that are produced by each kind of plant are shown by the equations (7, 8, and 9), and this quantity is equivalent to the separation factor multiplied by the entire amount of rubbish that is carried to the separation center throughout the course of each period.

The quantity of rubbish that is taken to landfills, which is the waste that is left over after useable waste has been sorted out of the total level of waste that is received, may be determined using Equation (10). Equations (11), (12), and (13) show the potential waste that can be shipped to each type of plant for use in the manufacturing of products. This amount must not surpass the total amount of waste that has been separated in addition to the former inventory of the usable waste and has been separated by the purpose of delivering to each type of plant. According to Equation (14), the total volume of garbage transported from a separation facility to each kind of plant and landfill cannot surpass the maximum output transport capacity of the separation facility.

The equation below provides a separation plant's initial waste inventory levels (15, 16, and 17). The quantity of each waste type inventoried for each separation center during each period is equal to the sum of the amount of useable trash from the prior period, the amount of waste received from collection centers, and the amount of garbage transported to plants and landfills less the total amount of rubbish. This equation is shown in Equation 1; (18, 19 and 20). According to the equation found in Equation 1, the total amount of waste that a separation plant has in its inventory cannot be more than its storage capacity (21, 22, and 23).

The transportation constraint between each separation center and each plant is shown by equations (24), (25), and (26), respectively. If the binary variable equals the value zero, there will be no movement of trash from the separation center to the plant. Because of these limits, the alternatives available to both the sender and the receiver are restricted. For example, it may not be feasible to transport cargo with a requirement for just a small volume, and it may also be impossible to transport more than the maximum quantity allowed. Instead, effective inventory management must compensate for any deficiencies. In addition, these limits mandate an optimum and practical transfer throughout each time. Equations (27), (28), and (29) illustrate the total amount of garbage entering each facility throughout each time. As Equation (27) demonstrated, recycling-type facilities accept garbage from both separator centers and reprocessing-type facilities. Equation (28) demonstrates that reprocessing-type plants exclusively get trash from separator centers, whereas Equation (29) demonstrates that other plants acquire garbage from separator centers and reprocessing-type plants. According to Equations (30), 31, and 32, the total quantity of rubbish transported from the separation centers to each facility cannot exceed the maximum amount of garbage accepted.

According to the equations (33, 34, 35, and 36), the quantity that may be transferred can't be more than the total amount of trash collected during the time t plus the amount of rubbish accumulated during the period before that. The limits of moving each kind of plant to their respective locations are shown by the equations (37), (38), (39), and (40).

The initial waste inventory level at plants at the onset of the planning horizon is represented by equations (41), (42), (43), and (44), respectively. Equations (45), (46), (47), and (48) are used to denote the trash inventory level at each plant after each period. These equations represent the quantity of waste available from the period before the current one, the amount of garbage received during each period minus the amount of waste supplied. The following equation represents each facility's maximum capacity for waste storage: (49, 50, 51, and 52).

Equations (53 and 54) limit greenhouse gas production. Equation (53) implies that the total amount of greenhouse gases created in each period by trash transportation over the whole network must be less than the associated threshold. Equation (54) suggests that plants' total amount of greenhouse gases produced in each period through waste processing must also be below the associated threshold. Table I to Table IV reveal the details and mathematical formulations of our proposed model: Sets, parameters, variables, objectives, and constraints.

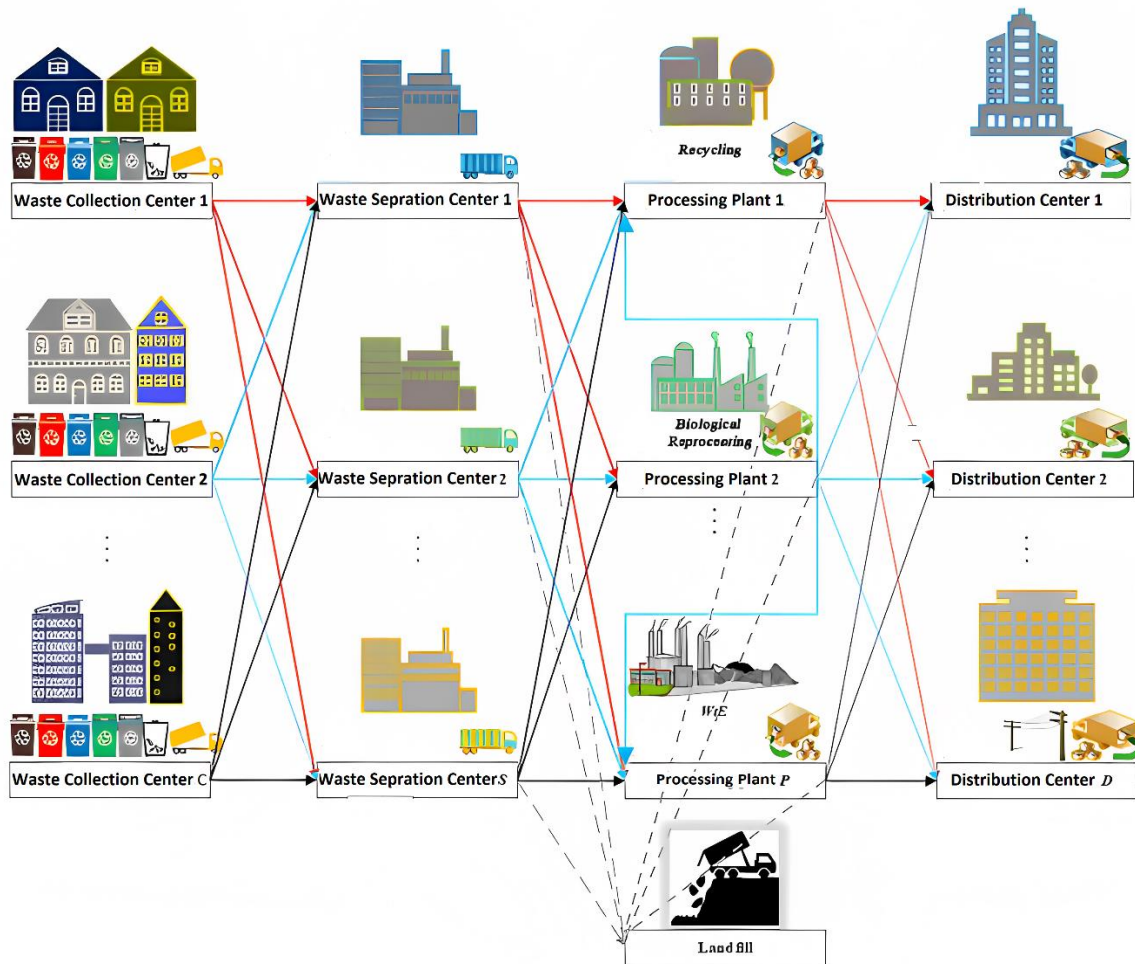


Fig. 1. The structure of waste management.

TABLE I. SETS

W	Waste type
c	Collecting center (city)
s	Separating center
l	Landfill
p_{rep}	Waste reprocessing plant
p_{rec}	Waste recycling plant
p_{wte}	Waste energy recovering
J	Distribution center
V	Vehicle type
T	Period
μ	$c \cup s \cup l \cup p_{rep} \cup p_{rec} \cup p_{wte} \cup j$

TABLE II. PARAMETERS

A_{wct}	Tonnage of garbage collected from city c during time t .
p_{wjt}	Selling price of waste w in distribution center j in period t (€/ton or €/kWh)

$c_{\mu\nu}$	Cost of transporting waste from each node of the network to another one by vehicle ν (€)
$c_{w\mu}$	Cost of processing on waste w in node μ
$GHG_{\mu\nu}$	Greenhouse gas produced by vehicle ν from each node of the network to another one
$GHGP_{w\mu}$	Greenhouse gas produced in node μ by processing on waste w
L_ν	Capacity limit of vehicle type ν (yd3)
$TC_{wst}^{in}, TC_{wst}^{out}$	Capacity of incoming and outgoing waste transportation in separation centers S for period t (ton)
$TL_{wsp_{rec}t}^{low}, TL_{wsp_{rep}t}^{low}, TL_{wsp_{wte}t}^{low}, TL_{wsp_{rec}t}^{up}, TL_{wsp_{rep}t}^{up}, TL_{wsp_{wte}t}^{up}$	Lower and higher transit limits for waste w from separation centers s to recycling, reprocessing, and energy recovery plants p during time t . (ton)
TC_{wlt}^{in}	Input transport capability for waste w in landfill l during time t (ton)
$TC_{w_{p_{rec}t}}^{in}, TC_{w_{p_{rep}t}}^{in}, TC_{w_{p_{wte}t}}^{in}$	Input transportation capacity for waste w in the recycling, reprocessing, and energy recovery type plant p throughout the time t . (ton)
$CL_{w_{p_{rec}j}}^{low}, CL_{w_{p_{rec}j}}^{up}$	Lower and higher transport limits for waste materials from the recycling facility to the distribution location (ton)
$CL_{w_{p_{wte}j}}^{low}, CL_{w_{p_{wte}j}}^{up}$	Lower and upper restrictions for transporting trash w from the recycling plant p to the distribution center j . (ton)
$CL_{w_{p_{rec}p_{wte}t}}^{low}, CL_{w_{p_{rec}p_{wte}t}}^{up}$	Lower and maximum transport limits for waste materials from a reprocessing facility to an energy recovery plant \acute{p} (ton)
$CL_{w_{p_{rec}p_{rec}t}}^{low}, CL_{w_{p_{rec}p_{rec}t}}^{up}$	Lower and maximum transportation limits for waste being transported from a reprocessing facility to a recycling plant \acute{p} (ton)
$S_{ws}^{rec}, S_{ws}^{rep}, S_{ws}^{wte}$	Storage capacity of trash in separation facilities for energy recovery, recycling, and reprocessing (ton)
$S_{ws}^{rec}, S_{ws}^{rep}, S_{ws}^{wte}$	Storage capacity for trash in the recycling, reprocessing, and energy recovery plants' separation facilities (ton)
$U_{wst}^{p_{rec}}, U_{wst}^{p_{rep}}, U_{wst}^{p_{wte}}$	Initial waste w inventory in separation centers for recycling plant, reprocessing plant, and energy recovery plant p . (ton)
$U_{w_{p_{rec}t}}, U_{w_{p_{wte}t}}$	Initial inventory level of waste w in recycling type plant p and reusing kind plant \acute{p} (ton)
$U_{w_{p_{rep}t}}^{rec}, U_{w_{p_{rep}t}}^{wte}$	Initial stock amount of waste w in reprocessing type plant p destined for energy recovery and recycling plants (ton)
$\alpha_{ws}^{sep-rec}$	Factors that separate waste in centers for waste separation throughout the recycling process (%)
$\alpha_{ws}^{sep-rep}$	Factors used to separate waste in waste separation facilities for the reprocessing process (%)
$\alpha_{ws}^{sep-wte}$	Separating factors for trash in separation facilities for the process of recovering energy (%)

TABLE III. POSITIVE VARIABLES AND BINARY VARIABLES

q_{wcsvt}	Amount of waste w transported from city c to separation centers s by vehicle type ν during time interval t (ton)
$q_{wsp_{rec}vt}$	Amount of w from separation centers s to recycling plants p by vehicle type ν during time t . (ton)
$q_{wsp_{rep}vt}$	Amount of waste transported from separation centers to reprocessing plants during time t , broken down by vehicle type (ton)
$q_{wsp_{wte}vt}$	Amount of garbage transported from separation centers to energy recovery plants in time t , broken down by vehicle type (ton)
q_{wslvt}	Amount of garbage transported from separation centers to landfills during the period t , broken down by vehicle type (ton)

$q_{wp_{rec}jt}, q_{wp_{wte}jt}, q_{wp_{rec}jt}$	Amount of waste w distributed from recycling and energy recovery kind plant p to distribution center j in period t (ton)
$q_{wp_{rep}p_{rec}vt}$	Quantity of waste w distributed from reprocessing kind plant p to recycling kind plant \acute{p} in period t (ton)
$q_{wp_{rep}p_{wte}vt}$	Amount of waste w distributed from reprocessing kind plant p to energy recovery kind plant \acute{p} in period t (ton)
q_{wst}^{in}	Amount of waste w transferred to separation center s in period t (ton)
$q_{wst}^{sep-rec}$	Amount of separated waste w in separation center s by the purpose of sending to recycling kind plant in period t (ton)
$q_{wst}^{sep-rep}$	Amount of separated waste w in separation center s by the purpose of sending to reprocessing kind plant in period t (ton)
$q_{wst}^{sep-wte}$	Amount of separated waste w in separation center s by the purpose of sending to energy recovery kind plant in period t (ton)
q_{wlt}	Amount of waste w inlet to landfill l in period t (ton)
$q_{wp_{rec}t}^{in}, q_{wp_{rep}t}^{in-rec}, q_{wp_{rep}t}^{in-wte}, q_{wp_{wte}t}^{in}$	Amount of waste w transported to recycling, reprocessing, and energy recovery kind plant p in period t (ton)
$i_{wst}^{rec}, i_{wst}^{rep}, i_{wst}^{wte}, i_{wp_{rec}t}, i_{wp_{wte}t}, i_{wp_{rep-rec}t}, i_{wp_{rep-wte}t}$	The amount of garbage that is now being kept in centers for recycling, reprocessing, and energy recovery; waste w stored in recycling, reprocessing, and energy recovery kind plant p; (ton)
$Z_{wsp_{rec}t}^{tran}, Z_{wsp_{rep}t}^{tran}, Z_{wsp_{wte}t}^{tran}$	Equals one if w is moved from a sorting facility to a factory that performs recycling, reprocessing, or energy recovery in time period t; if not, it equals zero.
$Z_{wp_{rep}p_{wte}t}^{sent}$	Equals one if w is moved from a reprocessing type plant to an energy recovery type plant in time t; if not, equals zero.
$Z_{wp_{rep}p_{rec}t}^{sent}$	Equals one if w is moved from a reprocessing type facility to a recycling type plant in period t; if not, it equals zero.
$Z_{wp_{wte}jt}^{sent}$	Equals one if w is moved from energy recovery plant p to distribution center j during time t; else equals zero.
$Z_{wp_{rec}jt}^{sent}$	Equals one if waste w is moved from reprocessing plant p to distribution center j during the time t; else, equals zero.

TABLE IV. OBJECTIVES AND CONSTRIANTS

$$\min \sum_t \sum_\mu \sum_\mu \sum_v (Z_{\mu\mu vt} \times GHG_{\mu\mu v}) + \sum_\mu \sum_w (q_{w\mu t}^{in} \times GHGP_{w\mu})$$

$$\max \sum_w \sum_{p_{rec}} \sum_j \sum_t \left\{ \left(\sum_v q_{wp_{rec}jvt} \right) \times p_{wp_{rec}jt} \right\} + \sum_w \sum_{p_{wte}} \sum_j \sum_t \left\{ \left(\sum_v q_{wp_{wte}jvt} \right) \times p_{wp_{wte}jt} \right\} \quad (1)$$

$$- \sum_t \sum_\mu \sum_\mu \sum_v (Z_{\mu\mu vt} \times c_{\mu\mu v}) + \sum_t \sum_\mu \sum_w (q_{w\mu t}^{in} \times c_{w\mu})$$

$$A_{wct} = \sum_s \sum_v q_{wcsvt} \quad (3)$$

$$y_{csvt} - 1 \leq \frac{\sum_w (\gamma_w \cdot q_{wcsvt})}{L_v} \leq y_{csvt} \quad (4)$$

$$q_{wst}^{in} = \sum_c \sum_v q_{wcsvt} \quad (5)$$

$$q_{wst}^{in} \leq TC_{wst}^{in} \quad (6)$$

$$q_{wst}^{sep-rec} = \alpha_{ws}^{sep-rec} \times q_{wst}^{in} \quad (7)$$

$$q_{wst}^{sep-rec} = \alpha_{ws}^{sep-rec} \times q_{wst}^{in} \quad (8)$$

$$q_{wst}^{sep-wte} = \alpha_{ws}^{sep-wte} \times q_{wst}^{in} \quad (9)$$

$$\sum_l \sum_v q_{wslvt} \leq q_{wst}^{in} - q_{wst}^{sep-rec} - q_{wst}^{sep-rec} - q_{wst}^{sep-wte} \quad (10)$$

$$\sum_p \sum_v q_{wspvt}^{rec} \leq i_{ws(t-1)}^{rec} + q_{wst}^{sep-rec} \quad (11)$$

$$\sum_p \sum_v q_{wspvt}^{rep} \leq i_{ws(t-1)}^{rep} + q_{wst}^{sep-rec} \quad (12)$$

$$\sum_p \sum_v q_{wspvt}^{wte} \leq i_{ws(t-1)}^{wte} + q_{wst}^{sep-wte} \quad (13)$$

$$\sum_l \sum_v q_{wslvt} + \sum_p \sum_v q_{wspvt} \leq TC_{wst}^{out} \quad (14)$$

$$i_{wst}^{rec} = U_{wst}^{rec} \quad (15)$$

$$i_{wst}^{rep} = U_{wst}^{rep} \quad (16)$$

$$i_{wst}^{wte} = U_{wst}^{wte} \quad (17)$$

$$i_{wst}^{rec} = i_{ws(t-1)}^{rec} + q_{wst}^{sep-rec} - \sum_p \sum_v q_{wspvt}^{rec} \quad (18)$$

$$i_{wst}^{rep} = i_{ws(t-1)}^{rep} + q_{wst}^{sep-rec} - \sum_p \sum_v q_{wspvt}^{rep} \quad (19)$$

$$i_{wst}^{wte} = i_{ws(t-1)}^{wte} + q_{wst}^{sep-wte} - \sum_p \sum_v q_{wspvt}^{wte} \quad (20)$$

$$i_{wst}^{rec} \leq S_{ws}^{rec} \quad (21)$$

$$i_{wst}^{rep} \leq S_{ws}^{rep} \quad (22)$$

$$i_{wst}^{wte} \leq S_{ws}^{wte} \quad (23)$$

$$TL_{wsp_{rect}^{low}} \cdot Z_{wsp_{rect}^{tran}} \leq \sum_v q_{wsp_{rec}vt} \leq TL_{wsp_{rect}^{up}} \cdot Z_{wsp_{rect}^{tran}} \quad (24)$$

$$TL_{wsp_{rept}^{low}} \cdot Z_{wsp_{rept}^{tran}} \leq \sum_v q_{wsp_{rep}vt} \leq TL_{wsp_{rept}^{up}} \cdot Z_{wsp_{rept}^{tran}} \quad (25)$$

$$TL_{wsp_{wte}^{low}} \cdot Z_{wsp_{wte}^{tran}} \leq \sum_v q_{wsp_{wte}vt} \leq TL_{wsp_{wte}^{up}} \cdot Z_{wsp_{wte}^{tran}} \quad (26)$$

$$q_{wp_{rec}t}^{in} = \sum_s \sum_v q_{wspvt}^{rec} + \sum_{P_{rep}} \sum_v q_{wp_{rep}P_{rec}vt} \quad (27)$$

$$q_{wp_{rept}t}^{in} = \sum_s \sum_v q_{wsp_{rep}vt}^{rep} \quad (28)$$

$$q_{wp_{wte}t}^{in} = \sum_s \sum_v q_{wsp_{wte}vt}^{wte} + \sum_{P_{rep}} \sum_v q_{wp_{rep}P_{wte}vt} \quad (29)$$

$$q_{wp_{wte}t}^{in} \leq TC_{wp_{wte}t}^{in} \quad (30)$$

$$q_{wp_{rept}t}^{in} \leq TC_{wp_{rept}t}^{in} \quad (31)$$

$$q_{wp_{wte}t}^{in} \leq TC_{wp_{wte}t}^{in} \quad (32)$$

$$\sum_j q_{wp_{rec}jt} \leq i_{wp_{rec}(t-1)} + q_{wp_{rec}t} \quad (33)$$

$$\sum_j q_{wp_{wte}jt} \leq i_{wp_{wte}(t-1)} + q_{wp_{wte}t} \quad (34)$$

$$\sum_{P_{rec}} q_{wp_{rep}P_{rec}vt} \leq i_{wp_{rep-rec}(t-1)} + q_{wp_{rep}t}^{rec} \quad (35)$$

$$\sum_{P_{wte}} q_{wp_{rep}P_{wte}vt} \leq i_{wp_{rep-wte}(t-1)} + q_{wp_{rep}t}^{wte} \quad (36)$$

$$CL_{wp_{rep}P_{rec}}^{low} \cdot z_{wp_{rep}P_{rec}t}^{sent} \leq q_{wp_{rep}P_{rec}t} \leq CL_{wp_{rep}P_{rec}}^{up} \cdot z_{wp_{rep}P_{rec}t}^{sent} \quad (37)$$

$$CL_{wp_{rep}P_{wte}}^{low} \cdot z_{wp_{rep}P_{wte}t}^{sent} \leq q_{wp_{rep}P_{wte}t} \leq CL_{wp_{rep}P_{wte}}^{up} \cdot z_{wp_{rep}P_{wte}t}^{sent} \quad (38)$$

$$CL_{wp_{rec}j}^{low} \cdot z_{wp_{rec}jt}^{sent} \leq q_{wp_{rec}jt} \leq CL_{wp_{rec}j}^{up} \cdot z_{wp_{rec}jt}^{sent} \quad (39)$$

$$CL_{wp_{wte}j}^{low} \cdot z_{wp_{wte}jt}^{sent} \leq q_{wp_{wte}jt} \leq CL_{wp_{wte}j}^{up} \cdot z_{wp_{wte}jt}^{sent} \quad (40)$$

$$i_{wp_{rect}} = U_{wp_{rect}} \quad (41)$$

$$i_{wp_{rect}}^{rec} = U_{wp_{rect}}^{rec} \quad (42)$$

$$i_{wp_{rect}}^{wte} = U_{wp_{rect}}^{wte} \quad (43)$$

$$i_{wp_{wte}t} = U_{wp_{wte}t} \quad (44)$$

$$i_{wp_{rect}} = i_{wp_{rec}(t-1)} + q_{wp_{rect}-\sum_j q_{wp_{rec}jt}} \quad (45)$$

$$i_{wp_{rep-wte}t} = i_{wp_{rep-rec}(t-1)} + q_{wp_{rep-wte}t} - \sum_j q_{wp_{rep-wte}jt} \quad (46)$$

$$i_{wp_{rep-wte}t} = i_{wp_{rep-rec}(t-1)} + q_{wp_{rep-rec}t} - \sum_j q_{wp_{rep-rec}jt} \quad (47)$$

$$i_{wp_{wte}t} = i_{wp_{wte}(t-1)} + q_{wp_{wte}t} - \sum_j q_{wp_{wte}jt} \quad (48)$$

$$i_{wp_{wte}t} \leq S_{wp_{wte}} \quad (49)$$

$$i_{wp_{rect}} \leq S_{wp_{rec}} \quad (50)$$

$$i_{wp_{rep-rec}t} \leq S_{wp_{rep-rec}} \quad (51)$$

$$i_{wp_{rep-wte}t} \leq S_{wp_{rep-wte}} \quad (52)$$

$$\sum_{\mu} \sum_v (Z_{\mu vt} \times GHG_{\mu v}) \leq \max GHG_t \quad (53)$$

$$\sum_{w\mu} (q_{w\mu t}^{in} \times GHGP_{w\mu}) \leq \max GHGP_t \quad (54)$$

$$L_p = \left(\sum_{j=1}^k w_j \left[\frac{f_j(x^{\max j}) - f_j(x)}{f_j(x^{\max j}) - f_j(x^{\min j})} \right]^p \right)^{\frac{1}{p}} \quad (55)$$

IV. SOLUTION APPROACH

The presented model is a multi-objective model, therefore to solve this model, it is essential to combine the model into a single objective problem [18, 19]. In this regard, we use the LP-Metric approach based on Eq. (55).

After that, we have a single objective deterministic model to solve the model, we code it in GAMS software to achieve a precise solution, but as the size of the problem grows, the GAMS approach leads to a long solving time and massive CPU usage. Therefore we use the grasshopper algorithm (GOA) to solve large-scale problems. We code the algorithm in MATLAB and solve the problems in rational duration and CPU usage.

This algorithm tries to simulate grasshoppers' manners and normal living for solving operation research problems [20].

This mathematical model tries to simulate the attraction and repulsion forces between grasshoppers. The repulsion forces enable grasshoppers to investigate the solution space (problem space), but the attraction forces encourage them to stay in the motivator solution area (local optimum solutions).

To balance exploring the solution space and staying in local optimum solutions, GOA uses a coefficient to reduce the conformability of grasshoppers in local optimum solutions [21]. Ultimately, the best-found solution using a swarm will be achieved and improved. This algorithm is in the group of nature-inspired algorithms and is used to solve ongoing optimization problems [22].

V. CONCLUSION AND FUTURE STUDIES

This research sheds light on the issue of urban solid waste management in supply chains with many tiers. A mixed integer linear programming issue is presented in the following

optimization challenge. It encompasses different tasks, including waste transportation between processing facilities, waste processing in factories, collecting waste in cities, and separating them in segregation centers. In addition, since managing urban waste is vital to the more significant problem of environmental degradation, one of our goals was considering a green approach. Also, to improve the margin profit of the total SC through the use of environmental friendly methods and to limit the transportation, storage, and production capacities of separation centers, factories, and distribution hubs, the main objective of the model was to determine the optimal distribution of waste among all units. An in-depth case study was carried out to evaluate the usefulness and efficacy of the recommended model. This model is used to precisely tackle the numerical problem using the GAMS program and the grasshopper metaheuristic algorithm. The outcomes demonstrate that it is feasible to implement a distributed processing system to reuse MSW while maximizing the supply chain's net profit. The effectiveness of the supply chain is evaluated using sensitivity studies, which consider the influence of various factors, including time and product pricing. In addition, the obtained Pareto solutions can provide decision-makers with valuable insights for selecting the solution that represents the best compromise among the considered objectives. To mention future studies, the model can be extended to consider waste management in regions where waste management has not been established or where there is no established method of waste control. In addition, this work can serve as a starting point for the addition of additional objectives, such as social, safety, and health objectives, among others, as well as the waste management system's schedule. Additionally, the model can be expanded to account for associated uncertainty.

REFERENCE

- [1] M Dehghan-Bonari, J Heydari. How a novel option contract helps a green product to enter a traditional product's retailing channel: A mathematical modeling approach. *Journal of Retailing and Consumer Services*, 69, 103090 (2022).
- [2] M Dehghan-Bonari, A Bakhshi, A Aghsami, F Jolai. Green supply chain management through call option contract and revenue-sharing contract to cope with demand uncertainty. *Cleaner Logistics and Supply Chain*, 2, 100010. <https://doi.org/10.1016/j.clscn.2021.100010>. (2021).
- [3] D Hoornweg, P Bhada-Tata. *What a Waste: A Global Review of Solid Waste Management*. World Bank, Washington, DC. (2012).
- [4] N Ejaz, N Akhtar, H N Hashmi, U A Naem. Environmental impacts of improper solid waste management in developing countries: A case study of Rawalpindi city. *Sustain. World*.(2010), pp. 379–388.
- [5] Mohammadi, M., Jämsä-Jounela, S. L., & Harjunkoski, I. (2019). Optimal planning of municipal solid waste management systems in an integrated supply chain network. *Computers & Chemical Engineering*, 123, 155-169.
- [6] Tanwer, A. K., Prajapati, D. R., & Singh, P. J. (2014). Green Supply Chain Management: An Environmental Approach For Manufacturing Industry. In *Proceedings of National Conference on Advancements and Futuristic Trends in Mechanical Engineering*. Retrieved from <http://www.supply-chain.com/info/faq.html>.
- [7] A Soltani, K Hewage, B Reza, R Sadiq. Multiple stakeholders in multi-criteria decision-making in the context of municipal solid waste management: a review. *Waste Manage. (Oxford)* 35, (2015), pp318–328.
- [8] A Tolis, A Rentizelas, K Aravossis, I Tatsiopoulos. Electricity and combined heat and power from municipal solid waste; theoretically optimal investment decision time and emissions trading implications. *Waste Manag. Res.*(2010) 28 (11), pp 985–995.
- [9] K Özdenkçi, C De Blasio, H.R Muddassar, H.R Muddassar, K Melin, P Oinas, K Koskinen., G Sarwar, M Järvinen. A novel biorefinery integration concept for lignocellulosic biomass. *Energy Convers. Manage.*(2017) 149, pp 974–987.
- [10] H. Y Yap, J.D Nixon. A multi-criteria analysis of options for energy recovery from municipal solid waste in India and the UK. *Waste Manage. (Oxford)* 46,(2015).
- [11] S. Y Pan, M.A Du, I.T Huang, I.H Liu, E.E Chang, P.C Chiang. Strategies on implementation of waste-to-energy (WTE) supply chain for circular economy system: a review. *J. Cleaner Prod.* (2015) 108, pp 409–421.
- [12] D Kovacic, J Usenik, M Bogataj. Optimal decisions on investments in urban energy cogeneration plants - extended MRP and fuzzy approach to the stochastic systems. *Int. J. Prod. Econ.*(2017) 183, pp583–595.
- [13] T Sabbas, A Poletini, R Pomi, T Astrup, O Hjelmar, P Mostbauer, G Cappai, G Magel, S Salhofer, C Speiser, S Heuss-Assbichler, R Klein, P Lechner. Management of municipal solid waste incineration residues. *Waste Manage. (Oxford)* 23 (1)(2003), pp 61–88.
- [14] M. C Cooper, D.M Lambert, J.D Pagh. Supply chain management: more than a new name for logistics. *Int. J. Logist. Manag.* (1997) 8 (1), pp 1–14.
- [15] S Cohen, J Roussel. *Strategic Supply Chain Management: The Five Disciplines for Top Performance*. McGraw-Hill, New York, NY. (2005).
- [16] C Hicks, O Heldrich, T McGovern, T Donnelly. A functional model of supply chains and waste. *Int. J. Prod. Econ.*(2004) 89, pp 165–174.
- [17] A. M Niziolek, O Onel, C A Floudas. Municipal solid waste to liquid transportation fuels, olefins, and aromatics: Process synthesis and deterministic global optimization. *Comput. Chem. Eng.* (2017) 102, pp169–187.
- [18] M Alipour-Vaezi, A Aghsami., & M. Rabbani. Introducing a novel revenue-sharing contract in media supply chain management using data mining and multi-criteria decision-making methods. *Soft Computing*, (2022a) 26(6), pp 2883-2900.
- [19] R Yazdani, M Alipour- K Vaezi, Kabirifar, A Salahi Kojour, F Soleimani. A lion optimization algorithm for an integrating maintenance planning and production scheduling problem with a total absolute deviation of completion times objective. *Soft Computing*, (2022), pp 1-16.
- [20] M Masoumi, A Aghsami, M Alipour-Vaezi., F Jolai, & B Esmailifar. An M/M/C/K queueing system in an inventory routing problem considering congestion and response time for post-disaster humanitarian relief: a case study. *Journal of Humanitarian Logistics and Supply Chain Management*. (2021).
- [21] M. Alipour-Vaezi, A. Aghsami, & F.Jolai. Prioritizing and queueing the emergency departments' patients using a novel data-driven decision-making methodology, a real case study. *Expert Systems with Applications*, 195, 116568. (2022b).
- [22] S Saremi, S Mirjalili, & A. J. A. i. E. S Lewis. Grasshopper optimisation algorithm: theory and application. (2017) 105, pp 30-47.

Improved Tuna Swarm-based U-EfficientNet: Skin Lesion Image Segmentation by Improved Tuna Swarm Optimization

Khaja Raoufuddin Ahmed, Siti Zura A Jalil, Sahnius Usman

Razak Faculty of Informatics and Technology, Universiti Teknologi Malaysia Kuala Lumpur, Malaysia

Abstract—Skin cancers have been on an upward trend, with melanoma being the most severe type. A growing body of investigation is employing digital camera images to computer-aided examine suspected skin lesions for cancer. Due to the presence of distracting elements including lighting fluctuations and surface light reflections, interpretation of these images is typically difficult. Segmenting the area of the lesion from healthy skin is a crucial step in the diagnosis of cancer. Hence, in this research an optimized deep learning approach is introduced for the skin lesion segmentation. For this, the EfficientNet is integrated with the UNet for enhancing the segmentation accuracy. Also, the Improved Tuna Swarm Optimization (ITSO) is utilized for adjusting the modifiable parameters of the U-EfficientNet to minimize the information loss during the learning phase. The proposed ITSU-EfficientNet is assessed based on various evaluation measures like Accuracy, Mean Square Error (MSE), Precision, Recall, IoU, and Dice Coefficient and acquired the values are 0.94, 0.06, 0.94, 0.94, 0.92 and 0.94 respectively.

Keywords—Skin lesion; skin cancer; segmentation; deep learning model; optimization; EfficientNet; UNet

I. INTRODUCTION

The most prevalent fatal disease with the fastest rate of growth is skin cancer. According to the World Health Organization, melanoma accounts for one out of every three cases of cancer. With five million patients per year, the disease is the most widely recognized type of cancer in the United States [1]. Timely skin cancer detection contributes to better health care delivery. As melanocytes multiply indiscriminately, very first trace of hyper-pigmentation appears. Melanoma is the term used to describe this type of skin cancer. Around 9000 people die from cancer each year in the world, making it the deadliest kind [2]. In people suffering from advanced melanoma, the survival rate after beyond five years is 95%, whereas in those with early melanoma, the mortality rate is 1.62%. The importance of early detection, treatment, and recovery can indeed be emphasized in the case of melanoma [3].

Microscopic (Dermoscopic) and macroscopic (clinical) images are the two imaging modalities most frequently used in advanced skin lesion diagnosis [4]. Although dermatologists sometimes lack access to dermoscopic images that are enabled by the examination of lesion characteristics that are imperceptible to the bare eye. Conversely, whereas they are more readily available, clinical photographs taken with traditional cameras have lesser quality [5,6]. Dermoscopy is a

non-invasive skin imaging method that helps dermatologists diagnose skin lesions by enabling them to see beyond the skin's surface. Nonetheless, based on the clinician's knowledge and expertise, the prognostic value of dermoscopy might vary significantly, from 24% to 77% [7]. In addition, when used by untrained dermatologists, dermoscopy may actually reduce detection ability. Thus, it is essential to develop Computer-Aided Diagnosis (CAD) systems in order to minimize diagnosis mistakes brought on by the challenging nature of visual assessment, the subjectivity involved, and to lessen the burden of skin illnesses and the inaccessibility of dermatologists [8, 9].

By evaluating clinical images, CAD is a significant equivalent that aids healthcare practitioners in their everyday treatment diagnostic. For computer vision tasks, deep learning (DL) has provided a strong basis, and Designs aren't an exception [10]. Dermoscopic images can potentially be stored and retrieved on processors using the digitized dermoscopic devices that are already accessible [11]. CAD systems would aid less-experienced dermatologists and have a lesser impact for inter-subject variation because dermoscopy diagnosis reliability is always demonstrated to rely upon the knowledge of the dermatologist. The conventional method for automatic dermoscopic image assessment typically involves the following phases: lesion categorization, extraction of features, and segmentation of image [12, 13]. Since precision constitutes one of segmentation's primary qualities, it is considered as the most crucial stages in diagnosing the skin cancer [14]. Segmentation is challenging, though, due to the wide range of lesion colors, sizes, and types, as well as the various skin types and textures [15].

The separation of an image into useful areas is known as segmentation. In instance, segmentation classifies the essential area with the proper classes and labels [16]. Here, the approach utilized for skin lesions is binary task, i.e., differentiating the tumor from the skin surrounding. Contrast and Lighting problems, occlusions, artefacts, inherent intra-class variability and inter-class similarities, and the variety of other imaging issues make automated skin lesion segmentation a difficult task [17, 18]. A further issue that prevents both the training of models and the accurate evaluation of those models is the unavailability of big datasets with expert-generated ground-truth segmentation masks [19]. The segmentation of skin lesions can be divided into four categories: deep learning approaches, conventional intelligence-based approaches, edge and region-based

approaches and threshold and clustering-based approaches [20]. Each class's benefits and drawbacks were noted. Deep learning approaches also outperform traditional approaches in the analysis of complicated issues [21]. To analyze medical images, there are many different analytical methods. Yet, in recent years, there have been notable improvements in computer hardware and software systems as well as a sharp rise in the volume and complexity of data [22]. Deep learning techniques for precise and accurate medical image analysis have proliferated and improved as a result of these breakthroughs [23].

The first effort to apply convolutional layers in the task of segmenting disease diagnosis was made in the previous ten years [24]. Following that, a number of designs were put forth to improve segmentation accuracy, not just in the healthcare profession but in general. Such designs included Fully Convolutional Network (FCN), FC-DenseNet, and U-Net for segmenting clinical data [25]. Several structures improved image segmentation for images from the medical area, for example. In terms of State of the Arts (SOTA) efficiency, the encoder-decoder and skip links network U-Net has excelled in the segmentation of medical images [26]. To that purpose, several adaptations have been introduced for diverse clinical uses using better image sources. Such approaches share a similar flaw in that they are unable to accurately localize feature representations for monotone segmentation outcomes by capturing long-range contextual data. Due to the convolution layers' constrained receptive field, this flaw results from the Convolutional Neural Network (CNN) weakness [27]. In the medical area, where precise separation of tissue and organ boundaries areas is required, the degradation of conceptual localization information over the levels is not the preferred outcome for semantic segmentation [28][39-43]. A novel framework must therefore be created employing a deep learning architecture in order to achieve the higher efficiency in the segmentation algorithm.

Hence, the goal of the research is to devise a novel deep learning strategy for segmenting the skin lesion with enhanced accuracy for detecting the cancer more effectively in the future. The artefact removal along with the optimized hybrid deep learning approach is utilized for performing the segmentation. The major contributions of the research are:

- **Design of ITSO Algorithm:** The Improved Tuna Swarm Optimization (ITSO) algorithm is designed by integrating the TSO with the effective solution updating behaviour of the Pelican for enhancing the convergence rate and to eliminate the movement of solution away from the optimal region.
- **Design of ITSU-EfficientNet:** The ITSU-EfficientNet is designed by integrating the EfficientNet and the UNet, wherein the encoder part of the UNet is replaced with the EfficientNet for enhancing the segmentation accuracy. Besides, the adjustable parameters of the hybrid deep learning model are tuned using the ITSO algorithm to reduce the information loss during the information learning phase.

The organizations of the research are: Section II details the literature review along with the problem statement. The

proposed skin lesion segmentation is detailed in Section III and the experimental outcome with its interpretation is provided in Section IV and Section V concludes the work.

II. RELATED WORK

Skin lesion segmentation using the semi-supervised learning was designed by [29], wherein the hybrid Transformer encoders and CNN were combined to acquire the global and local attributes. The designed model was most suited for solving the challenges like over fitting and instability. In this, the semantic attributes were learned by the semi supervised model that enhances the learning capability of the model. The devised model accomplished superior performance compared to the traditional methods of skin lesion segmentation. Still, the performance gets degraded due to the noisy annotation criteria while enriching the data sample.

A hybrid deep learning approach for skin lesion segmentation was devised by [30], wherein the ResNet and AlexNet were combined together for enhancing the segmentation accuracy. Initially, the color constancy of the image was enhanced through the pre-processing stage using the gray world algorithm. Also, the resizing was also devised for making the input more appropriate to the segmentation module. Here, the loss functions like Tversky loss function and cross entropy were considered minimizing the loss during the lesion segmentation. The devised model accomplished superior performance in terms of segmentation accuracy with minimal computation overhead. Still, the image with low contrast and color variations affects the performance of the model.

Skin lesion segmentation using the Grab cut approach was devised by [31], wherein the skin hair removal and corner borders removal were devised in the image pre-processing for enhancing the performance of the model. In the hair removal task, the detection of hair contour was devised and then the mask was generated for removing the hair from the input image. After removing the hair, the contrast was improved through the equalization strategy. Finally, the segmentation was performed using the Grab cut approach and accomplished better performance in terms of Dice and Jaccard coefficients. However, the method was not applicable for segmenting small lesion.

The lesion segmentation using the deep learning was designed by [32] for enhancing the accuracy of segmentation. In this method, the hair in the image was removed through the morphological filters and inpainting algorithms. Followed by, the data augmentation was devised for enriching the database, because the classifier learned with larger amount of data elevates the generalization capability that enhances the detection accuracy. The augmented image is fed into the hybrid deep learning model designed by combining ResNet and UNet. The enhanced performance was acquired by the model based on the assessment measures like the recall and precision. Besides, the post-processing was utilized in the model for enhancing the accuracy of model. Still, the issues like under and over segmentation may occur while evaluating the performance using larger data.

Skin lesion segmentation using the metaheuristic approach was designed by [33] through a hybrid optimization strategy. In this, differential evolution and the artificial bee colony algorithms were combined together for performing the segmentation task. Here, the entropy, intensity values and the number of edge pixels were considered for the evaluation of the objective function. The designed model accomplished superior performance compared to the conventional methods. Still, the requirement of the additional sharpening and smoothing approaches enhances the noise that in turn degrades the performance of the model.

A. Motivation and Problem Statement

The first stage in computerized dermoscopic image processing is effectively separating the tumor from the skin that surrounds it. The fact that melanoma typically has a wide range of physical attributes in terms of color, shape, and size, as well as various textures and skin types, makes the process challenging. The difference in brightness among the lesion and the surrounding skin can also vary, with some lesions having fuzzy and uneven edges. In a variety of medical imaging applications and pattern recognition, deep learning techniques recently demonstrated encouraging results. Hence, in this research, an automatic skin lesion segmentation based on deep learning is introduced to overcome the above-mentioned challenges. The initial pre-processing stage removes the artefacts from the image. Followed by, the optimized hybrid deep learning approach enhances the detection accuracy with minimal computation burden.

III. METHODOLOGY

The skin lesion segmentation is utilized for the detection and classification of the cancer to identify the severity of the disease. The more accurate detection of the disease is employed through the efficient segmentation approach. Deep learning technique is widely utilized in image processing any several other computer vision applications due to the promising outcome. Hence, in this research skin lesion detection is devised using the deep learning approach. For this, improved tuna swarm optimization based UNet-EfficientNet (ITSU-EfficientNet) is introduced. In this, the input skin image is taken from the dataset and is initially pre-processed using the median filtering for the removal of artefacts from the image. Followed by, the skin segmentation is devised using the novel U-EfficientNet, which is designed by integrating the UNet and EfficientNet. Here, the optimal parameters of the classifier are tuned using the proposed ITSU algorithm. It is designed by integrating the TSO with the effective solution updating strategy of the Pelican optimization algorithm.

The introduced ITSU algorithm has the balanced exploration and exploitation phases for obtaining the global best solution. The workflow of the proposed ITSU-EfficientNet is depicted in Fig. 1.

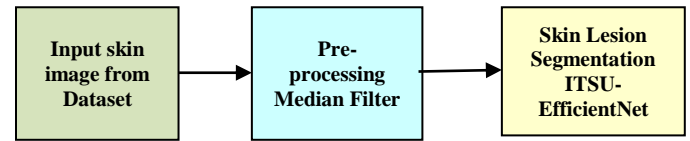


Fig. 1. Block diagram of proposed ITSU-EfficientNet for skin lesion segmentation.

A. Image Acquisition

The input skin is acquired from the publicly available dataset, wherein the dataset N comprises of n number of images, wherein N_i^{th} image is taken for processing the proposed method. It is represented as,

$$N = \{N_1, N_2, \dots, N_i, \dots, N_n\} \quad (1)$$

B. Removing Artefacts

To eliminate noise and artefacts from the input image acquired from the patient, image pre-processing is devised. The median filtering technique is used in this instance of the suggested work for image pre-processing. The clean composites that aid in removing noise are produced by computing the median value for each pixel in the image. Thus, the image produced after the pre-processing is represented as P_s , which is fed into the segmentation module.

C. Skin Lesion Segmentation using ITSU-EfficientNet

The artefact removed image is fed into the proposed ITSU-EfficientNet for segmenting the skin lesion. In this, the UNet and EfficientNet are integrated together and the adjustable parameters like the weights and bias are tuned using the improved ITSU algorithm. The detailed description is given below.

1) *Architecture of UNet*: Lightweight features, feature map fusion, and Local receptive field are common characteristics of deep learning models including UNet. The over fitting issues of the deep learning models are minimized through the parallel structure that makes the computation simpler and more flexible. Contrary to a full convolutional neural network (FCN), the significant characteristics like the feature mapping based on splicing criteria and the structure of the skip connection makes the UNet simpler with minimal computation overhead. According to Fig. 2, the midway link between up and down sampling adds low-level attributes to the final process, which minimizes the losses of beneficial properties in skin lesion segmentation [34].

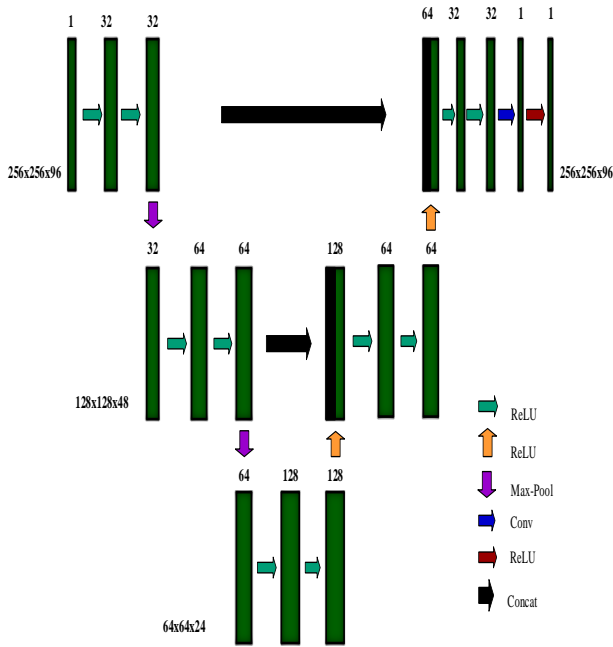


Fig. 2. Architecture of UNet.

In UNet, skip connection, down sampling (pooling), up sampling, and convolution techniques are widely employed. Max pooling is a popular down sampling approach that is used to get abstract features and high-level features with an emphasis on the semantic content of images while reducing image resolution. Common up-sampling methods include regular forward propagation backwards and de-convolution without gradient updating. It is possible to define UNet's in the field of image segmentation for enhancing the detection accuracy.

2) *Architecture of EfficientNet*: EfficientNet-v2 for the estimation of the loss function utilizes smaller kernel sizes of 3x3 with minimal memory access overhead. Besides, the last stride-1 is eliminated for the reduction of the memory access overhead and size of parameter. The runtime overhead is minimized through network capacity elevation and the training overhead along with higher memory are minimized by restricting the interference of image. The learning capability of the EfficientNet-v2 is higher by making original interference size for learning that depicts the scaling characteristics of the loss function estimator [35]. The building blocks of the EfficientNet-v2 are fused MBConv long with the mobile inverted bottleneck MBConv and are portrayed in Fig. 3.

The resolution, depth and width of the network are balanced by the EfficientNet-v2 to enhance the accuracy of skin lesion segmentation. Here, the compound coefficient η is utilized for the scaling the network parameters and is expressed as,

$$resolution = \mu^\eta; \quad depth = \beta^\eta; \quad width = \chi^\eta \quad (2)$$

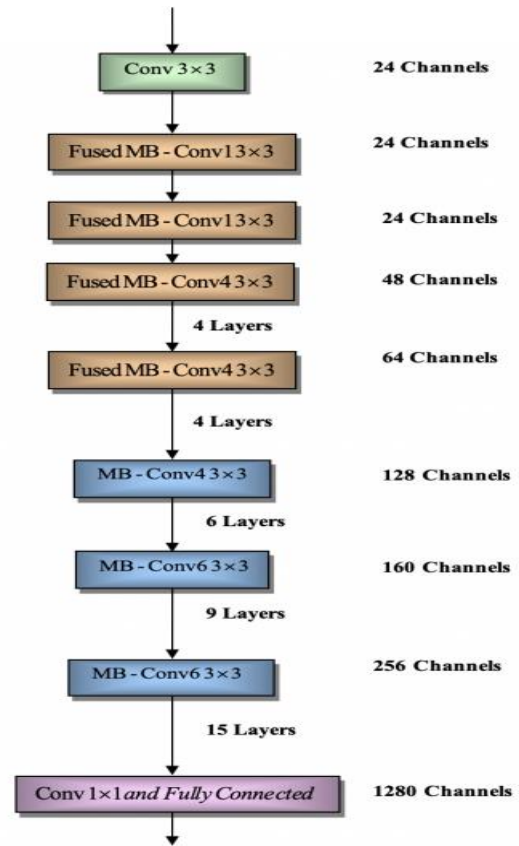


Fig. 3. Architecture of EfficientNet-v2.

where,

$$\beta^2 \cdot \chi^2 \cdot \mu \approx 2$$

$$\beta, \chi, \mu \geq 1 \quad (3)$$

Here, the factors β, χ, μ decides the distribution of the external resources in the network and η refers to the coefficient that is identified based on β, χ, μ .

D. Proposed ITSU-EfficientNet based Skin Lesion Segmentation

The skin lesion segmentation using the proposed ITSU-EfficientNet is designed by hybridizing the UNet and EfficientNet as shown in Fig. 4, wherein the ITSU is utilized for tuning the adjustable parameters. UNet architecture is comprised of two parts, encoder and decoder. In the proposed model UNet encoder is replaced by EfficientNet B7 and decoder is similar as UNet decoder. UNet decoder comprises of block of 3x3 conv and feature maps are

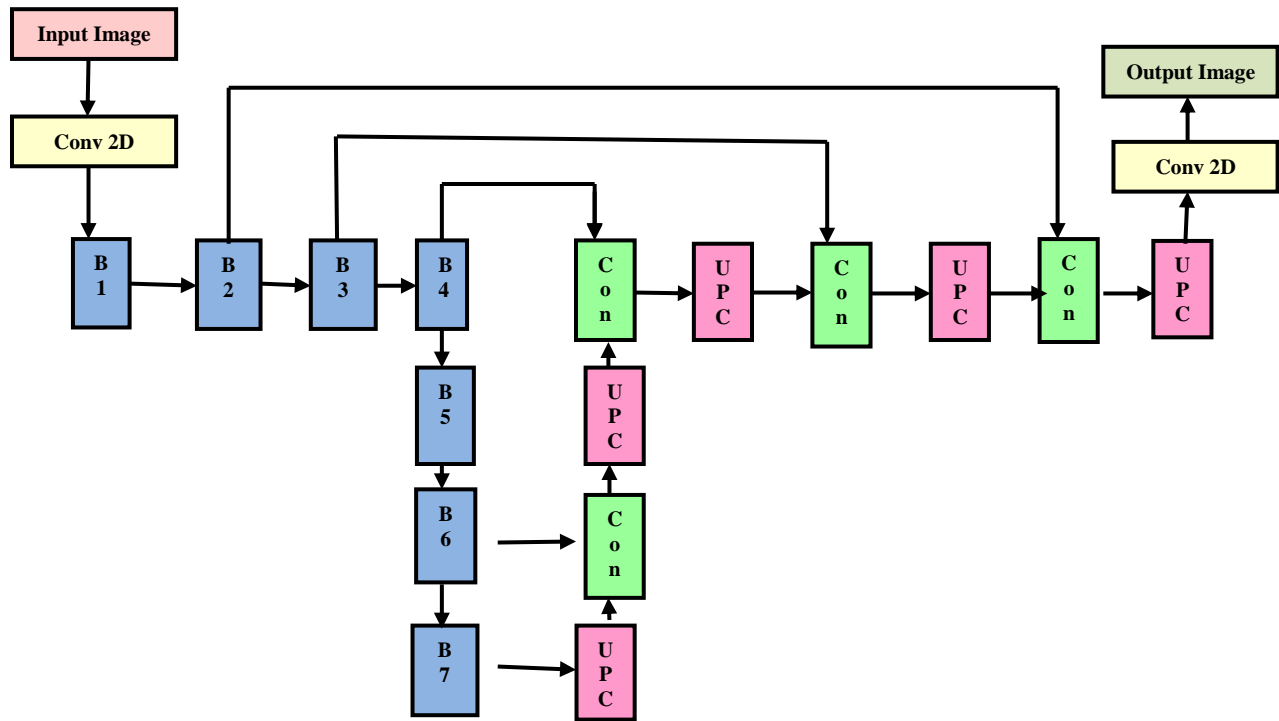


Fig. 4. Architecture of proposed U-EfficientNet.

unsampled after each block and concatenate the features from encoder and forward them to next block of 3x3 convolutions. After last block a 1x1 conv is used to generate segmentation map.

1) *Improved Tuna Swarm Optimization (ITSO)*: A metaheuristic algorithm with the balanced diversification and intensification helps to obtain the global best solution for solving the optimization issues. The Tuna Swarm Optimization (TSO) is the one that has the balanced diversification and intensification, which designed based on the marine predator named Tuna. This marine predator follows the fishtail shape swimming behaviour that is unique and faster in a continuous manner. Still, the swimming capability of the predator is very slower compared to the small nimble fish. The marine predator follows the swarm behaviour for capturing the prey (target). Hence it uses two various approaches for capturing the target fish.

- **Spiral Diving**: The swarm of tuna follows the spiral diving approach to capture the prey intending it (prey) to move towards the swallow water. This strategy helps to capture the target more easily.
- **Parabolic Structure**: The second approach of the tuna in capturing the target is the parabolic structure formation. In this, the tuna of swarm forms the parabolic structure one after another for encircling the prey and capture it.

2) *Mathematical Modelling*: The mathematical modelling of the ITSO comprises of three various steps like initialization, diversification and intensification. Here, initialization is nothing but the initialization of candidates (Tuna) and target in

the feature space. The second step is the diversification phase, wherein the candidates explore the feature space for the acquisition of *global* best solution. For this, the spiral diving strategy is utilized by the candidates in the feature space. Finally, the intensification phase is devised for deeply exploiting the feature space that is already identified in the diversification phase [36]. Here, the movement of solution away from the optimal location is minimized by incorporating the effective solution updating behaviour of the Pelican in the Pelican optimization algorithm [37]. The capturing of the target is the solution accomplished by the algorithm for tuning the optimal parameters of the lesion segmentation technique.

Initialization: In the feature space, the candidates are located randomly and is represented as,

$$S_m^\tau = k \cdot (U - V) + V, m = 1, 2, \dots, Z \quad (4)$$

where, the lower and upper boundaries of the feature space is notated as V and U respectively and the random number chosen from the uniform distribution in the range of $[0,1]$ is indicated as k , and the m^{th} candidate in the feature space at the iteration τ is indicated as S_m^τ .

Fitness Estimation: After initializing the candidates in the feature space, the fitness is estimated based on mean square error and is formulated as,

$$F_{ITSO} = \frac{1}{T_{sol}} \sum_{i=1}^{T_{sol}} (SS_{obser} - SS_{tar})^2 \quad (5)$$

where, the fitness of the solution is referred as F_{ITSO} , the total count of samples is indicated as T_{sol} , the observed solution is indicated as SS_{obser} and the target solution is indicated as SS_{tar} .

Diversification: In the diversification phase, the spiral diving-based foraging is devised by the candidates for capturing the target. The prey tries to escape from the candidate by changing the direction of swimming. Thus, the candidates form the tight spiral to capture the prey and hence the escaping capability of the prey gets reduced. In addition, the information sharing among the candidates helps to explore more area in the feature space. The position updating of the candidates in the diversification phase is formulated as,

$$S_m^{\tau+1} = \begin{cases} \delta_1 \cdot (S_G^\tau + \gamma \cdot |S_G^\tau - S_m^\tau|) + \delta_2 \cdot S_m^\tau, & m = 1 \\ \delta_1 \cdot (S_G^\tau + \gamma \cdot |S_G^\tau - S_m^\tau|) + \delta_2 \cdot S_{m-1}^\tau, & m = 2, 3, \dots, Z \end{cases} \quad (6)$$

$$\delta_1 = q + (1-q) \cdot \frac{\tau}{\tau_{max}} \quad (7)$$

$$\delta_2 = (1-q) - (1-q) \cdot \frac{\tau}{\tau_{max}} \quad (8)$$

$$\gamma = e^{pn} \cdot \cos(2\pi p) \quad (9)$$

$$n = e^{3 \cos\left(\left(\left(\frac{\tau_{max} + 1}{\tau}\right) - 1\right)\pi\right)} \quad (10)$$

where, at $\tau + 1^{th}$ iteration, the position of the m^{th} candidate in the features space is indicated as $S_m^{\tau+1}$, the optimal best candidate in the τ^{th} iteration is indicated as S_G^τ , the movement of the individual candidate in the feature space is controlled by the weight coefficients δ_1 and δ_2 , wherein the movement extend is decided by the constant q . The random number that has the range $[0,1]$ is indicated as p and the maximal number of iterations is indicated as τ_{max} .

When the optimal candidate failed to capture the target; then, the random candidate is chosen from the swarm and hence the exploration criteria is enhanced and the position updating is formulated as,

$$S_m^{\tau+1} = \begin{cases} \delta_1 \cdot (S_k^\tau + \gamma \cdot |S_k^\tau - S_m^\tau|) + \delta_2 \cdot S_m^\tau, & m = 1 \\ \delta_1 \cdot (S_k^\tau + \gamma \cdot |S_k^\tau - S_m^\tau|) + \delta_2 \cdot S_{m-1}^\tau, & m = 2, 3, \dots, Z \end{cases} \quad (11)$$

where, the randomly chosen candidate is indicated as S_k^τ . Here, the efficient position updating behaviour of the Pelican

optimization is hybridized with the position updation of the TSO for avoiding the solution escaping from the optimal solution. The solution updation based on the ITSO is formulated as,

$$S_m(\tau) = \begin{cases} S_i(\tau+1) & F_{ITSO}(\tau) < F_{ITSO}(\tau+1) \\ S_i(\tau+1) & \text{Otherwise} \end{cases} \quad (12)$$

Thus, the solution updated by the candidates using the effective solution updating criteria guides the solution towards the optimal location that enhances the convergence rate of the algorithm.

Transition Phase: After identifying the target in the feature space, the candidate's moves from the diversification to intensification phase for capturing the target. The formulation for the transition phase is expressed as,

$$S_m^{\tau+1} = \begin{cases} \delta_1 \cdot (S_k^\tau + \gamma \cdot |S_k^\tau - S_m^\tau|) + \delta_2 \cdot S_m^\tau, & m = 1 \\ \delta_1 \cdot (S_k^\tau + \gamma \cdot |S_k^\tau - S_m^\tau|) + \delta_2 \cdot S_{m-1}^\tau, & m = 2, 3, \dots, Z & \text{if } k < \frac{\tau}{\tau_{max}} \\ \delta_1 \cdot (S_G^\tau + \gamma \cdot |S_G^\tau - S_m^\tau|) + \delta_2 \cdot S_m^\tau, & m = 1 \\ \delta_1 \cdot (S_G^\tau + \gamma \cdot |S_G^\tau - S_m^\tau|) + \delta_2 \cdot S_{m-1}^\tau, & m = 2, 3, \dots, Z & \text{if } k \geq \frac{\tau}{\tau_{max}} \end{cases} \quad (13)$$

Intensification: In the intensification phase, the parabolic structure-based capturing is devised by the candidates. Here, the target is considered as the point of reference and the parabolic structure is formed. The expression for the intensification-based position updation is defined as,

$$S_m^{\tau+1} = \begin{cases} S_G^\tau + k \cdot (S_G^\tau - S_m^\tau) + M \cdot a^2 \cdot (S_G^\tau - S_m^\tau), & \text{if } k < 0.5 \\ M \cdot a^2 \cdot S_m^\tau, & \text{if } k \geq 0.5 \end{cases} \quad (14)$$

$$a = \left(1 - \frac{\tau}{\tau_{max}}\right) \left(\frac{\tau}{\tau_{max}}\right) \quad (15)$$

where, the random number with the range $[-1,1]$ is indicated as M . Here, also the effective solution updating behaviour of the Pelican is utilized and is expressed as,

$$S_m(\tau) = \begin{cases} S_i(\tau+1) & F_{ITSO}(\tau) < F_{ITSO}(\tau+1) \\ S_i(\tau+1) & \text{Otherwise} \end{cases} \quad (16)$$

Thus, the solution acquired by the candidate in the search space through the effective solution updating criteria provides the solution for solving the optimization issues.

Re-estimation of fitness: The feasibility of the solution obtained in the previous phase is estimated by re-estimating the fitness presented in equation (5).

Termination: The acquisition of global best solution or the attainment of τ_{max} the iteration of algorithm gets terminated. Pseudo-code for ITSO algorithm is presented in Algorithm 1.

Algorithm 1: Pseudo-code for ITSO algorithm

1	Input: The values τ^{\max} and Z are initialized
2	Output: Best solution S_G^τ
3	Locate the candidates in the feature space $S_m(m=1,2,\dots,Z)$
4	The factor q is defined
5	while ($\tau < \tau^{\max}$)
6	Estimate the fitness
7	Update S_G^τ
8	For (all candidates) do
9	Update δ_1, δ_2 and a
10	Update the candidate solution using equation (11)
11	Update the candidate solution using equation (12)
12	Update the candidate solution using equation (13)
13	Update the candidate solution using equation (16)
14	End for
15	$\tau = \tau ++$
16	End while
17	Return the best solution

Thus, the solution updation using the proposed ITSO algorithm elevates the segmentation accuracy with minimal error and fast convergence rate.

E. Experimental Setup

The ITSU-EfficientNet model is implemented using keras framework and backend as Tensorflow 2.1.0. Google colabatory Pro IDE is used for coding and training. Tesla P100 GPU and 32 GB of RAM is used for our experiments. In all 2594 images, 20% of images are utilized for testing and 80% data is used for training. During experiment, we scaled down the size of images as original image sizes for ISIC 2018 challenge dataset is higher and not uniform. EfficientNet B7 which is trained on ImageNet is used as backbone. Here, mean squared error (MSE) is considered as loss function. Adam optimizer is used as initial optimizer and ITSO is used to further fine tune the weights during training. Model is trained for 200 epochs.

F. Dataset Description

The ISIC 2018 challenge dataset [38] is used for training and testing. The dataset provided by ISIC 2018 challenge is for diagnosing skin lesion. It offers classification task and skin lesion segmentation task. From various clinics and institutions

around the world the data was collected. Compared to all publicly available dermoscopic image libraries, ISIC archive is largest one. For skin lesion segmentation, the challenge provides 2594 images with ground truth masks. The image dimensions for segmentation are 2016×3024 .

IV. RESULT AND DISCUSSION

The experimental outcome along with the comparative analysis of the ITSU-EfficientNet is detailed in this section.

A. Assessment Measures

To measure the performance of proposed model we use following standard metrics. We evaluate model using Dice Coefficient (DC), precision ($Pr e$), recall (Re), intersection over union (IoU), specificity (Spe) and sensitivity (Sen). These evaluation measures are defined as follows:

$$DC = \frac{2 * SL_{tp}}{2 * SL_{tp} + SL_{fp} + SL_{fn}} \tag{17}$$

$$Pr e = \frac{SL_{tp}}{SL_{tp} + SL_{fp}} \tag{18}$$

$$Re = \frac{SL_{tp}}{SL_{tp} + SL_{fn}} \tag{19}$$

$$IoU = \frac{SL_{tp}}{SL_{tp} + SL_{fp} + SL_{fn}} \tag{20}$$

$$Spe = \frac{SL_{tn}}{SL_{tn} + SL_{fp}} \tag{21}$$

$$Sen = \frac{SL_{tp}}{SL_{tp} + SL_{fn}} \tag{22}$$

where, SL_{tp} , SL_{fp} , SL_{tn} and SL_{fn} represents true positive, false positive, true negative and false negative respectively. SL_{tp} denotes correctly segmented lesion pixels, SL_{fp} denotes segmented non-lesion pixels, SL_{tn} denotes un-segmented non-lesion pixels and SL_{fn} denotes un-segmented lesion.

B. Experimental Outcome

The experimental outcome of the ITSU-EfficientNet is depicted in Fig. 5, wherein the skin image acquired from the dataset is depicted in Fig. 5(a), the corresponding ground truth the depicted in Fig. 5(b) and finally, the outcome of the ITSU-EfficientNet is portrayed in Fig. 5(c).

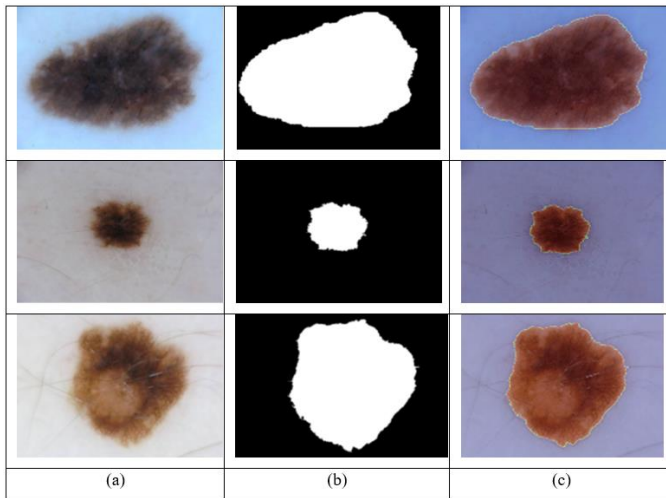


Fig. 5. Experimental outcome (a) Input, (b) Ground truth and (c) segmentation outcome.

C. Performance Assessment

The performance of the ITSU-EfficientNet by varying the epoch is depicted in Fig. 6 based on various assessment measures. In this, the analysis depicts that the higher number of epochs and the training percentage enhances efficiency of the skin lesion segmentation. The epoch is nothing but the learning cycle utilized by the classifier for performing the skin lesion segmentation for the unknown test image. For example, if the number of epochs utilized by the classifier 40 means, the classifier is trained 40 times with the same data for improving the generalization ability. The outcome of the skin lesion segmentation based on the various assessment measures by varying the epoch interprets that the proposed method accomplished better outcome with maximal epoch of 100.

D. Comparative Assessment

The comparative Assessment of the proposed method with the conventional skin lesion segmentation approaches like ResNet+ UNet [32], ResNet + AlexNet [30], DS-TransUNet [29], and DE-ABC [33]. The assessment based on various evaluation measures is depicted in Fig. 7. Here, with 50 % of data learning, the accuracy estimated by ITSU-EfficientNet is 0.90, which is 9.49%, 9.06%, 2.03%, 1.94%, and 0.36% better than conventional ResNet+UNet, ResNet+AlexNet, DS-TransUNet, and DE-ABC methods. The minimal MSE estimated by ITSU-EfficientNet with 60% data learning is 0.09, which is 35.55%, 33.63%, 18.10%, and 16.09% better than conventional ResNet+UNet, ResNet+AlexNet, DS-TransUNet, and DE-ABC methods. The precision estimated by ITSU-EfficientNet is 0.90 with 70% data learning, which is 6.28%, 5.81%, 2.26%, and 2.06% better than conventional ResNet+UNet, ResNet+AlexNet, DS-TransUNet, and DE-ABC methods. With 80% of data learning the recall evaluated by ITSU-EfficientNet is 0.92, which is 9.30%, 8.85%, 3.89%, and 1.47% better than conventional ResNet+UNet, ResNet+AlexNet, DS-TransUNet, and DE-ABC methods. The maximal IoU evaluated by ITSU-EfficientNet is 0.92, which is 9.33%, 8.88%, 6.07%, and 1.54% better than conventional ResNet+UNet, ResNet+AlexNet, DS-TransUNet, and DE-ABC methods with

90% of data learning. The maximal Dice coefficient evaluated by ITSU-EfficientNet is 0.90, which is 6.73%, 6.27%, 2.82%, and 1.69% better than conventional ResNet+UNet, ResNet+AlexNet, DS-TransUNet, and DE-ABC methods with 60% of data learning. Here, the proposed method accomplished superior performance compared to the conventional skin care segmentation method. The analysis is devised by varying the training percentage of the proposed model, wherein the performance elevates with increase in training data. The reason behind the enhanced performance is the higher generalization capability of the skin lesion segmentation technique. Also, the optimal adjustment of the hyper-parameters reduces the information loss during the training phase and enhances the outcome of the proposed model. The detailed analysis of the comparative analysis is presented in Table I.

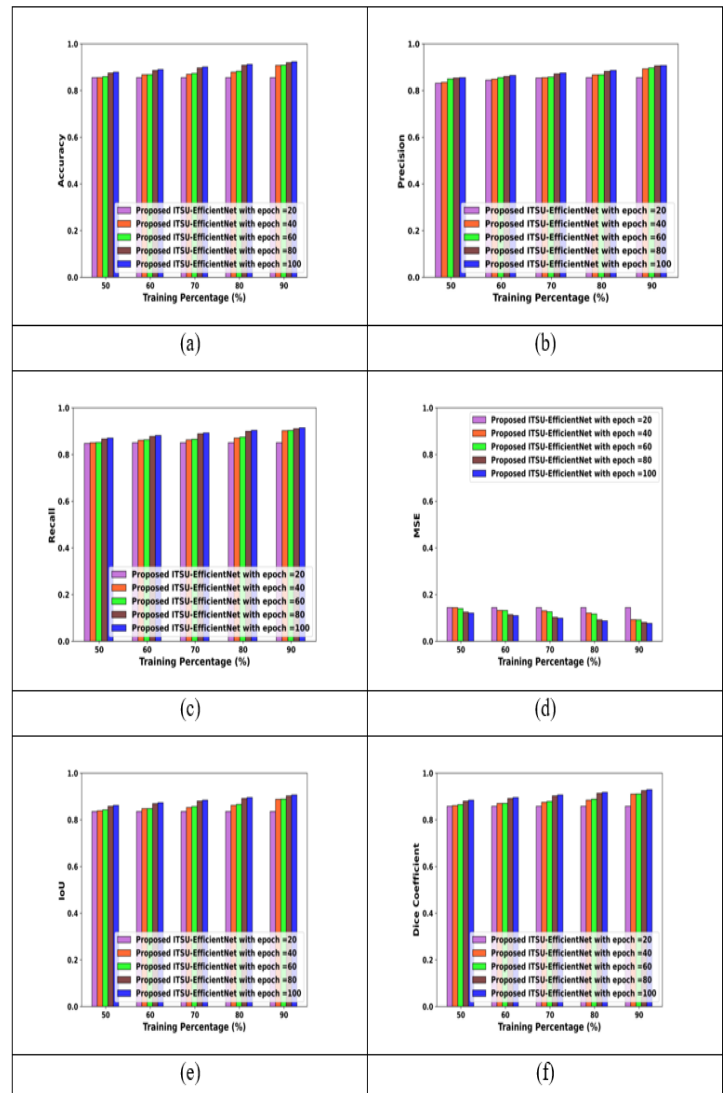


Fig. 6. Performance assessment based on (a) Accuracy, (b) Precision, (c) Recall, (d) MSE, (e) IoU and (f) Dice coefficient.

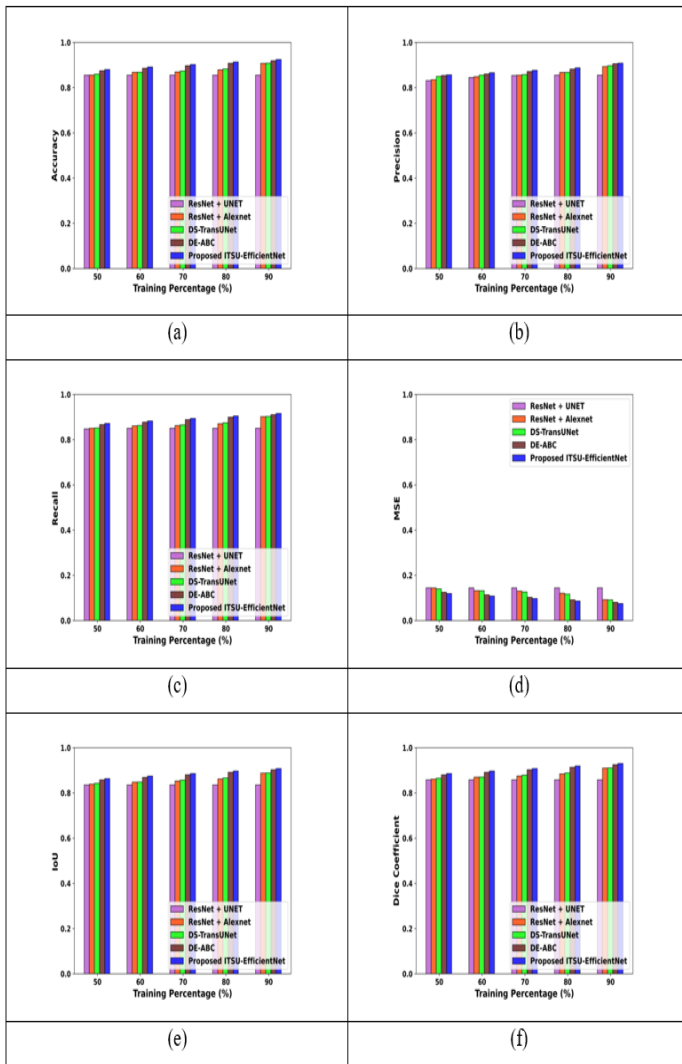


Fig. 7. Comparative assessment of proposed method with conventional methods based on (a) Accuracy, (b) Precision, (c) Recall, (d) MSE, (e) IoU and (f) Dice coefficient.

E. Comparative Discussion

The comparative discussion of the proposed method with existing UNet based methods of skin cancer segmentation approaches is depicted in Table II.

The analysis depicts the superior performance of the ITSU-EfficientNet based on the various assessment measures like Dice coefficient, Precision, Recall and IoU. The reason behind the superiority of the model is the hybrid deep learning model along with the optimal network parameter learning capability. The EfficientNet offers the enhanced performance in skin lesion segmentation with minimal number of parameters. Also, the UNet provides the superior performance in the image segmentation task. Thus, the hybridized model offers the superior performance in skin lesion segmentation compared to the comparative model. Besides, the optimal network parameters tuning using the ITSO algorithm minimizes the information loss during the training phase through the global best solution. The deep learning model with minimal loss elevates its generalization capability and hence it

provides the superior performance while analyzing the performance with unknown test image.

TABLE I. COMPARATIVE ASSESSMENT BY VARYING THE TRAINING DATA

Methods/ Training Percentage	50	60	70	80	90
Accuracy					
ResNet+ UNet	0.81	0.85	0.86	0.86	0.87
ResNet + AlexNet	0.82	0.86	0.87	0.87	0.87
DS-TransUNet	0.88	0.88	0.88	0.88	0.88
DE-ABC	0.88	0.89	0.90	0.91	0.93
ITSU-EfficientNet	0.90	0.91	0.92	0.92	0.94
MSE					
ResNet+ UNet	0.19	0.15	0.14	0.14	0.13
ResNet + AlexNet	0.18	0.14	0.13	0.13	0.13
DS-TransUNet	0.12	0.12	0.12	0.12	0.12
DE-ABC	0.12	0.11	0.10	0.09	0.07
ITSU-EfficientNet	0.10	0.09	0.08	0.08	0.06
Precision					
ResNet+ UNet	0.80	0.83	0.84	0.84	0.85
ResNet + AlexNet	0.80	0.84	0.85	0.85	0.86
DS-TransUNet	0.86	0.87	0.88	0.88	0.88
DE-ABC	0.87	0.88	0.88	0.91	0.92
ITSU-EfficientNet	0.90	0.90	0.90	0.92	0.94
Recall					
ResNet+ UNet	0.79	0.82	0.83	0.83	0.84
ResNet + AlexNet	0.79	0.83	0.84	0.84	0.84
DS-TransUNet	0.85	0.86	0.87	0.88	0.88
DE-ABC	0.86	0.87	0.88	0.91	0.93
ITSU-EfficientNet	0.90	0.90	0.90	0.92	0.94
IoU					
ResNet+ UNet	0.78	0.82	0.83	0.83	0.83
ResNet + AlexNet	0.78	0.82	0.83	0.83	0.84
DS-TransUNet	0.85	0.85	0.86	0.86	0.86
DE-ABC	0.85	0.86	0.86	0.89	0.91
ITSU-EfficientNet	0.88	0.88	0.88	0.90	0.92
Dice Coefficient					
ResNet+ UNet	0.80	0.84	0.85	0.85	0.86
ResNet + AlexNet	0.81	0.84	0.85	0.85	0.86
DS-TransUNet	0.87	0.87	0.88	0.89	0.89
DE-ABC	0.88	0.88	0.89	0.91	0.93
ITSU-EfficientNet	0.90	0.90	0.90	0.92	0.94

TABLE II. COMPARATIVE DISCUSSION

Method	Dice Coefficient	Precision	Recall	IoU
Unet with Focal Tversky Loss[39]	85.6	89.6	92.6	-
MultiScale Residual Fusion N [40]	88.24	93.48	88.93	83.73
Dense Residual Unet [41]	86.1	91.1	88.2	-
Double Unet[42]	89.62	94.59	87.8	82.12
∇^N -Net [43]	89.6	97.07	96.36	88.83
ITSU- EfficientNet (Proposed)	94.36	91.33	99.17	92.9

Also, the additional artefact removal process removes the noise from the image and enhances the quality of the image. Hence, the combined performance of the proposed skin lesion segmentation process accomplished the superior performance.

V. CONCLUSION

This research introduced an optimized deep learning model named ITSU-EfficientNet for the skin lesion segmentation approach. The newly devised TSU-EfficientNet combines the ITSU algorithm, UNet and EfficientNet, wherein the learnable parameters of the deep learning model are tuned using the ITSU algorithm. Here, the balanced intensification and diversification phase of the ITSU algorithm eliminates information loss during the data learning phase. Also, the hybrid deep learning model with the combined UNet and EfficientNet provides the enhanced accuracy in skin lesion segmentation. The faster convergence rate of the algorithm reduces the computation time without compromising the performance of the model. The performance assessment based on various measures like Accuracy, MSE, Precision, Recall, IoU, and Dice Coefficient and acquired the values of 0.94, 0.06, 0.94, 0.94, 0.92 and 0.94 respectively. However, the proposed model is not used to analyze the skin lesion classification using the segmentation outcome. Hence, in the future a novel classification method will be devised for identifying the skin lesion type and its severity.

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REFERENCES

[1] Keerthana, D., Venugopal, V., Nath, M.K. and Mishra, M., 2023. Hybrid convolutional neural networks with SVM classifier for classification of skin cancer. *Biomedical Engineering Advances*, 5, p.100069.
[2] Daia, W., Liua, R., Wua, T., Wanga, M., Yinb, J. and Liua, J., 2022. HierAttn: Effectively Learn Representations from Stage and Branch Attention for Skin Lesions Diagnosis.
[3] Innani, S., Dutande, P., Baheti, B., Baid, U. and Talbar, S., 2023. Deep Learning based Novel Cascaded Approach for Skin Lesion Analysis. *arXiv preprint arXiv:2301.06226*.

[4] Adinegoro, A.F., Sutapa, G.N., Gunawan, A.N., Anggarani, N.K.N., Suardana, P. and Kasmawan, I., 2023. Classification and Segmentation of Brain Tumor Using EfficientNet-B7 and U-Net. *Asian Journal of Research in Computer Science*, 15(3), pp.1-9.
[5] Fraiwan, M. and Faouri, E., 2022. On the Automatic Detection and Classification of Skin Cancer Using Deep Transfer Learning. *Sensors*, 22(13), p.4963.
[6] Lavanya, G., Vinoci, K.L., Samvardani, D. and Subiksa, V., 2023. A Hybrid Model for Brain Tumor Detection using EfficientNet and Fuzzy C Means Clustering Algorithm. *Journal of Survey in Fisheries Sciences*, 10(2S), pp.219-232.
[7] SM, J., Aravindan, C. and Appavu, R., 2022. Classification of skin cancer from dermoscopic images using deep neural network architectures. *Multimedia Tools and Applications*, pp.1-16.
[8] Belattar, K., Adadj, M., Bakir, M. and Ait Mehdi, M., 2022. A Comparative Study of CNN Architectures for Melanoma Skin Cancer Classification.
[9] Lama, N., Kasmir, R., Hagerty, J.R., Stanley, R.J., Young, R., Miinch, J., Nepal, J., Nambisan, A. and Stoecker, W.V., 2022. ChimeraNet: U-Net for Hair Detection in Dermoscopic Skin Lesion Images. *Journal of Digital Imaging*, pp.1-10.
[10] Bindhu, A. and Thanammal, K.K., 2023. Segmentation of skin cancer using Fuzzy U-network via deep learning. *Measurement: Sensors*, p.100677.
[11] Grignaffini, F., Barbuto, F., Piazzi, L., Troiano, M., Simeoni, P., Mangini, F., Pellacani, G., Cantisani, C. and Frezza, F., 2022. Machine Learning Approaches for Skin Cancer Classification from Dermoscopic Images: A Systematic Review. *Algorithms*, 15(11), p.438.
[12] Ravi, V., 2022. Attention Cost-Sensitive Deep Learning-Based Approach for Skin Cancer Detection and Classification. *Cancers*, 14(23), p.5872.
[13] Krishna, P.R. and Rajarajeswari, P., 2022, March. Early Detection Of Melanoma Skin Cancer Using Efficient Netb6. In *2022 8th International Conference on Advanced Computing and Communication Systems (ICACCS) (Vol. 1, pp. 01-05)*. IEEE.
[14] Popescu, D., El-Khatib, M., El-Khatib, H. and Ichim, L., 2022. New trends in melanoma detection using neural networks: a systematic review. *Sensors*, 22(2), p.496.
[15] Silva, G.M., Lazzaretti, A.E. and Monteiro, F.C., 2022, October. Deep Learning Techniques Applied to Skin Lesion Classification: A Review. In *2022 International Conference on Machine Learning, Control, and Robotics (MLCR) (pp. 106-111)*. IEEE.
[16] Nambisan, A.K., Maurya, A., Lama, N., Phan, T., Patel, G., Miller, K., Lama, B., Hagerty, J., Stanley, R. and Stoecker, W.V., 2023. Improving Automatic Melanoma Diagnosis Using Deep Learning-Based Segmentation of Irregular Networks. *Cancers*, 15(4), p.1259.
[17] Dayı, B., Üzen, H., Çiçek, İ.B. and Duman, Ş.B., 2023. A Novel Deep Learning-Based Approach for Segmentation of Different Type Caries Lesions on Panoramic Radiographs. *Diagnostics*, 13(2), p.202.
[18] Hauser, K., Kurz, A., Hagggenmüller, S., Maron, R.C., von Kalle, C., Utikal, J.S., Meier, F., Hobelsberger, S., Gellrich, F.F., Sergon, M. and Hauschild, A., 2022. Explainable artificial intelligence in skin cancer recognition: A systematic review. *European Journal of Cancer*, 167, pp.54-69.
[19] Kousis, I., Perikos, I., Hatzilygeroudis, I. and Virvou, M., 2022. Deep learning methods for accurate skin cancer recognition and mobile application. *Electronics*, 11(9), p.1294.
[20] Rana, S., 2022. SkinCan AI: A Deep Learning-Based Skin Cancer Classification and Segmentation Pipeline Designed Along with a Generative Model (Doctoral dissertation, University of Windsor (Canada)).
[21] Hoang, L., Lee, S.H., Lee, E.J. and Kwon, K.R., 2022. Multiclass skin lesion classification using a novel lightweight deep learning framework for smart healthcare. *Applied Sciences*, 12(5), p.2677.
[22] Yang, G., Luo, S. and Greer, P., 2023. A Novel Vision Transformer Model for Skin Cancer Classification. *Neural Processing Letters*, pp.1-17.

- [23] Rout, R., Parida, P. and Dash, S., 2023, March. A Hybrid Deep Learning Network for Skin Lesion Extraction. In Proceedings of the 14th International Conference on Soft Computing and Pattern Recognition (SoCPaR 2022) (pp. 682-689). Cham: Springer Nature Switzerland.
- [24] Younis, M., 2022. Melanoma Skin Lesion Classification Using Neural Networks: A systematic review. AL-Rafidain Journal of Computer Sciences and Mathematics, 16(2), pp.43-55.
- [25] Rehman, H.U., Nida, N., Shah, S.A., Ahmad, W., Faizi, M.I. and Anwar, S.M., 2022. Automatic melanoma detection and segmentation in dermoscopy images using deep RetinaNet and conditional random fields. Multimedia Tools and Applications, 81(18), pp.25765-25785.
- [26] Alfi, I.A., Rahman, M.M., Shorfuazzaman, M. and Nazir, A., 2022. A non-invasive interpretable diagnosis of melanoma skin cancer using deep Learning and ensemble stacking of machine learning models. Diagnostics, 12(3), p.726.
- [27] Alom, M.Z., Rahman, M.M., Nasrin, M.S., Taha, T.M. and Asari, V.K., 2020. COVID_MTNNet: COVID-19 detection with multi-task deep learning approaches. arXiv preprint arXiv:2004.03747.
- [28] Öztürk, Ş. and Özkaya, U., 2020. Skin lesion segmentation with improved convolutional neural network. Journal of digital imaging, 33, pp.958-970.
- [29] Alahmadi, M.D. and Alghamdi, W., 2022. Semi-Supervised Skin Lesion Segmentation With Coupling CNN and Transformer Features. IEEE Access, 10, pp.122560-122569.
- [30] Barn, S. and Güraksin, G.E., 2022. An automatic skin lesion segmentation system with hybrid FCN-ResAlexNet. Engineering Science and Technology, an International Journal, 34, p.101174.
- [31] Rehman, M., Ali, M., Obayya, M., Asghar, J., Hussain, L., K. Nour, M., Negm, N. and Mustafa Hilal, A., 2022. Machine learning based skin lesion segmentation method with novel borders and hair removal techniques. Plos one, 17(11), p.e0275781.
- [32] Ashraf, H., Waris, A., Ghafoor, M.F., Gilani, S.O. and Niazi, I.K., 2022. Melanoma segmentation using deep learning with test-time augmentations and conditional random fields. Scientific Reports, 12(1), p.3948.
- [33] Malik, S., Akram, T., Ashraf, I., Rafiullah, M., Ullah, M. and Tanveer, J., 2022. A Hybrid Preprocessor DE-ABC for Efficient Skin-Lesion Segmentation with Improved Contrast. Diagnostics, 12(11), p.2625.
- [34] Nawaz, M., Nazir, T., Masood, M., Ali, F., Khan, M.A., Tariq, U., Sahar, N. and Damaševičius, R., 2022. Melanoma segmentation: a framework of improved DenseNet77 and UNET convolutional neural network. International Journal of Imaging Systems and Technology, 32(6), pp.2137-2153.
- [35] Akyel, C. and Arıcı, N., 2022. Linknet-b7: Noise removal and lesion segmentation in images of skin cancer. Mathematics, 10(5), p.736.
- [36] Xie, L., Han, T., Zhou, H., Zhang, Z.R., Han, B. and Tang, A., 2021. Tuna swarm optimization: a novel swarm-based metaheuristic algorithm for global optimization. Computational intelligence and Neuroscience, 2021, pp.1-22.
- [37] Trojovský, P. and Dehghani, M., 2022. Pelican optimization algorithm: A novel nature-inspired algorithm for engineering applications. Sensors, 22(3), p.855.
- [38] P. Tschandl, C. Rosendahl, and H. Kittler, "The HAM10000 dataset, a large collection of multi-source dermatoscopic images of common pigmented skin lesions," Scientific Data 2018 5:1, vol. 5, no. 1, pp. 1-9, Aug. 2018.
- [39] Abraham, N. and Khan, N.M., 2019, April. A novel focal tversky loss function with improved attention u-net for lesion segmentation. In 2019 IEEE 16th international symposium on biomedical imaging (ISBI 2019) (pp. 683-687). IEEE.
- [40] Srivastava, A., Jha, D., Chanda, S., Pal, U., Johansen, H.D., Johansen, D., Riegler, M.A., Ali, S. and Halvorsen, P., 2021. Msrf-net: A multi-scale residual fusion network for biomedical image segmentation. IEEE Journal of Biomedical and Health Informatics, 26(5), pp.2252-2263.
- [41] Jafari, M., Auer, D., Francis, S., Garibaldi, J. and Chen, X., 2020, April. DRU-Net: an efficient deep convolutional neural network for medical image segmentation. In 2020 IEEE 17th International Symposium on Biomedical Imaging (ISBI) (pp. 1144-1148). IEEE.
- [42] Jha, D., Riegler, M.A., Johansen, D., Halvorsen, P. and Johansen, H.D., 2020, July. Doubleu-net: A deep convolutional neural network for medical image segmentation. In 2020 IEEE 33rd International symposium on computer-based medical systems (CBMS) (pp. 558-564). IEEE.
- [43] Alom, M.Z., Aspiras, T., Taha, T.M. and Asari, V.K., 2019. Skin cancer segmentation and classification with NABLA-N and inception recurrent residual convolutional networks. arXiv preprint arXiv:1904.11126.

Analysis and System Construction of ALSTM-LSTM Model-based Sports Jumping Rope Movement

Peng Su, Zhipeng Li*, Weiguo Li, Yongli Yang

Basic Teaching Department, Hebei Women's Vocational College, Shijiazhuang, 050000, China

Abstract—Computer technology's maturity has enabled intelligent and interactive sports training. Jumping rope test in secondary school faces difficulties due to bulky testing equipment and inefficient data measurement. An ALSTM-LSTM model based on visual human posture estimation is proposed for motion system analysis. Joint pose features are fused through LSTM, and the attention mechanism assigns weights to feature sequences to achieve motion recognition, considering the data's multidimensional and hierarchical nature. The model's precision value is 95.83. Its average accuracy is much higher than LSTM, ML-KNN, and RSN models. Additionally, the model has 95.2% accuracy in localizing jump rope stance movements with low data consumption. The model can improve the accuracy of the analysis of the jump rope sport's posture based on the characteristics of human movement, and inspire new technical tools for teaching instruction.

Keywords—ALSTM-LSTM model; jumping rope exercise; Sports; human posture estimation algorithm; attention mechanisms

I. INTRODUCTION

The development and maturity of computer vision and intelligent technology has provided new research tools and ideas for human motion analysis. They are also applied in pattern recognition, image processing, and interaction between real and imaginary scenes. In addition, the application of computer vision and intelligence technology to sports training makes the analysis of movement types and posture recognition possible. The estimation of human posture is achieved by using algorithms to identify and locate the position of the body's joints [1-2]. With the development of national fitness activities, strengthening the integration of artificial intelligence and the sports industry is an important direction for development. As a sport with regularity and requiring coordination and cooperation, jumping rope is crucial for the enhancement of individual fitness and the development of children's intellectual ability [3]. The bulky nature of traditional sports jumping rope monitoring equipment and the high cost of manual measurement make it difficult to train effectively and to provide normative guidance on student performance [4]. Existing human motion recognition algorithms suffer from poor accuracy due to overburdening and have less application in posture assessment [5]. Common jumping rope detection is often calculated using instruments or manual calculations, which lack stability in algorithm accuracy and effectiveness. There are few common applications for posture assessment in jumping rope, and the dynamic nature of its jumping behavior greatly reduces the accuracy of traditional posture estimation. In order to better adapt to the action analysis of students in the jumping rope

scene, the research first introduced short-term memory network for in-depth learning based on the mobile visual characteristics of the action, and fused multi-level features to improve the target detection performance. The proposed algorithm is to give full play to the complementary feature of information detection in different dimensions and levels, so as to ensure that the classification data can recognize the information in dynamic and static scenes. According to the differences in the role and speed of different limb movements in jumping rope, image distortion is inevitable. Therefore, the study introduced the concept of learning weight into the network structure for different feature extraction. The study starts with the analysis and characteristics of the movements of the research object (jumping rope), and proposes continuous improvement and optimization of network structure features to achieve accuracy in motion capture and analysis. The study aims to effectively detect jumping rope movements, and construct corresponding systems to provide reference and guidance for improving the quality of physical education teaching.

II. RELATED WORKS

The progressive development of society and the increase in economic have led to a greater focus on physical exercise, while the maturation of the theory of intelligent technology has provided new tools and instruments for the analysis of sports. The mathematical model based on the acceleration sensor was developed by Xu to better analyse the experimental data of the rope and hand during jumping rope. A control group and an experimental group were set up, and volunteers were selected to carry out experimental observations of exercise energy consumption. It was proved that the sensor can construct and generate a model of the multidimensional data of the subjects, and can effectively analyse the energy consumption of the experimental group. The results of this experiment can effectively provide new ideas for improving the teaching of jumping rope sports [6]. In order to ensure the fitness of jumping rope while enhancing its safety, Wang and other scholars applied the inverse mechanics model to the analysis of jumping rope movement and combined big data to analyse the changes of each joint position during the movement. The results showed that the validity of the motion analysis of fancy jump rope was better and the introduction of fancy jump rope in university physical education had high significance and value [7]. Nie proposed a hierarchical contextual refinement network for the estimation of human posture in order to reduce the problem of poor joint localization performance, i.e., to achieve the transfer detection of diffuse joints. The method effectively achieved the

detection of joint points in the hierarchical state and is less affected by interference factors [8]. Cao and other scholars proposed a motion detection system based on deep learning guidance for better analysis of motion data. It was proved that it is more than 95% accurate in the evaluation of jumping rope data and its recall values were high. The wearable device under this monitoring system can effectively analyse the sports data [9]. Yu innovated the application of EMG signal acquisition to sports. Based on the actual needs of athletes, the individual differences and wavelet principal component model for sports recognition was proposed. The wavelet-based model had high accuracy and detail observation of motion recognition, and also has high theoretical value [10]. For the detection and recognition of specific motion, Cust and others used the help of inertial measurement units and computer vision for in-depth analysis. Database search results show that support vector machines and convolutional neural networks as well as long and short-term memory architectures are mostly used for data processing and target motion feature recognition [11]. Ramirez Campillo R scholars used a meta-analysis system to analyze the jumping rope training for effectively improving the physical fitness of athletes. The analysis including resting heart rate, body mass index, fat mass, cardiopulmonary endurance, and so on [12]. They analyzed the impact mechanism between enhanced jumping training (PJT) and athlete's repetitive sprint ability (RSA) [13]. Layne T scholars believed that using sports technology feedback education for jumping performance testing can effectively stimulate the potential of athletes [14].

Deep learning algorithms have good data processing and information extraction capabilities. It can provide new tools for the recognition of sports analysis and can effectively reduce the influence of objective factors and individual differences in performance on the results [15-16]. The team of Rana found that the emergence of wearable inertial sensors provided a convenient tool to carry out sports analysis, and the device could effectively provide solutions based on the characteristics of different athletes compared to the original manual analysis of athletes' data metrics [17]. The edge box method was used to refine the scale of the tracker, while a convolutional network was used under the recursive concept to implement frame video image recognition. The results show that the improved method is highly effective and efficient for the analysis of sports videos [18]. To address the difficulty of quantifying feature extraction, Mathis and Mamidanna proposed a bit-pose estimation method with deep neural networks and migrated the method to markerless applications to avoid the impact of intrusive markers on motion control. Experimental results demonstrated the high accuracy as well as versatility of the framework approach and the accuracy of its data tests was comparable to the real values [19]. Kong

scholars proposed to accelerate the analysis and prediction of trajectory data under localization technology based on real-time location and long time access are the more common services. The study proposed spatio-temporal long- and short-term memory for data analysis, and the results showed that the method can link and predict historical visit information backwards and forwards, with a high fit between the real values [20]. Nadeem scholar team identified human behaviors with the help of entropy Markov model, and added contour detection and multidimensional cues to the original automatic human posture estimation method. They implemented action recognition through image preprocessing and image noise removal as part model construction. The method can detect limb movements with high recognition accuracy, and its interactive advantage has good applicability in other fields [21]. He introduced three-dimensional space technology in image processing and established a sports tracking system with the help of particle filtering to improve its accuracy. A similarity estimation method was proposed according to the characteristics of volleyball. The method has good tracking performance and its success rate exceeds 80% [22]. Jalal introduced a pseudo-2D model to the original human pose estimation method to achieve the extraction of contour features and pose point features He introduced a K-ary tree hashing algorithm to optimize the data set. The results proved that the method has an accuracy of more than 80% in key point detection in motion datasets, which is a good application in sports [23].

The aforementioned studies suggest that enhancing feature recognition in sport is a key focus for improving video data analysis and the quality of sports. Some scholars have proposed sensor design, short and long term memory networks, convolutional neural networks and entropic Markov models to achieve information recognition and data analysis. Therefore, this study will improve on the long-short memory network and apply it to the analysis of sports jumping rope to improve its posture recognition accuracy, and provide a new tool for the improvement of physical education.

III. ANALYSIS OF SPORT JUMPING ROPE MOVEMENT AND SYSTEM CONSTRUCTION BASED ON ALSTM-LSTM MODEL

A. ALSTM-LSTM Model based on Human Posture Recognition

Human pose recognition is a key problem in human behaviour analysis and is currently a hot topic of research. It is widely used in robot training, motion tracking, film production and sports analysis. The OpenPose pose estimation open source library extracts information from the human bone nodes with good real-time performance and accuracy [24-25]. The architecture is shown in Fig. 1.

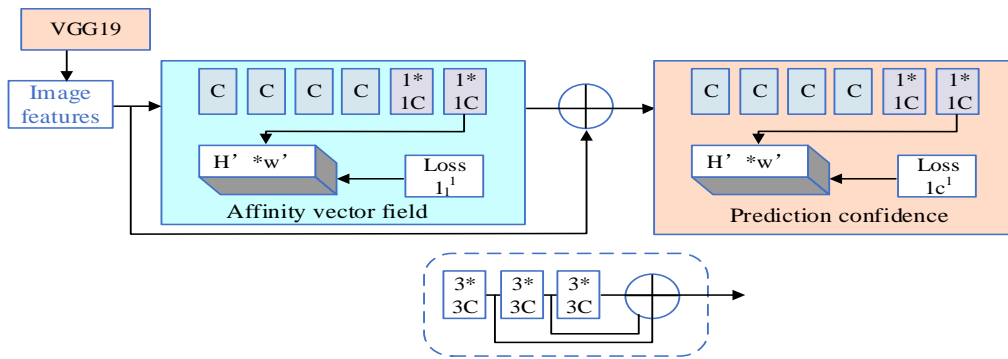


Fig. 1. OpenPose network structure diagram.

The confidence map expression formula for the location of key points in motion recognition is equation (1).

$$\begin{cases} C_{j,k} = \exp\left(\frac{\|p - X_{j,k}\|_2^2}{\delta^2}\right) \\ C_j(p) = \max_k S_{j,k}(p) \end{cases} \quad (1)$$

In equation (1), j denotes the joint point of the human body, k is the target person in the image, p is the predicted coordinates of the person, $X_{j,k}$ is the specific coordinate position, and δ denotes the minimal value. The length of the limb between two joint points can be expressed as $l_{c,k} = \|X_{j2,k} - X_{j1,k}\|_2$. The study introduces weight values and penalty terms in the loss function of the model to reduce the impact of branching losses on the accuracy results, and the mathematical expression is shown in equation (2).

$$f = \sum_l^T (\alpha f_s^l + \beta f_L^l + \theta) \quad (2)$$

In equation (2), $f = \sum_l^T (\alpha f_s^l + \beta f_L^l + \theta)$ denotes the confidence and affinity domain of the predicted key points,

$f = \sum_l^T (\alpha f_s^l + \beta f_L^l + \theta)$ is the corresponding weight value and

$f = \sum_l^T (\alpha f_s^l + \beta f_L^l + \theta)$ denotes the penalty term. In the jumping rope movement analysis, the movement involves the head, shoulders, wrist, ankle and other limbs of the human posture parts. This real-time movement and limb movement quality assessment can be affected by a variety of factors, so the research is based on the characteristics of mobile vision for movement analysis, and introduces the Long Short-Term Memory (LSTM) models. The LSTM network algorithm can effectively process long time sequences of data and information, and selectively forget new information and accumulated information by introducing a gating mechanism. By using memory units to transfer information cyclically, the model can effectively avoid the problem of gradient disappearance during the training process. Fig. 2 shows the structure of the recurrent unit of the LSTM network.

Based on the LSTM input human action data, the formulae for input gate i_t , forgetting gate f_t and output gate o_t at moment t are shown in equation (3).

$$\begin{cases} f_t = \sigma(M_f \cdot [h_{t-1}, x_t] + b_f) \\ i_t = \sigma(M_i \cdot [h_{t-1}, x_t] + b_i) \\ o_t = \sigma(M_o \cdot [h_{t-1}, x_t] + b_o) \end{cases} \quad (3)$$

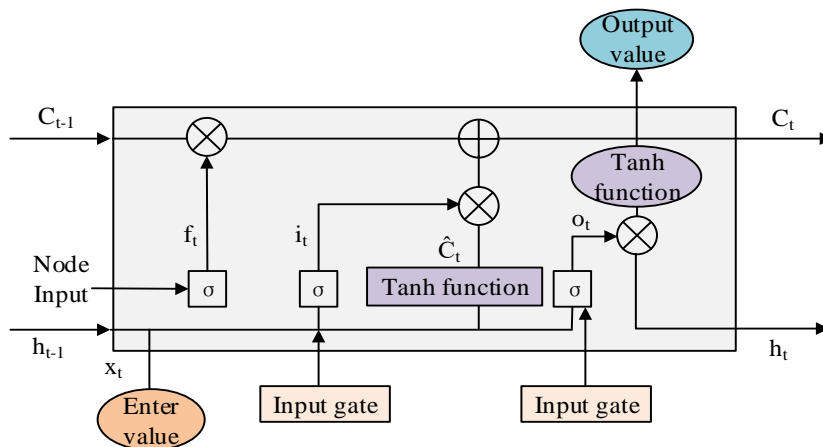


Fig. 2. Schematic diagram of network cycle unit structure.

In equation (3), h_{t-1} is the output of the previous layer and the information of the structure, h_t is the output, σ is the gate activation function, x_t is the input value and M, b denote the weight matrix and the deviation value. The long-term memory state at moment t can be expressed as equation (4).

$$c_t = f_i \circ c_{t-1} + i_t \tanh(W_c * [h_{t-1}, x_t] + b_c) \quad (4)$$

In equation (4), W_c, b_c denote the weight value and bias of the input gate, and \circ denotes multiplication by element. The LSTM network fuses static and dynamic features when classifying action recognition. Changes in different nodes can have an impact on action pose recognition, and degree discrimination of node importance can effectively highlight the information data of valid actions, so the study introduces an attention mechanism for weighting [26-28]. The attention mechanism assigns different weight values to different input feature sequences to show the difference in their attention, which can effectively improve the LSTM network to treat different feature states the same, ignoring the multi-dimensionality and hierarchy of features. The study represents the degree of correlation between information features and output values with the help of a one-layer perceptron, the mathematical expression of which is shown in equation (5).

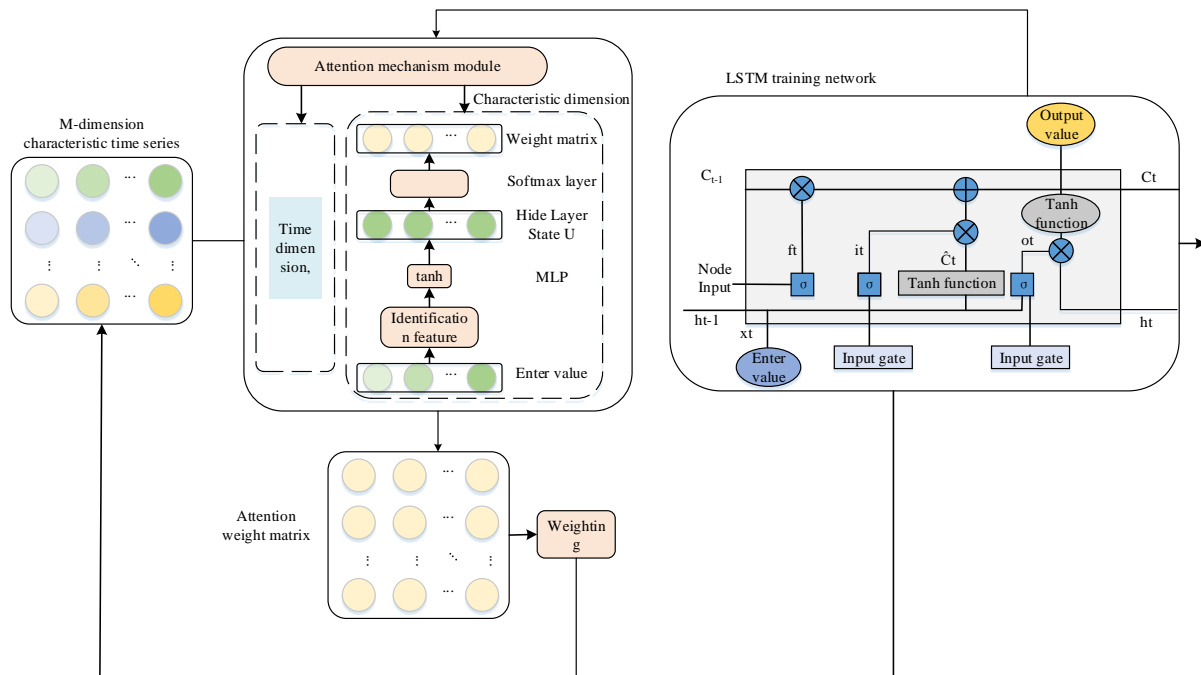
$$s_i = MLP(h_i', \tilde{y}) = v^T \tanh(W_1 h_i + W_2 \tilde{y}) \quad (5)$$

In equation (5), h_i' is the intermediate layer state after LSTM recognition, \tilde{y} is the target intent and v, W_1, W_2 are the learning parameters. The normalisation is performed to obtain the attention weights of the features, see equation (6).

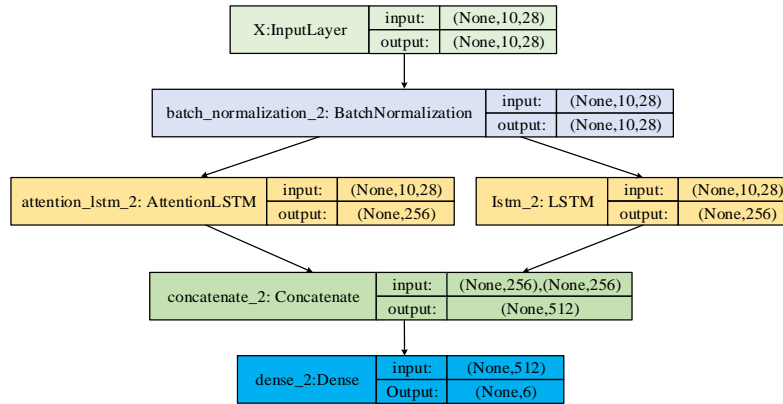
$$Att_i = \text{soft max}(s_i) = \frac{\exp(s_i)}{\sum_{j=1}^m \exp(s_j)} \quad (6)$$

In equation (6), s_i is the learning degree of the feature and m denotes the number of features. Fig. 3 shows the network architecture of the introduced attention mechanism.

The analysis of human posture during jumping rope can be regarded as a label classification problem with temporal and sequential characteristics, and the body movements involved in it can also have an impact on the continuity and integrity of jumping rope when deviations and movements occur. The study incorporates an attention mechanism into the LSTM model, as shown in Fig. 3(b). The ALSTM-LSTM model consists of five aspects: the input layer, the batch normalisation layer, the ALSTM-LSTM layer, the connection layer and the sigmoid layer. The data is normalized by BatchNorm to ensure predictability of the data gradient and to reduce the data fluctuation problem of the problem solution, allowing the algorithm performance to achieve high convergence within the learning rate range. Traditional jump rope physical education is taught through demonstration by the physical education teacher as well as explanation of the movements, followed by the students exercising on their own [29-30]. Since there is a large variability among individual students, their mastery of the ability varies. Therefore, the study introduced an attention mechanism into the LSTM model to make the extraction of effective movement information more effective. Fig. 4 is the schematic diagram of the analysis model for jumping rope movements.



(a) LSTM network architecture based on attention mechanism



(b) Model diagram of ALSTM-LSTM

Fig. 3. Network architecture of introducing attention mechanism.

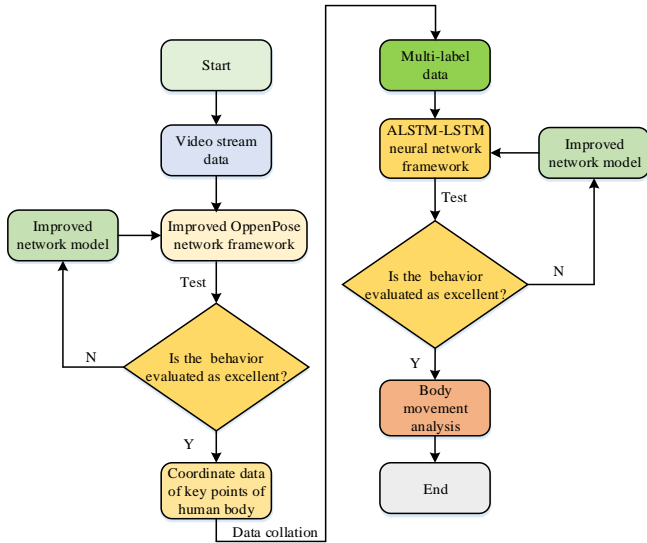


Fig. 4. Schematic diagram of analysis model flow of rope skipping.

The ALSTM-LSTM model can effectively transform the posture of the athlete during the jumping rope movement into a classification problem, and carry out a before-and-after correlation analysis. It makes a comprehensive judgment on the key points of the limbs in the posture analysis to achieve an effective analysis of the jumping rope movement.

B. Analysis of Physical Education Campaigns to Improve the CDA Module

Human motion detection is highly difficult in the computer recognition process due to the complexity of the movement of the human target and the interference of the external environment. Enhancing the relevance and accuracy of motion target detection and human motion recognition is the focus of

current research. Most current human motion detection algorithms include both centroid-based and high-resolution feature-based examinations. Among them, anchor frame definition network features are more prone to target detection bias as well as sample imbalance problems, and they require higher accuracy in target detection for the interaction ratio between the labeled and real frames [31-32]. There are differences in limb node movements driven by jumping rope behaviour, and the task of detecting targets at different locations increases the difficulty of information processing and hyperparameter overload. Therefore, the study uses multi-level features for fusion to improve the target detection performance and give full play to the complementary feature of different dimensional levels of information detection. Content Descriptive Attention (CDA) module is introduced to achieve multi-scale feature extraction and adaptivity of fused information. Fig. 5 shows a schematic diagram of adaptive feature fusion.

Consistency in image size maintenance as well as non-linear characteristics is important to ensure that features are extracted by the CDA module. This means that the input image is sampled for matching, the convolution of the sampled image, the acquisition of features that feel different scales and the selection of features. It fuses several aspects to achieve the output of the processed image [33]. The global average pooling of the feature data gives the channel information, as equation (7).

$$Z_c = \frac{\sum_{i=1}^H \sum_{j=1}^W u_c(i, j)}{H * W} \quad (7)$$

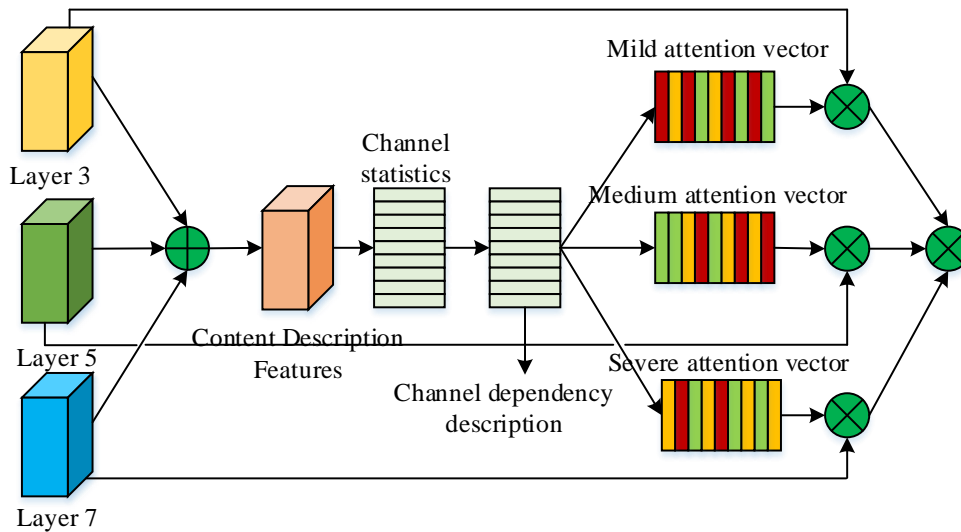


Fig. 5. Schematic diagram of adaptive feature fusion process.

In equation (7), Z_{uc} represents the channel information and descriptive features, H, W are the two aspects of the spatial dimension and i, j are the number of elements in the channel information. The channel dependencies are described with the help of the fully connected layer (FC), for which the extracted mathematical expressions are given in equation (8).

$$s = \delta(W_0 z) \tag{8}$$

In equation (8), δ, W_0 denote the activation function and the weight of the first connected layer, respectively. The output value of the features under feature fusion is the product of the feature representation of each component and its corresponding attention vector. The output value of the CAD module can be a representation of the semantic features extracted from the network, and the mathematical expression is shown in equation (9).

$$U_{in} = U_{out} \square U_{att} + U_{out} \tag{9}$$

In equation (9), U_{in}, U_{out} represent the inputs and outputs of the network, U_{att} is the attention map in the module and \square is the Hadamard product. Fig. 6 shows a schematic diagram of the application of the CAD module in target detection.

The High Resolution Network (HRNet), which is often applied to feature fusion, only adjusts and directly fuses features of different resolutions, without taking into account the differences in the representation of different resolution feature images and feature information data [34]. To reduce the distortion of image accuracy with direct fusion manipulation, a WFHRNet network that adds learning weights to the input features is proposed for feature extraction to distinguish the importance of different features in the overall network. The mathematical expression is shown in equation (10).

$$O_k = \sum_{i=1}^x \sigma(w_i) \cdot f(I, k) \tag{10}$$

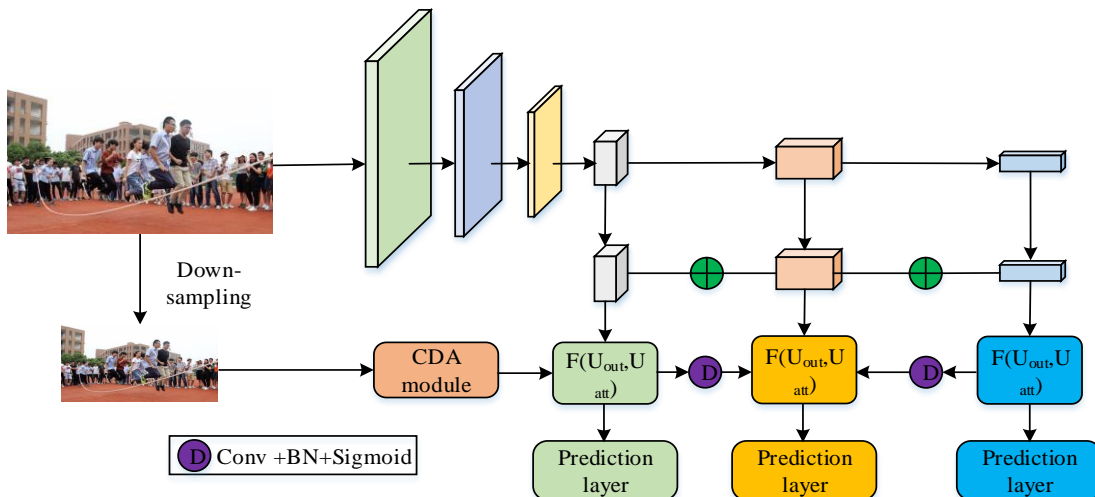


Fig. 6. Application diagram of CAD module in target detection.

In equation (10), σ denotes the Sigmoid function, w_i is the learning scalar, and $f(I_i, k)$ denotes the input resolution I_i adjusted to the k resolution via the sampling step. The size of the distance between prediction frames in different images can have an impact on information recognition. Non Maximum Suppression (NMS) processing is mostly used to remove redundant frames, but this method uses the intersection ratio metric to assess the difference of the assessed frame and the real frame. When the intersection ratio of the two targets is high, the correctly predicted prediction frames will be removed due to non-maximum suppression, resulting in the algorithm missing detection. The overlap of the redundant prediction frames and the equi-position relationship between different prediction frames will make the algorithm accuracy impaired. Therefore, the research proposes to improve the NMS with Manhattan Distance based Non Maximum Suppression (MD-NMS), which can represent the sum of the distances of the prediction frames in the vertical and horizontal directions. Its mathematical expression is given in Equation (11).

$$MD(B_1, B_2) = MD(m, n) + MD(n, v) + MD(C_{B1}, C_{B2}) \quad (11)$$

In equation (11), $(m, n), (n, v)$ denote the point in the vertical direction of the upper left and lower right corners of the two prediction frames B_1, B_2 , and C_{B1}, C_{B2} is the centroid of B_1, B_2 . There is an inverse relationship between the value of Manhattan distance and image similarity. The mathematical expression of MD-NMS is shown in equation (12).

$$S_i = \begin{cases} S_i, & loU(M, b_i) - nom(MD(M, b_i)) < N_i \\ 0, & loU(M, b_i) - nom(MD(M, b_i)) \geq N_i \end{cases} \quad (12)$$

In equation (12), loU denotes the intersection ratio, S_i is the threshold, b_i is the confidence score of the prediction frame, and M denotes the prediction frame at the highest confidence level.

IV. ANALYSIS OF EXPERIMENTAL RESULTS FOR THE ANALYSIS OF PHYSICAL EDUCATION AND SPORTS TEACHING

The participants' body movements during jumping rope were analyzed and identified, and the network was constructed after identifying the key points through the human body. The MPII motion data set and the jumping rope data set were used for this experimental dataset. The jumping rope data set was obtained from an experimental secondary school. In the process of data acquisition, the height and width of the video frames of different sizes were set uniformly in order to detect the node position of the research subject in the jumping rope movement. During the analysis of the posture estimation jumping rope movements, the data analysis and visualization effects were displayed with the help of the Jupyter Notebook interactive application. The hardware environment was set as: CPU: Intel Core i7-8700K, 3.70GHz; memory: 32G; GPU: GTX 1080Ti. Performance evaluation of the ALSTM-LSTM model proposed in the study was carried out, and the results are shown in Fig. 7.

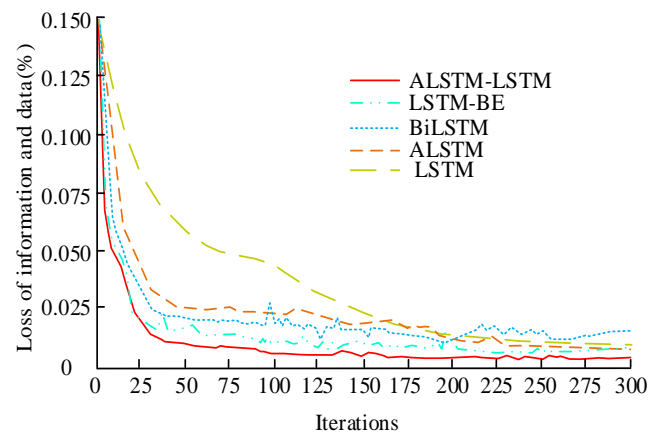


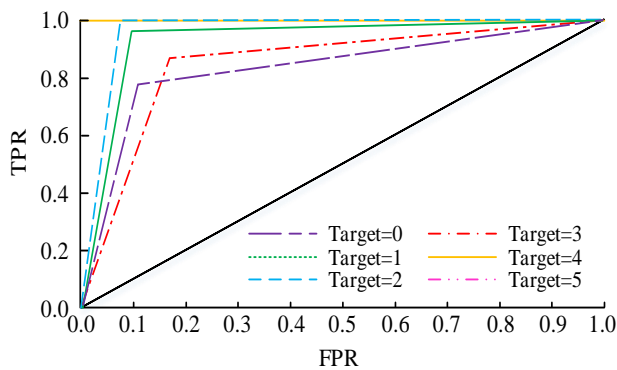
Fig. 7. Error comparison results of different algorithm functions for moving image analysis.

What can be seen from Fig. 7 is that there are large differences in the error results of different algorithmic models under different numbers of iterations. Specifically, when it is less than 25, the data loss curves of the five algorithm models are slanted larger, and the error values between different models do not exceed 0.2%. When the number of iterations increases, the increase of data information will cause different degrees of redundancy to the algorithm performance. The average error in information for the LSTM model is 4.23% between 25 and 200 iterations, and only gradually plateaus when the number of iterations exceeds 200, with the value remaining at 1.37%. Meanwhile, the maximum error in information extraction between the LSTM model and the proposed ALSTM-LSTM model reached 26.35% at more than 25 iterations. The LSTM model with the addition of a residual network (ResNet), the LSTM model with a bi-directional mechanism (Bi-directional) and the LSTM model with a unidirectional attention mechanism all showed varying degrees of improvement in algorithmic loss compared to the single LSTM model. The loss curves also leveled off in the later stages of the algorithm, with the average errors of 15.24%, 10.28% and 9.36%, respectively, but the fluctuations of the nodes were more obvious. The above results indicate that the proposed model can enhance the information extraction accuracy capability. Subsequently, the model performance was further explored, and for the convenience of data statistics, the study referred to the five algorithmic models as Models 1-5, where the model proposed in the study was Model 1. Two other models are added, namely the Multi-label k-Nearest Neighbor algorithm (Model 6) and the Channel-Split Human Pose Estimation algorithm (Channel-SplitResidual StepsNetwork (Channel-SplitRSN) (Model 7). The result is Fig. 8.

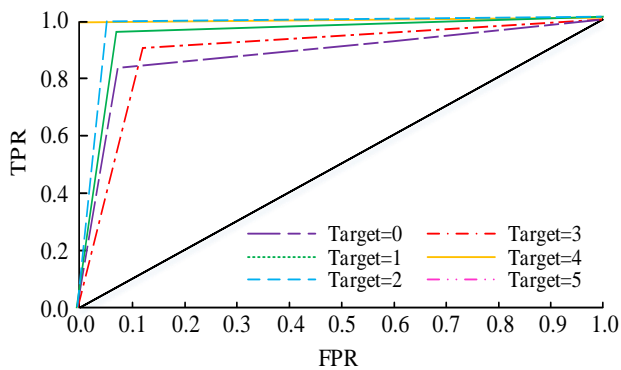
What can be seen in Fig. 8 is that the performance expressed by the different algorithmic models varies considerably. In terms of accuracy values, the models with values above 90 are models 1-4, while models 5-7 have accuracy values in the range 60-75. The average accuracy of models 1-7 is 95.83, 94.73, 93.23, 92.13, 63.43, 75.53 and 74.43 respectively, which reflects the stable performance of the algorithm in information extraction. The average accuracy of several models improved compared with LSTM in the

figure is basically above 40%, among which the average accuracy of the model proposed in the study reaches 62.57%, and its accuracy error is 22.3% higher than the traditional LSTM model, and 19.32% and 17.31% higher than the ML-KNN model and RSN model. The results in Fig. 8(b) show that the models performing in order from best to worst in terms of recall metrics are ALSTM-LSTM model > LSTM-BN model > ALSTM-BN model > LSTM model > BiLSTM model > RSN model > ML-KNN model. The recall rate of the proposed model was 94.21%, corresponding to an F1 value of 94.1, and the maximum difference between this model and the other models in terms of recall index was 17.9. The above results show that the ALSTM-LSTM model can better take into account the correlation between sequence information, achieve the extraction of feature information data, and effectively avoid the problem of missing and omitted data. To further evaluate the performance of the ALSTM-LSTM model, the study was designed to compare it with the LSTM model at different values, the results of which are shown in Fig. 9.

In Fig. 9, the two models exhibit different ROC curve characteristics under different target fetch values. In Fig. 9(a), the single LSTM model is more influenced by the fetching values and the AUC areas under each label are 0.781, 0.829, 0.891, 0.765, 0.831 and 0.944 respectively. In Fig. 9(b), the improved LSTM model has a higher accuracy rate in image information prediction selection and is less disturbed by the fetching values, and its average accuracy reached 86.37%. The above data tells that the model created in the study has good application performance. The results of limb movement localization in jumping rope movements were then analyzed and the results are shown in Table I.



(a) Curves for single-layer LSTM models



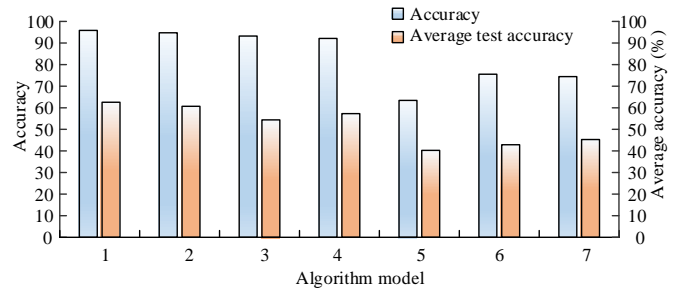
(b) Curves of the ALSTM-LSTM model

Fig. 9. ROC and AUC curves of LSTM model and ALSTM-LSTM model.

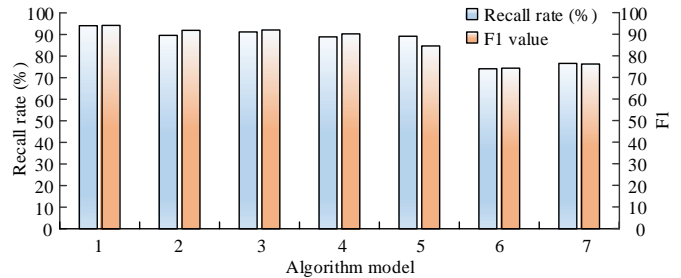
TABLE I. LIMB POSITIONING RESULTS OF ROPE SKIPPING UNDER DIFFERENT ALGORITHM MODELS

Model	Head	Shoulder	Elbow	Wrist	Hip	Knee	Ankle
ALSTM-LSTM	95.2	87.3	75.8	72.5	78.6	70.1	64.8
ALSTM-BE	90.4	82.5	71	67.7	73.8	65.3	60.4
LSTM-BE	78.3	70.4	58.9	55.6	61.7	53.2	47.9
BiLSTM	78.9	71.0	59.5	56.2	62.3	53.8	48.5
LSTM	81.8	73.9	62.4	59.1	65.2	56.7	51.4
ML-KNN	76.1	68.2	56.7	53.4	59.5	51.2	45.7
RSN	71.7	63.8	52.3	49	55.1	46.6	41.3

The results in Table I show that the ALSTM-LSTM model has a high localization accuracy for feature extraction of different limb parts with a maximum value of 95.2 and it performs best in the comparison results with other models with a high improvement in the loss of data. The maximum localization accuracy values of the other six models were 90.4, 78.3, 78.9, 81.8, 76.1 and 71.7 respectively, all of which were smaller than the proposed mode in the study. It was then analyzed and the results are shown in Fig. 10.



(a) Accuracy and average accuracy of different algorithmic models



(b) Recall and F1 values for different algorithmic models

Fig. 8. Performance comparison of different algorithm models.

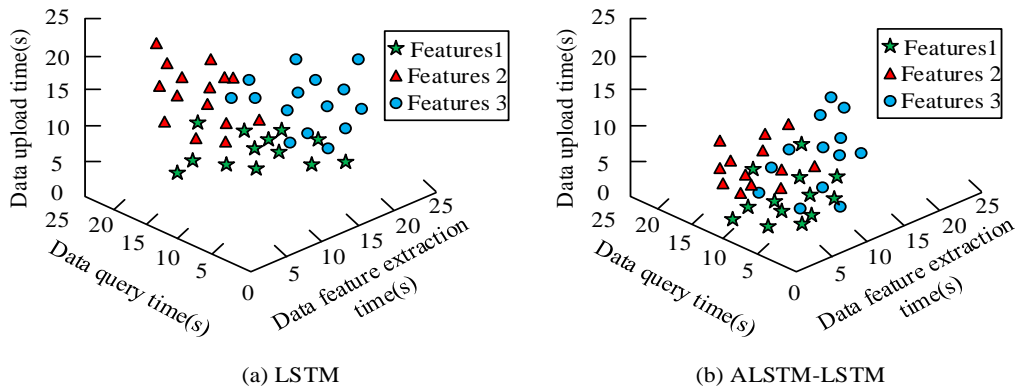


Fig. 10. System test results of two models.

In Fig. 10, the system processing performance of the LSTM model for all three pose features is poor, with the average time consumed for data upload, data query and feature extraction all greater than 15s. The system processing performance of the ALSTM-LSTM model proposed in the study is better and more balanced, with an average time consumption of 11.23s. The human posture recognition algorithm is applied to the classroom evaluation of a certain jumping rope teaching, and it evaluates students' physical performance in the final stage. Firstly, perform a result analysis on its matching accuracy, as shown in Fig. 11.

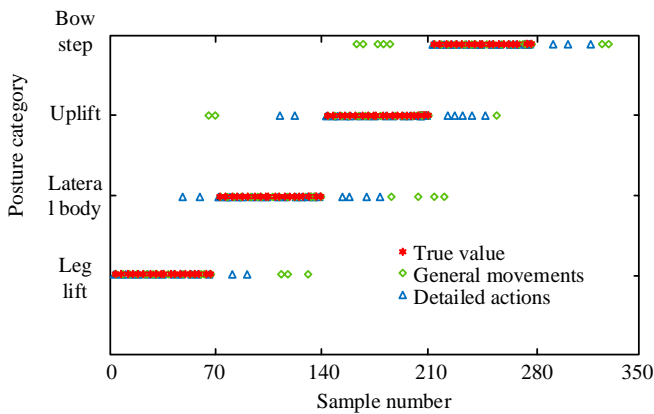


Fig. 11. Evaluation accuracy of human pose recognition algorithm.

The results in Fig. 11 indicate that the pose recognition model proposed in the study achieved motion recognition accuracy of 94.7% and 93.5% for the general and detailed movements of jumping rope on two types of data, respectively. Among them, the matching accuracy of the lunge movement was the highest (98.77%), and its posture matching error situation was effectively improved. The results indicate that the recognition algorithm has good application effect in physical education teaching evaluation. The satisfaction of students is collected during the evaluation process, and the results are shown in Fig. 12.

In Fig. 12, the satisfaction score obtained by the action recognition algorithm used in the study in student sports evaluation reached over 90 points. Compared to other algorithms, students are more satisfied with the proposed one. The results indicate that the recognition algorithm can

effectively assist in the jumping rope sport teaching and help students improve their academic performance. In future sports teaching, teachers can use this motion analysis system to help students master the standard movements of jumping rope. Appropriate teaching strategy adjustments can be made based on the feedback from students, in order to continuously improve teaching effectiveness and quality.

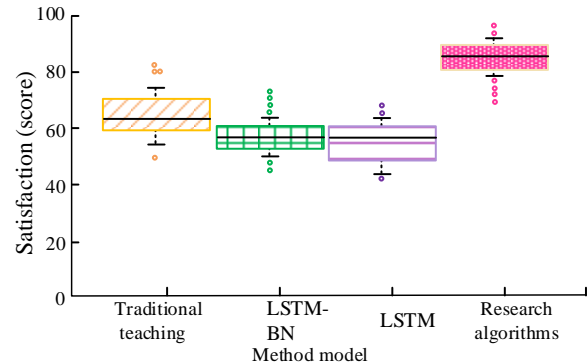


Fig. 12. Student satisfaction in the evaluation process of physical education teaching.

V. CONCLUSION

The study analyses the pose in jumping rope movement scenarios and introduces an attention mechanism to improve the neural network, converting the video analysis problem into a limb key point coordinate analysis problem. The results of the proposed model system were analyzed and it was found that the average error of the LSTM model information extraction between 25 and 200 iterations was 4.23%, which gradually leveled off at more than 200 iterations and remained at 1.37%. It was much larger than the maximum error of information extraction of the proposed ALSTM-LSTM model at more than 25 iterations, which was 26.35%. The maximum error in information extraction with the proposed ALSTM-LSTM model at more than 25 iterations was 26.35%, larger than that of the LSTM-RE, BiLSTM and ALSTM models at 15.24%, 10.28% and 9.36%. For information extraction accuracy, the accuracy value of the ALSTM-LSTM proposed in the study reached 95.83, and its average accuracy was 62.57%, which was 22.3%, 19.32% and 17.31% higher compared with the LSTM model, ML-KNN model and RSN model. The ALSTM-LSTM model also has a larger AUC area

than the single LSTM model, with a maximum value of 95.2 for the localization of the subdivision of the jumping rope pose movements. The jumping rope motion system constructed with the ALSTM-LSTM model shows better performance. Further research is needed to enhance the motion scene analysis ability and to widen the dimension of pose estimation.

REFERENCES

- [1] Eler N, Acar H. The Effects of the Rope Jump Training Program in Physical Education Lessons on Strength, Speed and VO 2 Max in Children. *Universal Journal of Educational Research*, 2018, 6(2): 340-345.
- [2] Munz M, Engleder T. Intelligent assistant system for the automatic assessment of fall processes in sports climbing for injury prevention based on inertial sensor data. *Current Directions in Biomedical Engineering*, 2019, 5(1): 183-186.
- [3] Bunker R P, Thabtah F. A machine learning framework for sport result prediction. *Applied computing and informatics*, 2019, 15(1): 27-33.
- [4] Pratama N E, Mintarto E, Kusnanik N W. The influence of ladder drills and jump rope exercise towards speed, agility, and power of limb muscle. *Journal of Sports and Physical Education*, 2018, 5(1): 22-29.
- [5] Lutsenko L, Bodrenkova I, Lutsenko Y. Relationship Between Special Physical Preparedness Indicators of Athletes Andstructural Components of Thecompetition Program in Acrobatic Rock and Roll. *Slobozhanskyi herald of science and sport*, 2021, 9(2): 49-61.
- [6] Xu W, Zhou Y. Prediction Method of Rope Skipping Energy Consumption Based on Smart Phone Sensor[C]//*Journal of Physics: Conference Series*. IOP Publishing, 2021, 2037(1): 012125.
- [7] Wang D. Simulation research on safety detection of pattern rope jumping motion based on large data background. *Connection Science*, 2021, 33(4): 1047-1059.
- [8] Nie X, Feng J, Xing J, Xiao S, Yan A. Hierarchical contextual refinement networks for human pose estimation. *IEEE Transactions on Image Processing*, 2018, 28(2): 924-936.
- [9] Cao L, Zhan C. Exploration of new community fitness mode using intelligent life technology and AIoT. *International Journal of Grid and Utility Computing*, 2022, 13(1): 57-65.
- [10] Yu Y. Research on athlete skipping surface electromyography and energy consumption based on principal component analysis of wavelet packet. *Journal of Intelligent & Fuzzy Systems*, 2021, 40(2): 2217-2227.
- [11] Cust E E, Sweeting A J, Ball K, Robertaon S. Machine and deep learning for sport-specific movement recognition: a systematic review of model development and performance. *Journal of sports sciences*, 2019, 37(5): 568-600.
- [12] Ramirez-Campillo R, Andrade D C, Nikolaidis P T, et al. Effects of plyometric jump training on vertical jump height of volleyball players: a systematic review with meta-analysis of randomized-controlled trial. *Journal of sports science & medicine*, 2020, 19(3): 489.
- [13] Ramirez-Campillo R, Gentil P, Negra Y, et al. Effects of plyometric jump training on repeated sprint ability in athletes: a systematic review and meta-analysis. *Sports Medicine*, 2021, 51(10): 2165-2179.
- [14] Layne T, Simonton K, Irwin C. Effects of a sport education instructional model and heart rate monitor system on the physical activity and jump rope performance of fourth grade students. *Journal of Physical Education and Sport*, 2022, 22(4): 889-899.
- [15] Noroozi F, Corneanu C A, Kamińska D. Survey on emotional body gesture recognition. *IEEE transactions on affective computing*, 2018, 12(2): 505-523.
- [16] Bunker R P, Thabtah F. A machine learning framework for sport result prediction. *Applied computing and informatics*, 2019, 15(1): 27-33.
- [17] Rana M, Mittal V. Wearable sensors for real-time kinematics analysis in sports: a review. *IEEE Sensors Journal*, 2020, 21(2): 1187-1207.
- [18] Kong L, Huang D, Qin J, Wang Y H. A joint framework for athlete tracking and action recognition in sports videos. *IEEE transactions on circuits and systems for video technology*, 2019, 30(2): 532-548.
- [19] Mathis A, Mamidanna P, Cury K M, Abe T, Murthy V N, Mathis M W, Bethge M. DeepLabCut: markerless pose estimation of user-defined body parts with deep learning. *Nature neuroscience*, 2018, 21(9): 1281-1289.
- [20] Kong D, Wu F. HST-LSTM: A hierarchical spatial-temporal long-short term memory network for location prediction[C]//*IJCAI*. 2018, 18(7): 2341-2347.
- [21] Nadeem A, Jalal A, Kim K. Automatic human posture estimation for sport activity recognition with robust body parts detection and entropy markov model. *Multimedia Tools and Applications*, 2021, 80: 21465-21498.
- [22] He D, Li L, An L. Notice of violation of ieeepublication principles: study on sports volleyball tracking technology based on image processing and 3D space matching. *IEEE Access*, 2020, 8: 94258-94267.
- [23] Jalal A, Akhtar I, Kim K. Human posture estimation and sustainable events classification via pseudo-2D stick model and K-ary tree hashing. *Sustainability*, 2020, 12(23): 9814-9815.
- [24] Hou X, Liu C. Rope Jumping Strength Monitoring on Smart Devices via Passive Acoustic Sensing. *Sensors*, 2022, 22(24): 9739-9739.
- [25] Chung J L, Ong L Y, Leow M C. Comparative Analysis of Skeleton-Based Human Pose Estimation. *Future Internet*, 2022, 14(12): 380-381.
- [26] Wang D. Simulation research on safety detection of pattern rope jumping motion based on large data background. *Connection Science*, 2021, 33(4): 1047-1059.
- [27] Singh U, Ramachandran A K, Ramirez-Campillo R, et al. Jump rope training effects on health-and sport-related physical fitness in young participants: A systematic review with meta-analysis. *Journal of Sports Sciences*, 2022, 40(16): 1801-1814.
- [28] Chen C F, Wu H J. The Effect of an 8-Week Rope Skipping Intervention on Standing Long Jump Performance. *International Journal of Environmental Research and Public Health*, 2022, 19(14): 8472.
- [29] Eler N, Acar H. The Effects of the Rope Jump Training Program in Physical Education Lessons on Strength, Speed and VO 2 Max in Children. *Universal Journal of Educational Research*, 2018, 6(2): 340-345.
- [30] Wang D. Simulation research on safety detection of pattern rope jumping motion based on large data background. *Connection Science*, 2021, 33(4): 1047-1059.
- [31] Ramirez-Campillo R, Andrade D C, García-Pinillos F, et al. Effects of jump training on physical fitness and athletic performance in endurance runners: A meta-analysis: Jump training in endurance runners. *Journal of sports sciences*, 2021, 39(18): 2030-2050.
- [32] Yu H B, Li J, Zhang R, et al. Effects of jump-rope-specific footwear selection on lower extremity biomechanics[J]. *Bioengineering*, 2022, 9(4): 135.
- [33] Munz M, Engleder T. Intelligent assistant system for the automatic assessment of fall processes in sports climbing for injury prevention based on inertial sensor data. *Current Directions in Biomedical Engineering*, 2019, 5(1): 183-186.
- [34] Wang D. Simulation research on safety detection of pattern rope jumping motion based on large data background. *Connection Science*, 2021, 33(4): 1047-1059.

A Novel Label Propagation Method for Community Detection Based on Game Theory

Mengqin Ning¹, Jun Gong^{2*}, Zhipeng Zhou³

Philosophy School, Beijing Normal University, Beijing, China¹
Software School, Jiangxi Normal University, Nanchang, China^{2,3}

Abstract—Community is a mesoscopic feature of the multi-scale phenomenon of complex networks, which is the bridge to revealing the formation and evolution of complex networks. Due to high computational efficiency, label propagation becomes a topic of considerable interest within community detection, but its randomness yet produces serious fluctuations. Facing the inherent flaws of label propagation, this paper proposes a series of solutions. Firstly, this paper presents a heuristic label propagation algorithm named Label Propagation Algorithm use Cliques and Weight (LPA-CW). In this algorithm, labels are expanded from seeds and propagated based on node linkage index. Seeds are produced from complete subgraph, and node linkage index is related to neighboring nodes. This method can produce competitive modularity Q but not Normalized Mutual Information (NMI), and compensate with existing methods, such as Stepping Community Detection Algorithm based on Label Propagation and Similarity (LPA-S). Secondly, in order to combine the advantages of different algorithms, this paper introduces a game theory framework, design the profit function of the participant algorithms to attain Nash equilibrium, and build an algorithm integration model for community detection (IA-GT). Thirdly, based on the above model, this presents an algorithm, named Label Propagation Algorithm based on IA-GT model (LPA-CW-S), which integrates LPA-CW and LPA-S and solves the incompatibility between modularity and NMI. Fully tested on both computer-generated and real-world networks, this method gives better results in indicators such as modularity and NMI than existing methods, effectively resolving the contradiction between the theoretical community and the real community. Moreover, this method significantly reduces the randomness and runs faster.

Keywords—Community detection; label propagation; node linkage; complete subgraph; game theory

I. INTRODUCTION

Human beings are surrounded by systems that are unprecedentedly complicated. Behind each complex system, there is an intricate network that encodes the interactions among these system components. Among those networks, the most influential ones are social networks, communication networks, world wide web and cognitive neural networks etc. [1], which are characterized by small-world [2], scale-free [3], community structure [4]. Since Newman [4] put forward the problem of complex network community structure in 2002, domestic and foreign scholars have devoted themselves to studying the community nature of networks and proposed a large number of community discovery algorithms, which can be broadly divided into bottom-up community discovery and top-down community discovery [5]. The bottom-up method

can efficiently expand the community gradually from nodes based on heuristic rules, which can be divided into three categories: modularity optimization class, local extension class and label propagation class. With the outstanding algorithm efficiency, the label propagation community discovery method has been widely concerned. However, the randomness of the existing methods cannot guarantee the stable and reliable results of community division, and each algorithm has its own advantages and disadvantages, so it cannot adapt to all scenarios alone.

Inspired by relevant theories in sociology, mathematics, biology and other fields, the idea of this paper is originated from three points. Fig. 1 is a vivid description of them.

- Inspiration 1: Social identity theory in sociology [6] and acquaintance model. In social relationship, the number of friends, the degree of intimacy and the co-neighbor relationship greatly affect the social relationship. Based on relational model in sociology, a node link relationship model is proposed in this paper, which provides a theoretical basis for label selection strategy.
- Inspiration 2: Classical game theory in mathematics and evolutionary game theory in biology [7]. There exist conflict, competition and cooperation among nodes in complex network, and their microscopic dynamic evolution mechanism can be described by game model.
- Inspiration 3: The contradiction exists between the theoretical community division and the real-world division. Community detection algorithms are mainly based on graph theory and quality function, and the results of community detection are usually refined, but small and large communities are not effective for communication. Therefore, community scale in the real world tend to be greater.

These ideas improve the initialization, propagation, and convergence processes in the new algorithm. Meantime, this paper introduces game theory to explain the cooperation and competition among nodes in complex networks, and propose an algorithmic integration model for community detection, and then a novel algorithm is proposed based on this model. Fig. 2 shows the theoretical framework and technical route of this paper. The main contributions can be summarized in the following three points:

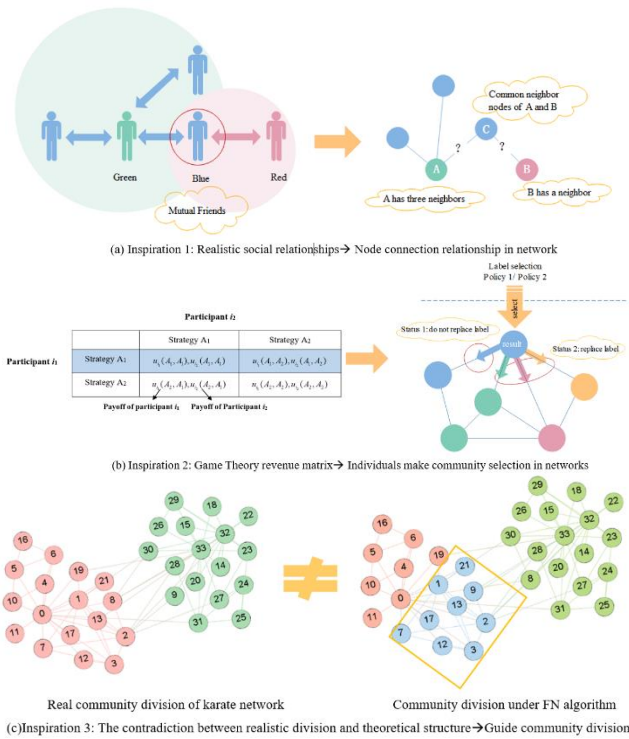


Fig. 1. Source of inspirations for this paper.

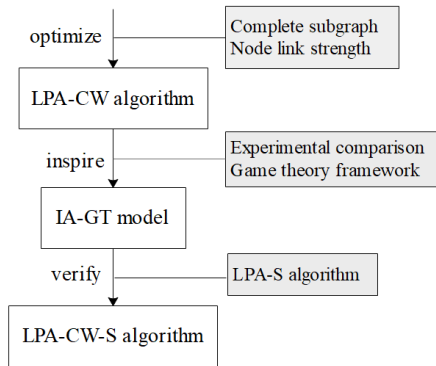


Fig. 2. The theoretical framework of this paper.

- Contribution 1:** This paper proposes a label propagation community detection algorithm (LPA-CW) based complete subgraphs and Node Link Strength. In the initialization phase, non-overlapping complete subgraphs are introduced as the seed community, and Node Link Strength based mechanism is introduced in the propagation phase, which improves the stability and accuracy of the community division, suitable for large-scale networks.
- Contribution 2:** This paper proposes an integrated model of community detection algorithms, IA-GT model, based on game theory. The model sets the payoff function of the participant algorithm, derives and verifies the Nash equilibrium under the mixed strategy, which can theoretically realize the complementary advantages of different algorithms and hence has strong scalability.

- Contribution 3:** Based on this new IA-GT model, LPA-CW algorithm and LPA-S algorithm are selected as the combination objects, and then LPA-CW-S algorithm is proposed. Experiments have proved that the game mechanism effectively takes into account the contradiction between the theoretical community structure and the real community division, and performs well in metrics such as modularity and NMI, which improves the efficiency and decreases the randomness and volatility.

The remainder of this paper is organized as follows. Section II introduces the research status of label propagation algorithm and the research status of introducing game theory framework to solve the problem of community discovery. Section III and IV respectively describe the LPA-CW algorithm, IA-GT game theory model and LPA-CW-S integrated algorithm. Section V is the experimental setting and result analysis, and Section VI gives conclusions.

II. RELATED WORK

This section introduces the research status of community detection algorithm based on label propagation and game theory, and then proposes the existing limitations and research direction.

A. Label Propagation Algorithm

In 2002, Zhu et al. first proposed the label propagation algorithm (LPA), which predicts the label information of unlabeled nodes with the labeled nodes. In 2007, Raghavan et al. [8] applied LPA to community detection for the first time. LPA can detect community structure in a near-linear time, which is greatly attractive. In 2009, Barber et al. [9] redefined LPA as an equivalent optimization problem, expanding the scope of application, and proposed the LPAm by modifying the objective function, which is applicable to both two-part network and single-part network. In 2017, Li et al. [10] proposed Stepping-LPA-S (short for LPA-S) aiming at reducing side effects of community merging by introducing a new quality function.

This search for LPA optimization has attracted much interest in recent years due to the side effects of propagation instability. Liu et al. [11] introduced node influence, network propagation update and node attribute characteristics in LPA. SUN et al. [12] transformed node partition problem into link partition problem in LPA. Kouni et al. [13] introduced node aggregation coefficient in LPA to evaluate node importance. ZHANG et al. [14], from the perspective of human society and radar transmission, defined four node capabilities (propagation, attraction, emission and reception), label influence and a novel label propagation mechanism to cope with instability and efficiency. In the field of community detection, LPA optimization is still a research hotspot, but it is trapped in homogeneity without breakthrough.

- Limitation 1:** Most algorithms emphasize on network structure, ignoring node importance during network formation.
- Limitation 2:** The improvement mainly focuses on the label selection stage, ignoring the overall

consideration for other stages, such as initialization and convergence.

Inspired by clique percolation and sociological relationship theory, this paper optimizes most stages including initialization, propagation and convergence, and proposes a novel algorithm.

B. Game Theory

Since the publication of Von Neumann's article "Theory of Parlor Games" [15], game theory has been widely applied to psychology, economics, sociology, politics and many other fields. However, game theory rarely appears in the field of community detection. Chen et al. [16] first introduced game theory framework to solve the problem of community detection, which reflects the formation of real-world communities and detects communities by the gain and loss function. Ioana et al. [17] proposed a dynamic community detection method based on game theory elements and extremum optimization, but its experimental results had unobvious advantage compared with existing algorithms, and there were few related studies since then.

Since 2019, there has been a series of new improvements. For example, Hesamipour et al. [18] used the Adamic/Adar (AA) index to detect the local host node and extended its surrounding community based on the game theory. ZHOU et al. [19] proposed an edge weight calculation method for computing node and alliance Shapley values in combination with game theory for community detection. Kumar et al. [20] used a game theory method (Dynamic Clustering game, DCFG) to analyze the clustering problem of attribute graphs, and provided a solution for balancing topology structure and node attributes. Obviously, there are some new entry points to combine game theory with community detection, but there are still some limitations.

- **Limitation 1:** Most game theory based community detection algorithms can't get satisfactory results in benchmark experiments, and improvement bottlenecks still exist compared with classical algorithms.
- **Limitation 2:** The game selection didn't effectively solve the contradiction between the theoretical optimization of community division and the real world needs, and didn't take full advantage of game theory.

Considering the above problems, this paper views some community detection algorithms as participants, and proposes an extensible model.

III. A COMMUNITY DETECTION ALGORITHM FOR LABEL PROPAGATION BASED ON COMPLETE SUBGRAPHS AND NODE LINK STRENGTH

A. Problem Formulation

Given $G = (V, E)$ represents a complex network, where $V = \{v(i) | i = 1, 2, \dots, n\}$ represents the set of nodes in the network, and $E = \{e(i) | i = 1, 2, \dots, m\}$ represents the set of edges. Communities are subsets of nodes highly linked among themselves but loosely connected to the rest of the network. Communities are believed to play a central role in the

functional properties of complex structures. They are represented by $C = \{C_1, C_2, \dots, C_K\} (1 \leq K \leq |V|)$ and K is the number of network communities.

- **Definition 1:** Direct link strength. It denotes the direct contribution to the link strength of edge $e_{v(1),v(2)}$ of nodes $v(1)$ and $v(2)$ concerning their neighbor nodes, which is marked as $DL_{v(1),v(2)}$ and the equation is as follows:

$$DL_{v(1),v(2)} = \frac{1}{d_{v(1)} + d_{v(2)}} \quad (1)$$

In which $d_{v(1)}$ and $d_{v(2)}$ respectively represent the number of neighbor nodes of nodes $v(1)$ and $v(2)$, namely the degree. The larger the node degree is, the more important the node is, but the smaller contribution to the link intensity value.

- **Definition 2:** Indirect link strength. It denotes the indirect contribution degree of the link strength of edge $e_{v(1),v(2)}$ between nodes $v(1)$ and $v(2)$ according to the common neighbor nodes, which is marked as $IL_{v(1),v(2)}$ and the equation is as follows:

$$IL_{v(1),v(2)} = \frac{(|N(v(1)) \cap N(v(2))| + 1)}{d_{v(1)} + d_{v(2)}} \quad (2)$$

In which $N(v(1))$ and $N(v(2))$ denote neighbor node sets of nodes $v(1)$ and $v(2)$, respectively, $N(v(1)) \cap N(v(2))$ represents common neighbor node sets of nodes $v(1)$ and $v(2)$. The more common neighbors between nodes are, the stronger their connectivity is.

- **Definition 3:** Node link strength. It denotes the joint contribution of nodes $v(1)$ and $v(2)$ to the link strength of edges $e_{v(1),v(2)}$ via direct link and indirect link strength, which is marked as $LS_{v(1),v(2)}$ and the equation is as follows:

$$LS_{v(1),v(2)} = \begin{cases} DL_{v(1),v(2)} & \text{if } d_{v(1)} = 1 \text{ or } d_{v(2)} = 1 \\ DL_{v(1),v(2)} + 2 * IL_{v(1),v(2)} & \text{if } d_{v(1)} > 1 \text{ and } d_{v(2)} > 1 \end{cases} \quad (3)$$

According to neighbor nodes between node $v(1)$ and $v(2)$, if exists, the direct link and indirect link strength are calculated, and if not, only the direct link strength is calculated.

B. Description of LPA-CW Algorithm

1) *Label initialization based on non-overlapping complete subgraph:* In the traditional LPA, a unique label is assigned to each node during initialization, which causes the scattered labels. In the subsequent propagation process, it is hard to converge and easy to lead to fluctuation. The node-link relationship tells us that the community structure is highly

similar to complete subgraph. Therefore, identifying the non-overlapping complete subgraph first can improve label propagation.

The label initialization process is as follows, sorting all the unassigned nodes in descending order of degree, then looking for a complete subgraph starting from the node with greatest degree, and then process continuously cycles until each node have been assigned to some subgraph, finally assigning the same label to nodes in the same complete subgraph. Approximation strategy ensures algorithm efficiency, making subsequent label propagation process converge faster. The pseudocode of this procedure is as follows:

Algorithm 1 Find Nonoverlapping Complete Subgraph

```

Data: Graph
Output: nonoverlapping cliques
1: node ← nodes of G sorted by degree in descending order
2: done ← [0 for each i in node] #0:unassigned, 1:assigned to some clique
3: c ← [[] for each i in node]
4: t ← 0 #record the number of cliques
5: while node is not empty do
6:   n ← node[0] #node with the largest degree among unassigned nodes
7:   done[n] ← 1
8:   node.remove(n)
9:   c[t].append(n)
10:  for each j in neighbors of n sorted by degree in descending order do
11:    if done[j] = 0 and j have edge(i,j) for each i in c[t] then
12:      done[j] ← 1
13:      node.remove(j)
14:      c[t].append(j)

```

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15: end if
16: end for
17: t++
18: end while
19: c ← c[:t]
20: return c

```

2) *Label update strategy based on node link strength:*
When a node has multiple neighbor labels with the same highest frequency, one of these labels will be randomly selected as its own label, which is the traditional problem of LPA. This randomness greatly reduces accuracy and stability of community division.

To minimize randomness, this paper uses the node link strength to set a new label update strategy. Label update rules are defined as follows: (1) calculate the link strength $LS_{v(i),v(j)}$ between any two nodes in the network, according to the random access order, for the current nodes $v(i)$, find out all the node sets R_{label_n} with the same label in its neighbor $r(j)$ (according to Equation 4). Then calculate the link strength cumulative sum between node $v(i)$ and each node set R_{label_n} (according to Equation 5). Find the label $label_n$ corresponding to the accumulated and largest node set, and the node $v(i)$ label is updated to $label_n$.

$$R_{label_n} = \{r(1), r(2), \dots, r(|R_{label_n}|)\}$$

$$R = \{R_{label1}, R_{label2}, \dots, R_{label_n}\} \quad (4)$$

$$L = \left\{ \sum_{j=1}^{|R_{label1}|} LS_{v(i),r(j) \in R_{label1}}, \sum_{j=1}^{|R_{label2}|} LS_{v(i),r(j) \in R_{label2}}, \dots, \sum_{j=1}^{|R_{label_n}|} LS_{v(i),r(j) \in R_{label_n}} \right\} \quad (5)$$

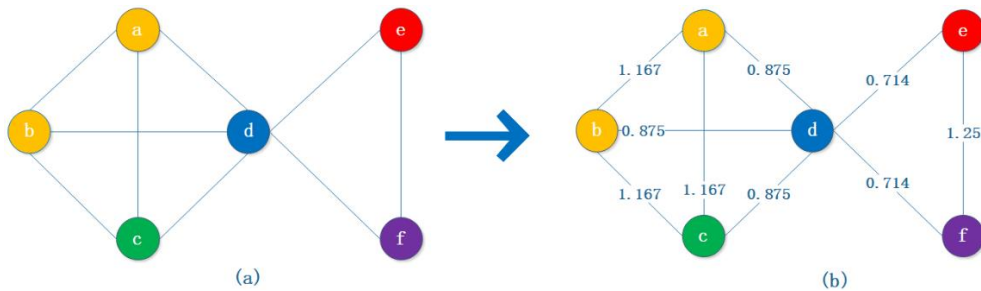


Fig. 3. A simple example for node link strength.

As shown in Fig. 3, calculate node link strength of $v(a)$ - $v(b)$ and $v(a)$ - $v(d)$ according to Equation 3. The calculation steps for the above two are as follows:
 $LS_{v(a),v(b)} = 1 / (3+3) + 2 * (2+1) / (3+3) = 1.167$
 $LS_{v(a),v(d)} = 1 / (3+5) + 2 * (2+1) / (3+5) = 0.875$. Here node

color denotes node label, set current node = $v(d)$, and its neighbor node set with identical labels is $R = \{\{r(a), r(b)\}, \{r(c)\}, \{r(e)\}, \{r(f)\}\}$. Then accumulate node link strength with the same labels and the result is calculated as $L = \{1.75, 0.875, 0.714, 0.714\}$, so the

maximal value 1.75 is selected and node $v^{(d)}$ is updated for the yellow label.

3) *Algorithm procedure:* The algorithm procedure of LPA-CW is shown in Fig. 4, and its pseudo-code is described in Algorithm 1.

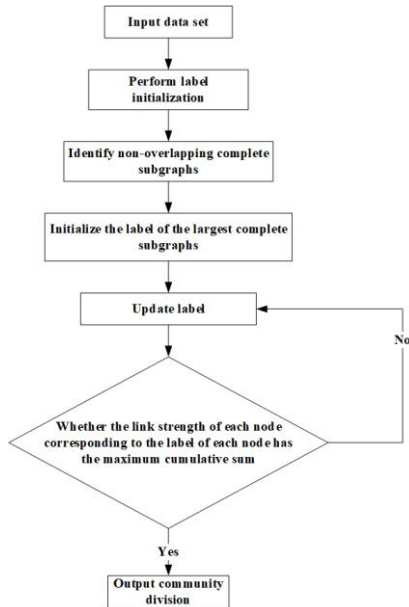


Fig. 4. Flow chart of LPA-CW algorithm.

Algorithm 1 Pseudocode of Label Propagation Algorithm use Cliques and Weight

Input: Graph
Output: partition
1: $addWeight(G)$
2: $labeling \leftarrow v : k \text{ for } k, v \text{ in } enumerate(G)$
3: $cliques \leftarrow getCliques(G)$
4: $maxc \leftarrow maxLength(cliques)$
5: **for** i **in** $cliques$ **do**
6: **if** $length(cliques[i]) == maxc$ **then**
7: $maxLabel = max(i)$
8: **for** j **in** i **do**
9: $labeling[j] \leftarrow maxLabel$
10: **end for**
11: **end if**
12: **end for**
13: **while** **not** $labelCompleteEdgeWeight(labeling, G)$ **do**
14: **for** n **in** $G.nodes()$ **do**
15: $updateLabelEdgeWeight(n, labeling, G)$
16: **end for**
17: **end while**
18: $partition \leftarrow getResult(labeling)$
19: **return** $partition$

4) *Algorithm analysis:* Assuming that the network has n nodes and m edges, the average degree of nodes is denoted by k , and the number of non-overlapping complete subgraphs searched in IIIA is denoted by λ .

The running time is mainly consumed during two stages. The first stage is the initialization phase, and it takes $O(kn \log n)$ to identify non-overlapping complete subgraphs, then label assignment to the subgraph is $O(\lambda)$, and calculating node link strength is $O(n+2m)$. The second stage is the label propagation process, and it takes $O(n+2m)$ to access neighbor nodes, and takes $O(r \cdot (n+2m))$ to loop iteration r times. The value of r is related to data sets, when the scale of the data set increases or the average degree increases, r will also increase. Generally, r is in [3,6].

In summary, the time complexity of the new algorithm is $O(r \cdot (n+2m))$. In the subsequent experiment section, it can be proved that this algorithm is prone to faster convergence.

IV. COMMUNITY DETECTION ALGORITHM INTEGRATION MODEL BASED ON GAME THEORY

A. Problem Formulation and Basic Definitions

According to the analysis of experimental data in Section VB of this paper, LPA-CW algorithm has obvious advantages in modularity Q, which shows that community partition is of high quality and refinement; the comparison algorithm LPA-S [10] has complementary advantages in standard mutual information NMI, and has high accuracy in comparison with real community partition. Therefore, this paper introduces the game model to explain the individual choice and overall stability maintenance in the process of community formation. Firstly, in this paper, the combination of label propagation algorithms, namely LPA-CW algorithm and LPA-S algorithm, is selected.

The strategic game G is represented by the set $G = \{N, \{A_i\}_{i=1}^N, \{u_i\}_{i=1}^N\}$, where $N = \{1, \dots, N\}$ is the set of participants, $A_i = \{A_1, A_2, \dots, A_n\}$ is the set of strategies available to the participant i , and u_i is the payoff of the participant i . When constructing the model, this paper uses the payoff matrix and mixed strategy in game theory.

B. IA-GT Community Detection Model Construction and Verification

The IA-GT (Integration Algorithm-Game Theory) community detection model is divided into three stages. Fig. 5 shows the frame diagram of the model construction. This model is an extensible model that can be flexibly replaced and combined. In the first step, the selection of participants must be based on the principle of the algorithm itself and the game theory, which has theoretical integration and practical significance. The second step is to define the payoff function of the participant according to the selected strategy and the core parameters of the algorithm. In the third step, the Nash equilibrium solution result needs to be verified by algorithm experiment.

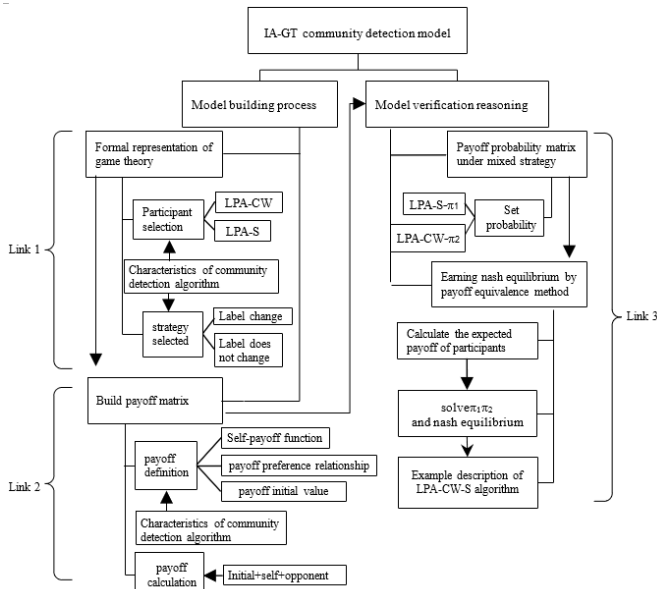


Fig. 5. IA-GT community detection model.

1) *Integrated model building process*: According to the game theory, this paper uses the payoff matrix to construct the model, with LPA-CW algorithm and LPA-S algorithm as two participants. Combining the core principles of the two algorithms, first initialize the network label, and then update the node label according to the game theory selection algorithm. The community label of each node has two states "changed" or "unchanged". In this model, the strategy of the two participants is to "change (c)" or "don't change (d)" the label of the current processing node. Symbolizing the above game process can be obtained:

$$G = \{ \{ LPA-S, LPA-CW \}, \{ A_{LPA-S}, A_{LPA-CW} \}, \{ u_{LPA-S}, u_{LPA-CW} \} \}$$

Participants: $N = \{ LPA-S, LPA-CW \}$ represents two algorithms;

Strategy: $A_{LPA-S} = A_{LPA-CW} = \{c, d\}$ use c and d to indicate change and don't change.

$$\text{Payoff: } u_{LPA-S}(c, c), u_{LPA-CW}(c, c); u_{LPA-S}(c, d), u_{LPA-CW}(c, d);$$

$$u_{LPA-S}(d, c), u_{LPA-CW}(d, c); u_{LPA-S}(d, d), u_{LPA-CW}(d, d);$$

In game theory, the payoff function needs to be defined according to the problem domain. For example, for the strategy group $A(d, c)$, $u_{LPA-S}(d, c)$ is the payoff of the participant LPA-S under this set of strategies, not only related to its own strategy choice, but also related to the opponent (LPA-CW) strategy choice and initial profit value during the interaction. Combining the label update rules of LPA-S and LPA-CW, define the participant's own benefits and the preference relationship between participants, under the selected strategy.

- **Definition 4**: Participant LPA-S's own benefits under the c strategy: The maximum value of similarity between the current processing node $v(i)$ and its neighbors minus the maximum value of similarity

between node $v(i)$ and the neighbors with the same label as node $v(i)$, the equation denoted as I_{LPA-S} is as follows.

$$I_{LPA-S} = \max\{S_1\} - \max\{S_2\}$$

$$S_1 = \{s_{v(i),r(1)}, s_{v(i),r(2)}, \dots, s_{v(i),r(j)}\}, r(j) \in N(v(i)) \quad (6)$$

$$S_2 = \{s_{v(i),r(1)}, s_{v(i),r(2)}, \dots, s_{v(i),r(h)}\}, r(h) \in R_{labeli}$$

Where $s_{v(i),r(1)}$ is the similarity between the node $v(i)$ and its neighbors [21], $N(v(i))$ is the set of all neighbors of node $v(i)$, R_{labeli} is the set of neighbors with the same label as node $v(i)$, S_1 is the set of similarity between node $v(i)$ and all its neighbors $r(j)$, S_2 is the set of similarity between node $v(i)$ and its neighbor $r(h)$ with the same label as node $v(i)$. The LPA-S algorithm changes the label according to the neighbor with the greatest similarity, and the label doesn't need to be changed if it is the same. The overall value of I_{LPA-S} is between $(-1, 1)$, When $I_{LPA-S} \in (-1, 0]$, it is required to treat it as $I_{LPA-S} = 0$ uniformly, and the label is not changed; when $I_{LPA-S} \in (0, 1)$, the greater the difference, the higher the payoff gained from label changes.

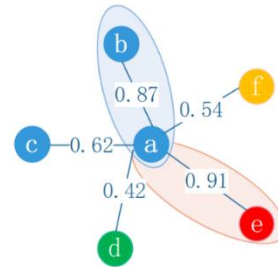


Fig. 6. Example of label selection for LPA-S.

Fig. 6 shows an example, the neighbor with the largest similarity of current processing node $v(a)$ is node $r(e)$. Among neighbors $r(b)$ and $r(c)$ that have the same label as node $v(a)$, the similarity of $r(b)$ is greater. According to the calculation, $S_1 = \{0.87, 0.62, 0.42, 0.91, 0.54\}$, $S_2 = \{0.87, 0.62\}$ and $I_{LPA-S} = 0.91 - 0.87 = 0.04$.

- **Definition 5**: Participant LPA-CW's own benefits under the c strategy: The maximum value in the cumulative sum of Link Strengths between the current processing node $v(i)$ and each neighbor node set $R_{labelin}$ minus the cumulative sum of Link Strengths between the node $v(i)$ and its neighbors with the same label, the equation denoted as I_{LPA-CW} is as follows.

$$I_{LPA-CW} = \max\{L\} - \sum_{h=1}^{|R_{labelin}|} LS_{v(i),r(h) \in R_{labelin}} \quad (7)$$

Where the Node Link Strength $LS_{v(i),r(h)}$, set L , $R_{labelin}$ are defined in detail in section IIIB2). The LPA-CW algorithm

changes the label according to the neighbor set with the largest accumulation of Node Link Strength, and the label doesn't need to be changed if it is the same. By performing standard normalization treatment on I_{LPA-CW} to get I_{LPA-CW}' , When $I_{LPA-CW} \in (-1, 0]$, the label is not changed; when $I_{LPA-CW} \in (0, 1)$, the greater the difference, the higher the payoff gained from label changes.

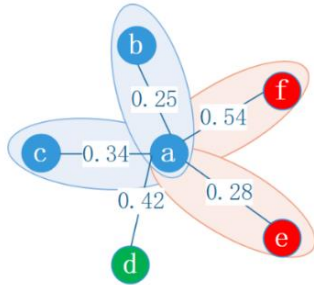


Fig. 7. Example of label selection for LPA-CW.

Fig. 7 shows an example, the current processing node $v(a)$, all node sets with the same label in its neighbors are $R = \{\{r(b), r(c)\}, \{r(d)\}, \{r(e), r(f)\}\}$, the corresponding Node Link Strength accumulation is $L = \{0.59, 0.42, 0.82\}$, $\max\{L\} = 0.82$. Where the neighbors with the same label as node $v(a)$ are $r(b)$ and $r(c)$, the cumulative sum of their Node link strengths is 0.59, according to the calculation, $I_{LPA-CW} = 0.82 - 0.59 = 0.23$.

- **Definition 6:** The preference relationship between payoff of IA-GT community detection model: Under the selected strategy group, the influence of opponent's choice on the payoff of participants [22].

Combined with the idea of label propagation algorithm, the convergence result of community division is that the labels will no longer change, so it is assumed that the initial payoff value of each node is 0. When the participant chooses the "change" strategy, its own payoff is calculated according to definitions 4 and 5. At this time, if the opponent also chooses the "change" strategy, the participants' overall payoff minus 1, but if the opponent chooses the "don't change" strategy, there will be no impact. When participants choose "don't change" strategy, its own payoff is 0, at this time if the opponent choose "change" strategy, the participants' overall payoff minus 1, if the opponent also choose "don't change" strategy, the participants' overall payoff plus 1.

According to definitions 4, 5, and 6, calculate the overall payoff of the participants LPA-S and LPA-CW under the selected strategy group, and construct the payoff matrix of the IA-GT model as shown in Fig. 8.

$$A(c, c) : u_{LPA-S}(c, c) = I_{LPA-S} - 1; u_{LPA-CW}(c, c) = I_{LPA-CW}' - 1$$

$$A(c, d) : u_{LPA-S}(c, d) = I_{LPA-S}; u_{LPA-CW}(c, d) = 0 - 1 = -1$$

$$A(d, c) : u_{LPA-S}(d, c) = 0 - 1 = -1; u_{LPA-CW}(d, c) = I_{LPA-CW}'$$

$$A(d, d) : u_{LPA-S}(d, d) = 0 + 1 = 1; u_{LPA-CW}(d, d) = 0 + 1 = 1$$

		LPA-CW	
		Change(c)	Don't change(d)
LPA-S	Change(c)	$I_{LPA-S} - 1, I_{LPA-CW}' - 1$	$I_{LPA-S}, -1$
	Don't change(d)	$-1, I_{LPA-CW}'$	1, 1

Payoff of LPA-S Payoff of LPA-CW

Fig. 8. Payoff matrix of IA-GT community detection model.

2) Reasoning verification of integrated model: After the payoff matrix is determined, the participants will randomly choose different strategies according to a certain probability distribution, at this time, and then Nash equilibrium under mixed strategies can be solved. Based on the integration needs of the two algorithms, this paper chooses the payoff equivalent method to calculate.

When two participants choose different strategies, for the current processing node $v(i)$, it is assumed that the probability of community label change is π_1 when LPA-S algorithm is applied, and the probability is π_2 when LPA-CW algorithm is applied. Fig. 9 shows the payoff probability matrix of IA-GT community detection model under mixed strategy.

		LPA-CW	
		Change(c), π_2	Don't change(d), $1 - \pi_2$
LPA-S	Change(c), π_1	$I_{LPA-S} - 1, I_{LPA-CW}'$	$I_{LPA-S}, -1$
	Don't change(d), $1 - \pi_1$	$-1, I_{LPA-CW}'$	1, 1

Fig. 9. Payoff probability matrix of IA-GT community detection model under mixed strategy.

According to game theory, the participants's expected payoff is evaluated by the probability of opponents choosing strategies, that is, the expected payoff of LPA-CW algorithm is evaluated by π_1 . For LPA-CW algorithm:

Expected payoff from choosing "change" strategy:
 $Eu_{LPA-CW}(c) = (I_{LPA-CW}' - 1) \times \pi_1 + I_{LPA-CW}' \times (1 - \pi_1);$

Expected payoff from choosing "don't change" strategy:
 $Eu_{LPA-CW}(d) = -1 \times \pi_1 + 1 \times (1 - \pi_1);$

According to the Nash Equilibrium Payoff Equivalence Method:

$$Eu_{LPA-CW}(c) = Eu_{LPA-CW}(d), \pi_1 = 1 - I_{LPA-CW}';$$

The same can be obtained $\pi_2 = 1 - I_{LPA-S}$.

Both π_1 and π_2 are the probability when the label changes, so only the case of $I_{LPA-CW}', I_{LPA-S} \in (0, 1)$ need to be considered, because when the two are less than 0, the label doesn't change.

According to Equation 6 and 7:

$$\pi_1 = 1 - (\max\{L\} - \sum_{h=1}^{|R_{label}|} LS_{v(i),r(h) \in R_{label}}) \quad (8)$$

$$\pi_2 = 1 - (\max\{S_1\} - \max\{S_2\}) \quad (9)$$

$$p = \{\{\pi_1, 1 - \pi_1\}, \{\pi_2, 1 - \pi_2\}\} \quad (10)$$

π_1 and π_2 are related to the payoff of the two participants' algorithms, and they are both solved. The result of mixed strategy game is mixed strategy Nash equilibrium, so Nash equilibrium is obtained, as shown in Equation 10. This paper combines the game theory with the community detection problem, and constructed the IA-GT community detection algorithm integration model.

C. Model Application: Description of LPA-CW-S Algorithm

In the previous section, this paper has theoretically proved the effectiveness of the IA-GT model. Through dynamic analysis, with the update of each node's label by community detection, the payoff size of algorithm implementation and strategy selection probability will also change correspondingly. According to the game payoff matrix, at this time the algorithm needs to choose the optimal strategy for processing. Fig. 10 shows an application example of the model, namely LPA-CW-S algorithm, which proves the feasibility of the model from the experimental point of view.

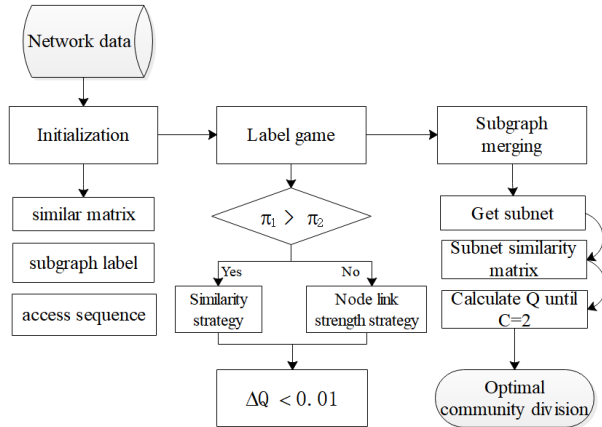


Fig. 10. The framework of LPA-CW-S.

1) *Algorithm steps:* According to the above theory, LPA-CW-S integration algorithm steps are as follows:

a) *Initialization stage:* Initialize all labels, search for the non-overlapping minimum complete subgraph in the graph, and let the clique with the largest number of nodes assign the same label. Initialize the similarity matrix, and refer to LPA-S for calculation; creating a random access sequence of nodes.

b) *Label game operation stage:* According to the obtained access sequence, the following values are calculated one by one: π_1 , applying LPA-CW algorithm, the probability of community label change; π_2 , applying LPA-CW algorithm, the probability of community label change; If $\pi_1 >$

π_2 , the label is updated by similarity strategy, otherwise, it is updated by Node Link Strength strategy. After each traversal, the modular Q is calculated once, and if the difference between the two times is less than 0.01, the first operation is finished.

c) *Sub-graph merging operation stage:* Preparation stage: get subnets from the current G, and then obtain the similarity matrix between subnets, save the current partition results. Operation stage: Initialize the subnet random access sequence; Calculate modularity Q once every time a subnet is updated. If Q is larger than the Q of previous partition results, save the current partition results to obtain the optimal solution, until there are two communities left.

d) *Complete and return the optimal partition result:* According to the above steps, the LPA-CW-S algorithm is divided into three stages. In the first stage, Algorithm 2-1 for the pseudo-code of initialization; in the second stage, Algorithm 2-2 for the pseudo-code of label game; and in the third stage, Algorithm 2-3 for the pseudo-code of subgraph merging.

Algorithm 2-1 Initialization

```

Data: A network  $G = (V, E)$ 
1:  $G1 \leftarrow G.copy()$ 
2:  $initializeLabel(G)$ 
3:  $addWeight(G)$ 
4:  $sDict \leftarrow initializeSimilarityMatrix(G)$ 
5:  $nodeOrder \leftarrow initializeNodeOrder(G)$ 
6:  $cliques \leftarrow getCliques(G)$ 
7:  $maxc \leftarrow maxLength(cliques)$ 
8: for  $i$  in  $cliques$  do
9:   if  $length(cliques[i]) == maxc$  then
10:     $maxLabel = max(i)$ 
11:   for  $j$  in  $i$  do
12:     $G.nodes[j][label] \leftarrow maxLabel$ 
13:   end for
14: end if
15: end for

```

Algorithm 2-2 Propagation step one

```

1:  $state1 \leftarrow False$ 
2:  $oldQ \leftarrow 1$ 
3: while  $state1 == False$  do
4:   for  $i$  in  $nodeOrder$  do
5:     $pi1 \leftarrow getPi1(G, i)$ 
6:     $pi2 \leftarrow getPi2(G, i)$ 
7:    if  $pi1 \geq pi2$  then
8:      $updateNodeLabelUseSimilarity(G, sDict, i)$ 
9:    else
10:      $updateNodeLabelUseEdgeWeight(G, i)$ 
11:    end if
12:   end for
13:    $partition \leftarrow getCurrentPartition(G)$ 
14:    $newQ \leftarrow modularity(G1, partition)$ 
15:    $changeQ \leftarrow abs(oldQ - newQ)$ 
16:   if  $changeQ \leq 0.01$  then
17:     $state1 \leftarrow True$ 
18:   end if
19: end while

```

Algorithm 2-3 Propagation step two

Result: Communities $P = \{C1, C2, \dots, Cn\}$
1: $labelForNetwork \leftarrow getSubNetwork(G)$
2: $sSubDict \leftarrow initializeSubSimilarityMatrix(G)$
3: $partition \leftarrow getResult(labelForNetwork)$
4: $state2 \leftarrow False$
5: **while** $state2 == False$ **do**
6: **if** $len(partition) == 2$ **then**
7: **break**
8: **end if**
9: $labelOrder \leftarrow initializeLabelOrder(labelForNetwork)$
10: $curPartition \leftarrow getResult(labelForNetwork)$
11: $maxQ \leftarrow modularity(G1, curPartition)$
12: **for** $label$ in $labelOrder$ **do**
13: $updateNetworkLabel(labelForNetwork, label)$
14: **end for**
15: $curPartition \leftarrow getResult(labelForNetwork)$
16: $currentQ \leftarrow modularity(G1, curPartition)$
17: **if** $currentQ \geq maxQ$ **then**
18: $partition \leftarrow curPartition$
19: **end if**
20: **if** $len(labelForNetwork) == 2$ **then**
21: $state2 \leftarrow True$
22: **break**
23: **end if**
24: **end while**
25: **return** $partition$

2) *Algorithm complexity analysis:* According to the step analysis of LPA-CW-S algorithm, the running time is mainly used in three stages. The first stage is the initialization stage, the complexity of identifying non-overlapping complete subgraphs is $O(k \log n)$, the complexity of initializing the label assignment to the subgraphs is $O(\lambda)$, and the complexity of initializing the similarity matrix is $O(n^2)$. The second stage is the first label propagation stage, which calculates that the Link Strength and similarity complexity of nodes are both $O(n+2m)$, the number of loop iterations is r_1 , so the complexity is $O(r_1 \cdot (n+2m))$. The third stage is the second step of label propagation, if the number of iterations is r_2 , the time complexity is $O(r_2 \cdot (n+2m))$.

Because of the influence of the network size, average degree and other factors, the final time complexity of the LPA-CW-S algorithm takes the highest value among the above three stages depending on the specific situation.

V. EXPERIMENTAL RESULTS

In this paper, the algorithm is implemented in Python3.9, and the experiment is carried out on the Windows 10 desktop with a 4-core i5@2.4GHz CPU and 16G memory. The LPA-CW, LPA-CW-S, LPA [8], LPA_m [23], LPA-S [10], CNM [24] algorithms will be contrasted on 10 real network and 9 artificial network, which have different parameter settings. This part analyzes the experimental results from the

perspectives of community division, modularity, stability, and time efficiency to verify the superiority of the algorithm proposed in this paper.

A. Datasets and Evaluation Index

1) *Real network datasets:* In this paper, four commonly used labeled network data sets, such as Karate, and six unlabeled network data sets, such as Lesmis, are selected. It contains real networks with different scales of nodes and different practical application scenarios, which can comprehensively evaluate the performance of the algorithm. Its parameter characteristic are shown in the following Table I.

TABLE I. BASIC STRUCTURAL PARAMETERS OF REAL NETWORK

Network	Reference	N	M	c	$\langle k \rangle$
Karate	[25]	34	78	2	4.588
Dolphins	[26]	62	159	2	5.129
Football	[4]	115	613	12	10.661
Polbooks	[27]	105	441	3	8.400
Lesmis	[28]	77	254	-	6.579
Jazz	[29]	198	2742	-	27.697
Sandi	[30]	674	613	-	1.819
Netscience	[31]	1589	2742	-	3.451
Facebook	[32]	4039	88234	-	43.691
Power	[33]	4941	6594	-	2.669

2) *Artificial network:* Artificial network is generated by benchmark of Lancichinetti et al. [34] LFR benchmark can generate networks with real network characteristics based personal demand. Its parameter characteristic is shown in the following Table II.

TABLE II. PARAMETER DESCRIPTION OF LFR BENCHMARK ARTIFICIAL NETWORK GENERATION

Parameter	Meaning
N	number of nodes
k	average degree
$maxk$	the maximum degree of nodes
mu	mixing parameter
$t1$	power law distribution index of node degree
$t2$	power law distribution index of community size
$minc$	the minimum community size
$maxc$	the maximum community size

μ represents the probability that the node linking with the community outside. N represents the number of nodes. The bigger the μ , the less obvious the boundary of the community and the difficult it is to detect the community structure. LFR-1 to LFR-5 are set to N to 1000, μ to 0.1 to 0.5 arithmetic increments. LFR-6 to LFR-9 are set to 2000 to 5000 arithmetic increments, μ to 0.3. Their parameter setting is listed in the following Table III.

TABLE III. PARAMETER SETTING OF ARTIFICIAL NETWORK DATASET

Network	N	k	$maxk$	mu	$minc$	$maxc$
LFR-1	1000	10	40	0.1	30	60
LFR-2	1000	10	40	0.2	30	60
LFR-3	1000	10	40	0.3	30	60
LFR-4	1000	10	40	0.4	30	60
LFR-5	1000	10	40	0.5	30	60
LFR-6	2000	10	40	0.3	30	60
LFR-7	3000	10	40	0.3	30	60
LFR-8	4000	10	40	0.3	30	60
LFR-9	5000	10	40	0.3	30	60

3) *Evaluation index*: The evaluation indicators about the community detection mainly include the following two, both of which are scientifically evaluated and have different focuses, and can comprehensively evaluate the performance of the algorithm from many aspects such as graph theory structure and real division.

Modularity, proposed by Newman and Girvan [27,35], this evaluation index does not have a priori requirements for the internal structure of the community, and only needs to count the total number of edges inside and outside the community as shown in Equation 11:

$$Q = \frac{1}{2m} \sum_{c=1}^n [2lc - \frac{dc^2}{2m}] \quad (11)$$

Among the equation, c is the community number, n is the number of communities, lc is the number of edges in community c , dc is the sum of node degrees in community c , and m is the number of all edges in the entire network. The bigger the Q value, the better the effect of community division. The value of Q ranges in $[-0.5, 1)$. When the value of Q is in $[0.3, 0.7]$, it indicates that the quality of community clustering is great.

NMI (normalized mutual information), proposed by DanonL [36] in 2005 is generally used to measure the difference between the community structure divided by the algorithm and the result of the real community division. This indicator can evaluate the accuracy and stability of the community discovery algorithm as shown in Equation 12:

$$NMI(A,B) = \frac{-2 \sum_{i=1}^{c_A} \sum_{j=1}^{c_B} N_{ij} \log(\frac{N_{ij}N}{N_i N_j})}{\sum_{i=1}^{c_A} N_i \log(\frac{N_i}{N}) + \sum_{j=1}^{c_B} N_j \log(\frac{N_j}{N})} \quad (12)$$

Among the equation, c_A represents the number of real community divisions, c_B represents the number of algorithmic community divisions, the sum of the i -th row of the matrix N_{ij} is denoted as N_i , and the sum of the j -th column is denoted as N_j . The value range of the NMI is $[0, 1]$, and the bigger the NMI value, it indicates that the detected community structure is closer to the real community division.

B. Experimental Result of LPA-CW

1) *Real network experiment comparison*: The labeled network has the real division of the community, and the algorithm performance can be compared through the Q value of the algorithm community division result and the NMI index. The unlabeled network does not have the real community division, and only the Q value can be used to compare the algorithm performance.

a) *Labeled network*: As can be seen from the modularity comparison curve in Fig. 11, the value of the division result of the LPA-CW algorithm on the labeled real network data set is generally higher than that of other comparison algorithms, indicating that the algorithm has the quality and stability of community division. The superiority is precisely because the sub-graph structure and node link strength guidance are added to the algorithm, which makes the divided community structure stronger and the clustering quality higher. By observing the comparison curve in the figure, it can be found that the NMI index of LPA-CW algorithm is not ideal, while the NMI index of LPA-S algorithm is much higher than other comparison algorithms. Comparing the Q value and NMI index of the two algorithms in Table IV, it can be seen that the LPA-CW algorithm and the LPA-S algorithm are complementary. This paper considers combining these two algorithms. The above-mentioned experimental phenomena and the label selection characteristics of label propagation algorithms provide experimental basis for the combination of algorithms.

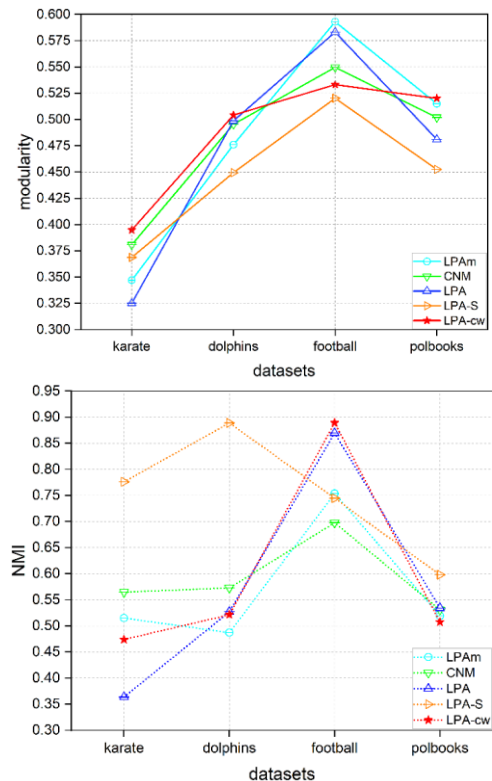


Fig. 11. Comparison of experimental results Q and NMI on labeled real network.

TABLE IV. COMPARISON OF ALGORITHM INDEX DATA ON LABELED REAL NETWORK

Network	Criterion	LPA	LPAm	LPA-S	CNM	LPA-CW(ours)
Karate	Q	0.3251	0.3470	0.3688	0.3807	0.3949
	NMI	0.3636	0.5150	0.7760	0.5646	0.4738
Dolphins	Q	0.4986	0.4760	0.4494	0.4955	0.5042
	NMI	0.5270	0.4870	0.8888	0.5727	0.5214
Football	Q	0.5831	0.5930	0.5203	0.5497	0.5331
	NMI	0.8697	0.7536	0.7447	0.6977	0.8892
Polbooks	Q	0.4811	0.5150	0.4525	0.5020	0.5201
	NMI	0.5341	0.5190	0.5979	0.5308	0.5075

b) *Unlabeled network*: At present, most networks in the real world are unlabeled networks and do not yet have real division results. Therefore, it is very important to continuously improve the modularity and time efficiency of community detection algorithms, which can be used to further guide community activities and behaviors in the real world. As shown in Table V, since CNM is based on modularity optimization algorithms, it has more advantages in modularity comparison, but it is also susceptible to the limitation of modularity resolution [37]. The real world network is complex and the data is huge. In most cases, the LPA-CW algorithm has obtained better community division results. The Q value is higher than that of similar label propagation algorithms and has higher time efficiency. It has great adaptability for large-scale network community detection.

TABLE V. COMPARISON OF Q RESULTS ON UNLABELED REAL NETWORK

Network	LPA	LPA-S	CNM	LPA-CW(ours)
Lesmis	0.5267	0.4492	0.5006	0.5312 (1)
Sandi	0.7796	0.8037	0.9313	0.8439 (2)
Jazz	0.2816	0.1719	0.4389	0.2822 (2)
Facebook	0.7369	0.6977	0.7774	0.7885 (1)
Power	0.6271	0.6012	0.9346	0.6478 (2)
Netscience	0.9074	0.8102	0.9551	0.8589 (3)

2) *Artificial network experiment comparison*: The analysis of real network experiment results has proved that compared with other classic community discovery algorithms, the LPA-CW algorithm has better community division quality and is complementary to the LPA-S algorithm. The algorithm is based on the optimization of the classic LPA algorithm, so in order to further verify the internal performance of the LPA-CW algorithm, this paper adopts the artificial network dataset of control variables (see section VA2) for R1-R5 parameters), and verify the LPA-CW through experiments compared with the LPA algorithm, whether the LPA-CW algorithm can effectively reduce the randomness and instability of label selection in the process of label propagation.

As shown in Fig. 12 and Table VI, under the same conditions, the modularity Q and the NMI index are decreasing when the mu is from 0.1 to 0.5. The greater the coincidence, the more difficult it is to identify the characteristics of the community structure. The modularity Q and NMI index obtained by the division results of the LPA-CW algorithm are mostly higher than those of the LPA algorithm. At the same time, it also solves the problem of the lower resolution of the

LPA algorithm as the community boundary in the network becomes less obvious. The improvement measures of the algorithm on the LPA algorithm have obvious effects, and the resolution of network recognition with unobvious community boundaries has been improved.

C. Analysis of Experimental Results of LPA-CW-S Algorithm

Based on the experiment in Section VB, it can be seen that the LPA-CW algorithm has a higher modularity and a lower NMI index and the LPA-S algorithm has a higher NMI index and a lower modularity, because LPA-CW-S algorithm is obtained by combining game theory model. The experiment in this section will prove whether the performance of the algorithm after the combination is improved based on both, and the advantages are complementary.

As shown in Fig. 13 and Table VII, it can be found that the LPA-CW-S algorithm that combines the two games has shown great results in terms of modularity Q value. The modularity of the Dolphins and Football datasets is higher than that of the LPA-CW algorithm. The modularity of the other two data sets is also almost close to the LPA-CW algorithm, and higher than the LPA-S algorithm, which verifies that the probability game of adding similarity and node link strength in the label propagation process is preferential. Similarly, in terms of NMI index, the LPA-CW-S algorithm that combines the two games is much higher than the LPA-S algorithm and the LPA-CW algorithm on the Football dataset. On the Polbooks dataset, the NMI has reached LPA-S algorithm level, the NMI on the other two data sets is also significantly improved compared to the LPA-CW algorithm, verifying that the subgraph merging in the second stage of the algorithm can make the final community division result better.

TABLE VI. COMPARISON OF ALGORITHM INDEX DATA ON ARTIFICIAL NETWORK

Network	Criterion	LPA	LPA-CW(ours)
R1	Q	0.8330	0.8321
	NMI	0.9712	0.9848
R2	Q	0.7100	0.7378
	NMI	0.9230	0.9878
R3	Q	0.5713	0.6242
	NMI	0.8041	0.9424
R4	Q	0.4892	0.4363
	NMI	0.7662	0.7684
R5	Q	0	0.3470
	NMI	0	0.6991

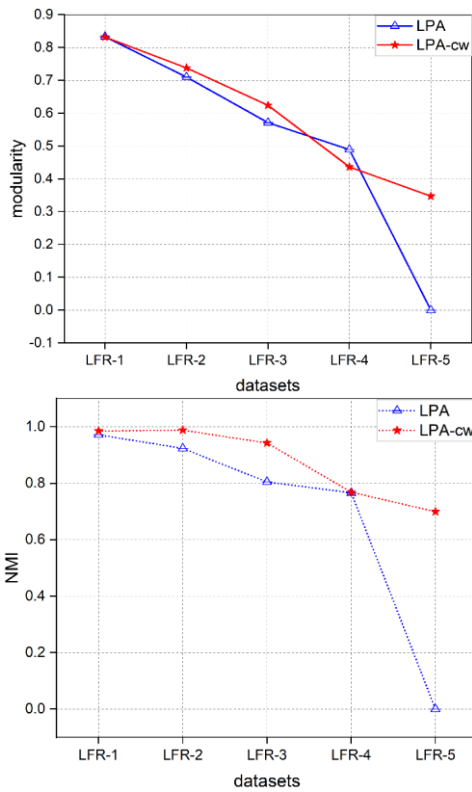


Fig. 12. Comparison of Q and NMI when N=1000 and μ changes from 0.1 to 0.5.

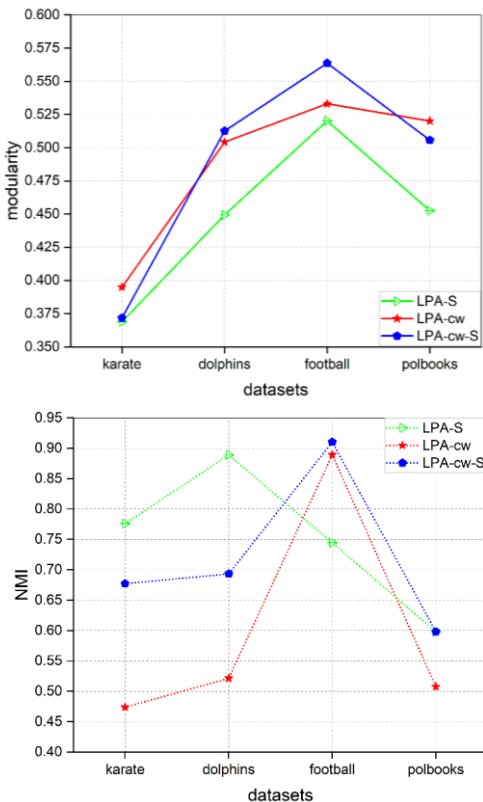


Fig. 13. Comparison of experimental results Q and NMI on real network.

TABLE VII. COMPARISON OF ALGORITHM EVALUATION INDEX RESULTS ON REAL NETWORK

Network	Criterion	LPA-S	LPA-CW	LPA-CW-S(GT)
Karate	Q	0.3688 (3)	0.3949 (1)	0.3718 (2)
	NMI	0.7760 (1)	0.4738 (3)	0.6772 (2)
Dolphins	Q	0.4494 (3)	0.5042 (2)	0.5126 (1)
	NMI	0.8888 (1)	0.5214 (3)	0.6932 (2)
Football	Q	0.5203 (3)	0.5331 (2)	0.5637 (1)
	NMI	0.7447 (3)	0.8892 (2)	0.9102 (1)
Polbooks	Q	0.4525 (3)	0.5201 (1)	0.5056 (2)
	NMI	0.5979 (1)	0.5075 (3)	0.5979 (1)

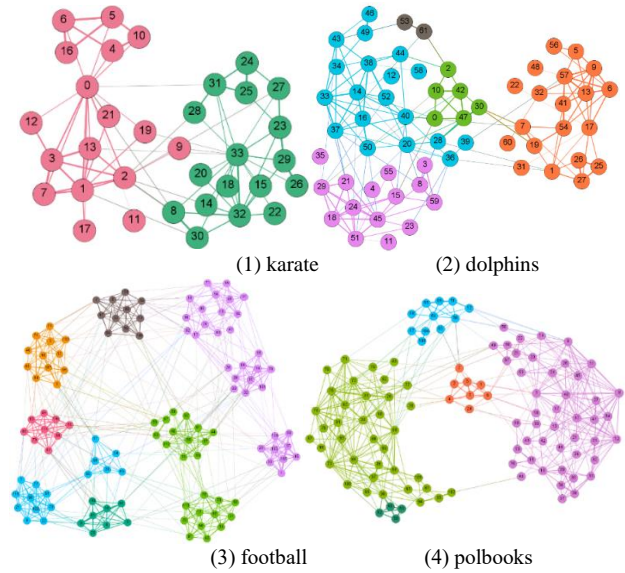


Fig. 14. Community division results of real network under LPA-CW-S algorithm.

Fig. 14 shows the visualization of the algorithm results. The network partition is complete, the clustering effect is obvious and clear, the nodes within the community are tightly connected, and the nodes between the communities are sparsely connected. From the perspective of the community structure, the division results obtained by the LPA-CW-S algorithm are reasonable and effective.

In summary, in the comparison of the overall modularity Q of the above dataset and the NMI, the game theory LPA-CW-S algorithm is more global than the two participant algorithms. The experiment proves the feasibility and rationality of the IA-GT model in this paper. It shows that game selection and subgraph merging can well neutralize the contradiction between the theoretical community structure and the actual community division, which helps to improve the accuracy and rationality of the community division results.

D. Analysis of Stability

In statistical description, variance [38] is an important equation in statistics, used to measure the stability of a set of data, the smaller the variance, the more stable the set of data, on the contrary, the more unstable the set of data. As shown in Equation 13.

TABLE VIII. COMPARISON OF ALGORITHM STABILITY DATA

	Karate	Dolphins	Football	Polbooks	Lesmis	Sandi	Jazz	Facebook	Power	Netscience
LPA-S	0.0003	0.0010	0.0004	0.0009	0.0002	0.0003	0.0012	0.0096	0.0125	0.0073
LPA-CW	0	0	0	0	0	0	0	0	0	0
LPA-CW-S	0.0002	0.0002	0.0003	0.0006	0.0001	0.0001	0.0009	0.0013	0.0078	0.0065

$$s^2 = \frac{1}{n} \sum_{i=1}^n (\bar{x} - x_i)^2 \quad (13)$$

In the above equation, s^2 represents the variance, x_i represents the modularity value during the i -th run and \bar{x} represents the average value of this group of modularity Q values.

Considering the combination of the LPA-CW algorithm and the LPA-S algorithm, this article evaluates the stability of the algorithm partitioning results. Table VIII shows the variance of the modularity Q calculated by the LPA-S algorithm, the LPA-CW algorithm, and the LPA-CW-S integrated algorithm running on the real network dataset for 17 times on average.

Table VIII shows that the stability of the LPA-S algorithm is worse than that of the LPA-CW algorithm proposed in this article. The LPA-CW-S algorithm after the game combination neutralizes the algorithm of the two participants, and the stability is improved compared with the LPA-S algorithm. As the number of nodes continues to increase and the scale of the network continues to increase, the stability improvement becomes more obvious. The above experimental results prove that through the combination of game theory framework while retaining the advantages of algorithm community division, it also reduces the instability and volatility of the algorithm.

E. Analysis of Time Efficiency

Label propagation algorithms are widely used due to their close to linear time complexity. To understand the time efficiency of the LPA-CW algorithm and the game theory LPA-CW-S algorithm proposed in this paper, Table IX shows its comparison with the comparison algorithm. The comparison of time complexity is analyzed from the perspective of orders of magnitude. The CNM algorithm is a modular optimization algorithm based on the improvement of the FN algorithm that uses the heap data structure to calculate and update the

network. It is close to linear time complexity and the LPA-S algorithm time complexity is at the square level. The LPA-CW algorithm proposed in this paper is complex. The degree is also close to linear. The game theory LPA-CW-S algorithm proposed in this paper is a three-stage algorithm and its time complexity is the highest among the three stages according to the data set size, which is between linear and square.

TABLE IX. COMPARISON OF TIME COMPLEXITY OF ALGORITHMS

Algorithm	Complexity
CNM	$O(n \log^2 n)$
LPA	$O(n + m)$
LPA-S	$O(n^2)$
LPA-CW	$O(r \cdot (n + 2m))$
LPA-CW-S	$O(n^2) / O(r_1 \cdot (n + 2m)) / O(r_2 \cdot (n + 2m))$

At the same time, in order to further verify the superiority of the algorithm in this paper, as shown in Table X, the experimental point of proof is given. Under the same condition of $\mu=0.3$, the number of nodes increases from 1000 to 5000. The time efficiency of the LPA-CW algorithm proposed is similar to that of the LPA algorithm and it is also close to linear time complexity. The LPA-CW algorithm is obviously more efficient than the CNM algorithm.

The time efficiency of the LPA-CW-S algorithm is between the LPA-CW and LPA-S algorithms, but it is much higher than the LPA-S algorithm. Although it is no longer linear complexity, it is better than some modular optimization algorithms. Algorithms such as the GN and FN algorithms are faster. At the same time, the experiments in the last two sections also prove that the algorithm in this paper has obvious advantages in the accuracy of community division. Therefore, the LPA-CW-S algorithm achieves a compromise between time cost and accuracy, and this computational complexity is acceptable in practice.

TABLE X. COMPARISON OF TIME EFFICIENCY DATA OF ALGORITHMS (s)

Network	CNM	LPA	LPA-S	LPA-CW	LPA-CW-S(GT)
LFR-3	0.8846	0.0747	14.7138	0.2753	1.7833
LFR-6	2.2111	0.1536	61.1946	0.5585	5.5451
LFR-7	3.8703	0.2533	130.5576	0.8487	10.826
LFR-8	6.6011	0.2942	332.1598	0.9365	18.5639
LFR-9	9.355	0.4159	430.2665	1.4511	30.6681

VI. CONCLUSION

In this paper, LPA-CW algorithm is proposed to reduce the initialization time of labels by identifying non-overlapping holograms. The label update strategy based on Node Link Strength reduces the randomness in label propagation, and improves the accuracy of community division results. Combined with game theory, this paper proposes an IA-GT community detection algorithm integration model to simulate individual community selection behavior in complex networks. From a new modeling point of view, this paper reasonably explains the individual's choice and the overall stability maintenance in the process of community formation. This paper also puts forward LPA-CW-S algorithm for model verification, experiments show that the contradiction between theoretical community structure and real community division can be well neutralized by game selection, which can reduce the volatility and randomness of the algorithm, and improve the time efficiency. This compromise strategy will better adapt to the real community detection application scenario.

Through the double verification of theoretical model and experimental algorithm, this paper holds that complex networks and game theory are naturally combinable. The future work is as follows:

- Optimize the balance of various evaluation indexes through game theory, and explore the combination of more community detection algorithms by combining the integrated model of community detection algorithms (IA-GT) proposed in this paper, and extend it to the field of overlapping community detection.
- Apply game theory to other directions in complex networks, such as evolutionary networks. Or it can be applied to spatio-temporal dynamic network [39] in combination with spatio-temporal location, providing solutions for more practical application scenarios.

REFERENCES

- [1] A. L. Barabási, Network science. Cambridge University Press, New York, 2014.
- [2] J. S. Kleinfield, "The small world problem," *Society*, vol. 39, pp. 61–66, 2002.
- [3] A. L. Barabási, R. Albert, "Emergence of scaling in random networks," *Science*, vol. 286, no. 5439, pp. 509–512, 1999.
- [4] M. Girvan, M. E. J. Newman, "structure in social and biological networks," *PNAS*, vol. 99, no. 12, pp. 7821–7826, 2002.
- [5] S. Souravlas, A. Sifaleras, S. Katsavounis, "A classification of community detection methods in social networks: a survey," *International Journal of General Systems*, vol. 50, no. 1, pp. 63–91, 2021.
- [6] H. Tajfel, "Experiments in intergroup discrimination," *Scientific American*, vol. 223, no. 5, pp. 96–102, 1970.
- [7] S. Z. Guo, Z. M. Lu, "The basic theory of complex network," Science Press, Beijing, pp. 292–303, 2012.
- [8] U. N. Raghavan, R. Albert, S. Kumara, "Near linear time algorithm to detect community structures in large-scale networks," *Physical review E.*, vol. 76, 036106, 2007.
- [9] M. J. Barber, J. W. Clark, "Detecting network communities by propagating labels under constraints," *Physical review E.*, vol. 80, 026129, 2009.
- [10] W. Li, C. Huang, M. Wang, X. Chen, "Stepping community detection algorithm based on label propagation and similarity," *Physica A*, vol. 472, pp. 145–155, 2017.
- [11] S. C. Liu, F. X. Zhu, L. Gan, "Overlapping community discovery algorithm based on label propagation probability," *Journal of Computer Science*, vol. 39, no. 04, pp. 717–729, 2016.
- [12] H. L. Sun, J. Liu, J. B. Huang, G. T. Wang, X. L. Jia, Q. B. Song, "LinkLPA: A Link-Based label propagation algorithm for overlapping community detection in networks," *Computational Intelligence*, vol. 33, no. 2, pp. 308–331, 2017.
- [13] I. B. E. Kouni, W. Karoui, L. B. Romdhane, "Node importance based label propagation algorithm for overlapping community detection in networks," *Expert Systems With Applications*, vol. 162, 113020, 2019.
- [14] Y. Zhang, Y. Liu, J. Zhu, C. Yang, W. Yang, S. Zhai, "NALPA: A node ability based label propagation algorithm for community detection," *IEEE Access*, vol. 8, pp. 46642–46664, 2020.
- [15] J. V. Neumann, O. Morgenstern, "Theory of Game and Economic Behavior," *Journal of the American Statistical Association*, New York, 1944.
- [16] W. Chen, Z. M. Liu, X. R. Sun, Y. J. Wang, "A game-theoretic framework to identify overlapping communities in social networks," *Data Mining and Knowledge Discovery*, vol. 21, no. 2, pp. 224–240, 2010.
- [17] R. I. Lung, C. Chira, A. Andreica, "Game theory and extremal optimization for community detection in complex dynamic networks," *Plos One*, vol. 9, no. 2, e86891, 2014.
- [18] S. Hesamipour, M. A. Balafar, "A new method for detecting communities and their centers using the Adamic/Adar Index and game theory," *Physica A*, vol. 535, 122354, 2019.
- [19] X. Zhou, S. Cheng, Y. Liu, "A cooperative game theory-based algorithm for overlapping community detection," *IEEE Access*, vol. 8, 68417–68425, 2020.
- [20] M. Kumar, R. Gupta, "Overlapping attributed graph clustering using mixed strategy games," *Applied Intelligence*, vol. 51, pp. 5299–5313, 2021.
- [21] T. Zhou, L. Lü, Y. C. Zhang, "Predicting missing links via local information," *Eur. Phys. J. B.*, vol. 71, pp. 623–630, 2009.
- [22] X. Zhang, Z. Y. Xia, S. W. Xu, J. D. Wang, "Ensemble method: Community detection based on game theory," *International Journal of Modern Physics B*, vol. 28, no. 30, 1450211, 2014.
- [23] M. J. Barber, J. W. Clark, "Detecting network communities by propagating labels under constraints," *Physical review E.*, vol. 80, 026129, 2009.
- [24] A. Clauset, M. E. J. Newman, C. Moore, "Finding community structure in very large networks," *Physical review E.*, vol. 70, 066111, 2004.
- [25] W. W. Zachary, "An information flow model for conflict and fission in small groups," *Journal of Anthropological Research*, vol. 33, no. 4, pp. 452–473, 1977.
- [26] D. Lusseau, "The emergent properties of a dolphin social network," *Royal Society*, vol. 270, 0057, 2003.
- [27] M. E. J. Newman, M. Girvan, "Finding and evaluating community structure in networks," *Physical review E.*, vol. 69, 026113, 2004.
- [28] D. E. Knuth, "The Stanford GraphBase: A platform for combinatorial computing," *ACM-SIAM symposium*, pp. 41–43, 1993.
- [29] P. M. Gleiser, L. Danon, "Community structure in jazz," *Advances in Complex Systems*, vol. 6, pp. 565–573, 2003.
- [30] V. Batagelj, A. Mrvar, Pajek datasets, 2006.
- [31] M. E. J. Newman, "Finding community structure in networks using the eigenvectors of matrices," *Physical review E.*, vol. 74, 036104, 2006.
- [32] J. McAuley, J. Leskovec, "Learning to discover social circles in ego networks," *NIPS*, pp. 539–547, 2012.
- [33] D. J. Watts, S. H. Strogatz, "Collective dynamics of small-world networks," *Nature*, vol. 393, pp. 440–442, 1998.
- [34] A. Lancichinetti, S. Fortunato, F. Radicchi, "Benchmark graphs for testing community detection algorithms," *Physical review E*, vol. 78, no. 4, 046110, 2008.
- [35] M. E. J. Newman, "Modularity and community structure in networks," *PNAS*, vol. 103, no. 23, pp. 8577–8582, 2007.

- [36] L. Danon, A. Diaz-Guilera, J. Duch, A. Arenas, "Comparing community structure identification," *Journal of Statistical Mechanics: Theory and Experiment*, P09008, 2005.
- [37] S. Fortunato, M. Barthélemy, "Resolution limit in community detection," *PNAS*, vol. 104, no. 1, pp. 36-41, 2007,
- [38] R. A. Fisher, "The Correlation between relatives on the supposition of mendelian inheritance," *Transactions of the Royal Society of Edinburgh*, vol. 52, no. 2, pp. 399-433, 1919,
- [39] T. Zhou, Z. K Zhang, G. R. Chen, X. F. Wang, et al., "Opportunities and challenges of complex network research," *Journal of University of Electronic Science and Technology of China*, vol. 43, no. 1, pp. 1-5, 2014.

Intelligent Brake Controller Based on Intelligent Highway Signs to Avoid Accidents on Algerian Roads

AHMED MALEK Nada, BOUDOUR Rachid

Embedded Systems Laboratory, Badji Mokhtar Annaba-University, Algeria

Abstract—Despite the considerable efforts of the Algerian authorities to reduce the high number of accidents, therefore, fatalities on the country's roads, the problem persists. To address this worrying situation, it is necessary to adopt new technologies and approaches that can assist Algerian drivers forcing them to comply with driving rules, thus putting an end to this concerned issue. This research aims to primarily assist Algerian drivers in reducing the mortality rate, which is primarily caused by speeding and poor road conditions, including outdated and inadequate road signs. To achieve this objective, a complete system consisting of two complementary subsystems: intelligent traffic signs and an interactive and smart speed limiter, has been proposed. Existing projects in this field have shown deficiencies, particularly in the context of real-time critical systems. This work offers improved precision, real-time responsiveness, adaptability to changes, and reduced infrastructure dependency compared to existing solutions. The new approach has been tested with the SUMO simulator, and a prototype based on Arduino cards has been developed approving its feasibility. However, the results obtained from this study demonstrate that the proposed system can significantly reduce the mortality rate on Algerian roads.

Keywords—Intelligent Transportation Systems (ITS); Intelligent System Adaptation (ISA); road accidents; intelligent road signalization; decision

I. INTRODUCTION

Every year, a significant number of accidents occur on roads, with speeding and unsafe road infrastructure being major factors; they are responsible for 29% and 3% of fatal road accidents respectively [1]. In 2021, Algeria experienced one of the worst road safety reports with 6195 accidents, of which 2294 were killed, equivalent to 192 deaths per month, and 9963 injured, without forgetting to mention the considerable economic losses caused by these accidents which amount to billions of dinars annually weakening insurance companies financially [2] (SAA, CAAR, CAAT, etc.). The government and authorities of road safety around the world devote considerable resources to deal with accident causes and reduce the number of fatalities on the roads. Particularly by the use of Information and communications technology for the construction of smart vehicles and infrastructures which can assist road users to respect traffic laws and enjoy safer traffic.

Several projects and initiatives are subscribed to improve safety on roads, including Intelligent System Adaptation which is known by the abbreviation ISA [3]. These systems assist

drivers in maintaining speed limits or even prevent the vehicle to overtake them on all routes and at all times. Although they have proven their effectiveness in reducing the risk of accidents and their severity (i.e., saving lives), reducing emissions of carbon monoxide (environmental) as well as improving traffic flow (e.g., a gain of substantial time for users) [4], there are still some shortcomings that engineers are endeavoring to eliminate. In addition to communication between the vehicle and the infrastructure, smart road signalization is another aspect that can improve road accident statistics, by avoiding inconsistency of current signs with the state of the road and weather conditions, especially in underdeveloped countries [5].

This work focuses on addressing the problem of inappropriate speed limits and excessive speeding, both of which contribute significantly to the high number of accidents on Algerian roads. Despite this scourge which mourns thousands of Algerian families every year, no radical solution has so far been introduced; therefore, this work lays the foundation stone for the improvement of transportation and, ultimately, significantly reducing the number of deaths on our roads. By tackling these crucial aspects, this work aims to create a safer road environment and significantly reduce the mortality rate.

What sets this work apart from others is its interactive nature, where decisions are based on direct communication between the two subsystems. By integrating advanced technologies and intelligent systems, we create a seamless interaction between intelligent traffic signs and the interactive speed limiter which provides improved precision by enabling accurate transmission of speed limit information. Real-time responsiveness ensures quick adjustments to speed limits based on road conditions. The method is adaptable to changes, allowing for prompt updates in response to temporary modifications. It reduces infrastructure dependency by utilizing wireless communication, making it more cost-effective. Overall, this method enhances the effectiveness and efficiency of the speed limitation system, improving road safety.

In addition to the introduction and conclusion, this paper will be organized into three main sections. The initial section will present an overview of existing intelligent transportation systems for safety and address the criticisms associated with them. While the second section explains our proposal to reduce the number of road accidents on roads by introducing an intelligent road sign that can make a decision on the optimal

speed and communicate it with an intelligent brake controller to monitor the vehicle speed. Our approach supposes that each highway sign allows continuous broadcasting of information such as speed limit, location, wind strength, road traffic, etc. Data is gathered and processed by the controller to assist the driver in the most efficient way possible, this may include visualizing messages, using text-to-speech technology, and applying the brakes in extreme cases. The last section, discusses the obtained results from simulation on SUMO and Arduino's prototype.

II. RELATED WORKS

A. ISA Systems

1) *Presentation of ISA systems:* Intelligent speed adaptation (ISA) is a generic term for a class of intelligent transportation systems (ITS) in which the driver is warned and/or the vehicle speed is automatically limited when the conductor moves above the authentic speed intentionally or inadvertently [5].

Essentially ISA continuously monitors restrictions on "local" speed as well as the vehicle speed and reacts in case of exceeding the limit. The type of the system depends on the reaction which can be either "passive", where the driver is warned, or "active", where an automated control over the vehicle speed is imposed due to embedded devices of ISA such as sensors of speed's knowledge.

Carsten et al [6,7,8] present a review of the various tests and estimate the effectiveness of ISA. They consider three levels of control: advisory, voluntary (active but the driver can turn it off), obligatory (active all the time), and three types of speed limits: fixed, variable and dynamic. In a fixed system, there is one speed per area, which is unchangeable, in the dynamic system; we opt for a fixed speed, suitable for several variables, such as weather conditions or unexpected events. In a variable system, an individual or an entity is responsible for the decision-making and taking actions (e.g., road construction).

For comparison, based on recorded data from the test of a passive ISA system working with fixed speed limits, Regan [9] estimated that the system can reduce fatalities by 8% and serious injury accidents by 6%. However, the author noted that they were likely to be underestimated.

2) *Technologies used in ISA systems:* All ISA systems are based on the knowledge of the authentic speed limit. This can be achieved through the use of the mentioned function according to different existing technologies, the main ones are:

- GPS Global Positioning System: GPS technique is based on the localization of the vehicle and the extraction of the related speed from the database of "speed cards", that are embedded in the vehicle [10,11,12].

- Despite its popularity, the GPS is submitted to a certain number of fundamental issues related to the precision of determining the position and the construction of the database
- RFID - The Radio Beacons: Radio beacons function by transmitting data to a receiver integrated into the vehicle. Tags emit continuous data, and the receiver captures it at each passage [13,14,15].
- Unfortunately, these systems can be used only for slow vehicles. For vehicles traveling at high speed, it is difficult to collect and process data in real-time, this is in addition to the constraint of the vehicle that must be close to the transmitter to determine the speed limit.
- Image Recognition: This system uses a camera mounted on the vehicle to capture continuous images on the road. The image is processed to find if there is a traffic signal. Once the sign is found, another algorithm is used to define the pattern of the image to recognize it. Following the recognized symbol the ISA system reacts.
- The major constraint of this system is the lack of recognition combined with the imprecision of items, especially during unfavorable weather conditions (heavy rain). Additionally, even in relatively simple situations, these systems are incapable of dealing with fixed obstacles reliably which can lead to erroneous conclusions [16,17,18].
- Dead Reckoning: Dead Reckoning (DR) uses a mechanical system linked to the drive unit to predict the path taken by the vehicle [19,20,21].
- This system requires the establishment of multiple sensors on the vehicle, which can be expensive. However, its reliability and accuracy remain uncertain since the user may at any time deviate from its originally estimated road based on information that can sometimes be wrong.

B. Intelligent Road Signs

The design developed on intelligent road signs is intentionally redundant because it currently serves research purposes.

We can classify technologies used to improve the road signs' deployment into:

- Deep learning methods: Given the emergence of deep learning, several works have been registered using it. This work is known as ATDR for Automatic Traffic Sign Detection, the ATDR is mainly used to recognize and classify the different forms of road signs on vehicles. They are mainly used to improve the driver's attention to avoid possible accidents. [22,23,24,25]

- Generally, these methods are inefficient in unfavorable weather conditions, reduced brightness. Furthermore, they may not be effective in dealing with speeders.
- Google Street View methods: these methods are used to solve some problems encountered using deep learning. Based on Google Street View (GSV) as the source image and database of road signs with relevant coordinates. [26].
- This promising approach unfortunately inherits large database and precise location problems, besides, they may not have the ability to deal with the speeders.
- In addition to the cited problems of the two aforementioned methods, neither of them takes into consideration the regulations during climate change or other incidents on the road.
- Systems multi-agent: this solution uses an agent architecture, based on virtual sensors at the agent's body, to perceive the environment [27]. This solution inherits the problems of multi-agent systems and only focuses on the case of fog.

III. SYSTEM DESCRIPTION

A recent study was carried out to determine the main causes of road accidents in Yunnan Province mountain in China [28], which shows that despite complying with the speed limit the accident rate is still high. This raises the question of why this is the case.

Analysis of the prior study as well as the figures obtained from the road authorities in Algeria leads us to the realization that several factors including unfavorable weather conditions, peak hours, incidents, light, and the experience of the driver, must be taken into consideration. This eventually motivates us to believe that it is imperative to work quickly towards a radical solution taking into account at least the causes and aggravating factors of road accidents. Aiming to mitigate the problems previously mentioned, we suggested an intelligent system composed of a speed limiter and intelligent road signs communicating directly (I2V communication) through two devices, one installed on the panel and the other embedded in the vehicle.

This current solution can be implemented initially in high-risk areas before being generalized for the entire Algerian territory.

A. System Structure

The proposed system will be divided into two main parts:

1) *Vehicle*: The first part embedded in the vehicle is mainly composed of a communication unit: which is represented by a reception antenna of the signal that ensures the communication between the vehicle and the road sign; a decoding unit: which decodes the received signal, a treatment unit: which is made up of an ECU (Engine Control Unit) and a speedometer, being used to operate the speed limiter or the

brake depending on the situation in which the vehicle is in (see next section). A limitation system: which is made up of a fuel injector and a brake, and it is responsible to decelerate the vehicle by acting either on the fuel's flow rate injected from the combustion room of the vehicle or on the brake pedal or even on both of them.

Besides the components described previously and taking into account the importance of human-machine interactions in the transport field, our system is equipped with a luminous indicator and a display screen.

2) *Infrastructure*: The second part has been installed on traffic signs, which can communicate with a vehicle that is equipped with a limitation system. The sign panel includes a location unit: which is used to locate the position of the sign (in front of a school, on motorways, in built-up areas, on mountains, and so on.). Generally, to recover the coordinates, the location unit uses GPS (Global Position System). It includes also Sensors: for gathering information from the external environment such as (sensors for snow, temperature, rain, fog, pavement condition, and camera). A communication unit: represented by a unidirectional transmitting antenna covering a distance of at most 300 m, which serves to broadcast the suitable speed. A Decision unit: this is the main component responsible for processing the collected information and performing the necessary calculations to obtain the required speed. A coding unit: to code the limit speed as a signal and transmit it to the vehicle. The energy source is necessary for the functioning of the system, it can be obtained from public lighting poles, solar energy, or others.

B. System Architecture

Fig. 1 includes all the components of our system along with the various possible interactions between them. These interactions are denoted by numbered arrows.

Firstly, the system starts collecting initial information concerning the road's nature, road number, and incident (for example works, collision, congestion), using GPS coordinates to define the initial speed (in normal situations). After that, the installed sensors gather information about weather and road conditions (arrow 1) and then transmit it to the decision unit, the decision unit treats all the collected data so that the system can determine the appropriate speed (arrow 2), then it codes the signal (arrow 3) before displaying it in real-time, and sends it via the antenna to the road users (arrow4). Secondly, the vehicle antenna receives the information and transmits it to the engine control unit (ECU), which decodes the information and compares it to the vehicle's speed (arrow 5).

Lastly, if the vehicle's speed is higher than that of the sign (comparison effected by arrow 6), the ECU operates the fuel injector to reduce the speed (arrow 7); in other situations, for example, downhill, the fuel injector only is not enough to reduce the speed, we need the intervention of the ECU on the brake.

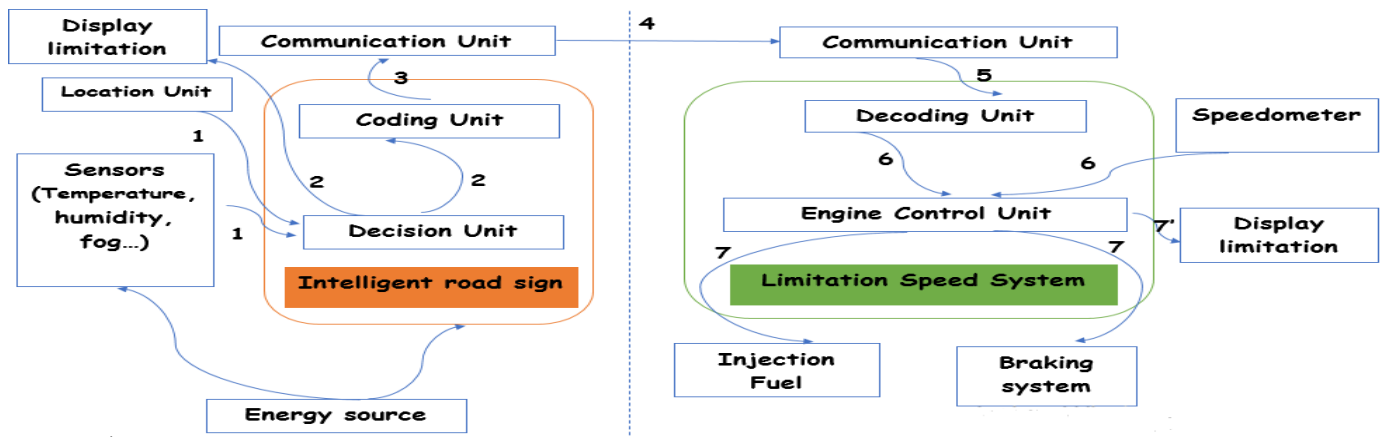


Fig. 1. Proposed system's components and communication.

Information is displayed in real-time on the vehicle's console (Screen LCD) and a beep sound will be played to alert the driver (arrows 7).

C. General Functioning

1) *Operating scenarios on vehicles:* Before implementing the proposed system, we surveyed to know people's opinions about autonomous vehicles and especially voluntary and obligatory ISA systems.

On a population of 820 Algerians, we obtained these results summarised by the histogram shown in Fig. 2.

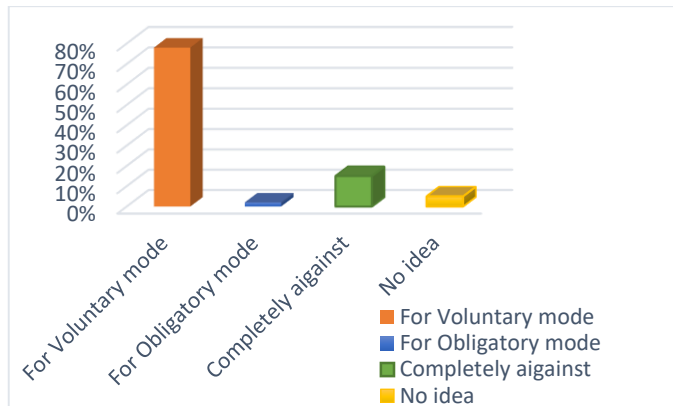


Fig. 2. Histogram representing survey results.

- Based on the survey results, we proposed two operating processes: the half-automatic mode which is an informative mode. It is used to alert the driver by a sonar or luminous signal if the maximum authorized speed is exceeded, and the limiter mode which plays the role of a reducing speed device that prevents vehicles from exceeding the authorized speed.
- So once the system is started, the half-automatic mode is required by default since it is a familiar mode with the usual operation of the vehicle and it is controllable by the driver, who can change the mode constantly and at any time.
- Once we are in the half-automatic mode, if the speed is higher than the road regulation by 10 km/h, the system will automatically switch to automatic mode (forced

deceleration) to decrease the risk factors of serious accidents. This decision was taken based on the following findings: 50% of the drivers operate above the authorized speed limit [29]. Generally, the drivers exceed the speed limit lower than 20 km/h, and a number of them exceed the limits of more than 20 km/h, which does not measure the incurred serious risks at all, nor the consequences caused by these excesses. Consequently, it is estimated that approximately 10% of the victims could be prevented if most motorists who usually drive at speeds higher than 10 km/h were encouraged to respect limitations. Approximately 20% of the victims could be prevented if all the vehicles respected the speed regulations.

- we have also taken into consideration the scenarios that may encounter our system, which include:
- First scenario: (highways, tunnel):
- At the entrance of a tunnel or on the exit of a highway, we generally notice the presence of an indication for a specific way (Fig. 3). So, to support this specificity we can use a directional antenna at the entrance of the tunnel at the exit of the highway.



Fig. 3. Specific way limited by 80 km/h.

- Second scenario: (intersections):
- We locate the presence of an intersection by the presence of directional signs or priority of a street sign, pedestrian crossings, and traffic lights. So, the sign read transmits the relative information to the taken road. It carries also information about nearby crossroads.
- Fig. 4 illustrates an intersection, where the driver can continue on the same path, or change direction. It is supposed that the white car is on the way which RW320 A, the red car is on the way to RN48B and the yellow one is on RN48A. The four panels carry information about the roadways of the intersection: if the white car turns left through the detection's sensors to determine the direction of the path, the system saves information RN48B and ignores the others.
- The vehicle can change directions by updating its information with those received from the panel.

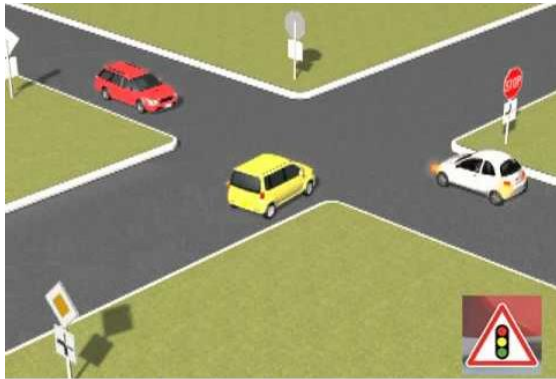


Fig. 4. An intersection.

- Third scenario: (different speed limit according to the class of vehicle):
- Fig. 5 illustrates the situation. In this case, we add information containing the class range of the vehicle (example: A: for motorcycles, B: for light vehicles, and C: for heavy vehicles), we also include the same class range information of the vehicle in the signal code for the speed limit.
- When the vehicle receives data, the system compares the category and decides which one concerns it.



Fig. 5. Different speed limits according to the vehicle category.

2) *Operating scenarios on infrastructures:* In this subsection, we are going to present the architecture of the proposed decision unit, including the different components involved in its functioning: We suggest using a hybridized CBR method to the AHP method to get an optimal limitation by using the approach described in [30], the decision can be improved by adding an order of priority to the determining factors. we first apply the CBR process during the calculation of the similarity value after, we add the weights and then, we apply AHP to have a more reliable decision.

The different proposed speeds in studied cases are proposed according to Algerian norms.

IV. RESULTS, ANALYSIS, AND DISCUSSION

This work can be divided into two main parts:

The first clarified the process of detecting the optimum speed taking into consideration: the geometry of the road, the road surface, the weather conditions, the road traffic situation.

The figure below (Fig. 6) illustrates and summarizes the detection of the optimal speed process.

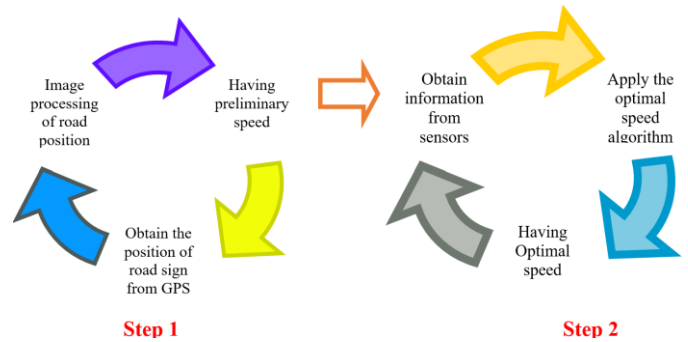


Fig. 6. Process to have the optimal speed.

Initially, we ensure that the panel is placed accurately by utilizing GPS technology, which provided us with the Latitude and Longitude coordinates, we have used Google Static Maps API to capture a personalized image of the geographical map of the location.

The card is retrieved in general, and to determine its type and style. For this, we have used the following types of cards, see Fig. 7:

- Terrain which specifies a physical relief map image, displaying topography and vegetation, this type of map was used to detect whether the location is a built-up area.
- Roadmap which specifies a standard road map image to detect the type of the road (a turn, a straight road).



Fig. 7. Terrain (left) and roadmap (right).

- After retrieving the necessary images, we proceed to the image processing phase:
- The Terrain type image: it is a two-color image where one color is for space and the other one is for man-made structures. After the indexing of the image, we obtain a matrix of 300x300 which contains two possible values 0 or F.
- 0 for the structures and F in hexadecimal for the void if the count of pixels containing the value 0 in the matrix exceeds a certain threshold, the location is then located in an Agglomeration zone, otherwise, it is considered to be located outside the built-up area.
- The Roadmap type image: it is a two-color image. A color for the void, and another for the roads, after the indexing of the image we obtain a matrix of 300x300 which contains two possible values: 0 for the roads and F in hexadecimal for the void. (Step 1. A).

To determine the shape of the road a form recognition is necessary. To expedite this process, we have created a database of 200 images containing roads, each with the appropriate speed according to Algerian regulations. Then we calculated the distance between the indexing matrix of the Roadmap type image and the matrices of our pre-indexed images stored in the database (Step1.B).

The recognition of the shape of the road is done by calculating the distance (color/location) between each image in the base and the image retrieved from the road.

The base image that has the smallest distance from the retrieved image represents the closest image. Each image in the base has an associated proposed speed, which is applied to the

road that has the smallest distance from the base image; it is called the preliminary speed (Step1.D).

After completing the image processing phase by calculating the preliminary Speed as a result of the previous phase, the next step is to calculate the optimal speed. This is achieved by using the values obtained from sensors and environment by applying the hybridized algorithm CBR-AHP (Step 2. A). At the end of this step, we have the optimum speed.

The second main part focuses on how the vehicle receives the final optimal speed, as shown in Fig. 8. The process involves transmitting the speed from a transmission antenna to a receiving antenna on the vehicle. Once received, the speed is limited by a speed limiter system integrated into the car, the steps mentioned above are carried out by information processing software systems. The next figure summarises the process.

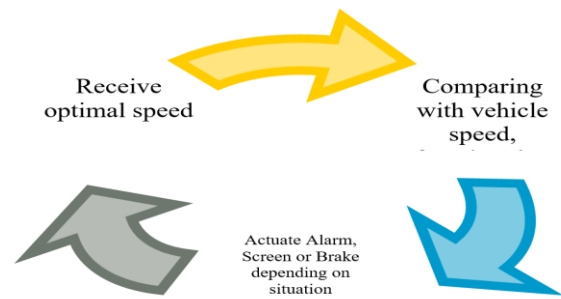


Fig. 8. Process to actuate screen, alarm, or brake depending on the situation.

To validate our approach, we opted for a simulation with SUMO (Simulation of Urban Mobility), which is a widely used traffic simulation software that enables the modeling and analysis of transportation systems in urban areas. By utilizing SUMO, researchers, and transportation planners can simulate real-world scenarios and assess the impact of different factors on urban transportation systems [31].

The following figure (Fig. 9) is an extract of Annaba's street roads in Algeria. The cars in green are vehicles respecting the limitation, those in light blue operate under the semi-automatic mode, while those in dark blue do not comply with the law, therefore the automatic mode activates automatically.

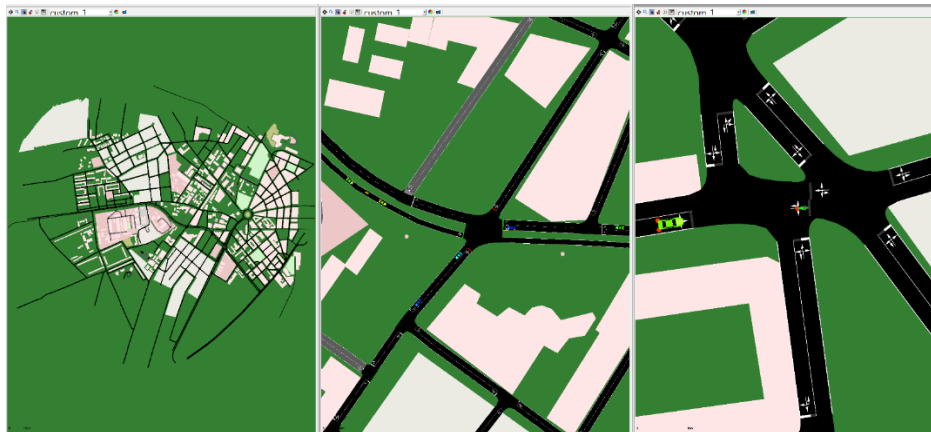


Fig. 9. Annaba's street roads-Algeria from SUMO simulator.

To check our method once again, we opted for a simulation of the same environment with the same conditions, and the same number of vehicles and pedestrians twice. The first time, the vehicles circulate in a random way not subjecting to any regulation obligatorily (like the actual situation in Algeria). However, in the second simulation, vehicles were forced to submit to the principle previously proposed and described by this article.

The results of the collisions that occurred during the two simulation runs are summarized in Table I.

Based on the obtained results, it is evident to notice that a significant decrease in the number of crashes has been observed, with the rate dropping from 33.01% during the first simulation to 19.23% in the second one. This remarkable drop can be mainly attributed to the change in the method of vehicle circulation, where, they were forced to respect the regulations, which seems encouraging. The findings prompted us to create a prototype with Arduino cards, implementing the functionalities of our desired system, to prove its feasibility.

The next illustrations represent the realized prototype. For this, we used several modules including Driver motor L293D, which is used to activate the rotation motor, Bluetooth HC-05 module, which is used to assure the communication between the panel and the vehicle.

Fig. 10 illustrates the prototype produced, part A represents the vehicle equipped with an LCD screen to display the speed and the operating mode; a Bluetooth to receive the speed of the panel.

Part B illustrates the smart panel equipped with several sensors and electronic components such as GPS, water sensor, light sensor, and temperature sensor. It describes the external conditions that can play a role in the decision process for example day or night, sunny or rainy.

The realized prototype controls the speed under the two modes described above.

In summary, despite being in the modeling and prototyping stage, the approach described in this paper has a lot of potential and yields encouraging results.

The originality of this work lies in the creation of a complete speed control system that encompasses both traffic signs and vehicle's speed limiter. This distinguishes it from previous works on smart panels in many aspects. First, it is more comprehensive, incorporating all the Algerian traffic standards (Each country can adapt the model according to its standards) as well as all the environmental factors leading to the change in speed. Without forgetting to mention that this hardware solution shows great potential compared to software solutions (such as a method with multi-agent systems) since ultimately it is a critical system that does not support a long waiting time.

TABLE I. RESULTS OF SIMULATION

	FISRT SIMULATION	SECOND SIMULATION
Pedestrians number	99	99
Vehicle number (Cars, Bus, Motorcycles, Bicycle)	1522	1522
Vehicle collision with pedestrians	12	7
Vehicle collision with another vehicle	318	192
Percentage of collisions with pedestrians	12,12%	7,07%
Percentage collisions with another vehicle	20,89%	12,16%
Total percentage collision	33,01%	19,23%

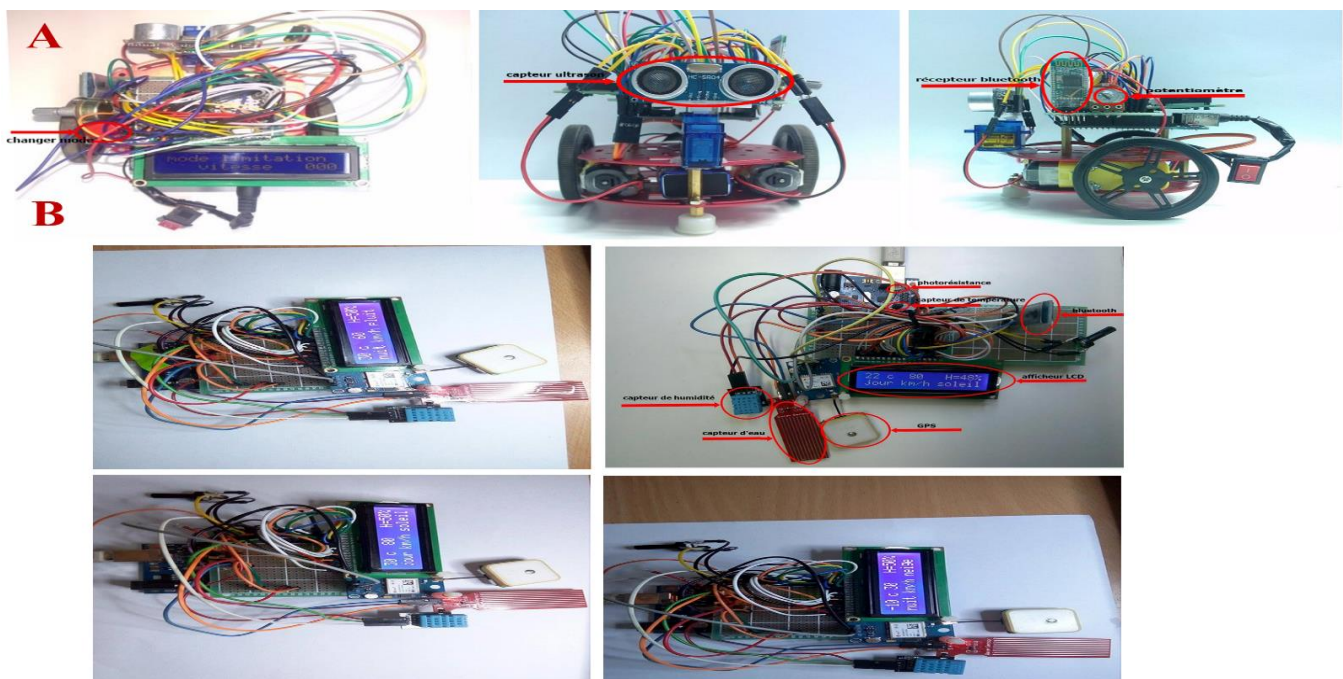


Fig. 10. Prototype with arduino cards.

Second, all existing ISA systems are based on the knowledge of the authentic speed limit often determined using GPS technology as we mentioned previously in Section II, which is due to its low cost and widespread availability. However, despite the popularity and functionality of GPS, there are fundamental problems with this system, most of which are related to the accuracy of the determined GPS has inherent inaccuracies due to uncertainties in satellite ephemeris, propagation errors, timing errors, multiple signal propagation paths, and reception noise, which can be particularly problematic in areas with a high-speed road adjacent to lower-speed residential streets. Additionally, GPS signals can be completely blocked in tunnels or under large structures. Updating the database with new road works data also presents a significant challenge. These issues highlight the need for a more comprehensive and robust speed control system, which the proposed hardware solution aims to address.

This work offers a mechanical solution that addresses the challenges faced by existing methods combining two subsystems; it provides a flexible, intelligent, and complete system that effectively addresses the problem of speeding. This new approach overcomes the limitations of existing methods, such as the inaccuracies and constraints of GPS, and offers a more reliable and adaptable solution. Overall, this work promises to provide a coherent and effective solution to the problem of speeding on the road.

TABLE II. COMPARISON WITH RELATED WORKS ON ISA SYSTEMS

Solution	Advantages	Disadvantages
GPS	<ul style="list-style-type: none"> - Access to precise and global positioning data. - Wide availability of map data. 	<ul style="list-style-type: none"> - Dependency on a stable GPS signal. - Limited accuracy in dense urban areas.
RFID	<ul style="list-style-type: none"> - Access to specific information from traffic signs. - Precise use of speed limits on specific road segments. 	<ul style="list-style-type: none"> - Difficult to collect and process data in real-time for vehicles traveling at high speed. - Vehicle must be close to the transmitter
Image processing	<ul style="list-style-type: none"> - Utilization of onboard cameras or existing sensors. - Adaptability to different types of traffic signs. 	<ul style="list-style-type: none"> - Dependency on visibility conditions and image quality. - Requirement for sufficient computational power for real-time image processing.
Dead reckoning	<ul style="list-style-type: none"> - Less dependency on external signals. 	<ul style="list-style-type: none"> - Limited accuracy over time and distance traveled. - Accumulation of measurement errors. - Need for regular calibration and recalibration of sensors to maintain accuracy.
Antenna communication	<ul style="list-style-type: none"> - Improved precision of speed limit information. - Real-time responsiveness for speed limit updates. - Adaptability to temporary changes in speed limits. 	<ul style="list-style-type: none"> - Dependency on reliable wireless communication. - Need for integration with existing traffic signs.

TABLE III. COMPARISON WITH EXISTING WORKS ON PANELS

Solution	Deep learning	Google Street Map	multiagent system	hardware-based
Real-time capabilities	Limited	Limited	Limited	Strong
Speed of processing	Fast	Fast	Fast	Fast
Adaptability	Moderate	Moderate	Moderate	High
Accuracy	High	High	Moderate	High
Robustness	Moderate	High	High	High

For better readability and by comparing the method used here with the existing ones, the tables (Table II and III) summarize the advantages and disadvantages of all approaches and techniques in the two subsystems.

V. CONCLUSION

This work falls under the continuity of seeking works to improve road traffic and reduce the amount of mortality. We are mainly interested in the problem of traffic accidents due to speeding. Despite this scourge that touches thousands of Algerian families every year, no radical solution has so far been introduced, therefore this work lays the foundation stone for the improvement of transport and the significant reduction in deaths on our roads. Based on a new system ISA, which communicates directly with the smart road signs, the proposed system has been simulated with SUMO, and a prototype is realized with Arduino to prove its validity.

Several perspectives could be considered to extend this work. We cite without limitation, the realization of a physical system, which will highlight our expectations and estimations.

Additionally, integrating radar functionality into the smart panel could increase its productivity and effectiveness, ultimately leading to a solution for addressing speeding drivers.

REFERENCES

- [1] World Health Organization, "Global status report on road safety 2018: Summary" Switzerland, 2018.
- [2] Report of Algerian National Gendarmerie on road accidents, Mars 2022.
- [3] B. Karthikeyan, M. Tamileniyar "Dynamic Data update for Intelligent Speed Adaptation (ISA)" System International Journal of Computer Applications (0975 -8887) Volume 11- No.1, December 2010.
- [4] "Intelligent Speed Assistance -Myths and Reality ETSC position on ISA" ISBN NUMBER: 90-76024-23-5.
- [5] Oliver Carsten, "Speed management through vehicle measures/ Intelligent Transport Systems", Institute for Transport Studies, University of Leeds.
- [6] O. Carsten "ISA: the Best Collision Avoidance System?", Proceedings of 17th Conference on the Enhanced Safety of Vehicles, Netherlands.
- [7] O. Carsten "ISA - From Fields Trials to Reality", PACTS conference Targets 2010: No Room for Complacency, London, 10 February 2004.
- [8] Carsten O, Tate F "Intelligent Speed Adaptation: Accident Savings and Cost-Benefit Analysis", Accident Analysis and Prevention 37, 2005.
- [9] Regan M, Triggs T, Young K, Tomasevic N, Mitsopoulos E, Stephan K and Tingvall C "On-road Evaluation of ISA, Following Distance Warning, and Seat Belt Reminder Systems: Final Results of the TAC Safecar Project", Monash University Accident Research Centre, September 2006.
- [10] Abdulsalam Ya'u Gital and al. "Review of GPS-GSM Based Intelligent Speed Assistance Systems: Development and Research Opportunities",

- International Conference on Intelligent Communication and Computational Techniques (ICCT) 2023.
- [11] Shaik Mohammad Ali, Shaik Mulla Zubair, Zafar Ali Khan N, "Vehicle control speed based on GPS matching posted speeds/images "International Journal of Research Publication and Reviews, Vol 3, Issue 6, June 2022.
- [12] Vera Roberts, "External Vehicle Speed Control/Intelligent Speed Adaptation", Casebook of Traumatic Injury Prevention, January 2020.
- [13] Z. Yatao, W. Jiangfeng, C. Sijie, G. Zhijun and H. Haitao, "Multi-tag Information Interactive Communication Model based on Precise Position Detection in Vehicle-Infrastructure Collaboration Environment," 2020 IEEE 5th International Conference on Intelligent Transportation Engineering (ICITE), Beijing, China, 2020.
- [14] Irina Popova, Elena Abdullina, Igor Danilov, Aleksandr Marusin, Alexey Marusin, Irina Ruchkina, Alexander Shemyakin, « Application of the RFID technology in logistics, » Transportation Research Procedia, Volume 57.
- [15] Z. Meng, Y. Liu, N. Gao, Z. Zhang, Z. Wu, and J. Gray, "Radio Frequency Identification and Sensing: Integration of Wireless Powering, Sensing, and Communication for IoT Innovations," in IEEE Communications Magazine, vol. 59, no. 3, pp. 38-44, March 2021.
- [16] Y. Liu, X. Meng, and X. Huang, "Route Planning Strategy of intelligent car Based on Camera Sensor," 2022 IEEE Asia-Pacific Conference on Image Processing, Electronics and Computers (IPEC), Dalian, China, 2022.
- [17] S. Gao, G. Kang, L. Yu, D. Zhang, X. Wei and D. Zhan, "Adaptive Deep Learning for High-Speed Railway Catenary Swivel Clevis Defects Detection," in IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 2, pp. 1299-1310, Feb. 2022.
- [18] Masatoshi Ishikawa "High-Speed Vision and its Applications Toward High-Speed Intelligent Systems", Journal of Robotics and Mechatronics, October 2022.
- [19] Biao Yu and al. "A Dead Reckoning Calibration Scheme Based on Optimization with an Adaptive Quantum-Inspired Evolutionary Algorithm for Vehicle Self-Localization", Entropy, August 2022.
- [20] Maxim Freydin, Barak Or, "Learning Car Speed Using Inertial Sensors for Dead Reckoning Navigation", IEEE Sensors Letters, September 2022.
- [21] Martin Brossard, Axel Barrau, Silvère Bonnabel, "AI-IMU Dead-Reckoning" IEEE Transactions on Intelligent Vehicles, March 2020.
- [22] Canyong Wang "Research and Application of Traffic Sign Detection and Recognition Based on Deep Learning" International Conference on Robots & Intelligent Systems (ICRIS),2018, Changsha, China.
- [23] Domen Tabernik, Danijel Skočaj "Deep Learning for Large-Scale Traffic-Sign Detection and Recognition", IEEE Transactions on Intelligent Transportation Systems 2019.
- [24] Bao-Long Le, Gia-Huy Lam, Xuan-Vinh Nguyen, The-Manh Nguyen, Quoc-Loc Duong, Quang Dieu Tran, Trong-Hop Do & Nhu-Ngoc Dao "A Deep Learning Based Traffic Sign Detection for Intelligent Transportation Systems", International Conference on Computational Data and Social Networks, CSoNet 2021: Computational Data and Social Networks pp 129–137.
- [25] Rajesh Kannan Megalingam, Kondareddy Thanigundala, Sreevatsava Reddy Musani, Hemanth Nidamanuru, Lokesh Gadde "Indian traffic sign detection and recognition using deep learning", International Journal of Transportation Science and Technology, Available online 26 June 2022.
- [26] Andrew Campbell, Alan Both, Qian Sun "Detecting and mapping traffic signs from Google Street View images using deep learning and GIS", Computers Environment and Urban Systems 77, June 2019.
- [27] Fatma Outay, Stéphane Galland, Nicolas Gaud, Abdeljalil Abbas-Turki, "Simulation of connected driving in hazardous weather conditions: General and extensible multiagent architecture and models", Engineering Applications of Artificial Intelligence 104 (2021) 104412, Available online 6 August 2021.
- [28] Shu Gong & Gang Hua, "Decision Making Analysis of Traffic Accidents on Mountain Roads in Yunnan Province", International Conference on Machine Learning for Cyber Security ML4CS 2022: Machine Learning for Cyber Security pp 228–237.
- [29] International Transport Forum, "Speed and crash risk", International Traffic Safety Data and Analysis Group, Research Report,2018.
- [30] Fernando Ramos, Efraín Tovar-Sánchez, Hugo Saldarriaga, Héctor Sotelo-Nava, Juan Paulo Sánchez-Hernández, María Luisa Castrejón-Godínez, "A CBR–AHP Hybrid Method to Support the Decision-Making Process in the Selection of environmental Management Actions", Sustainability 2019.
- [31] Documentation - SUMO Documentation (dlr.de) <https://sumo.dlr.de/docs/index.html>

Experimentation on Iterated Local Search Hyper-heuristics for Combinatorial Optimization Problems

Stephen A. Adubi¹, Olufunke O. Oladipupo², Oludayo O. Olugbara³

Computer and Information Sciences Covenant University, Ota 112104, Ogun State, Nigeria^{1,2}
MICT SETA 4IR Center of Excellence, Durban University of Technology, Durban 4001, South Africa³

Abstract—Designing effective algorithms to solve cross-domain combinatorial optimization problems is an important goal for which manifold search methods have been extensively investigated. However, finding an optimal combination of perturbation operations for solving cross-domain optimization problems is hard because of the different characteristics of each problem and the discrepancies in the strengths of perturbation operations. The algorithm that works effectively for one problem domain may completely falter in the instances of other optimization problems. The objectives of this study are to describe three categories of a hyper-heuristic that combine low-level heuristics with an acceptance mechanism for solving cross-domain optimization problems, compare the three hyper-heuristic categories against the existing benchmark algorithms and experimentally determine the effects of low-level heuristic categorization on the standard optimization problems from the hyper-heuristic flexible framework. The hyper-heuristic categories are based on the methods of Thompson sampling and iterated local search to control the perturbation behavior of the iterated local search. The performances of the perturbation configurations in a hyper-heuristic were experimentally tested against the existing benchmark algorithms on standard optimization problems from the hyper-heuristic flexible framework. Study findings have suggested the most effective hyper-heuristic with improved performance when compared to the existing hyper-heuristics investigated for solving cross-domain optimization problems to be the one with a good balance between “single shaking” and “double shaking” strategies. The findings not only provide a foundation for establishing comparisons with other hyper-heuristics but also demonstrate a flexible alternative to investigate effective hyper-heuristics for solving complex combinatorial optimization problems.

Keywords—Combinatorial optimization; heuristic algorithm; heuristic categorization; local search; Thompson sampling

I. INTRODUCTION

Combinatorial optimization problems (COPs) are practically challenging because of the different characteristics of each problem domain and multiple conflicting constrictions to be adequately resolved. They are intrinsically non-deterministic polynomial-time hard problems with no single method that can generally outperform others across varying problem instances [1]. Due to the intrinsic hiccups of the earlier heuristic, and meta-heuristic methodologies, hyper-heuristic has emerged as a feasible search methodology for solving multifarious COPs occurring in varying practical

applications [2]. It has been effectively applied in multiple application domains, including scheduling [3], [4], timetabling [5], routing [6]–[8], software engineering [9], [10], and manufacturing [11]. In general, hyper-heuristics provide two different types of search space, which are low-level heuristics (LLHs) and acceptance mechanisms. However, how to select LLHs and combine them with an acceptance mechanism to realize an effective strategy for solving different COPs is particularly challenging.

In recent times, different methods, including machine learning have been investigated to improve the performance of hyper-heuristic optimization strategies. In this paragraph, we briefly review some related works that have attempted to improve the performance of hyper-heuristics. The Q-learning was utilized to select LLHs for a multi-objective route planning problem [12] and to choose an action in solving the interaction testing problem [9]. Deep Q-network [6] was applied as a heuristic selection mechanism to solve two routing problems from the library of hyper-heuristics flexible (HyFlex) [13]. In addition, Q-learning was applied to solve six problems from the HyFlex library by learning the pair of selection and acceptance mechanisms that are most suitable for an instance of a given problem [14]. Thompson sampling (TS) learning based on the selection of LLHs was recently introduced for solving COPs [15]–[17]. Moreover, TS has been applied to automatically configure the perturbation behavior of iterated local search (ILS) to solve six HyFlex COPs [18]. The evolutionary-based ILS hyper-heuristic was recently designed and tested on the extended HyFlex COPs to provide further evidence of the necessity for more categories of algorithms with improved perturbation strength [19].

A new perturbation strategy for ILS was proposed in [20] to solve the problems of pseudo-Boolean optimization where decision variables are perturbed to improve a local search strategy by maximizing the distance between solutions and maximizing the fitness similarity. An ILS algorithm was proposed in [21] for solving the problem of aircraft landing based on a search methodology that successively invokes a local search procedure to find a local optimum solution. The authors used a perturbation operator to modify the current solution to escape from the local optimum and provide a new solution for the local search procedure. The fair-share iterated local search (FS-ILS) [22] is a simple state-of-the-art selection hyper-heuristic that uses a conservative restart condition to prevent restarts, and only restart when a method is stuck and

enough time is available to attain a solution of similar quality. The work [23] presented an efficient algorithm for solving the problem of aircraft landing based on a mechanism that hybridizes the ILS and simulated annealing (SA) algorithms to find a feasible aircraft scheduling solution within the range of target time. The sequence-based selection hyper-heuristic inspired by a hidden Markov model was proposed in [24] as a general purpose hyper-heuristic for solving cross-domain COPs. However, the authors conceded that the performance of a selection hyper-heuristic may vary depending on the choice of the LLHs and that not all the heuristics contribute to the improvement of a candidate solution during the search process unless they are applied in a combination with sequences of heuristics.

Despite myriads of research publications on hyper-heuristics, the published results on cross-domain optimization algorithms still need further improvement. The confines shown by the existing algorithms for solving different COPs have provided a unique opportunity to improve the performance of a hyper-heuristic across different problem domains. The findings from the literature have generally suggested that identifying the right intensity of perturbation operations in ILS is challenging but warrants further investigation [20]. The focus of the present work is to extensively experiment with three categories of the TS-ILS hyper-heuristic [18] imbued with different perturbation behaviors and compare their performances against the existing benchmark algorithms on HyFlex COPs. The testing of a hyper-heuristic algorithm on standard problems with varying characteristics will enable a meticulous comparison of its generalization capability. Since an ILS-based hyper-heuristic is potentially targeted toward solving numerous COPs, an efficient strategy for determining its proper perturbation behavior on a specific problem is paramount to the success of ILS methodology [7], [21].

The overarching objectives of the present work are threefold. To describe three categories of the TS-ILS hyper-heuristic that combine low-level heuristics with an acceptance mechanism for solving standard HyFlex COPs. To experimentally compare the three categories of the TS-ILS hyper-heuristic against the existing benchmark algorithms on the standard HyFlex COPs. To experimentally determine the effects of LLHs categorization on the standard HyFlex COPs. The remaining parts of the paper are fleetingly organized as follows. Section II describes the TS-ILS hyper-heuristic with three categorizations of LLHs. Section III presents the experimental results of comparing the three categories of the TS-ILS hyper-heuristic against the existing benchmark algorithms on the standard HyFlex COPs. Section IV examines the effects of LLHs categorization on the standard HyFlex COPs. Section V discusses the study results and highlights the potential areas for further improvement. The paper is ultimately concluded in Section VI by explicating the category of the TS-ILS hyper-heuristic that recorded a good balance between “single shaking” and “double shaking” configurations.

II. THOMPSON SAMPLING ITERATED LOCAL SEARCH

Thompson sampling iterated local search (TS-ILS) hyper-heuristic is a probabilistic learning of profitable perturbation operations for a problem instance [19]. The hyper-heuristic augments the functional capabilities of TS and ILS to control the perturbation behavior of ILS. It selects LLHs and accepts or rejects a solution using the FS-ILS [22]. The local search phase of the hyper-heuristic is triggered after a perturbation process to improve the solution obtained from the perturbation stage, while the resultant solution is then considered for acceptance. There are six configurations in the $\text{config} = \{0, 1, 2, 3, 4, 5\}$ set and each one is an integer representation of a perturbation operation. Table I defines each element of a perturbation configuration set of length n , where the value of n was taken to be 6 in the present work.

TABLE I. PERTURBATION OPERATIONS OF THE TS-ILS HYPER-HEURISTIC

Value	Operation
0	Perturb with Mutation LLH + Mutation LLH (Mut + Mut)
1	Perturb with Mutation LLH + Ruin-Recreate LLH (Mut + RR)
2	Perturb with Ruin-Recreate LLH + Mutation LLH (RR + Mut)
3	Perturb with Ruin-Recreate LLH + Ruin-Recreate LLH (RR + RR)
4	Perturb with Mutation LLH only (Mut)
5	Perturb with Ruin-Recreate LLH only (RR)

The TS-ILS hyper-heuristic algorithm learns promising perturbation operations for the ILS by splitting the mutation (Mut) and ruin-recreate (RR) heuristics into two distinct entities as in the first two lines of Algorithm 1. The two vectors α and β are respectively representing the success and failure tallies for the perturbation configurations in the config set. The pair of elements in the two vectors at the same corresponding positions respectively correspond to the success and failure counts of the options in the config set. The initial solution for the problem instance being solved is generated. The resultant solution is then used to initialize the current solution S_0 and the best solution found so far (S_b). The Thompson sampling procedure generates the utility values for the elements of the config set based on tallies that are stored in the vectors α and β by sampling from a Beta distribution. This phase of the TS-ILS hyper-heuristic algorithm decides which of the perturbation operations that are represented in the config set is to be invoked. These perturbation operations can be seen as the alternative operators to be selected in the bandit problem. The corresponding first element, α_0 and β_0 of the α and β vectors are respectively passed as parameters to the sampling module to generate the utility value for the first element in the config set. The pseudocode for the TS-ILS hyper-heuristic algorithm is given by the following **Algorithm 1**.

Algorithm 1: TS-ILS Hyper-heuristic

```
 $M \leftarrow \{m_1, m_2, \dots, m_j\}$   
 $R \leftarrow \{r_1, r_2, \dots, r_k\}$   
config  $\leftarrow \{c_1, c_2, \dots, c_n\}$  ▷ Line 3  
 $\alpha \leftarrow \{0, \dots, 0\}$   
 $\beta \leftarrow \{0, \dots, 0\}$   
 $S_0 \leftarrow \text{generateInitialSolution}()$   
 $S_b \leftarrow S_0$   
while ( $\neg$ stopping_condition) do  
     $\Phi = \{\phi_1, \dots, \phi_i\} \leftarrow \text{generateUtilityValues}()$   
    select i from config:  $\phi_i$  maximizes  $\Phi$   
     $S' \leftarrow \text{perturb}(S_0, i)$   
     $S'' \leftarrow \text{localSearch}()$   
    if ( $S''$  is accepted) then  
         $S_0 \leftarrow S''$   
    end  
    if ( $S'' < S_b$ ) then  
         $\alpha_i \leftarrow \alpha_i + 1$   
        updateLS()  
        updateParam()  
    else  
         $\beta_i \leftarrow \beta_i + 1$   
    end  
    updateLLH()  
end
```

Studying the effects of LLHs categorization on the standard HyFlex COPs is paramount to the present work to determine the most appropriate algorithm for solving cross-domain COPs. Thus, TS-ILS1, TS-ILS2, and TS-ILS3 hyper-heuristics constitute three categories of the TS-ILS hyper-heuristic algorithm. The TS-ILS1 uses the subset {4, 5} and perturbs a solution once before intensification. The TS-ILS2 uses the subset {1, 2, 4, 5} and has been featured in the previous study [18]. The TS-ILS3 uses the entire set {0, 1, 2, 3, 4, 5} and all the options presented in Table I during the perturbation stage. The TS-ILS1 can only perturb a solution once before the intensification (single shaking) phase while the last two categories can perturb a resolution twice before the intensification (double shaking) phase. These differences are enforced by line 3 of Algorithm 1 [18] which has been extended in this study to any set of perturbation configurations. The categorizations have significantly affected the TS-ILS hyper-heuristic for solving diverse COPs. This is because the different perturbation strengths determine the effectiveness of the ILS-based hyper-heuristics [7], [20], [23].

The element of the set config that maximizes the utility values in Φ is selected, and the corresponding perturbation operation is carried out as designated in the next two lines. During the perturbation phase, the *speedNew* selection mechanism [14], [22] is employed to choose a given candidate LLH selected by the TS procedure. For example, if the selected configuration is 2, the selection mechanism chooses a perturbative LLH from the ruin-recreate set and applies it to a solution. The resultant solution is further perturbed by selecting and applying a perturbative LLH from the mutation set. The intensity of mutation and the depth of search are two parameter

archetypes in the HyFlex framework for parameterizing the use of LLHs [13]. A parameter value is chosen within the {0.0, 0.1, ..., 1.0} set of 11 values using a roulette-wheel procedure for the selected LLH to be analogously parameterized as in [24]. The local search module of the TS-ILS hyper-heuristic [18], [19] is triggered on the resultant solution to produce another solution (S''). The next operation decides if S'' is to be accepted to replace the current solution S_0 based on the accept probabilistic worse (APW) acceptance mechanism [14], [22].

The success tally (α_i) of the i element of the config set invoked in the current iteration is incremented only if the solution generated is strictly better than the best solution (S_b) found so far, otherwise, the value of β_i is incremented. This update scheme has enabled the TS-based probabilistic learning algorithm to adjust its preference according to the observed rewards of the alternative actions to be taken at every iteration. The function updateLLH() updates the parameters of the perturbative LLHs applied based on the speedNew selection mechanism. This update scheme does not apply to the local search heuristics and further details of how it is carried out can be found in [22]. The function updateLS() updates the data structures of the local search heuristics employed for the local search phase of the ILS hyper-heuristic. Finally, the function updateParam() updates the utility matrix used by the parameters of parameterized LLHs from the local search, mutation, and ruin-recreate operations. The entry for the parameter value selected by a roulette wheel procedure is updated after the iteration. The selection and update of values for the parameterized LLHs are analogous to the implementation in [24].

III. EXPERIMENTAL RESULTS

Three categories of the TS-ILS hyper-heuristic were implemented on an Intel i5-3340M CPU computer with random access memory of 8 gigabytes and a 2.70 gigahertz clock speed. The TS-ILS1, TS-ILS2, and TS-ILS3 hyper-heuristics were tested on the problem instances of Boolean satisfiability (SAT), Bin packing (BP), Personnel scheduling (PS), Permutation flow-shop (PFS), Travelling salesman problem (TSP), and Vehicle routing problem (VRP) reported in HyFlex v1.0. The testing was also performed on the ten instances of the Knapsack problem (KP), Quadratic assignment problem (QAP), and Maximum cut (MAC) problem reported in HyFlex v2.0. The execution time returned by a benchmark program on the computer machine is 507 seconds, which is the equivalent of 600 seconds on a standard testing machine according to the organizers of the cross-domain heuristic search challenge (CHeSC) in 2011.

The comparison of the different algorithms is based on the metrics of median objective function values (ofvs), formula one, μ -norm, and boxplot visualization as subsequently illustrated. The performances of the three categories of the TS-ILS hyper-heuristic were compared using the ofvs across nine HyFlex COPs. In addition, the performances of TS-ILS1, TS-ILS2, and TS-ILS3 were compared with those of the FS-ILS, NR-FS-ILS, AdapHH, EPH, SR-IE, SR-AM, and SSHH benchmark algorithms [25], [26] across eight HyFlex COPs. The results obtained for the PS problem by the existing algorithms could not be compared with those computed by TS-

ILS1, TS-ILS2, and TS-ILS3 because of the differences in the updated Java library used in the present work. The updated library has fixed a bug in the previous library that was used to produce the results [26]. The overall comparison of the algorithms will be prejudicial if an attempt is made to incorporate the results obtained for the PS problem. The data used for testing the existing algorithms, excluding the SSHH on HyFlex problems, were obtained online (<https://github.com/Steven-Adriaensen/hyflex>). The ofvs of the results computed by the SSHH algorithm can be found in [25]. In total, 60 instances of HyFlex COPs were tested for each of the three categories of TS-ILS hyper-heuristic based on the median ofvs. Moreover, 55 instances of the HyFlex COPs were tested separately for each of the three categories of the

TS-ILS hyper-heuristic. The three categories were also compared with seven benchmark algorithms based on the formula one, μ -norm, and boxplot visualization of median ofvs.

A. Comparison based on Median ofvs

Tables II and III highlight the performances of the TS-ILS categories in terms of the median ofvs obtained across the benchmark instances of the HyFlex COPs. The KP, QAP, and MAC problems of HyFlex v2.0 have ten benchmark instances which are five more than the first six problems of SAT, BP, PS, PFS, TSP, and VRP in HyFlex v1.0. The values in bold font denote the median ofv of the hyper-heuristic that reported the best performance for a problem instance.

TABLE II. MEDIAN OFVS OBTAINED BY CATEGORIES OF TS-ILS HYPER-HEURISTIC ON SIX HYFLEX V1.0 PROBLEMS

Problem	Category	Problem Instance				
		1	2	3	4	5
SAT	TS-ILS1	2.00000000	2.00000000	1.00000000	1.00000000	9.00000000
	TS-ILS2	2.00000000	3.00000000	1.00000000	1.00000000	8.00000000
	TS-ILS3	2.00000000	3.00000000	1.00000000	1.00000000	9.00000000
BP	TS-ILS1	0.02371400	0.00807447	0.00491703	0.10828062	0.01260111
	TS-ILS2	0.01876799	0.00350695	0.00052035	0.10828402	0.00142866
	TS-ILS3	0.01828719	0.00355599	0.00236484	0.10828455	0.00557662
PS	TS-ILS1	19.00000000	9546.00000000	3213.00000000	1609.00000000	330.00000000
	TS-ILS2	21.00000000	9548.00000000	3181.00000000	1550.00000000	330.00000000
	TS-ILS3	21.00000000	9570.00000000	3193.00000000	1593.00000000	335.00000000
PFS	TS-ILS1	6223.00000000	26755.00000000	6323.00000000	11327.00000000	26585.00000000
	TS-ILS2	6232.00000000	26785.00000000	6325.00000000	11340.00000000	26601.00000000
	TS-ILS3	6237.00000000	26788.00000000	6323.00000000	11354.00000000	26605.00000000
TSP	TS-ILS1	48194.92010000	20701672.20000000	6809.10000000	66194.70000000	53806.20000000
	TS-ILS2	48194.92010000	20779493.20000000	6805.30000000	66133.00000000	53762.40000000
	TS-ILS3	48194.92010000	20817079.70000000	6804.70000000	66150.80000000	53635.70000000
VRP	TS-ILS1	65151.40000000	13290.50000000	146927.10000000	20654.10000000	145865.40000000
	TS-ILS2	63709.00000000	13292.80000000	145401.50000000	20654.70000000	145205.40000000
	TS-ILS3	62658.50000000	13285.50000000	146801.90000000	20654.00000000	145436.20000000

TABLE III. MEDIAN OFV OBTAINED BY CATEGORIES OF TS-ILS HYPER-HEURISTICS ON THREE HYFLEX V2.0 PROBLEMS

Problem	Problem Instance	TS-ILS1	TS-ILS2	TS-ILS3
KP	0	-104046	-104046	-104046
	1	-1257913	-1258367	-1259059
	2	-242324	-242255	-242179
	3	-431342	-431340	-431336
	4	-396167	-396167	-396167
	5	-4254605	-4254402	-4252958
	6	-941561	-940026	-939070
	7	-1577175	-1577175	-1577175
	8	-1530489	-1530479	-1530470
	9	-1467357	-1467357	-1467357
QAP	0	152112	152132	152156
	1	153972	154036	154036
	2	147894	147952	147944
	3	149782	149768	149778
	4	21276862	21269484	21307840

	5	1187188954	1186656060	1186575184
	6	501189032	501487948	501258178
	7	44863086	44865718	44870864
	8	8154812	8155312	8153852
	9	273212	273228	273266
MAC	0	-41375743	-41417466	-41324351
	1	-277192517	-276843715	-277614604
	2	-3054	-3054	-3055
	3	-3032	-3034	-3034
	4	-3037	-3039	-3038
	5	-13217	-13216	-13227
	6	-1354	-1358	-1356
	7	-10077	-10093	-10084
	8	-456	-456	-456
	9	-2906	-2914	-2912

B. Comparison based on Formula One

The formula one scoring system has inspired one of the well-known metrics for evaluating hyper-heuristics [2]. Competing hyper-heuristics are assigned points based on the ofvs of their median best solutions obtained after 31 trials for each problem instance in the given test suite. The scores of 10, 8, 6, 5, 4, 3, 2, and 1 are respectively awarded to the best performing hyper-heuristic down to the eight-best one for a problem instance. Ties are handled by averaging the points that would have been given to one hyper-heuristic if there was no tie and assigning each of the hyper-heuristics the average score. In the rating system, the higher the score, the better the performance of a hyper-heuristic relative to the median results obtained by other hyper-heuristics.

The results of comparing eight hyper-heuristics on HyFlex COPs using formula one scores are presented in Table IV. The overall score in the table is the sum of scores obtained by a

given hyper-heuristic across problem instances. The categories of the TS-ILS hyper-heuristic can be observed to emerge as the most dominant hyper-heuristics across the HyFlex COPs considered. The overall performance of the categories of the TS-ILS hyper-heuristic on HyFlex v2.0 COPs was found to be superior to the performances of the other hyper-heuristics. The maximum score for each HyFlex v2.0 problem domain is 100 with the highest score of 10 for each problem instance. It can be inferred that the top three hyper-heuristics on HyFlex v1.0 problem based on the formula one scoring are TS-ILS2 with 162.8 points, followed by TS-ILS3 with 148.8 points, and TS-ILS1 with 146.9 points. The order of performances of the algorithms on HyFlex v2.0 problem instances is TS-ILS2 with 215.8 points, followed by TS-ILS1 with 214.8 points, and TS-ILS3 with 203.3 points. It is noticeable that there is a close race performance among the three categories of the TS-ILS hyper-heuristic on HyFlex v2.0, while TS-ILS2 outperformed the other categories on HyFlex v1.0. problems.

TABLE IV. FORMULA ONE RANKING OF CATEGORIES OF TS-ILS HYPER-HEURISTIC ON EIGHT HYFLEX PROBLEMS, EXCLUDING PS

Problem	AdapHH	EPH	FS-ILS	NR-FS-ILS	SR-AM	SR-IE	SSHH	TS-ILS1	TS-ILS2	TS-ILS3
SAT	21.00	10.00	34.85	23.35	0.00	5.00		35.10	34.85	30.85
BP	18.00	19.00	11.00	18.00	0.00	18.00		29.00	44.00	38.00
PFS	19.50	11.50	25.00	27.50	5.00	0.00		47.00	32.50	27.00
TSP	23.00	26.00	25.50	22.00	2.00	3.00		29.50	33.00	31.00
VRP	20.00	16.00	26.00	22.00	0.00	8.00		28.00	35.000	40.00
Overall	101.50	82.50	122.35	112.85	7.00	34.00		168.60	179.35	166.85
KP	59.23	49.33	6.21	11.21	19.85	7.83	48.33	69.33	62.33	56.33
QAP	40.00	26.00	31.50	40.50	20.00	0.00	2.00	84.00	74.00	72.00
MAC	28.50	5.00	14.50	20.00	36.50	1.00	68.50	61.50	79.50	75.00
Overall	127.73	80.33	52.21	71.71	76.36	8.83	118.83	214.83	215.83	203.33

C. Comparison based on μ -norm Metric

This section compares the performances of ten hyper-heuristics across eight HyFlex COPs based on the μ -norm scores [25], [26]. The μ -norm is the average normalized evaluation function value. It is a more robust evaluation metric than the formula one scoring because it evaluates the performance of a hyper-heuristic based on the quality of the 31 solutions obtained over 31 trials on a problem instance. The μ -norm metric enables all the obtained ofvs to be normalized within the range [0, 1], where 0 means a hyper-heuristic outperforms other hyper-heuristics on all the tested instances, and a value of 1 connotes the opposite.

Table V provides comparative results of the categories of TS-ILS hyper-heuristics against the existing ones using the μ -norm scores. The data for the existing hyper-heuristics on the problem domains presented in Table V were taken from the paper [26]. The categories of the TS-ILS hyper-heuristic jointly

won seven out of the eight HyFlex problems. They outperformed the other hyper-heuristics on the PFS, KP, and QAP. The only problem domain where none of the categories of the TS-ILS hyper-heuristic recorded the best μ -norm value is SAT, where FS-ILS emerged as the best hyper-heuristic. The AdapHH is the closest challenger to the top algorithm (TS-ILS1) on the Knapsack problem. The three categories of the TS-ILS hyper-heuristic dominated all others on the QAP and MAC problems because they all constituted the top three successful algorithms across the problem domains. The EPH and SR-IE algorithms obtained the worst results on the MAC problem. The overall performance in Table V further consolidates the observation that the three categories of the TS-ILS hyper-heuristic are general in their applications to HyFlex v2.0 problems. Overall, the next best algorithms based on the μ -norm score, after the three categories of the TS-ILS hyper-heuristic, are AdapHH and FS-ILS, while the SR-AM algorithm delivered the worst performance.

TABLE V. COMPARATIVE RESULTS USING μ -NORM ON EIGHT HYFLEX PROBLEMS, EXCLUDING PS

Problem	TS-ILS2	TS-ILS3	TS-ILS1	AdapHH	FS-ILS	NR-FS-ILS	EPH	SR-IE	SR-AM
SAT	0.0159	0.0184	0.0181	0.0276	0.0146	0.0238	0.0927	0.3787	0.8759
BP	0.0138	0.0316	0.0852	0.1828	0.1727	0.1581	0.1478	0.1769	0.9559
PFS	0.1676	0.1817	0.1263	0.2224	0.2059	0.1816	0.2671	0.7242	0.6223
TSP	0.0538	0.0556	0.0584	0.0677	0.0647	0.0626	0.0658	0.4993	0.5392
VRP	0.0623	0.0538	0.0731	0.0841	0.0687	0.0832	0.2186	0.2714	0.9347
KP	0.0315	0.0308	0.0276	0.0297	0.1513	0.0554	0.3625	0.3312	0.3970
QAP	0.0728	0.0795	0.0689	0.1089	0.1512	0.1396	0.1062	0.6363	0.1097
MAC	0.1018	0.0987	0.1112	0.2829	0.2585	0.5222	0.3772	0.7371	0.3946
Overall	0.0649	0.0688	0.0711	0.1258	0.1360	0.1533	0.2047	0.4694	0.6037

D. Comparison based on Boxplot Visualization of Median ofvs

Fig. 1 presents the boxplots of the normalized ofvs of ten hyper-heuristics in Table IV. The minimum–maximum normalization scheme was applied to obtain the normalized median ofv of a hyper-heuristic on a particular instance of a problem domain [25]. The performances of the categories of the TS-ILS hyper-heuristic were benchmarked against the existing hyper-heuristics on HyFlex problems [26].

KP, The median score of the TS-ILS2 appears to be closest to the base of the plot in Fig. 1(a) to indicate good performance. A similar phenomenon can be observed for the TS-ILS1 and TS-ILS3 categories. The TS-ILS2 and TS-ILS3 have smaller boxes than the TS-ILS1 category. The three categories performed better than any of the other algorithms on the HyFlex v1.0 problems. The gap in the performance of the categories of the TS-ILS hyper-heuristic and other hyper-heuristics is more glaring for the QAP, and MAC HyFlex v2.0 problems.

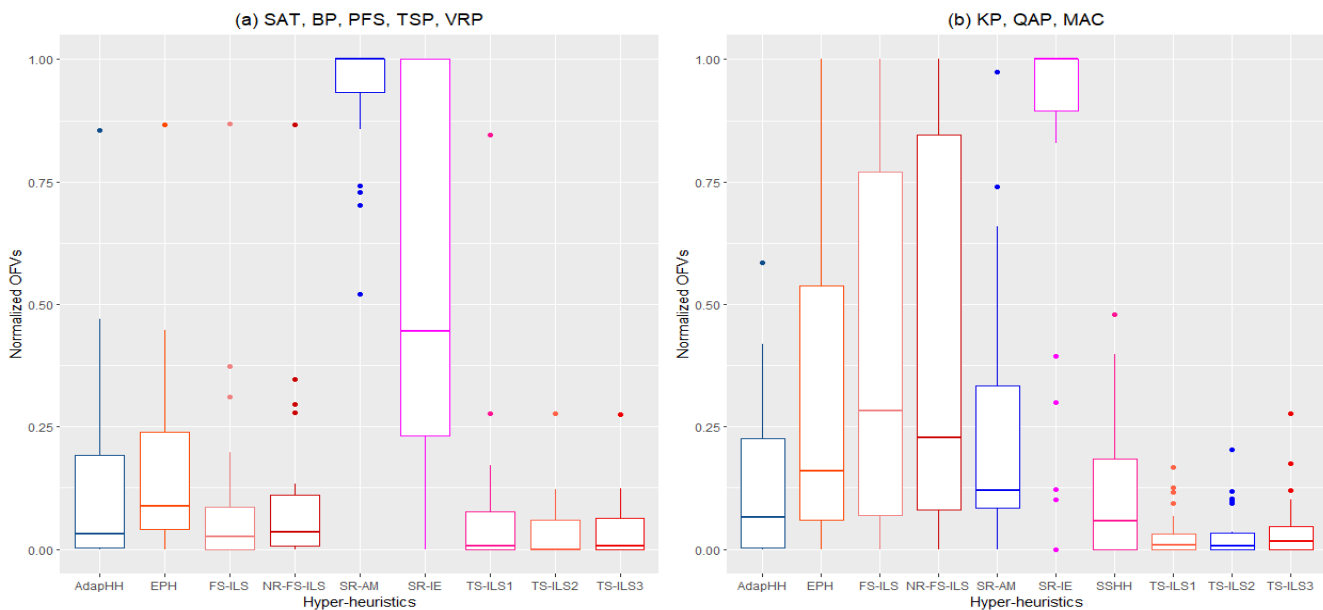


Fig. 1. Boxplots of the overall normalized median of fvs obtained by the hyper-heuristics in Table IV.

The sizes of the boxes in Fig. 1(b) support the dominance of the categories of the TS-ILS hyper-heuristic. The interquartile range of the boxplots of each of the three categories of the TS-ILS hyper-heuristic is a minimal value, denoting low variability in their data. Combining the interquartile range with the proximity of the boxes to the minimum score means that the categories have enjoyed dominance over other algorithms on almost all problem instances of Knapsack, Quadratic Assignment, and Maximum-Cut. The categories can be observed to generalize well across eight HyFlex problem domains in sharp contrast to the other standard ILS hyper-heuristics, like FS-ILS and NR-FS-ILS.

IV. EFFECTS OF LOW-LEVEL HEURISTICS CATEGORIZATION ON HYFLEX PROBLEMS

The effects of LLHs on HyFlex problems have been investigated in this work. The first TS-ILS1 hyper-heuristic does not employ the double shaking strategy, but the other two categories that respectively implemented four and six perturbation configurations do. The problem domains of Bin packing, Permutation flow-shop, Knapsack, Maximum cut, Vehicle routing, and Quadratic assignment were chosen to demonstrate the differences among the three categories of the TS-ILS hyper-heuristic. The values in the config set have been defined according to the entries in Table I. The parameter C1 represents the first option that applied two mutation heuristics in succession before the application of the intensification heuristic. The parameter C6 represents the application of only one ruin-recreate heuristic before applying the intensification heuristic. The heuristic calls were recorded throughout the problem-solving process to obtain the boxplots. In addition, the perturbation configurations applied at each iteration were recorded accordingly. If a successful iteration of the best new solution is produced, the selected tally of a configuration was recorded. The log files of the top three runs for each problem domain were congregated for each category of the TS-ILS hyper-heuristic as shown in Fig. 2 to 4.

It is important to explain Fig. 2 to 4 to provide more clarity before interpreting the results provided by the figures. The multiple bar charts provide the success rates of the six different perturbation configurations (C1 to C6) for the three TS-ILS categories of TS-ILS1 (red), TS-ILS2 (blue), and TS-ILS3 (black). TS-ILS1 is a single shaking variant that utilizes the two configurations of mutation only (C5) and ruin-recreate only (C6) and therefore, it explains why only two red bars appear in each of the charts. Similarly, TS-ILS2 utilizes four configurations (C2, C3, C5, and C6) and it explains why only a maximum of four blue bars can be seen on each chart. The most successful configuration for both the TS-ILS2 and TS-ILS3 is C6 using the BP9 instance of Fig. 2 as an example, while the most successful configuration for TS-ILS1 is C4. This means that the application of only the ruin-recreate heuristic (C6) has found more best new solutions than any other configuration during the run of TS-ILS1 and TS-ILS2. However, for TS-ILS3, the application of two ruin-recreate heuristics in succession before the intensification (C4) was found to be the most productive option. Consequently, because TS-ILS2 outperformed TS-ILS3 on the multiple trials on the BP9 instance, it could be said that TS-ILS3 having so many configurations (six) slowed down its performance on the BP9 instance when compared to the performance of TS-IL2. Finally, the presence of the double shaking configuration (C2) in both TS-IL2 and TS-ILS3 has made them superior solvers than TS-ILS1 on the BP9 instance because the configuration has contributed to almost 40% of the best solutions found during the runs of TS-ILS2 and TS-LS3.

Most successful iterations were achieved with the application of ruin-recreate heuristics for the TS-ILS1 on the BP problem domain. This can be seen in the C6 column of the TS-ILS1 which has the highest bar for all instances. The TS-ILS2 and TS-ILS3 are better algorithms for solving the BP problem. They utilize more pairing of heuristics, especially with the pairing of Mut and RR (C2). Though, an exception is observed in the BP10 instance, where a single application of

RR is the most rewarding strategy. This phenomenon explains why the TS-ILS1 category, which is the weakest algorithm on the BP problem, outperformed its counterparts on the BP10 instance. The reason is that it could easily focus on the RR among only two options with the second option of Mut (C5) being a bad choice. The overall comparison of the performances of the hyper-heuristics on the BP problem domain has shown in Table II that the TS-ILS2 and TS-ILS3 are better than the TS-ILS1 across four of the five problem instances. This can be traced to their heavy reliance on C2, which cannot be observed for the TS-ILS1 category.

The single application of perturbation heuristics from the Mut is the best strategy for solving the instances of the PFS problem as evidenced in the plots of PFS3, PFS8, PFS10, and PFS11. It is not surprising that the TS-ILS1 outperformed the TS-ILS2 and TS-ILS3 categories. The six options available to the TS-ILS3 have appeared to be noisy. The reason is that it would take a considerable number of epochs for the TS procedure to converge using only the Mut strategy (C5) while solving the instances of the PFS problem. The double shaking options available to the TS-ILS2 and TS-ILS3 somewhat mired them from performing at a higher level for most instances of KP2, KP5, and KP6 of the knapsack problem. Interestingly, the four instances of KP1, KP2, KP5, and KP6 perfectly present the TS-ILS2 with four options as the most balanced based on the number of perturbation configurations. Observing the behavior of the TS-ILS3 on the MAC problem instances, none of the double shaking options of Mut + RR, RR + Mut, RR + RR, and Mut + Mut have a lower bar than the single perturbation options. This observation implies the importance

of pairing heuristics for solving these instances, and it explains why the TS-ILS2 and TS-ILS3 outperformed the TS-ILS1 on the problem. More interestingly, the performance of the TS-ILS2 on the MAC problem diverges from the performance of the other categories. Comparing their median ofvs across the ten problem instances, the TS-ILS2 obtained a lower (better) value across five problem instances while the TS-ILS3 managed to achieve the same feat in only three problem instances. This means that the two double-shaking options available to it are sufficient to make it excel in solving the MAC problem instances.

The mutation heuristics are more appropriate for the VRP problem because the column for the application of mutation heuristics is way longer than the application of ruin-recreate heuristics for the three categories of the TS-ILS hyper-heuristic. It is innocuous to generally conclude that the TS-ILS3 is a better solver of the VRP problem instances. This assertion can be justified by comparing the figures for the TS-ILS1, TS-ILS2, and TS-ILS3 on the VRP problem with their median ofvs in Table II. The top two perturbation configurations of the TS-ILS hyper-heuristic are the application of Mut and Mut + Mut (Fig. 4). The latter may be why the TS-ILS3 has performed better than the TS-ILS1 and TS-ILS2 on the VRP problem according to the values presented in Table V. This is because only the TS-ILS3 possesses the Mut + Mut option. The TS-ILS1 effectively leveraged the effectiveness of mutation heuristics on the QAP, while the plot for the TS-ILS2 and TS-ILS3 have demonstrated their partial reliance on the Mut option only.

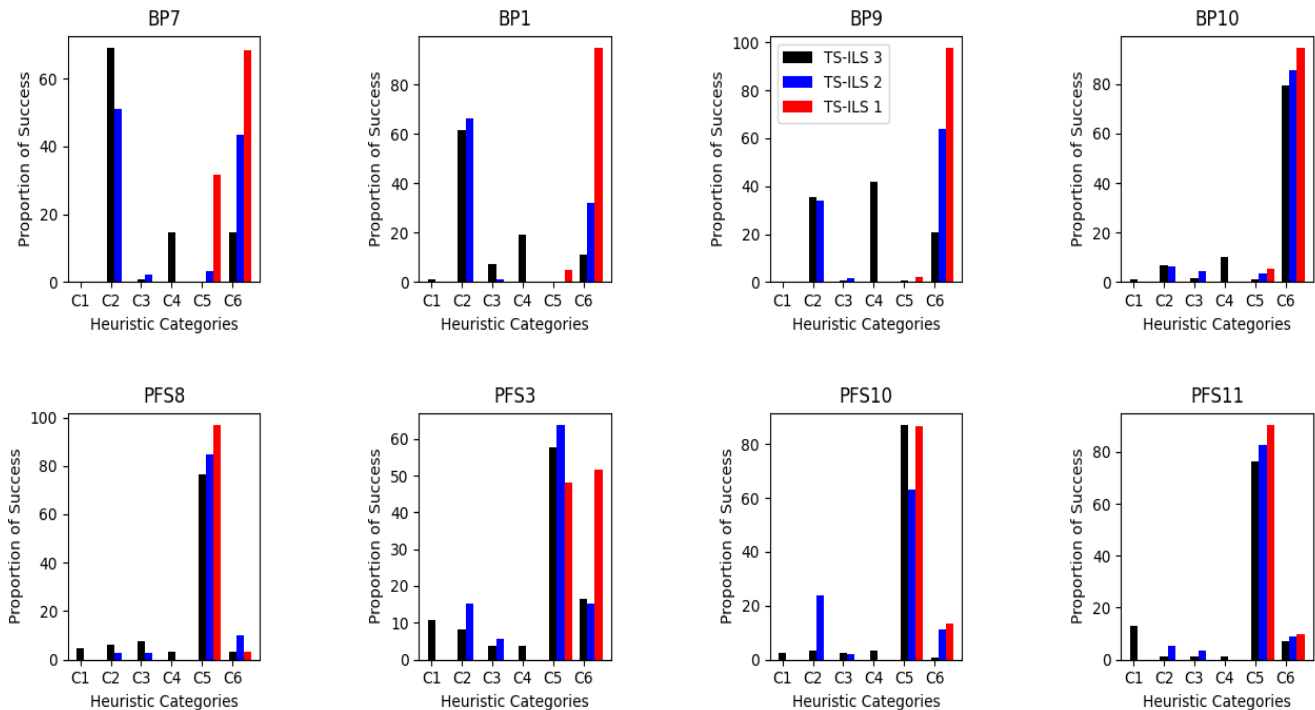


Fig. 2. The analysis of the perturbation configurations on the BP and PFS problems.

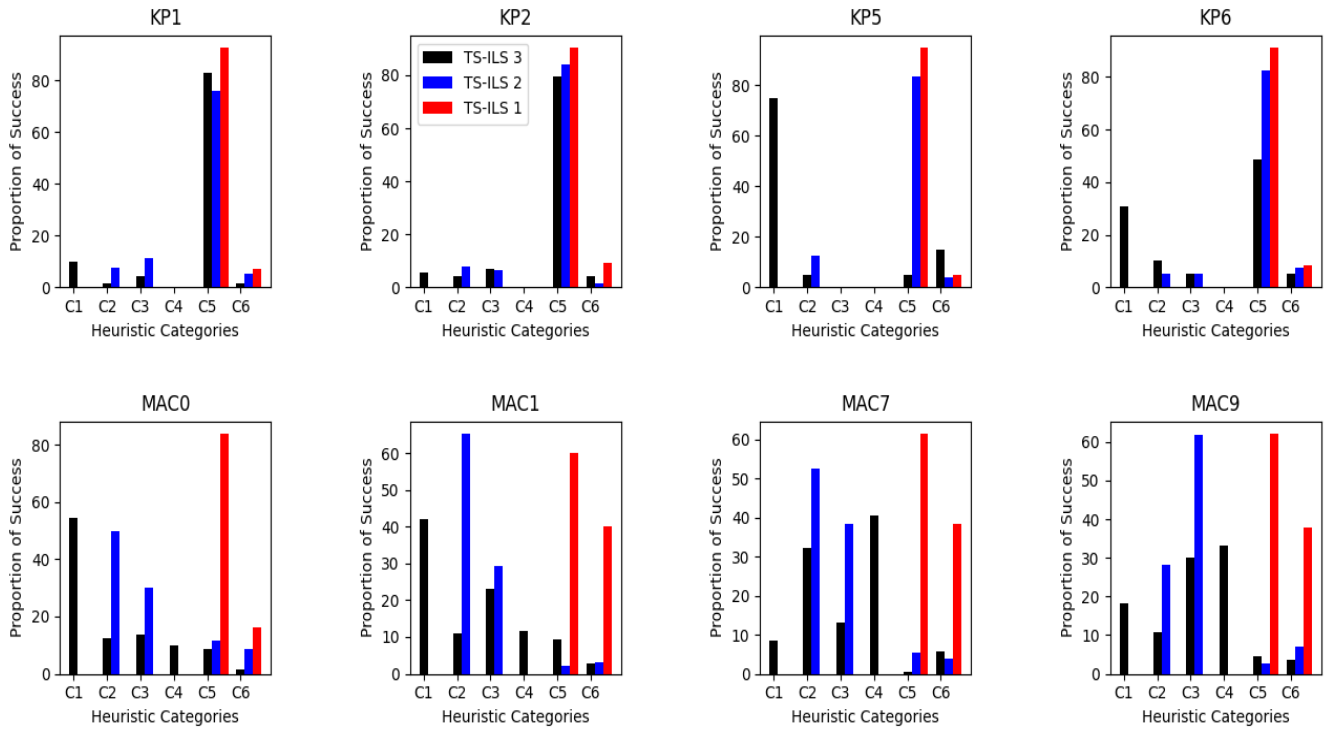


Fig. 3. The analysis of the perturbation configurations on the KP and MAC problems.

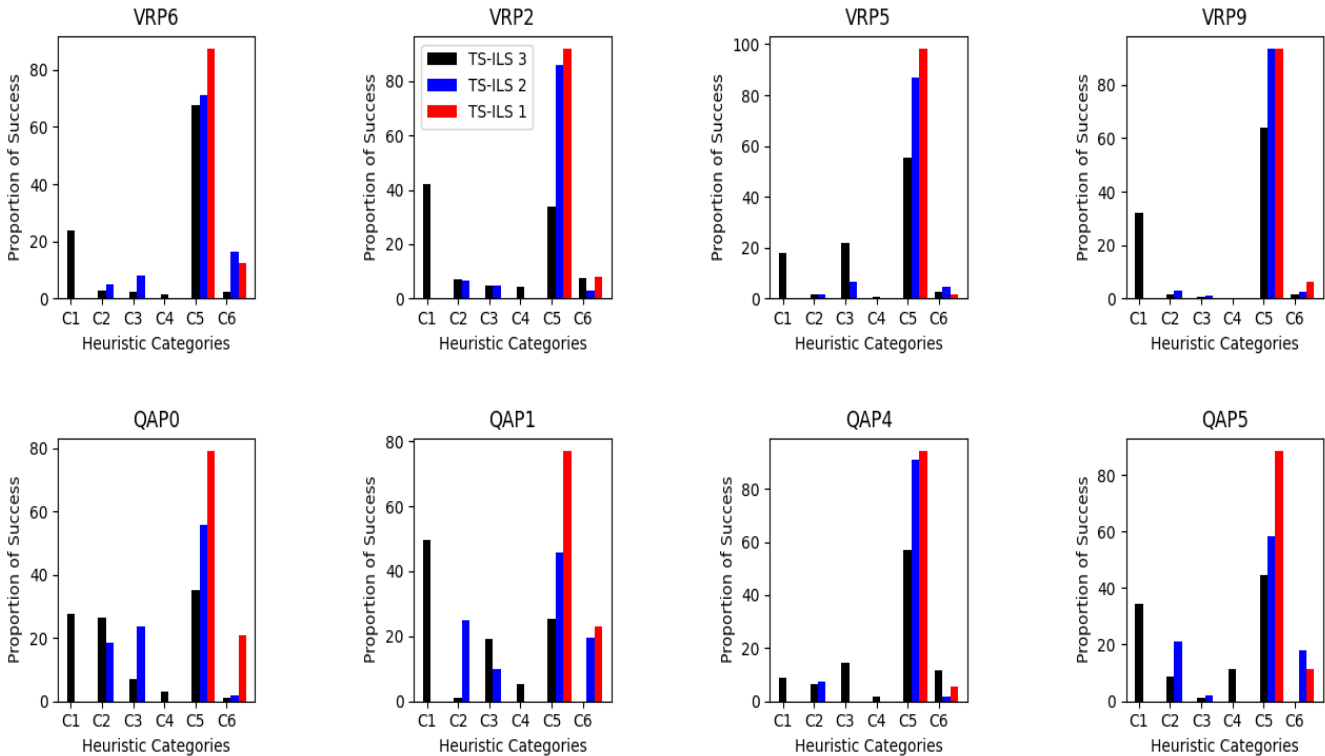


Fig. 4. The analysis of the perturbation configurations on the VRP and QAP problems.

V. DISCUSSION OF RESULTS

In this section, an extensive discussion of the results computed by the three categories of the TS-ILS hyper-heuristic

is provided. The study results generally indicate why the TS-ILS algorithm is effective using a component-based analysis of the hyper-heuristic. In addition, a few areas where further

improvement of the TS-ILS hyper-heuristic is required are highlighted in this section. The TS-ILS hyper-heuristics share similarities with existing ILS-based hyper-heuristics like FS-ILS [22]. The FS-ILS selects a single LLH heuristic during the perturbation stage by engaging a heuristic selection metric based on the ratio of the number of improvements made on an incumbent solution by an LLH to the total amount of its execution time when invoked. The TS-ILS hyper-heuristics use the same procedure to select LLHs, but the perturbation actions are governed by a Thompson sampling layer procedure that is featured in Algorithm 1.

Experimentation was set up to study the perturbation behavior of FS-ILS, TS-ILS1, TS-ILS2, and TS-ILS3 to reinforce the claim made in Section I about the need to control the depth of a perturbation. The experimentation profiles how these four hyper-heuristics solve cross-domain optimization problems, with results showing the weakness of some algorithms like FS-ILS, and why the successful categories of TS-ILS hyper-heuristics have overcome this weakness by varying perturbation control mechanisms. In the experimentation, three instances BP9, KP1, and MAC6 from three different problem domains were selected. The selected instances were taken from the problem domains where FS-ILS struggled to obtain good results to study if the perturbation control mechanisms of TS-ILS algorithms were responsible for their success. The four algorithms were run wherein each trial lasted for 279 secs, and the starting solution of each hyper-heuristics was initialized using the same seed. Tables VI, VII, and VIII present the results of the experiments for BP9, KP1, and MAC6 respectively.

There are seven trials for each algorithm, and the entries for the second trial of BP9 can be seen in the row “BP9-2”. This convention is used in all the tables for easy understanding. The average values obtained for the four algorithms in the order of appearance in the tables on the BP9 instance are captured in the following set {0.01247419, 0.00565258, **0.00137980**, 0.00400226}. Likewise, the average values for the KP1 instance are {-1235575.0, **-1256610.9**, -1249428.4, -1250803.0} and finally, for MAC6, it is {-1330.3, -1348.3, **-1354.9**, -1350.6}. Each entry in the last six columns (“Mut + Mut” to “RR”) represents the number of times a configuration was used during the run of a hyper-heuristic. For example, FS-ILS invoked 8,834 ruin-recreate heuristics and 7,324 mutation heuristics during its first trial as in row BP9-1 of Table VI.

The evaluation of the results presented in Table VI shows a huge discrepancy in the perturbation behavior of the FS-ILS

and TS-ILS algorithms. It can be observed that while the TS-ILS algorithms choose to use more ruin-recreate heuristics, FS-ILS did not discriminate amongst the two categories of perturbative heuristics, although it did slightly favor the ruin-recreate heuristics. This explains why FS-ILS did not perform well on Bin packing problems. The poor performance of FS-ILS for the trials on the instance of KP1 can be blamed on the issue that plagued it. Its relatively lower number of perturbation-intensification cycles (sum of the invocations of the number of perturbation and ruin-recreate heuristics) when compared with the TS-ILS algorithms. For the first three trials on KP1, FS-ILS completed an average of 173.3 cycles as opposed to 1,019.7 cycles for TS-ILS, 1,074 cycles for TS-ILS2, and 1,150 cycles for TS-ILS3. This means that FS-ILS did not have enough opportunity to search the heuristic space (and ultimately the solution space) unlike the TS-ILS variants. The main reason for this problem of FS-ILS is its excessive invocations of local search heuristics during the intensification phase, as reported in a previous study [19]. Finally, on the MAC6 instance, although the number of cycles completed by FS-ILS is not too far from that of TS-ILS2 and TS-ILS3, it still fell short in relative performance, as shown by its reported ofv per trial in Table VIII. The other algorithms concentrated their best perturbation efforts on invoking two perturbative heuristics in succession before entering the intensification phase. For example, the following phenomenon can be observed in the behavior of TS-ILS2 during the last three trials of Table VIII. The invocation of double shaking (Mut + RR or RR + Mut) was more favored (71.8% of the time) than the single shaking strategy.

The experiments performed in this work have shed more light on why the strategies of TS-ILS algorithms are effective. Moreover, it has provided a deeper understanding of the shortcomings of the previous ILS-based algorithms that do not affect the TS-ILS algorithms. The ability of TS-ILS to automate its perturbation behavior and utilize a local search module that is mindful of excessive invocations of local search heuristics elevated its performance and offered its better generalization ability across the nine problem domains from the extended HyFlex library. In future works, TS-ILS2 should be used in conjunction with tabu search, hidden Markov, and other adaptive perturbation strategies for performance improvement. In addition, investigating the variations of TS-ILS2 such as TS-ILS3 for different applications is an attractive venture. In particular, it should be exciting to apply The S-ILS2 algorithm in the field of evolutionary dynamic optimization, where perturbation strategy can assume an influential role.

TABLE VI. EXPERIMENTAL RESULTS OF PERTURBATION PROFILE ON BP9

Instance	Algorithm	Objective Function Value	Mut + Mut	Mut + RR	RR + Mut	RR + RR	Mut	RR
BP9-1	FS-ILS	0.01243285					7324	8384
	TS-ILS1	0.00701407					452	17674
	TS-ILS2	0.00256314		2628	70		521	12159
	TS-ILS3	0.00501827	66	2899	537	7230	71	542
BP9-2	FS-ILS	0.01334600					7612	8311
	TS-ILS1	0.00389196					1175	16989
	TS-ILS2	0.00148164		7376	622		60	5550
	TS-ILS3	0.00498399	134	2059	489	8304	134	1502
BP9-3	FS-ILS	0.01010801					7702	8139
	TS-ILS1	0.00500537					780	15476
	TS-ILS2	0.00270674		2776	1441		488	9560

	TS-ILS3	0.00279360	108	3551	522	6030	109	2286
BP9-4	FS-ILS	0.01136454					7035	7977
	TS-ILS1	0.00463139					176	17709
	TS-ILS2	0.00052194		8191	180		374	4714
	TS-ILS3	0.00138283	344	5168	102	5044	272	2625
BP9-5	FS-ILS	0.01116060					7699	8526
	TS-ILS1	0.00484655					81	15532
	TS-ILS2	0.00053781		4068	614		64	12111
	TS-ILS3	0.00495967	454	1188	477	7388	309	2850
BP9-6	FS-ILS	0.01224321					7247	7933
	TS-ILS1	0.00481612					172	16357
	TS-ILS2	0.00131507		7965	76		133	8121
	TS-ILS3	0.00499338	121	1222	1018	8292	323	2174
BP9-7	FS-ILS	0.01666414					6847	7709
	TS-ILS1	0.00936258					480	14971
	TS-ILS2	0.00053226		6796	346		378	7622
	TS-ILS3	0.00388404	70	2530	108	6627	111	3881

TABLE VII. EXPERIMENTAL RESULTS OF PERTURBATION PROFILE ON KP1

Instance	Algorithm	Objective Function Value	Mut + Mut	Mut + RR	RR + Mut	RR + RR	Mut	RR
KP1-1	FS-ILS	-1245175.0					117	63
	TS-ILS1	-1262316.0					659	109
	TS-ILS2	-1254037.0		115	391		348	376
	TS-ILS3	-1259804.0	99	100	181	109	586	57
KP1-2	FS-ILS	-1225378.0					95	41
	TS-ILS1	-1262078.0					899	211
	TS-ILS2	-1261056.0		169	100		563	94
	TS-ILS3	-1247433.0	464	104	57	116	56	59
KP1-3	FS-ILS	-1260047.0					150	54
	TS-ILS1	-1245069.0					863	318
	TS-ILS2	-1256584.0		116	68		758	124
	TS-ILS3	-1259408.0	97	206	117	61	922	59
KP1-4	FS-ILS	-1231437.0					113	56
	TS-ILS1	-1258008.0					735	142
	TS-ILS2	-1258850.0		310	129		1034	144
	TS-ILS3	-1259233.0	49	111	50	59	546	102
KP1-5	FS-ILS	-1242785.0					117	62
	TS-ILS1	-1258381.0					744	505
	TS-ILS2	-1229977.0		186	551		86	92
	TS-ILS3	-1250668.0	454	1188	477	7388	309	2850
KP1-6	FS-ILS	-1207909.0					113	35
	TS-ILS1	-1251513.0					840	183
	TS-ILS2	-1256018.0		150	80		978	77
	TS-ILS3	-1250344.0	286	66	144	68	393	224
KP1-7	FS-ILS	-1236294.0					90	39
	TS-ILS1	-1258911.0					729	126
	TS-ILS2	-1229477.0		338	246		79	274
	TS-ILS3	-1228731.0	252	80	79	252	80	83

TABLE VIII. EXPERIMENTAL RESULTS OF PERTURBATION PROFILE ON MAC6

Instance	Algorithm	Objective Function Value	Mut + Mut	Mut + RR	RR + Mut	RR + RR	Mut	RR
MAC6-1	FS-ILS	-1328.0					6343	10412
	TS-ILS1	-1350.0					11410	11894
	TS-ILS2	-1350.0		7648	6852		589	2371
	TS-ILS3	-1344.0	4796	3065	4220	2059	1489	291
MAC6-2	FS-ILS	-1320.0					6734	9871
	TS-ILS1	-1340.0					4744	19056
	TS-ILS2	-1348.0		4408	7677		3209	1889
	TS-ILS3	-1350.0	1407	2491	5584	2966	2026	3415
MAC6-3	FS-ILS	-1322.0					6286	10955
	TS-ILS1	-1348.0					14548	9450
	TS-ILS2	-1350.0		11251	5128		2348	405
	TS-ILS3	-1358.0	1635	6021	4021	5437	344	2943
MAC6-4	FS-ILS	-1346.0					6728	10178
	TS-ILS1	-1362.0					25825	8968
	TS-ILS2	-1354.0		10312	6789		356	1135
	TS-ILS3	-1354.0	5292	6626	344	1055	2740	3639

MAC6-5	FS-ILS	-1330.0					6251	10932
	TS-ILS1	-1346.0					8292	25385
	TS-ILS2	-1360.0		9655	3989		2625	4659
	TS-ILS3	-1350.0	3148	320	4529	8014	1003	2698
MAC6-6	FS-ILS	-1336.0					6208	11061
	TS-ILS1	-1346.0					18116	11993
	TS-ILS2	-1358.0		2309	8734		3611	1875
	TS-ILS3	-1348.0	4371	318	1912	7161	1320	3532
MAC6-7	FS-ILS	-1330.0					6223	10677
	TS-ILS1	-1346.0					8633	22889
	TS-ILS2	-1364.0		14213	2685		1525	2069
	TS-ILS3	-1350.0	2553	3022	3167	4293	483	1574

VI. CONCLUSION

The objectives of the present work have been achieved through the description of three categories of the TS-ILS hyper-heuristic, experimentally comparing the three categories against the existing benchmark algorithms and the determination of the effects of LLHs categorization on HyFlex COPs. The TS-ILS2 with {1, 2, 4, 5} subset configuration has edged out the other categories across eight HyFlex problems. It can be observed with a further granularity that the TS-ILS1 has struggled to effectively solve the instances of the Bin packing problem according to the comparison based on the μ -norm scores. This observation can be ascribed to the lack of double shaking or a stronger perturbation feature in its composition because it uses only {4, 5} configuration subset. Although the TS-ILS1 outshone the other categories on the problems of Permutation flow-shop, Knapsack, and Quadratic assignment, its weakness was badly exposed when it was applied to solve the Bin packing problem. This eventually had a strong effect on its overall performance when compared to the other categories. The overall performances of the algorithms on the HyFlex v2.0 problems suggest a close race among the three categories after TS-ILS2 emerged as the overall best algorithm based on formula one and μ -norm scores.

The comparative results show that the TS-ILS3 recorded the best performance on three problem domains while the TS-ILS2 gave the best performance on the remaining problems. The uncanny fact is that the TS-ILS2 outperformed the TS-ILS3 on all but one of the problem domains. The TS-ILS2 recorded a better performance than the TS-ILS3 on the KP and MAC problems according to the formula one score, while the TS-ILS3 fared better than TS-ILS2 on the same problem domains based on the μ -norm scores. The reasonable explanation for this scenario is that the TS-ILS3 with more strategy options can sometimes obtain poor runs because of the convergence of the Thompson sampling module on the sub-optimal selection. Hence, this will affect its median ofv on the problem domains, but it has failed to perform better than TS-ILS2 in certain situations. In conclusion, the TS-ILS2 has a good balance between “single shaking” and “double shaking” configurations and emerged as the best hyper-heuristic algorithm for solving COPs.

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REFERENCES

- [1] S. P. Adam, S.-A. N. Alexandropoulos, P. M. Pardalos, and M. N. Vrahatis, “No Free Lunch Theorem: A Review,” in *Approximation and Optimization*, I. C. Demetriou and P. M. Pardalos, Eds. Cham: Springer, 2019, pp. 57–82.
- [2] J. H. Drake, A. Kheiri, E. Özcan, and E. K. Burke, “Recent advances in selection hyper-heuristics,” *Eur. J. Oper. Res.*, vol. 285, no. 2, pp. 405–428, 2020.
- [3] A. Kheiri, A. Gretsista, E. Keedwell, G. Lulli, M. G. Epitropakis, and E. K. Burke, “A hyper-heuristic approach based upon a hidden Markov model for the multi-stage nurse rostering problem,” *Comput. Oper. Res.*, vol. 130, p. 105221, 2021, doi: 10.1016/j.cor.2021.105221.
- [4] H. B. Song and J. Lin, “A genetic programming hyper-heuristic for the distributed assembly permutation flow-shop scheduling problem with sequence dependent setup times,” *Swarm Evol. Comput.*, vol. 60, p. 100807, 2021, doi: 10.1016/j.swevo.2020.100807.
- [5] G. Mweshi and N. Pillay, “An improved grammatical evolution approach for generating perturbative heuristics to solve combinatorial optimization problems,” *Expert Syst. Appl.*, vol. 165, p. 113853, 2021, doi: 10.1016/j.eswa.2020.113853.
- [6] A. Dantas, A. F. do Rego, and A. Pozo, “Using deep Q-network for selection hyper-heuristics,” in *Proceedings of the Genetic and Evolutionary Computation Conference, 2021*, pp. 1488–1492. doi: 10.1145/3449726.3463187.
- [7] N. R. Sabar, S. L. Goh, A. Turky, and G. Kendall, “Population-based iterated local search approach for dynamic vehicle routing problems,” *IEEE Trans. Autom. Sci. Eng.*, pp. 1–11, 2021, doi: 10.1109/TASE.2021.3097778.
- [8] Y. Zhang, R. Bai, R. Qu, C. Tu, and J. Jin, “A deep reinforcement learning based hyper-heuristic for combinatorial optimisation with uncertainties,” *Eur. J. Oper. Res.*, vol. 300, no. 2, pp. 418–427, 2022.
- [9] B. S. Ahmed, E. Enou, W. Afzal, and K. Z. Zamli, “An evaluation of Monte Carlo-based hyper-heuristic for interaction testing of industrial embedded software applications,” *Soft Comput.*, vol. 24, no. 18, pp. 13929–13954, 2020, doi: 10.1007/s00500-020-04769-z.
- [10] G. Guizzo, F. Sarro, J. Krinke, and S. R. Vergilio, “Sentinel: A Hyper-Heuristic for the Generation of Mutant Reduction Strategies,” *IEEE Trans. Softw. Eng.*, pp. 1–16, 2020, doi: 10.1109/TSE.2020.3002496.
- [11] Y. Zhou, J. J. Yang, and L. Y. Zheng, “Multi-Agent Based Hyper-Heuristics for Multi-Objective Flexible Job Shop Scheduling: A Case Study in an Aero-Engine Blade Manufacturing Plant,” *IEEE Access*, vol. 7, pp. 21147–21176, 2019, doi: 10.1109/ACCESS.2019.2897603.
- [12] Y. Yao, Z. Peng, and B. Xiao, “Parallel Hyper-Heuristic Algorithm for Multi-Objective Route Planning in a Smart City,” *IEEE Trans. Veh. Technol.*, vol. 67, no. 11, pp. 10307–10318, 2018, doi: 10.1109/TVT.2018.2868942.
- [13] G. Ochoa et al., “HyFlex: A benchmark framework for cross-domain heuristic search,” in *European Conference on Evolutionary Computation in Combinatorial Optimization*, 2012, pp. 136–147.
- [14] S. S. Choong, L. P. Wong, and C. P. Lim, “Automatic design of hyper-heuristic based on reinforcement learning,” *Inf. Sci. (Ny)*, vol. 436, pp. 89–107, 2018.
- [15] A. Aslan, I. Bakir, and I. F. Vis, “A dynamic Thompson sampling hyper-heuristic framework for learning activity planning in personalized learning,” *Eur. J. Oper. Res.*, vol. 286, no. 2, pp. 673–688, 2020, doi: 10.1016/j.ejor.2020.03.038.

- [16] M. Lassouaoui, D. Boughaci, and B. Benhamou, "A multilevel synergy Thompson sampling hyper-heuristic for solving Max-SAT," *Intell. Decis. Technol.*, vol. 13, no. 2, pp. 193–210, 2019, doi: 10.3233/IDT-180036.
- [17] M. Scoczynski et al., "A selection hyperheuristic guided by Thompson sampling for numerical optimization," in *GECCO 2021 Companion - Proceedings of the 2021 Genetic and Evolutionary Computation Conference Companion*, 2021, pp. 1394–1402. doi: 10.1145/3449726.3463140.
- [18] S. A. Adubi, O. O. Oladipupo, and O. O. Olugbara, "Configuring the Perturbation Operations of an Iterated Local Search Algorithm for Cross-domain Search: A Probabilistic Learning Approach," in *2021 IEEE Congress on Evolutionary Computation (CEC)*, 2021, pp. 1372–1379.
- [19] S. A. Adubi, O. O. Oladipupo, and O. O. Olugbara, "Evolutionary Algorithm-Based Iterated Local Search Hyper-Heuristic for Combinatorial Optimization Problems," *Algorithms*, vol. 15, no. 11, p. 405, 2022, doi: 10.3390/a15110405.
- [20] R. Tinos, M. W. Przewozniczek, and D. Whitley, "Iterated local search with perturbation based on variables interaction for pseudo-boolean optimization," in *Proceedings of the Genetic and Evolutionary Computation Conference*, 2022, pp. 296–304.
- [21] N. R. Sabar and G. Kendall, "An iterated local search with multiple perturbation operators and time varying perturbation strength for the aircraft landing problem," *Omega*, vol. 56, pp. 88–98, 2015.
- [22] S. Adriaensen, T. Brys, and A. Nowé, "Fair-share ILS: A simple state of the art iterated local search hyperheuristic," in *Proceedings of the 2014 annual conference on genetic and evolutionary computation*, 2014, pp. 1303–1310.
- [23] A. I. Hammouri, M. S. Braik, M. A. Al-Betar, and M. A. Awadallah, "ISA: a hybridization between iterated local search and simulated annealing for multiple-runway aircraft landing problem," *Neural Comput. Appl.*, vol. 32, no. 15, pp. 11745–11765, 2020, doi: 10.1007/s00521-019-04659-y.
- [24] A. Kheiri and E. Keedwell, "A sequence-based selection hyper-heuristic utilising a hidden Markov model," in *GECCO 2015 - Proceedings of the 2015 Genetic and Evolutionary Computation Conference*, 2015, pp. 417–424.
- [25] A. Almutairi, E. Özcan, A. Kheiri, and W. G. Jackson, "Performance of selection hyper-heuristics on the extended hyFlex domains," in *International Symposium on Computer and Information Sciences*, 2016, pp. 154–162.
- [26] S. Adriaensen, G. Ochoa, and A. Nowé, "A benchmark set extension and comparative study for the HyFlex framework," in *2015 IEEE Congress on Evolutionary Computation, CEC 2015*, 2015, pp. 784–791.

Serious Game Design Principles for Children with Autism to Facilitate the Development of Emotion Regulation

Nor Farah Naquiah Mohamad Daud^{1*}, Muhammad Haziq Lim Abdullah², Mohd Hafiz Zakaria³

Center for Advanced Computing Technology (C-ACT)-Fakulti Teknologi Maklumat dan Komunikasi (FTMK), Universiti Teknikal, Malaysia, Melaka (UTeM)*

Abstract—Autism spectrum disorder (ASD) is a deficit-driven neurodevelopmental condition in three areas, which are social interactions, communication, and the presence of restricted interests and repetitive behaviours. Children with autism mainly suffer from emotional disturbance that emerges as meltdowns, tantrums, and aggression, increasing the risk of developing mental health issues. Several studies have assessed the use of serious games in helping children with autism enhance their communication, learning, and social skills. Significantly, these serious games focus on the strengths and weaknesses of the disorder to establish a comfortable and controlled environment that is able to support children with autism. However, there is still a lack of evidence in studies exploring the use of serious games for children with autism to facilitate the development of emotion regulation. The aim of this study is to consolidate and propose a new serious game design principle for children with autism to facilitate the development of emotion regulation. The target age of the children involved in this study ranged between 6 and 12. A review of previous literature on serious game design principles was conducted. More than 70 articles related to serious games for children with autism were analysed using thematic analysis. This study found 16 elements that influenced the designing and developing process of creating a serious game for children with autism. It has been organised and categorised into five attributes (user, game objectives, game elements, game aesthetics, and player experience). Certainly, this study demonstrates the needs and requirements of children with autism when designing serious games.

Keywords—Autism spectrum disorders; serious game; emotion regulation; serious game design principles

I. INTRODUCTION

Autism spectrum disorder (ASD) is one of the world's fastest-growing diseases. It is no longer considered an uncommon disorder in Malaysia but rather a developmental impairment that requires immediate assistance and understanding from all levels of society. Autism is a long-term neurodevelopmental condition distinguished by difficulties in interpersonal communication and social interactions, along with restricted, repetitive behaviour and interests [1-3]. Additionally, autism is referred to as a 'spectrum' disorder due to the wide range of symptoms that individuals experience. Presently, there is no known medical solution for autism, and researchers are still trying to figure out what causes it [4].

It is estimated that there are roughly 12,800 instances of autism in Malaysia, which is equivalent to 1 out of every 600

children [5]. Thus, the number of people diagnosed with ASD requesting services from the National Autism Society of Malaysia (NASOM) has increased by 30% across all age groups in recent years [6]. Besides that, males are more likely to have autism [7, 8] despite the fact that a recent meta-analysis found that the actual male-to-female ratio is closer to 3:1 than the previously reported 4:1; even though this study did not use the DSM-5 criteria [9].

Several studies have revealed that the majority of children with autism experience behavioural challenges, and certain characteristics of autistic children can be concerning to parents. Emotion regulation (ER) deficits were discovered to be a salient predictor of social and behavioural issues in children with autism [10] since they often exhibit excessive emotional reactivity or an emotional deficit compared to children with typical development [11]. Some children with autism who have limited verbal or nonverbal communication often face difficulties expressing themselves when they are frustrated or stressed [12]. As a result, children with autism are more likely to experience emotional disturbances such as meltdowns, tantrums, and aggression, which are risk factors for developing mental health disorders [13]. Besides that, disappointment induced by dysregulated emotions in children with autism may result in increased anxiety, despair, poor anger management, low frustration tolerance, impatience, despair, violence, mood dysregulation, and physical health implications [14, 15].

Conventional methods, such as paper-based and various therapeutic approaches have been suggested to support ER training for children with autism. However, paper-based aids are resource-intensive due to the need to craft the materials and intense instructions for children with autism [10], making them challenging for caregivers, teachers, and parents to utilise. Additionally, Sadka and Antle [16] also stated that the average delay in treatment for various mental health disorders surpasses ten years as a consequence of failure to notice symptoms, a lack of health care literacy, personal or social stigma associated with mental health care, and a lack of access to mental health therapy. Therefore, serious games have been shown to facilitate and support children with autism in acquiring academic, communication, job, and leisure skills [17]. Moreover, serious games bridge the gap between the tremendous demand for evidence-based interventions and the limited availability of professional autism services [18].

Despite the variety of technology-based interventions for children with autism, usability and uptake remain low. It is not surprising that there are few studies on serious game technology that may simulate the daily routine of children with autism to support emotion regulation [14, 19]. In fact, most of the existing studies fall into the social skills subcategory [20] focusing on facial expression [10, 21], or point to some aspects of the serious game, such as behavioural interventions and training methods [22, 23] without discussing in-depth analysis in the literature on serious games to develop emotion regulation [24] or promoting conventional emotion regulation training through serious games [25].

This study aims to better understand the user's needs and requirements to facilitate children with autism with their development of emotion regulation, such as recognising, interpreting, and generalising six basic emotions. The objective of this study is to consolidate and propose new serious game design principles for children with autism, focusing on the development of emotion regulation. Besides that, this study is driven to address the research question, which is: What are the appropriate serious game design principles for children with autism to facilitate their development of emotion regulation in their daily life activities? Significantly, this study focuses on filling the gap in the existing studies on facilitating the development of emotion regulation among children with autism using serious games.

II. RELATED WORKS

A. Autism Spectrum Disorder and Emotion Regulation

The term 'emotion' usually refers to a subjective state of being that is referred to as 'feelings' by most people. Emotions are an essential component of cognition and are closely tied to it [26]. Aside from that, emotions are generally thought to be actively felt and deliberate, whereas mood refers to a protracted, less intense affective state unrelated to whatever an individual encounters. Consequently, emotion recognition is considered a crucial skill that underpins more complicated emotional understanding and social abilities [27]. Additionally, emotion regulation is influenced by biology and through interactions with people in the environment [28].

Emotion regulation (ER) is defined as the voluntary management and modulation of emotional reactions through cognitive processes to regulate affective states in order to attain a goal [29]. Furthermore, emotions are also intertwined with an individual's daily life and have an impact on a variety of areas of human functioning, particularly communication and socialisation. As cited by Jinnah, et al. [30], it is mentioned that normally, typical infants begin to employ emotional expressions for social referencing between the ages of eight and ten months. However, children with autism may demonstrate little or no imitation of others' behaviour [1]. As a result, children with autism struggle to communicate, socialise, and maintain relationships with others [31].

Therefore, emotion regulation is a crucial skill that children with autism need in their lives. Certainly, emotion regulation has ended up as one of the critically highlighted issues in numerous areas, including Human Computer

Interaction (HCI). In addition, as cited by Sharma, et al. [32], emotion is crucial to understanding motivation in classroom interactions since teachers' instructional and interpersonal responses to children are often influenced by emotions. Thus, early intervention and evaluation of social and emotional skills in children with autism may help explain their observed traits [33].

B. Serious Games for Children with Autism to Facilitate Emotion Regulation

The most straightforward definition of 'video game' is interactive digital entertainment that is played on a computer, game console, or smartphone. It is also more commonly known as an electronic game that requires user interaction through a user interface that generates visual feedback. Furthermore, video games can be employed in a variety of sectors, including in the education field for people with special needs, despite being generalised as a source of entertainment only. Also, special education teachers are increasingly using technology-based interventions such as serious games to provide training to children with autism to enhance their social skills and quality of life [34]. Thereby, it should be noted that games have been employed as an additional tool for teaching and learning since the early nineteenth century.

According to Kokkalia, et al. [35], games in education are common because teachers frequently use games to create a more dynamic and creative learning experience. Besides that, video games and serious games have demonstrated that they can help children develop their cognitive and physical abilities owing to the consistent strategies for activity motivation and the feeling of personal pleasure gained from accomplishments [36]. Moreover, serious games have the ability to generate an emotional connection for people with special needs who are undergoing therapy or rehabilitation. In addition, previous studies claimed that games can be a joyful and pleasurable way for children to improve their skills [37]. Thus, several scholars believe that active exploration and immersion in games are able to enhance constructive, situational, and experienced learning [38].

Moreover, games have shown enormous potential as an intervention for children with ASD due to their ability to integrate attentively designed features with naturally occurring situations (i.e., having fun together) [39]. It is because game-based intervention is able to create a predictable environment to encourage attention and lessen the frustration of children with autism [40, 41]. For instance, a study found that training using virtual reality (VR) game approaches is able to improve the emotional and social skills of children with autism [42]. Additionally, game-based intervention is advantageous because it is predictable, repetitive, and devoid of stressful social demands, which are preferred by children with autism.

For instance, a previous study found that a game called FaceSay has successfully helped children with autism recognise facial expressions and feelings through the assistance of a realistic avatar [43]. Moreover, the visualisation of gaze in video games aids in the development of social attention and emotional abilities in children with autism [44]. Shams, et al. [45] also highlighted how the cosy and appealing aspects of serious games showed their ability to

improve emotion control in children with autism. Therefore, serious games are believed to have the potential to help children with autism improve their social communication skills and enhance their capacity to perceive and express emotions.

C. Designing Serious Games for Children with Autism

Game technology has been evolving with features and functions that defy expectations. Particularly, games have proven to be beneficial in a variety of fields, including the military, healthcare, and education. In fact, serious games have a lot of potential because they can foster relationships in a range of settings and contexts, such as realistic simulation games [46]. To emphasise, the usage of games in education has made learning more engaging and dynamic [47]. Therefore, game technology can be a promising tool for helping children with autism meet their needs by facilitating their therapy and skill development. In fact, games have the ability to capture the attention of children, including children with autism [48].

A large number of studies suggest that games can permanently prepare children physically and cognitively while also increasing their creativity, critical thinking, and sense of possibility. Additionally, studies have shown that ICTS is able to increase the interest and motivation of children with autism and support their social skills and social emotional domain skills development in a safe environment by using virtual environments that can replicate real-world situations [49]. Lee, et al. [50] also concede that animation, sound, and interface in technology-based intervention may reinforce and inspire children with autism.

As a result, a lot of guidelines and design principles have been produced to serve as a guide for designing and developing an appropriate game for a specified group, considering gameplay design, game mechanics, level design, reward systems, and other game aspects. Basically, the components that may be addressed in designing serious games include storylines, targeted skills, level progressions, feedback, and rewards [22, 51-53].

III. METHODOLOGY

This section describes the method used in this study. A comprehensive literature review on serious game design principles was conducted to retrieve and gather all the studies related to autistic people. A comprehensive literature analysis on serious game design principles was conducted to acquire and compile all studies that are relevant in facilitating children with autism with their development of emotion regulation. The children are aged between 6 and 12.

There are three stages of filtering and analysis used in the literature review stage. In the first stage, articles were extracted from Google Scholar, Science Direct, ACM Digital Library, IEEE Xplore, Scopus, Research Gate, and Springer Link between 2006 and 2021 using the key search criteria.

The primary search keywords were ‘Serious Games for Children with Autism Spectrum Disorder’, ‘Serious Games to promote Emotion Regulation of Children with Autism Spectrum Disorder’, and ‘Designing Serious Game for Children with Autism Spectrum Disorder’. In addition, search terms such as ‘Autism Spectrum Disorder’, ‘serious games’, ‘design principles’ and ‘emotion regulation’ were used to find additional articles. The keywords were gathered from academic journals, textbooks, technical reports, websites, and conference proceedings.

The first 70 articles in the search engine result were studied, and those that seemed relevant in terms of game-based interventions, serious games, and autism spectrum disorders (ASD) were chosen. In the first stage, the studies proposing serious games in the context of children with autism and review articles were accepted. Next, in the second stage, the articles were reduced to 48, which were discovered to be significant for analysis based on the suggested criteria related to the study. Then, these 48 articles were analysed in-depth to investigate the application design and existing guidelines in the third stage. The inclusion and exclusion criteria were described further in Table I. Iteratively, the analysed articles were taken into consideration and revisited, with a focus on serious game design principles for children with autism. In total, 24 articles were selected for critical examination and made it to the result table.

TABLE I. INCLUSION AND EXCLUSION CRITERIA

Inclusion Criteria	Exclusion Criteria
Studies from 2016 to 2022	Older than 2016
Serious Game, Game-Based Technology.	Any other computer-based intervention or assistive technology.
Focusing on designing games for autism spectrum disorder.	Studies that were not explained in literature or working paper.
Serious games that were tested on enough samples and in-game performance were validated.	Not enough studies and in +game performance were not validated.

After that, the 24 articles that were chosen were analysed and examined thoroughly, and the design principles were extracted using card sorting and thematic analysis. Prior to the complete system design, the card sorting technique was found to be very effective and an important way of getting the user’s input [54]. In addition, thematic analysis was used to extract the design principles. Thematic analysis is a technique for methodically detecting, organising, and interpreting patterns of meaning in a dataset. Besides, thematic analysis is a more divergent, compatible, and flexible research tool [55]. Thereby, the data were clustered thematically from the literature review.

In the first analysis, as shown in Fig. 1, the data was thematically clustered into five themes: user (green), game objectives (yellow), game aesthetics (pink), game elements (blue), and player experience (purple). Table II further explains the description for each theme.

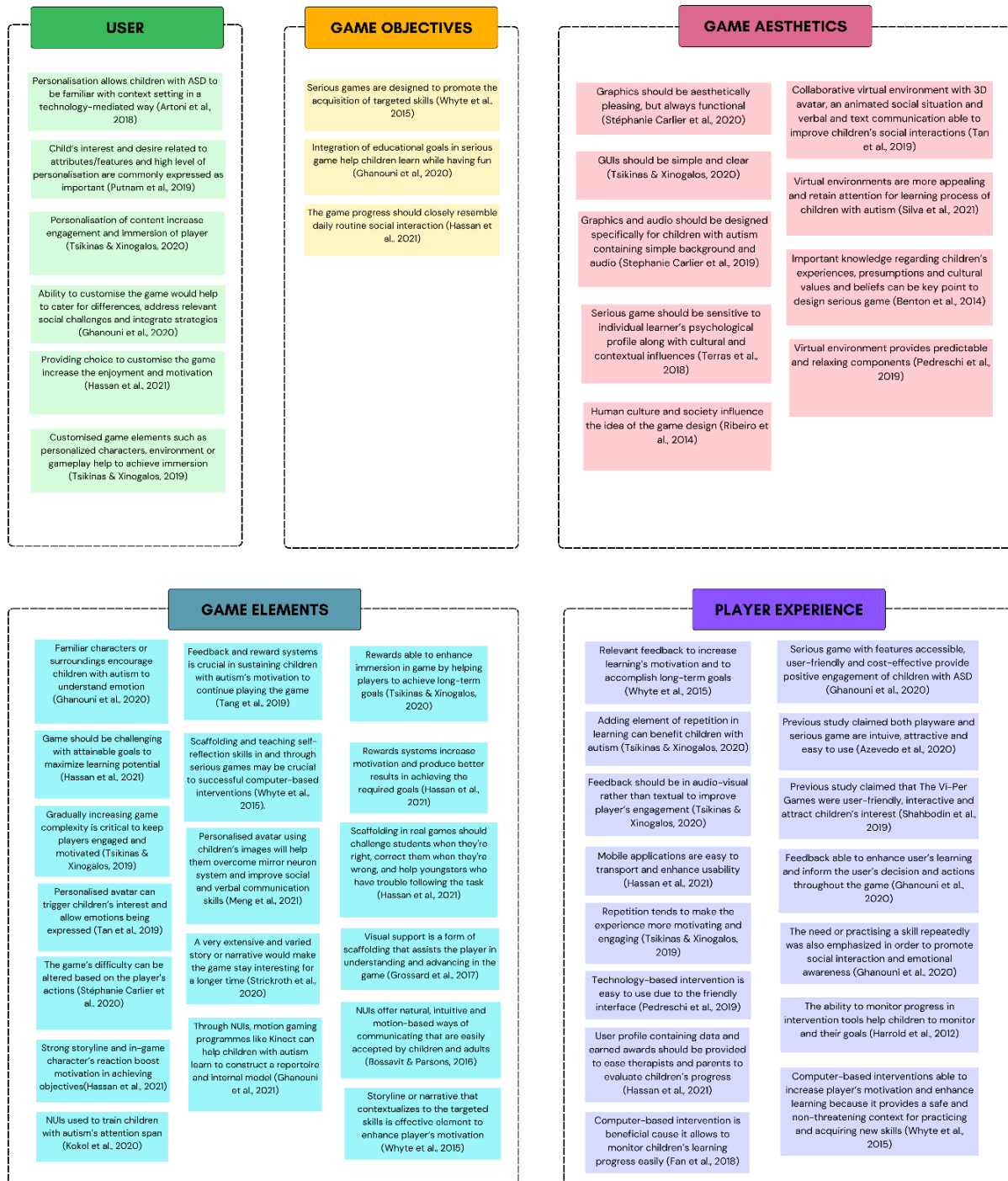


Fig. 1. First analysis: An iterative process in developing themes: user (green), game objectives (yellow), game aesthetics (pink), game elements (blue), and player experience (purple).

TABLE II. DESCRIPTION OF FIVE THEMES

Themes	Description	Colour coded
User	Represents the player profile.	Green
Game Objectives	Something that the player tries to achieve.	Yellow
Game Aesthetics	Sensory phenomena that the player encounters in the game/ Generalisation about art.	Pink

Game Elements	Components that make up the game.	Blue
Player Experience	Represents what the player goes through when playing the game.	Purple

In the second analysis, the themes were thoroughly examined to discover any possibilities for expanded sub-themes. As shown in Fig. 2, the User theme was refined to personalisation and customisation, the Game Objectives theme focused on the Individual Education Plan (IEP) goal of

children with autism, and the Game Aesthetics theme was narrowed to a graphical user interface, context settings, and virtual environment. The user was refined to personalisation and customisation in order to create a profile for children with autism, while the game objectives were refined to the individual education plan (IEP) goal since children with

autism have specific IEP goals to achieve. Meanwhile, the game aesthetics theme was refined to include a graphical user interface (GUI), virtual environment, and context settings that are able to ensure the game can provide comfortable environments and resemble the daily life activities of children with autism.

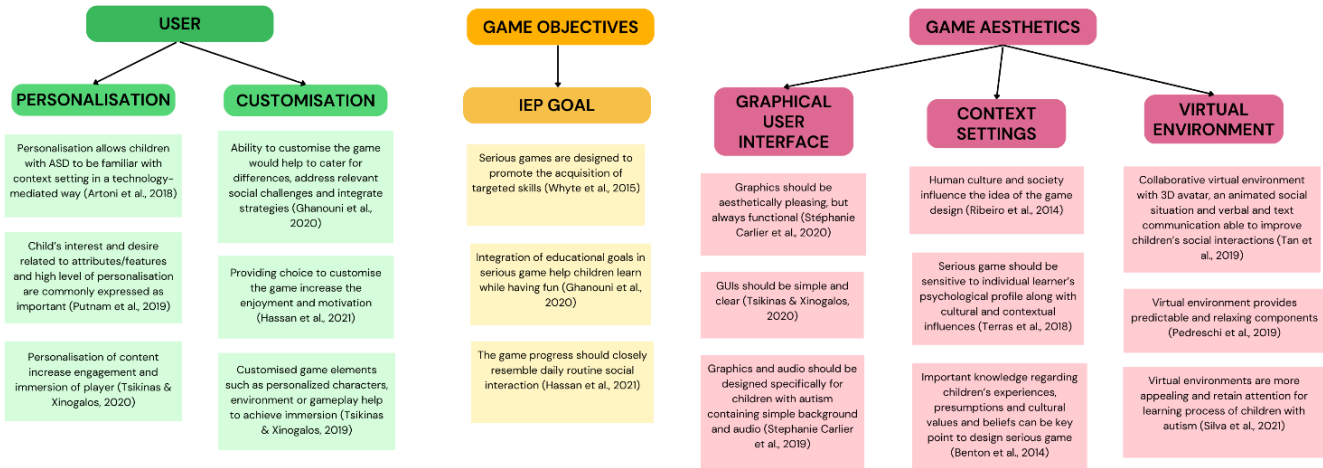


Fig. 2. Sub-themes for user, game objectives and game aesthetics.

Furthermore, in Fig. 3, the Player Experience theme was refined to feedback, repetition, usability, and monitoring in order to provide good responsive feedback and experience for children with autism when they interact with the game. Meanwhile, the Game Elements theme was clustered into

level progression, character, interaction, rewards, storyline, and scaffolding, which refer to the components that fulfil the design principles of serious games. Thereby, Table III shows the expanded themes with more sub-themes.

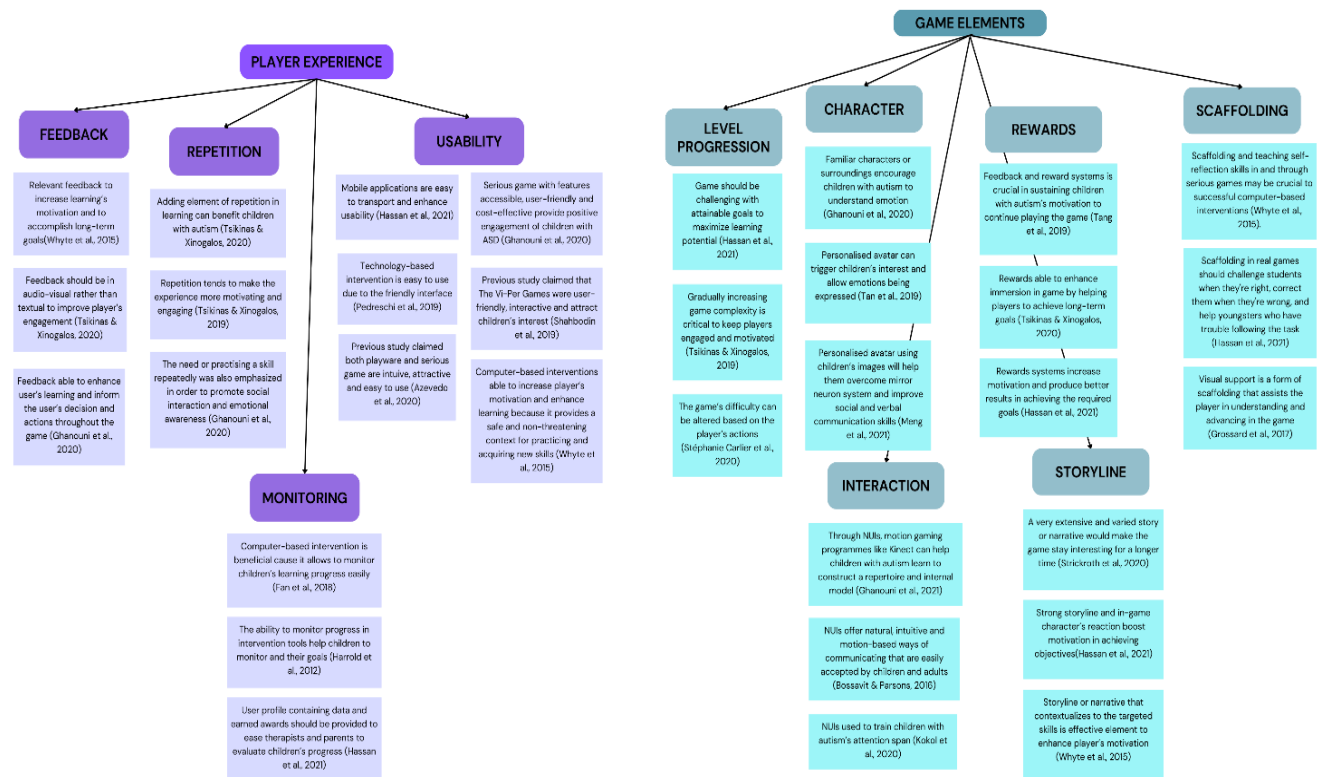


Fig. 3. Sub-themes for player experience and game elements.

TABLE III. RESULT OF SECOND ANALYSIS

Themes	Sub-themes
User	<ul style="list-style-type: none"> Personalisation Customisation
Game Objectives	<ul style="list-style-type: none"> IEP Goal
Game Elements	<ul style="list-style-type: none"> Level progression Character Interaction Rewards Storyline Scaffolding
Game Aesthetics	<ul style="list-style-type: none"> Graphical user interface (GUI) Virtual environment Context settings
Player Experience	<ul style="list-style-type: none"> Feedback Repetition Usability Monitoring

IV. RESULTS AND DISCUSSION

Through the comprehensive literature review on serious games for children with autism, Table IV is tabulated and presents the list of design principles for each of the components. There were 16 elements in the sub-themes found in this study, and they are clustered and organised into five attributes: (1) user, (2) game objectives, (3) game elements, (4) game aesthetics, and (5) player experience. This section briefly explains the five attributes of serious game design principles for children with autism.

TABLE IV. SERIOUS GAME DESIGN PRINCIPLES FOR CHILDREN WITH AUTISM

Attributes	Component	References
User	Personalisation	Allow content personalisation according to the needs [56-58].
	Customisation	Allow customising game elements to boost enjoyment and motivation [22, 52, 59].
Game Objectives	Individual education plan (IEP) goal	Specific targeted skills for children with autism to achieve that align with classroom activities [51, 53, 58].
Game Elements	Level progression	The game progression should gradually increase to motivate players [22, 52, 53].
	Character	Familiar and personalised character trigger children's interest [59-61]
	Interaction	Interactions should be natural and intuitive [59, 62, 63].
	Rewards	Player motivators [22, 23, 58].
	Storyline	Immersive, social-based stories and narratives [53, 64, 65].
	Scaffolding	Assist the player without controlling them through playing the game [22, 53, 66].
Game Aesthetics	Graphical user interface (GUI)	Visualisation should be clear, simple, and minimalist [12, 52, 67].
	Virtual environment	Provide immersive, relaxing, and attractive feelings by including animation, verbal, and text communication [61, 68, 69].
	Context settings	Culture and contextual influences should be considered [70-72].
Player Experience	Feedback	Relevant and responsive feedback should be considered to provide good engagement [52, 59, 65].
	Repetition	Repetition is needed to allow players to practise the targeted skills [58, 59, 73].
	Usability	The game should be easy to understand, safe, and child-friendly [53, 59, 68].

	Monitoring	Provide user profile containing data to monitor the progress [10, 22, 74].
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A. User

A user is considered a person who uses or operates the video game. In this case, children with autism are considered the users of the serious games. Since children with autism have difficulty processing inputs and social signals, they struggle to recognise emotions in social interactions [75]. Thus, personalisation and customisation are found to enable prioritising the child's needs.

Personalisation is important for children with autism, as parents or teachers can personalise the game according to the child's capabilities. Moreover, personalisation features in the games should be familiar and relate to children's interest and desire to increase their engagement and immersion experiences. According to Artoni, et al. [56], personalisation allows children with autism to become familiar with context in a technology-mediated way. Additionally, personalisation of both technology accessibility [76], content [58, 77], and the child's interest [57] is a critical key point when developing serious games for children with autism to increase engagement and immersion. Hence, game designers must have specific requirements to develop serious games that meet the autistic child's needs, especially focusing on facilitating the development of emotion regulation.

Customisation is also one of the important elements in the user category because games should provide the ability to customise certain game elements to increase enjoyment and motivation as well as cater to the children's needs. According to end-users, such as parents and therapists, customisation should be considered to ensure that children with autism properly provide feedback patterns [21]. Certainly, the ability to customise the game would aid in accommodating diversity, relevant social challenges, and integrating strategies [59]. Moreover, the ability to customise the characters, environment, or gameplay helps to achieve immersion and enhance the perception of uniqueness [22, 52].

It is important to consider personalisation and customisation when designing and developing games for children with autism to allow teachers and parents to personalise and customise the game according to the targeted skills. In fact, personalisation and customisation in games would also give flexibility to children with autism.

B. Game Objectives

Usually, any video game would have specific contents or objectives that would keep the game enjoyable to explore. This study found that serious games should have specific targeted skills and certain goals to be achieved or improved. Hence, a serious game for children with autism should have clear goals based on the individual education program (IEP) goals that teachers and parents want the child to achieve. Significantly, it is a critical component in designing serious games for children with autism because it requires specific content that aligns with the IEP goal, especially in facilitating the development of emotion regulation.

According to Hassan, et al. [22], when designing a serious game, the game content should closely reflect daily life

activities to ensure that children with autism are able to apply the skills in real-life scenarios. Besides, Tang, et al. [65] and Whyte, et al. [53] concede that the game objectives should be clear and must be classified as medium-term or long-term goals to ensure that players display greater intrinsic motivation when playing the game. Moreover, a game should have specific and clear objectives that are aligned with classroom activities or the curriculum [58]. Therefore, game designers should consider to using the IEP goals of children with autism to ensure the learning and training process is engaging and the targeted skills are achievable.

C. Game Elements

Game element is a term that refers to anything that is utilised and included in designing and developing a video game. Moreover, game elements are also known as the components that make up a game, which are called game attributes. Through the analysis, this study highlights six elements that have a good impact on designing serious games for children with autism.

Level progression is a crucial element in delivering the necessary content at every moment, and it reinforces progress for the player through a game's systems and mechanics. Level progression in games should not be too easy to avoid amotivation and frustration for the player. Hassan, et al. [22] emphasised that games should be challenging with attainable goals to maximise learning potential. In fact, the complexity of the game should gradually increase to keep players engaged and motivated [52]. Simply put, serious games cannot be so difficult that players become frustrated or so easy that they never learn new abilities [53].

Aside from that, character is also an important element to be considered when developing serious games for children with autism because characters can retain the child's attention as the game continues [73]. This is because familiar characters or surroundings encourage children with autism to get immersed in the game, especially in understanding the emotion [59]. In fact, Papoutsis, et al. [78] concede that familiar characters also make the user feel more at ease and improve the learning process. For instance, a mobile game application demonstrated that the use of a personalised avatar based on children's own pictures may elicit their emotions when they participate and engage in the activity [61]. Moreover, Meng, et al. [60] emphasised that children with autism can overcome the mirror neuron system and improve social and verbal communications with a personalised avatar. To summarise, character creation is an important element in designing serious games because it helps the player feel more immersed and interested to keep playing the game.

Besides that, interactions in games such as natural user interface (NUIs) enable children with autism who have sensitivity to interacting with technology intervention to benefit because NUIs provide a natural feeling using modalities such as touch, gestures, or voices. In fact, current Human Computer Interaction (HCI) paradigms indicate that interfaces should be natural and intuitive, leveraging motion-based touchless interactions known as NUIs [79]. According to Ghanouni, et al. [80], motion gaming programmes like Kinect are able to facilitate children with autism in learning to

create a repertoire of internal models through NUIs. For example, combining RGB cameras, depth detection, and careful user interface design in the Kinect visual sensor would provide better gaming and enjoyment experiences [62]. As a result, this study found that interactions play an important role in catering to the needs of children with autism.

This study also found that rewards provide a meaningful experience for children with autism since they can help motivate them to continue playing the game. Indeed, reward systems may be perceived as either motivators for players or as a means of mitigating disappointment [81]. In fact, Hassan, et al. [22] and Tsikinas and Xinogalos [58] concede that reward systems increase motivation and immersion in achieving medium-term and long-term goals. Additionally, Jouen, et al. [23] emphasised that gaming platforms offer a flexible and customisable manner of rewarding the player for achieving the objective, encapsulating the spirit of reward-based interventions. Eventually, when designing serious games for children with autism, designers should consider rewarding the player and the rewards should bring positivity to avoid frustration and give up.

Moreover, storylines in games are found to have a positive impact on children with autism by enhancing their motivation, attention, and interest in learning because they provide an interactive and immersive experience with a social-based context. Hassan, et al. [22] believe that a strong storyline and in-game characters' reactions are able to boost the player's motivation to achieve the objectives. In addition, a very extensive and varied narrative would keep the game interesting for a longer time [64]. A previous study also emphasised the importance of designing serious games underpinned by a motivating storyline to encourage players to keep playing [53, 65]. Therefore, this study concedes that a strong storyline with a social-based context is able to enhance social skills, foster intrinsic motivation to learn, and encourage them to pay attention.

Scaffolding is one of the strategies used in developmental learning and teaching. This is because scaffolding provides just enough assistance to ensure the children are successful in completing the given tasks on their own. This is why scaffolding can be an important element in designing serious games for children with autism. In fact, the affordances created by movement-driven avatars may have provided the best context for scaffolding engagement in autistic children [82]. Furthermore, Whyte, et al. [53] concede that scaffolding elements in serious games play an important role in successful game-based interventions as they intrinsically enhance the children's motivation to keep playing and learning. Certainly, scaffolding in games is a form of assistance to the player through playing the game by challenging them and correcting them in completing the tasks [22, 66]. Therefore, the game should include scaffolding elements to initiate engagement and interaction between player and game or player and peer, aside from assisting them through the game's progress.

D. Game Aesthetics

The sensory phenomena that players encounter in the games, such as visual, auditory, haptic, or embodied, are referred to as game aesthetics. Game aesthetics are an

expression of the game because the game itself needs precise degrees of interaction to function properly. Annetta [83] mentioned that visualisation is a powerful cognitive approach, and researchers have recognised it as an essential problem-solving strategy.

This study found that in designing serious games for children with autism, it is important to ensure the graphical user interface (GUI) is simple, clear, and minimalist. Subsequently, by improving the GUI design, higher usability and acceptance are able to be achieved [67]. In fact, children with autism may be overwhelmed and abandon the game or be distracted if the GUIs are complex, so the GUIs should be simple, clear, and appropriate [58]. In addition, to make the experience more user-friendly, researchers use basic and clear images with clear font text, huge navigation buttons presented clearly, and simple virtual reality aspects to avoid player distraction [52]. Carlier, et al. [12] concede that graphics and audio should be aesthetically pleasing but always functional. Hence, the GUIs in serious games for children with autism should be displayed clearly, not overlapped, and the use of colour should be minimised.

Immersion and engagement are important to attract the attention of children with autism, increase their attention span, and motivate them to keep playing. Thus, this study found that a virtual environment is able to teach children with autism to adapt to different situations in a safe way due to its feasibility. Additionally, children with autism can enhance their social interactions and comprehension by using collaborative virtual environments that include a 3D expressive avatar, an animated social setting, and verbal and text communication [61]. In fact, virtual environments are considered autistic-friendly because they provide predictable and relaxing feelings [68]. Moreover, virtual environments are appealing and able to retain the attention of children with autism in the learning process [69]. Hence, the simulated real world with 3D representations in a virtual environment is able to elicit interaction, the feeling of immersion, and the imagination of children with autism.

Other than that, context settings, localities, and cultural elements have been found to be considered when designing serious games for children with autism. This is because cultural and contextual settings would influence positive engagement. Ribeiro, et al. [71] concede that human culture and society influence the idea of game design. Besides that, important knowledge regarding children's experiences, presumptions, and cultural values and beliefs can be key points in designing serious games [70]. Additionally, developers should be sensitive to an individual learner's psychological profiles along with cultural and contextual influences when designing games [72]. Thus, the game elements should be integrated with cultural and contextual settings to provide familiarity to children with autism.

E. Player Experience

Serious games will be useless if the user finds them no longer engaging and entertaining, which means that a poor implementation would make it impossible to develop a game with a solid theoretical foundation. Moreover, immersion and exciting feelings in games entail more than just enjoying the game's storyline, graphics, and other game elements.

Therefore, in designing a serious game, especially for children with special needs such as autism, player experience should be contemplated.

This study found that feedback is important to provide a response between the player and the game through playing sessions. Indeed, it is also able to increase learning motivation and accomplish long-term goals [53]. Furthermore, feedback is needed in the game to inform the user's decision and action throughout the game, besides enhancing the user's learning [59]. Tang, et al. [65] emphasised that feedback in the game should be natural and provided through visual feedback such as text or animation. Additionally, Abirached, et al. [21] and Tsikinas and Xinogalos [58] concede that feedback in serious games for children with autism should be in an audio-visual format rather than textual to improve the player's motivation and maintain a high level of engagement. For instance, a previous study mentioned that the utilisation of appropriate immediate feedback in a serious game environment can lead to a state of flow or total engagement and immersion [84]. Thus, the feedback provided in the game should be audible or visual to maintain engagement, sustain motivation, and assist the players in game progress and performance.

Repetition, also known as repeatability, is the extent to which a player might want to play the game again after completing it once or more. In designing serious games for children with autism, it is crucial to allow repetition as the game progresses. This is because repetition tends to make the experience more motivating and engaging, which would benefit children with autism in acquiring certain skills [58]. This is supported by Ghanouni, et al. [59], where the value of repeated practice skills was beneficial to foster the development of social interaction and emotion recognition for children with autism. Repetition features in serious games for children are considered important because they can determine the player's mastery level and also make it possible to anticipate the following task [73]. Thus, repetition is a must because children with autism might want to repeat the game even though they accomplished it, possibly due to huge interest.

Besides that, usability is found to be another element that should be highlighted when designing serious games for children with autism to ensure the game is user-friendly, easy to use, and safe for the children. Technology-based intervention, such as mobile applications, web applications, or serious games, is easy to use due to the friendly interface that consists of interactive features that are able to attract children's interest [22, 68]. Importantly, serious games with accessible features, user-friendly, and cost-effective bring positive engagement from children with autism [59]. In addition, it is also able to increase the player's motivation and enhance the learning process as it provides a safe and non-threatening context to practice and acquire new skills [53]. In fact, the rise of toddler-friendly touch screens has had a positive effect on educational approaches for autism [85]. Then, developers should consider the usability of serious games when designing for children with autism.

Additionally, monitoring features have been found to be a crucial element in designing serious games for children with

autism because they provide accessibility, not only for the children but also for their parents, teachers, and therapists. It allows them to monitor the developmental progress of children with autism. Fan, et al. [10] mentioned that computer-based intervention is beneficial for parents and teachers because it can allow easy monitoring of the children's learning progress. This is why developers should consider having user profiles containing data and earned awards in the game to ease the teachers, therapists, and parents evaluation of the children's progress [22]. Moreover, the ability to monitor progress using intervention tools would help teachers and parents facilitate and support the child in developing their skills [74]. Thereby, monitoring progress is important in designing serious games for children with autism to allow teachers and parents to evaluate the developmental progress of the children's skills.

V. CONCLUSION

In conclusion, serious games show promising outcomes in many approaches to facilitating and supporting children with autism by enhancing a range of abilities. Significantly, serious games have shown to be quite beneficial in facilitating autistic people in enhancing their social and emotional domains, such as emotion regulation. This is because the player's emotions can be awakened to attain the game goals, accept challenges, follow game rules, engage with the game world, respond to feedback, or comprehend the game narrative.

Therefore, this study highlights the serious game design principles that should be included when designing a serious game for children with autism to develop their skills, especially emotion regulation skills. This study shows a significant presence of more appropriate design principles for developing serious games for children with autism by deeply understanding their needs and requirements. Therefore, a summary of the serious game design principles is presented in Table V.

TABLE V. A SUMMARY OF SERIOUS GAME DESIGN PRINCIPLES FOR CHILDREN WITH AUTISM

Design Principles	Recommendations
User <ul style="list-style-type: none">● Personalisation● Customisation	The game should be able to be customised and personalised according to the abilities of children with autism.
Game Objectives <ul style="list-style-type: none">● Individual education plan (IEP) goal	The game should have specific targeted skills that are aligned with each child's IEP goal or classroom activity.
Game Elements <ul style="list-style-type: none">● Level progression● Character● Interactions● Rewards● Storyline● Scaffolding	The game elements should make the children feel connected to the game and increase their motivation to keep playing the game.
Game Aesthetics <ul style="list-style-type: none">● Graphical user interface (GUI)● Virtual environment● Context settings	The game aesthetics should be simple and minimalist, especially for children with autism, to avoid distraction.
Player Experience <ul style="list-style-type: none">● Feedback● Repetition● Usability● Monitoring	The game should be responsive to player engagement and immediately respond to the player's interaction.

Besides that, the proposed serious game design principles that have been elicited from the existing study would undergo a validation process by experts, including special education teachers, academicians, and serious game experts who are experienced in developing serious games for special needs. A focus group discussion will be conducted to validate the proposed serious game design principles that have been identified in this study as suitable for designing serious games for children with autism. The feedback and suggestions from teachers and experts will be used to strengthen the serious game design principles for children with autism.

On the other hand, it is anticipated that these findings will serve as a guide for future researchers and future game developers who are interested in developing serious games for children with autism to facilitate their development skills, especially in supporting the development of emotion regulation. Following that, after the validation process in the focus group discussion, a prototype will be developed and tested with children with autism to identify the engagement and effect on their skill development.

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REFERENCES

- [1] A. American Psychiatric, Diagnostic and Statistical Manual of Mental Disorders (DSM-5). American Psychiatric Association, 2013, pp. 1-970.
- [2] J. Fuentes, M. Bakare, K. Munir, P. Aguayo, N. Gaddour, and O. Oner, "Autism Spectrum Disorder," in ACAPAP e-textbook of child and adolescent mental health. Geneva: International Association for Child and Adolescent Psychiatry and Allied Professions, 2012, pp. 1-27.
- [3] H. Hodges, C. Fealko, and N. Soares, "Autism spectrum disorder: Definition, epidemiology, causes, and clinical evaluation," in Translational Pediatrics vol. 9, ed: AME Publishing Company, 2020, pp. S55-S65.
- [4] S. M. Shamsudin and S. S. A. Rahman, "A Preliminary Study: Awareness, Knowledge and Attitude of People Towards Children with Autism," in Proceeding of the Social Sciences Research ICSSR, 2014, pp. 322-332. [Online]. Available: <http://WorldConferences.net>. [Online]. Available: <http://WorldConferences.net>
- [5] W. N. W. Yaacob, L. H. Yaacob, M. M. Zulkifli, and R. Muhamad, "A Journey towards Resilience: Coping Strategies Adopted by Parents with Children Having Autism Spectrum Disorder in Northeast Malaysia," International Journal of Environmental Research and Public Health, vol. 19, no. 4, 2022/2// 2022, doi: 10.3390/ijerph19042458.
- [6] S. Y. Eow, W. Y. Gan, P. Y. Lim, H. Awang, and Z. Mohd Shariff, "Factors associated with autism severity among Malaysian children with Autism Spectrum Disorder," Research in Developmental Disabilities, vol. 100, 2020/5// 2020, doi: 10.1016/j.ridd.2020.103632.
- [7] C. Demily et al., "Autism spectrum disorder associated with 49,XYYY: Case report and review of the literature," BMC Medical Genetics, vol. 18, no. 1, 2017/1// 2017, doi: 10.1186/s12881-017-0371-1.
- [8] N. R. Tartaglia et al., "Autism Spectrum Disorder in Males with Sex Chromosome Aneuploidy: XXY/Klinefelter Syndrome, XYY, and XYYY," Journal of Developmental and Behavioral Pediatrics, vol. 38,

- no. 3, pp. 197-207, 2017/4// 2017, doi: 10.1097/DBP.0000000000000429.
- [9] R. Loomes, L. Hull, and W. P. L. Mandy, "What Is the Male-to-Female Ratio in Autism Spectrum Disorder? A Systematic Review and Meta-Analysis," in *Journal of the American Academy of Child and Adolescent Psychiatry* vol. 56, ed: Elsevier Inc., 2017, pp. 466-474.
- [10] M. Fan, J. Fan, A. N. Antle, P. Pasquier, and S. Jin, "Emostory: A game-based system supporting children's emotional development," in *Conference on Human Factors in Computing Systems - Proceedings, 2018/4// 2018*, vol. 2018-April: Association for Computing Machinery, doi: 10.1145/3170427.3188594.
- [11] S. Cibralic, J. Kohlhoff, N. Wallace, C. McMahon, and V. Eapen, "A systematic review of emotion regulation in children with Autism Spectrum Disorder," in *Research in Autism Spectrum Disorders* vol. 68, ed: Elsevier Ltd, 2019.
- [12] S. Carlier, S. Van Der Paelt, F. Ongenaes, F. De Backere, and F. De Turck, "Using a serious game to reduce stress and anxiety in children with autism spectrum disorder," in *PervasiveHealth: Pervasive Computing Technologies for Healthcare, 2019/5// 2019: ICST*, pp. 452-461, doi: 10.1145/3329189.3329237.
- [13] N. Shah and F. Jameel, "Emotional Intelligence Assessment Tool for Children with Autism Spectrum Disorder," *International Journal of Learning*, vol. 5, no. 3, pp. 213-219, 2019/9// 2019, doi: 10.18178/IJLT.5.3.213-219.
- [14] L. Gillies-Walker, N. Ramzan, J. Rankin, E. Nibley, and K. Gillespie-Smith, "'You Feel Like You Kind of Walk Between the Two Worlds': A Participatory Study Exploring How Technology Can Support Emotion Regulation for Autistic People," *Journal of Autism and Developmental Disorders*, pp. 1-13, 2022, doi: 10.1007/s10803-021-05392-z.
- [15] V. Ting and J. A. Weiss, "Emotion Regulation and Parent Co-Regulation in Children with Autism Spectrum Disorder," *Journal of Autism and Developmental Disorders*, vol. 47, no. 3, pp. 680-689, 2017/3// 2017, doi: 10.1007/s10803-016-3009-9.
- [16] O. Sadka and A. Antle, "Interactive Technologies for Emotion Regulation Training: A Scoping Review," *International Journal of Human Computer Studies*, vol. 168, 2022/12// 2022, doi: 10.1016/j.ijhcs.2022.102906.
- [17] P. Kokol, H. B. Vošner, J. Završnik, J. Vermeulen, S. Shohieb, and F. Peinemann, "Serious Game-based Intervention for Children with Developmental Disabilities," *Current Pediatric Reviews*, vol. 16, no. 1, pp. 26-32, 2019/8// 2020, doi: 10.2174/1573396315666190808115238.
- [18] S. Kirst et al., "Fostering socio-emotional competencies in children on the autism spectrum using a parent-assisted serious game: A multicenter randomized controlled trial," *Behaviour Research and Therapy*, vol. 152, 2022/5// 2022, doi: 10.1016/j.brat.2022.104068.
- [19] C. Grossard, G. Palestra, J. Xavier, M. Chetouani, O. Grynspan, and D. Cohen, "ICT and autism care: State of the art," in *Current Opinion in Psychiatry* vol. 31, ed: Lippincott Williams and Wilkins, 2018, pp. 474-483.
- [20] S. Tsikinas, S. Xinogalos, and M. Satratzemi, "Review on Serious Games for People with Intellectual Disabilities and Autism," in *10th European Conference on games Based Learning*, 2016, pp. 696-703.
- [21] B. Abirached, Y. Zhang, and J. H. Park, "Understanding User Needs for Serious Games for Teaching Children with Autism Spectrum Disorders Emotions," in *EdMedia+ Innovate Learning, 2012: Association for the Advancement of Computing in Education (AACE)*, pp. 1054-1063.
- [22] A. Hassan, N. Pinkwart, and M. Shafi, "Serious games to improve social and emotional intelligence in children with autism," in *Entertainment Computing* vol. 38, ed: Elsevier B.V., 2021.
- [23] A. L. Jouen et al., "GOLIAH (Gaming open library for intervention in autism at home): A 6-month single blind matched controlled exploratory study," *Child and Adolescent Psychiatry and Mental Health*, vol. 11, no. 1, 2017/3// 2017, doi: 10.1186/s13034-017-0154-7.
- [24] D. Villani, C. Carissoli, S. Triberti, A. Marchetti, G. Gilli, and G. Riva, "Videogames for Emotion Regulation: A Systematic Review," *Games for Health Journal*, vol. 7, pp. 85-99, 2018/4// 2018, doi: 10.1089/g4h.2017.0108.
- [25] C. Lyu, H. Chen, X. Peng, T. Xu, and H. Wang, "DailyConnect: A Mobile Aid that Assists the Understanding of Situation-based Emotions for Children with ASDs," in *Conference on Human Factors in Computing Systems - Proceedings, 2021/5// 2021: Association for Computing Machinery*, doi: 10.1145/3411763.3451578.
- [26] D. A. Norman, *Emotional Design*. 2004, pp. 1-268.
- [27] D. W. Sosnowski et al., "Brief Report: A Novel Digital Therapeutic that Combines Applied Behavior Analysis with Gaze-Contingent Eye Tracking to Improve Emotion Recognition in Children with Autism Spectrum Disorder," *Journal of Autism and Developmental Disorders*, vol. 52, no. 5, pp. 2357-2366, 2022/5// 2022, doi: 10.1007/s10803-021-05101-w.
- [28] H. R. Bougher-Muckian, A. E. Root, C. G. Coogle, and K. K. Floyd, "The importance of emotions: the socialisation of emotion in parents of children with autism spectrum disorder," *Early Child Development and Care*, vol. 186, no. 10, pp. 1584-1593, 2016/10// 2016, doi: 10.1080/03004430.2015.1112799.
- [29] N. M. Reyes, R. Factor, and A. Scarpa, "Emotion regulation, emotionality, and expression of emotions: A link between social skills, behavior, and emotion problems in children with ASD and their peers," *Research in Developmental Disabilities*, vol. 106, 2020/11// 2020, doi: 10.1016/j.ridd.2020.103770.
- [30] Q. A. i. M. Jinnah, E. Dunstan, and T. K. Yin, "AR in Promoting Social Emotional Learning Among Children with Autism Spectrum Disorder in Malaysian Inclusive Preschool Classrooms," *Jurnal Pendidikan Bitara UPSI*, vol. 14, pp. 62-69, 2021, doi: 10.37134/bitara.vol14.sp2.7.2021.
- [31] S. F. Goldsmith and E. Kelley, "Associations Between Emotion Regulation and Social Impairment in Children and Adolescents with Autism Spectrum Disorder," *Journal of Autism and Developmental Disorders*, vol. 48, no. 6, pp. 2164-2173, 2018/6// 2018, doi: 10.1007/s10803-018-3483-3.
- [32] K. Sharma, S. Papavaslopoulou, and M. Giannakos, "Joint emotional state of children and perceived collaborative experience in coding activities," in *Proceedings of the 18th ACM International Conference on Interaction Design and Children, IDC 2019, 2019/6// 2019: Association for Computing Machinery, Inc*, pp. 133-145, doi: 10.1145/3311927.3323145.
- [33] R. Boily, S. E. Kingston, and J. M. Montgomery, "Trait and Ability Emotional Intelligence in Adolescents With and Without Autism Spectrum Disorder," *Canadian Journal of School Psychology*, vol. 32, no. 3-4, pp. 282-298, 2017/9// 2017, doi: 10.1177/0829573517717160.
- [34] K. Kaur and S. Pany, "Computer-Based Intervention For Autism Spectrum Disorder Children and Their Social Skills: Meta-Analysis," *Scholarly Research Journal for Humanity Science & English Language*, vol. 4, no. 23, 2017/9// 2017, doi: 10.21922/srjhsel.v4i23.9649.
- [35] G. Kokkalia, A. Drigas, and A. Economou, "The Use of Serious Games in Preschool Education," *International Journal of Emerging Technologies in Learning (iJET)*, vol. 12, no. 11, pp. 15-27, 2017, doi: 10.3991/ijet.v12.i11.6991.
- [36] M. A. Carreno-Leon, J. A. Sandoval-Bringas, I. D. Encinas, R. C. Castro, I. E. Cota, and A. L. Carrillo, "Managing emotions in autistic children through serious game with tangible interfaces," in *Proceedings - 2021 4th International Conference on Inclusive Technology and Education, CONTIE 2021, 2021: Institute of Electrical and Electronics Engineers Inc.*, pp. 126-133, doi: 10.1109/CONTIE54684.2021.00029.
- [37] I. Durango, A. Carrascosa, V. M. R. Penichet, and J. A. Gallud, "Tangible serious games with real objects to support therapies for children with special needs," in *ACM International Conference Proceeding Series, 2015/9// 2015*, vol. 07-09-September-2015: Association for Computing Machinery, doi: 10.1145/2829875.2829910.
- [38] C. Girard, J. Ecalte, and A. Magnan, "Serious games as new educational tools: How effective are they? A meta-analysis of recent studies," *Journal of Computer Assisted Learning*, vol. 29, no. 3, pp. 207-219, 2013/6// 2013, doi: 10.1111/j.1365-2729.2012.00489.x.
- [39] L. E. Boyd, K. E. Ringland, O. L. Haimson, H. Fernandez, M. Bistarkey, and G. R. Hayes, "Evaluating a collaborative iPad game's impact on social relationships for children with autism spectrum disorder," *ACM Transactions on Accessible Computing*, vol. 7, no. 1, pp. 1-18, 2015/6// 2015, doi: 10.1145/2751564.
- [40] N. A. Bartolome and B. G. Zapirain, "Technologies as support tools for persons with autistic spectrum disorder: A systematic review," in

- International Journal of Environmental Research and Public Health vol. 11, ed: MDPI, 2014, pp. 7767-7802.
- [41] H. Chen, "A Theoretic Review of Emotion Regulation," *Open Journal of Social Sciences*, vol. 04, no. 02, pp. 147-153, 2016, doi: 10.4236/jss.2016.42020.
- [42] S. N. V. Yuan and H. H. S. Ip, "Using virtual reality to train emotional and social skills in children with autism spectrum disorder," *London Journal of Primary Care*, vol. 10, no. 4, pp. 110-112, 2018/7// 2018, doi: 10.1080/17571472.2018.1483000.
- [43] A. Rouhi, M. Spitale, F. Catania, G. Cosentino, M. Gelsomini, and F. Garzotto, "Emotify: Emotional game for children with autism spectrum disorder based-on machine learning," in *International Conference on Intelligent User Interfaces, Proceedings IUI, 2019/3// 2019: Association for Computing Machinery*, pp. 31-32, doi: 10.1145/3308557.3308688.
- [44] K. Higuch et al., "Visualizing gaze direction to support video coding of social attention for children with autism spectrum disorder," in *International Conference on Intelligent User Interfaces, Proceedings IUI, 2018/3// 2018: Association for Computing Machinery*, pp. 571-582, doi: 10.1145/3172944.3172960.
- [45] Z. Shams, L. Kashani-Vahid, and H. Moradi, "Comparing the Effectiveness of 'EmoGalaxy Video Game' with 'Card games' on Emotion Regulation of Children with Autism Spectrum Disorder," in *Proceedings of the 2nd International Serious Games Symposium, ISGS 2020, 2020/12// 2020: Institute of Electrical and Electronics Engineers Inc.*, pp. 94-98, doi: 10.1109/ISGS51981.2020.9375321.
- [46] J. Chen, G. Wang, K. Zhang, G. Wang, and L. Liu, "A pilot study on evaluating children with autism spectrum disorder using computer games," *Computers in Human Behavior*, vol. 90, pp. 204-214, 2019/1// 2019, doi: 10.1016/j.chb.2018.08.057.
- [47] R. Y. Cai, A. L. Richdale, M. Uljarević, C. Dissanayake, and A. C. Samson, "Emotion regulation in autism spectrum disorder: Where we are and where we need to go," in *Autism Research* vol. 11, ed: John Wiley and Sons Inc., 2018, pp. 962-978.
- [48] J. M. Garcia-Garcia, V. M. R. Penichet, M. D. Lozano, and A. Fernando, "Using emotion recognition technologies to teach children with autism spectrum disorder how to identify and express emotions," *Universal Access in the Information Society*, vol. 21, no. 4, pp. 809-825, 2022/11// 2022, doi: 10.1007/s10209-021-00818-y.
- [49] A. Dapogny et al., "JEMImE: A serious game to teach children with ASD how to adequately produce facial expressions," in *Proceedings - 13th IEEE International Conference on Automatic Face and Gesture Recognition, FG 2018, 2018/6// 2018: Institute of Electrical and Electronics Engineers Inc.*, pp. 723-730, doi: 10.1109/FG.2018.00114.
- [50] C. S. C. Lee, S. H. F. Lam, S. T. K. Tsang, C. M. C. Yuen, and C. K. M. Ng, "The Effectiveness of Technology-Based Intervention in Improving Emotion Recognition Through Facial Expression in People with Autism Spectrum Disorder: A Systematic Review," in *Review Journal of Autism and Developmental Disorders* vol. 5, ed: Springer New York LLC, 2018, pp. 91-104.
- [51] J. S. Y. Tang, N. T. M. Chen, M. Falkmer, S. Bölte, and S. Girdler, "A systematic review and meta-analysis of social emotional computer based interventions for autistic individuals using the serious game framework," in *Research in Autism Spectrum Disorders* vol. 66, ed: Elsevier Ltd, 2019.
- [52] S. Tsikinas and S. Xinogalos, "Design guidelines for serious games targeted to people with autism," in *Smart Innovation, Systems and Technologies*, 2019, vol. 144: Springer Science and Business Media Deutschland GmbH, pp. 489-499, doi: 10.1007/978-981-13-8260-4_43.
- [53] E. M. Whyte, J. M. Smyth, and K. S. Scherf, "Designing Serious Game Interventions for Individuals with Autism," *Journal of Autism and Developmental Disorders*, vol. 45, no. 12, pp. 3820-3831, 2015/12// 2015, doi: 10.1007/s10803-014-2333-1.
- [54] M. Schmettow and J. Sommer, "Linking card sorting to browsing performance – are congruent municipal websites more efficient to use?," *Behaviour and Information Technology*, vol. 35, no. 6, pp. 452-470, 2016/6// 2016, doi: 10.1080/0144929X.2016.1157207.
- [55] A. Majumdar, "Thematic Analysis in Qualitative Research," in *Qualitative Techniques for Workplace Data Analysis*, (Advances in Business Information Systems and Analytics, 2019, ch. chapter 9, pp. 197-220.
- [56] S. Artoni et al., "Technology-enhanced ABA intervention in children with autism: a pilot study," *Universal Access in the Information Society*, vol. 17, no. 1, pp. 191-210, 2018/3// 2018, doi: 10.1007/s10209-017-0536-x.
- [57] C. Putnam, C. Hanschke, J. Todd, J. Gemmell, and M. Kollia, "Interactive Technologies Designed for Children with Autism: Reports of Use and Desires from Parents, Teachers, and Therapists," *ACM Transactions on Accessible Computing*, vol. 12, no. 3, 2019/8// 2019, doi: 10.1145/3342285.
- [58] S. Tsikinas and S. Xinogalos, "Towards a serious games design framework for people with intellectual disability or autism spectrum disorder," *Education and Information Technologies*, vol. 25, no. 4, pp. 3405-3423, 2020/7// 2020, doi: 10.1007/s10639-020-10124-4.
- [59] P. Ghanouni, T. Jarus, J. G. Zwicker, J. Lucyshyn, B. Fenn, and E. Stokley, "Design Elements during Development of Videogame Programs for Children with Autism Spectrum Disorder: Stakeholders' Viewpoints," *Games for Health Journal*, vol. 9, no. 2, pp. 137-145, 2020/4// 2020, doi: 10.1089/g4h.2019.0070.
- [60] J. Meng, X. Wu, and L. Liu, "An Avatar-Based Personal Pronouns Intervention System for Children with Autism Spectrum Disorder," in *TALE 2021 - IEEE International Conference on Engineering, Technology and Education, Proceedings, 2021: Institute of Electrical and Electronics Engineers Inc.*, pp. 1118-1123, doi: 10.1109/TALE52509.2021.9678755.
- [61] S. W. Tan, M. H. L. Abdullah, and N. F. N. Mohd Daud, "Mobile games for children with autism spectrum disorder to support positive behavioural skills," in *Lecture Notes in Networks and Systems*, vol. 67: Springer, 2019, pp. 475-490.
- [62] G. Gaudi, B. Kapralos, A. Uribe-Quevedo, and G. Hall, "Autism Serious Game Framework (ASGF) for Developing Games for Children with Autism," *Interactive Mobile Communication, Technologies and Learning*, pp. 3-12, 2021.
- [63] C. Wu and Q. Zheng, "Motion Sensing Games for Children with Autism Spectrum Disorder," *VR, Simulations and Serious Games for Education*, pp. 55-65, 2019, doi: 10.1007/978-981-13-2844-2_6.
- [64] S. Strickroth, D. Zoerner, T. Moebert, A. Morgiel, and U. Lucke, "Game-Based Promotion of Motivation and Attention for Socio-Emotional Training in Autism," *i-com*, vol. 19, no. 1, pp. 17-30, 2020/4// 2020, doi: 10.1515/icom-2020-0003.
- [65] J. S. Y. Tang, M. Falkmer, N. T. M. Chen, S. Bolte, and S. Girdler, "Designing a Serious Game for Youth with ASD - Perspectives from End-Users and Professionals," *Journal of Autism and Developmental Disorders*, vol. 49, no. 3, pp. 976-995, 2019.
- [66] C. Grossard, O. Grynspan, S. Serret, A. L. Jouen, K. Bailly, and D. Cohen, "Serious games to teach social interactions and emotions to individuals with autism spectrum disorders (ASD)," *Computers and Education*, vol. 113, pp. 195-211, 2017/10// 2017, doi: 10.1016/j.compedu.2017.05.002.
- [67] S. Shahid, J. Ter Voort, M. Somers, and I. Mansour, "Skeuomorphic, flat or material design: Requirements for designing mobile planning applications for students with autism spectrum disorder," in *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct, MobileHCI 2016, 2016/9// 2016: Association for Computing Machinery, Inc*, pp. 738-745, doi: 10.1145/2957265.2961866.
- [68] V. B. Pedreschi, D. A. O. Díaz, J. A. Aguirre, and P. A. Gonzalez, "A technological platform using serious game for children with Autism Spectrum Disorder (ASD) in Peru," in *Proceedings of the LACCEI international Multi-conference for Engineering, Education and Technology, 2019, vol. 2019-July: Latin American and Caribbean Consortium of Engineering Institutions*, doi: 10.18687/LACCEI2019.1.1.278.
- [69] R. Silva, D. Duque, M. Melo, and J. M. Moura, "The Benefits of Virtual Reality Technology for Rehabilitation of Children with Autism: A Systematic Review," in *ICGI 2021 - 2021 International Conference on Graphics and Interaction, Proceedings, 2021: Institute of Electrical and Electronics Engineers Inc.*, doi: 10.1109/ICGI54032.2021.9655278.

- [70] L. Benton, A. Vasalou, D. Gooch, and R. Khaled, "Understanding and fostering children's storytelling during game narrative design," in ACM International Conference Proceeding Series, 2014: Association for Computing Machinery, pp. 301-304, doi: 10.1145/2593968.2610477.
- [71] P. C. Ribeiro, B. B. P. L. De Araujo, and A. Raposo, "ComFiM: A Cooperative Serious Game to Encourage the Development of Communicative Skills between Children with Autism," in Brazilian Symposium on Games and Digital Entertainment, SBGAMES, 2014/12// 2014, vol. 2014-December: IEEE Computer Society, December ed., pp. 148-157, doi: 10.1109/SBGAMES.2014.19.
- [72] M. M. Terras, E. A. Boyle, J. Ramsay, and D. Jarrett, "The opportunities and challenges of serious games for people with an intellectual disability," British Journal of Educational Technology, vol. 49, no. 4, pp. 690-700, 2018/7// 2018, doi: 10.1111/bjet.12638.
- [73] A. Shapi'i, N. Atifah, A. Rahman, S. Baharuddin, and R. Yaakub, "Interactive Games Using Hand-Eye Coordination Method for Autistic Children Therapy," International Journal on Advanced Science Engineering Information Technology, vol. 8, no. 4-2, pp. 1381-1386, 2018.
- [74] N. Harrold, C. T. Tan, and D. Rosser, "Towards an Expression Recognition Game to Assist the Emotional Development of Children with Autism Spectrum Disorders," in Proceedings of the Workshop at SIGGRAPH Asia, 2012, pp. 33-37.
- [75] G. L. Wagener, M. Berning, A. P. Costa, G. Steffgen, and A. Melzer, "Effects of Emotional Music on Facial Emotion Recognition in Children with Autism Spectrum Disorder (ASD)," Journal of Autism and Developmental Disorders, vol. 51, no. 9, pp. 3256-3265, 2021/9// 2021, doi: 10.1007/s10803-020-04781-0.
- [76] N. Uzuegbunam, W. H. Wong, S. C. S. Cheung, and L. Ruble, "MEBook: Kinect-based self-modeling intervention for children with autism," in Proceedings - IEEE International Conference on Multimedia and Expo, 2015/8// 2015, vol. 2015-August: IEEE Computer Society, doi: 10.1109/ICME.2015.7177518.
- [77] R. Morris, C. Kirshbaum, and R. Picard, "Broadening Accessibility Through Special Interests: A New Approach for Software Customization," in Proceedings of the 12th international ACM SIGACCESS conference on Computers and accessibility, 2010: ACM, pp. 171-178.
- [78] C. Papoutsis, A. Drigas, and C. Skianis, "Mobile applications to improve emotional intelligence in Autism - A review," in International Journal of Interactive Mobile Technologies vol. 12, ed: International Association of Online Engineering, 2018, pp. 47-61.
- [79] B. Bossavit and S. Parsons, ""This is how I want to learn": High functioning autistic teens co-designing a serious game," in Conference on Human Factors in Computing Systems - Proceedings, 2016/5// 2016: Association for Computing Machinery, pp. 1294-1299, doi: 10.1145/2858036.2858322.
- [80] P. Ghanouni, T. Jarus, J. G. Zwicker, and J. Lucyshyn, "An interactive serious game to Target perspective taking skills among children with ASD: A usability testing," Behaviour and Information Technology, vol. 40, no. 16, pp. 1716-1726, 2021, doi: 10.1080/0144929X.2020.1776770.
- [81] H. Wang and C.-T. Sun, "Game Reward Systems: Gaming Experiences and Social Meanings," in DiGRA conference, 2011. [Online]. Available: <https://www.researchgate.net/publication/268351726>. [Online]. Available: <https://www.researchgate.net/publication/268351726>
- [82] A. Bhattacharya, M. Gelsomini, P. Pérez-Fuster, G. D. Abowd, and A. Rozga, "Designing motion-based activities to engage students with autism in classroom settings," in Proceedings of IDC 2015: The 14th International Conference on Interaction Design and Children, 2015/6// 2015: Association for Computing Machinery, Inc, pp. 69-78, doi: 10.1145/2771839.2771847.
- [83] L. A. Annetta, "The 'Ts' Have It: A Framework for Serious Educational Game Design," Review of General Psychology, vol. 14, no. 2, pp. 105-112, 2010, doi: 10.1037/a0018985.
- [84] K. Kiili, "Digital game-based learning: Towards an experiential gaming model," Internet and Higher Education, vol. 8, no. 1, pp. 13-24, 2005/3// 2005, doi: 10.1016/j.iheduc.2004.12.001.
- [85] S. Fletcher-Watson, H. Pain, S. Hammond, A. Humphry, and H. McConachie, "Designing for young children with autism spectrum disorder: A case study of an iPad app," International Journal of Child-Computer Interaction, vol. 7, pp. 1-14, 2016/1// 2016, doi: 10.1016/j.ijcci.2016.03.002.

A Novel Approach for an Outdoor Oyster Mushroom Cultivation using a Smart IoT-based Adaptive Neuro Fuzzy Controller

Dakhole Dipali¹, Thiruselvan Subramanian², G Senthil Kumaran³

Computer Science and Engineering, Presidency University, Bangalore, India^{1, 2}

Department of Agricultural Engineering, ICAR-Indian Institute of Horticultural Research, Bangalore, India³

Abstract—An automatic environment control systems for greenhouses are turning to be very significant because of food demand, and rise in temperature and population of the world. This article proposes to design and implement a low cost, robust and water efficient autonomous smart internet of things (IoT) system to monitor and control the temperature, and humidity of an outdoor oyster mushroom growing unit. The IoT-based control system involves DHT22 sensors, ESP32 controller and actuators (water pump and cooling fan) to facilitate the adequate amount of air for circulation to maintain temperature and water to maintain humidity inside an outdoor oyster mushroom growing unit as per its requirement. A real working prototype is developed and implemented on integrating fuzzy inference system (FIS) in ESP32 controller using Arduino C with the help of its integrated design environment. The FIS is designed to calculate the switching on/off time of water pump and cooling fan on sensing current temperature, and humidity inside oyster mushroom unit with respect to ambient temperature, and humidity respectively. The prototype provides inside temperature, humidity, ambient temperature, ambient humidity, water pump time and fan time on Thing-speak platform in real time. Furthermore, the data is used for design and simulation of Adaptive Neuro Fuzzy Inference Controller for an outdoor oyster mushroom growing unit in MATLAB/Simulink to improve the performance of the system. The practical applicability of the proposed ANFIS controller over FIS Controller and industrial PID Controller is shown by simulation findings with use of experimental data. The system reduces water use as well as an extremely extraordinary administration required for monitoring the mushroom unit. In addition, it increases robustness of the system.

Keywords—Precision agriculture; adaptive neuro fuzzy inference system; fuzzy inference system; oyster mushroom cultivation; internet of things

I. INTRODUCTION

Agricultural practices are utmost essential ways of subsistence over the period of human evolution. Henceforth, human beings depend on broad scale of agricultural goods in nearly every facet of life. However, today the changes in climatic conditions are affecting the growth of greenhouses drastically. In addition, increase in food demand with increasing world population, the traditional agricultural practices are transforming into artificial and smart practices. This study aims to address the problem of controlling the environment conditions in an oyster mushroom crop and

watering it without contamination, by providing sensor and actuators based smart autonomous controller, thereby removing much of efforts required by farmer.

The advent of new species of mushrooms for commercial growing during the past two decades has caused the mushroom industry worldwide to expand very quickly. Despite having a plenty of agricultural waste, and a rich fungal biodiversity, India's rise has received only unresponsive support. Presently, 0.13 million tons of mushrooms are produced in India [1]. From 2010 to 2017, the Indian mushroom market experienced an average annual growth of 4.3% (www.indiastat.com). This shows that the mushroom industry is expanding day by day and has potential to generate more money in the future. Since maintaining essential environmental conditions is necessary for mushroom growth, the key challenge is how to add value to the mushroom cultivation process. In order to link data to productivity gains, the Internet of Things (IoT) era is essential to the information technology revolution. The use of the IoT has the potential to help farmers to overcome a number of challenges, such as water shortages, a lack of adequate land for plantations, maintaining crucial parameter for crop growth, difficulty in managing costs, and meeting the global demand for food resources [2]. In order to help farmers to improve the quality, quantity, sustainability, and cost-effectiveness of agricultural production, smart agriculture uses IoT applications.

Oyster Mushroom has many advantages, including being high in proteins and having medicinal uses. These mushrooms can only grow in upland regions with specific humidity and temperature levels. Because it is more economical than other agricultural practices, the government encourages farmers to grow oyster mushrooms in lowland areas. Misting oyster mushrooms with clean water will keep them at the right humidity and temperature. It can develop normally in controlled environments where the temperature ranges from 24 to 27°C and the relative humidity ranges from 70 to 85% [3]. However, because it requires a significant financial commitment, farmers typically find it challenging to build air-conditioned farms. When growing mushrooms manually, humidity is maintained by hanging coir mats or gunny sheets along the walls, and it is kept moist by periodic watering during the cropping phase. It is also more difficult to maintain the proper humidity and moisture in the substrate during the summer because more water is lost due to evaporation. Watering the mushrooms extensively twice or three times a day is the solution, but this has the drawback of making the

mushrooms overly wet and producing unusable, low-quality product. Therefore, proper controlling mechanism is needed.

A smart oyster mushroom growing unit is an enclosed structure that offers mushrooms an environment that is properly controlled using IoT and Soft computing technology Fuzzy Inference System (FIS) to regulate mushroom growing conditions, to lower production costs and increase the revenues. The IoT-based control system involves DHT22 sensors, ESP32 controller and actuators water pump and cooling fan to facilitate the adequate amount of air for circulation to maintain the temperature and water to maintain the humidity inside the oyster mushroom growing unit as per its requirement. The real working prototype is developed and implemented on integrating FIS in ESP32 controller using Arduino C, and its integrated design environment. The FIS is designed to calculate the switching on/off time of water pump and cooling fan on sensing current temperature and humidity inside oyster mushroom unit with respect to ambient temperature and humidity respectively. The prototype provides inside temperature, humidity, ambient temperature, ambient humidity, water pump time and fan time on Thing-speak platform in real time. Furthermore, the data is used for design and simulation of Adaptive Neuro Fuzzy Inference Controller for an outdoor oyster mushroom growing unit in MATLAB/Simulink.

This research examines the modelling and controlling of inside temperature and humidity for an outdoor oyster mushroom growing unit with respect to ambient temperature and humidity. In addition, Proportional Derivative and Integrated (PID), Fuzzy logic control (FLC), and ANFIS are the control techniques that are discussed, compared and validated. The remainder of this article is presented as follows: literature review is discussed in Section II, all three controllers modelling are covered in Section III, a real time implementation of IoT prototype using FIS controller and all three controllers Simulink modelling is covered in Section IV, the experimental findings and discussions are included in Section V, and the conclusion of the work and future scope are covered in Section VI.

II. LITERATURE REVIEW

The adaptive neuro-fuzzy inference system (ANFIS) combines the concepts of neural networks and fuzzy logic. It is frequently used to solve engineering problems when traditional methods are unable to provide a quick and reliable solution [4]. Numerous academics have focused on the control design of the climate of smart mushroom houses over the last decade. A smart mushroom house environment was developed using a smart controller by MSA Mahmud et al [5] Thong-un, N. et al. [6], Ariffin, M. A. M. et al. [7], Sihombing, P. et al. [8], Chiochan, O. et al. [9], Marzuki, A. et al. [10], and Yin, H. et al. [11].

For controlling various green houses, a fuzzy system and neural network techniques were used by researchers Koutb, M. et al. [12], Lafont, F. et al. [13], Marquez-Vera et al. [14], Mote, T et al. [15], Revathi, S et al. [16], Xu, F. et al. [17], Fourati, F. et al. [18], Coelho, J. [19], Mohamed, S. et al. [20], Atia, D. M. et al. [21], Oubehar, H. et al. [22], Hernández-

Salazar et al. [23], Qiuying, Z. et al. [24], Khuntia, S. R. et al. [25], and Hamidane, H. et al. [26].

The significant contribution of the presented work is as follows:

- Designing of FIS system in MATLAB as per oyster mushroom cultivation requirement, includes input and output variable membership function design, setting fuzzy inference rules, and choosing a suitable defuzzification method.
- Design and implementing a low cost, autonomous IoT based monitoring, controlling FIS integrated system prototype that controls inside temperature and humidity of an outdoor oyster mushroom growing unit.
- Design and simulating an ANFIS controller in Simulink using real time data collected by IoT prototype.

III. PROPOSED AUTOMATIC ENVIRONEMNT CONTROLLERS FOR AN OUTDOOR MUSHROOM GROWING UNIT

A. Fuzzy Inference System

Fuzzy inference system (FIS) has three steps, fuzzification, inference engine and defuzzification. In fuzzification, the membership functions (MFs) are designed for input and output values. MFs are used to convert crisp value into fuzzy values. Trapezoidal MF is designed for input variables temperature, as shown in Fig. 1. The range of temperature considered is 0 to 50°C and the membership values are decided as Cold, Suitable, and Hot. Another input variable is humidity varying from 0 to 100%. Its membership values are considered as Dry, Suitable, and Wet with trapezoidal MF as shown in Fig. 2. The triangular MFs are designed for output variables water pump time, as well as fan time. Their range is considered from 0 to 60 seconds with Off, Slow, Medium, and Long membership values as shown in Fig. 3 and Fig. 4. The inference engine is the set of if-then rules, designed using expert suggestion and trial and error method as shown in Table I. In defuzzification, the fuzzy value is converted back into crisp value using center of gravity method.

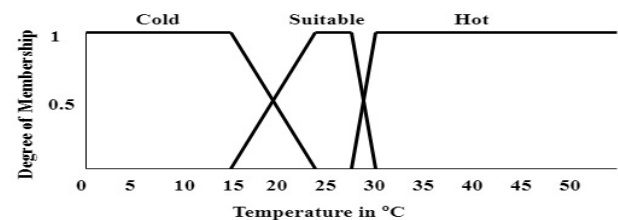


Fig. 1. Membership function for input temperature.

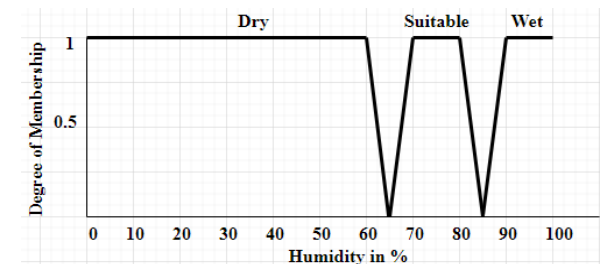


Fig. 2. Membership function for input humidity.

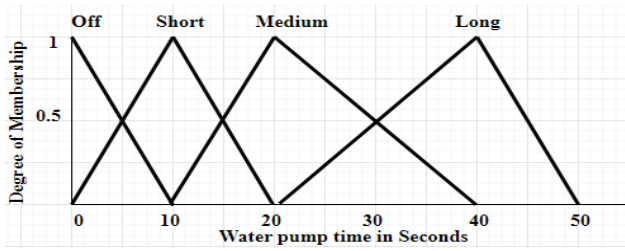


Fig. 3. Membership function for water pump time.

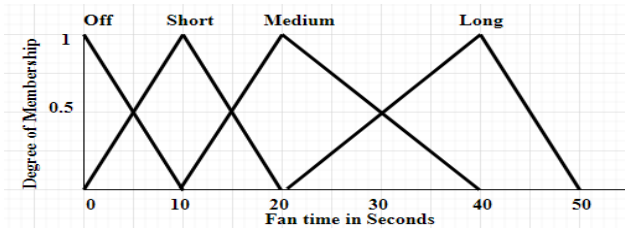


Fig. 4. Membership function for fan time.

TABLE I. FUZZY RULE BASE

Rule	Input Variables				Output Variables	
	Temperature		Humidity		Water Pump Time	Fan Time
1	Cold	AND	Dry	THEN	Short	Short
2	Suitable	AND	Dry	THEN	Medium	Medium
3	Hot	AND	Dry	THEN	Long	Long
4	Cold	AND	Suitable	THEN	Off	Off
5	Suitable	AND	Suitable	THEN	Off	Off
6	Hot	AND	Suitable	THEN	Off	Medium
7	Cold	AND	Wet	THEN	Off	Off
8	Suitable	AND	Wet	THEN	Off	Off
9	Hot	AND	Wet	THEN	Short	Short

The designing of FIS is done in MATLAB/Simulink to generate .fis file. It is converted into Arduino C code to upload into ESP32 controller of IoT prototype for real time implementation.

B. Adaptive Neuro Fuzzy Inference System

ANFIS is an adaptive network consisting of fuzzy logic and neural network. The fuzzy controllers developed by Takagi-Sugeno are simulated using an adaptive network. With a given input/output data set, ANFIS modifies all the parameters using the back propagation gradient descent methodology for non-linear parameters and the least squares kind of method for linear parameters. This section presents the five-layered ANFIS architecture and the learning process for the neural fuzzy network.

- Layer 1: Each node i in first layer is functional adaptive.

$$O_i^1 = \mu_{A_i}(x) = \frac{1}{1 + \left(\frac{x - c_i}{a_i}\right)^{2b_i}}, \quad i = 1, 2, \dots, 17 \quad (1)$$

Where, x is the input to adaptive node i , A_i is the fuzzy variable associated with node i . O_i^1 is the membership function provides the degree of membership to which A_i given x satisfy the quantifier A_i . The $\{a_i, b_i, c_i\}$ are the parameter set with changing values to get best bell-shaped function.

- Layer 2: Every node in this layer is a circle node labeled Π , which multiplies the incoming signals and sends the product out. For an instance,

$$w_i = \mu_{A_i}(x) * \mu_{A_i}(y), \quad i = 1, 2, \dots, 17 \quad (2)$$

- Layer 3: Each node in this layer is a circle node labeled N . The i^{th} node calculates the ratio of the i^{th} rule is firing strength to the sum of all rules firing strengths.

$$\bar{w} = \frac{w_i}{w_1 + \dots + w_{17}}, \quad i = 1, \dots, 17 \quad (3)$$

- Layer 4: Every node in this layer is a square node with a node function.

$$O_i^4 = \bar{w}_i f = \bar{w}(p_i x + q_i + r_i) \quad (4)$$

Where w_i is the output of layer 3, and $\{p_i, q_i, r_i\}$ is the parameter set. Parameters in this layer will be referred to as consequent parameters.

- Layer 5: The single node in this layer is a circle node labeled Σ that computes the overall output as the summation of all incoming signals.

$$O_1^5 = \sum \bar{w}_i f = \frac{\sum_i w_i f}{\sum_i w_i} \quad (5)$$

C. PID Controller

To validate the performance of the study, we compared ANFIS, FIS with a standard industrial controller Proportional, Integral, and Derivative (PID) control system. We have used an Ideal PID controller using the equation (6) [27].

$$\mu(t) = K_p e(t) + K_i \int_0^t e(t) dt + K_d \frac{d e(t)}{dt} \quad (6)$$

Here K_p is the proportional gain, K_i is the integral gain and K_d is the derivative gain along with time t . The values of K_p and K_i are tuned using self-tuning App in Simulink and K_d is adjusted to zero initially.

IV. IMPLEMENTATION OF AUTOMATIC ENVIRONEMNT CONTROLLERS FOR AN OUTDOOR OYSTER MUSHROOM GROWING UNIT

A. Experimental Setup

The studied smart autonomous outdoor oyster mushroom growing unit is illustrated in Fig. 5. It is a small outdoor unit with dimensions 6 x 4 x 6 feet and designed and implemented at the Mushroom Lab, Indian Institute of Horticulture Research, ICAR, Hessaraghatta Lake Post, Bengaluru, India. It is loaded with 70 oyster mushroom bags each of weight 1kg and spawned with 50g of oyster mushroom spawns. It is covered with two layers of gunny sheets, which must be wet to keep the required climate inside the mushroom unit.

A smart IoT based climate control system is designed, implemented and deployed in an outdoor oyster mushroom

growing unit. It has two parts, an applied environment system and an internet of things (IoT) node as shown in Fig. 6. An applied environment system consist of AC cooling fan, a DC water pump and 6 mm diameter plastic pipe with length 25m. The water pump flows the water through the plastic pipe, which is positioned around gunny sheets to sprinkle water on it to maintain humidity inside the unit. The other part of system is an IoT node as shown in Fig. 7. It consists of two DHT22 sensors, ESP32 controller, and two relays. DHT22 sensors used to sense inside and outside temperature and humidity of the unit. The ESP32 controller is used to control the inside temperature and humidity on actuating water pump and cooling fans using FIS system. FIS is integrated with the ESP32 controller and used to calculate the water pump and cooling fan times. It helps ESP32 controller to trigger the actuator relays to turn them on and off. A built in Wi-Fi module of ESP32 controller is used to collect data in ThingSpeak platform after every 30 seconds. The data is collected from 17th, January 2023 to 31st, January 2023. The platform logs the temperature, ambient temperature, humidity, ambient humidity, water pump time, and cooling fan time. This experimental data is utilized for further implementation of ANFIS controller to control temperature and humidity of an outdoor oyster mushroom growing unit.

B. Implementation of ANFIS Controller

The ANFIS approach creates a FIS using a collected primary data. A backpropagation algorithm either alone or in conjunction with a least squares approach is used to tune (change) the membership function parameters. The FIS structure works alike a neural network that converts inputs into outputs by first mapping input membership functions and associated parameters to outputs.

As ANFIS is multiple input single output (MISO), two ANFIS models are generated. ANFIS-1 predicts the water pump time and ANFIS-2 predicts fan time. In both models, humidity and temperature are the input variables. In this study, the five-layered ANFIS simulates the operation of a fuzzy inference system as shown in Fig. 8. The input and output linguistic variables are represented by the fuzzy nodes in layer one and four, respectively. The term nodes in second layer serve as membership functions for input variables. The third layer's neurons represent a fuzzy rule, with input connections standing in for its prerequisites and output connections for its results. All of these layers are initially fully connected, signifying every potential rule.

The membership functions assigned to two input variables temperature and humidity is Gaussian as shown in Fig. 9 and Fig 10. The closed-loop control mechanism in the ANFIS model is dependent on the prior expert data. In this system, the humidity, temperature, and water pump time training data (with data points 14668) are used to train the ANFIS to obtain the membership function (MFs), which enables the ANFIS to estimate an accurate correlation between inputs and outputs. The expert data is used in the system input-output trial to design the controller with the least degree of error. Throughout 1,000 epochs, the training error is reduced until it is less than 1.9986. This implies that the ANFIS-1 system output is close to the desired training values.

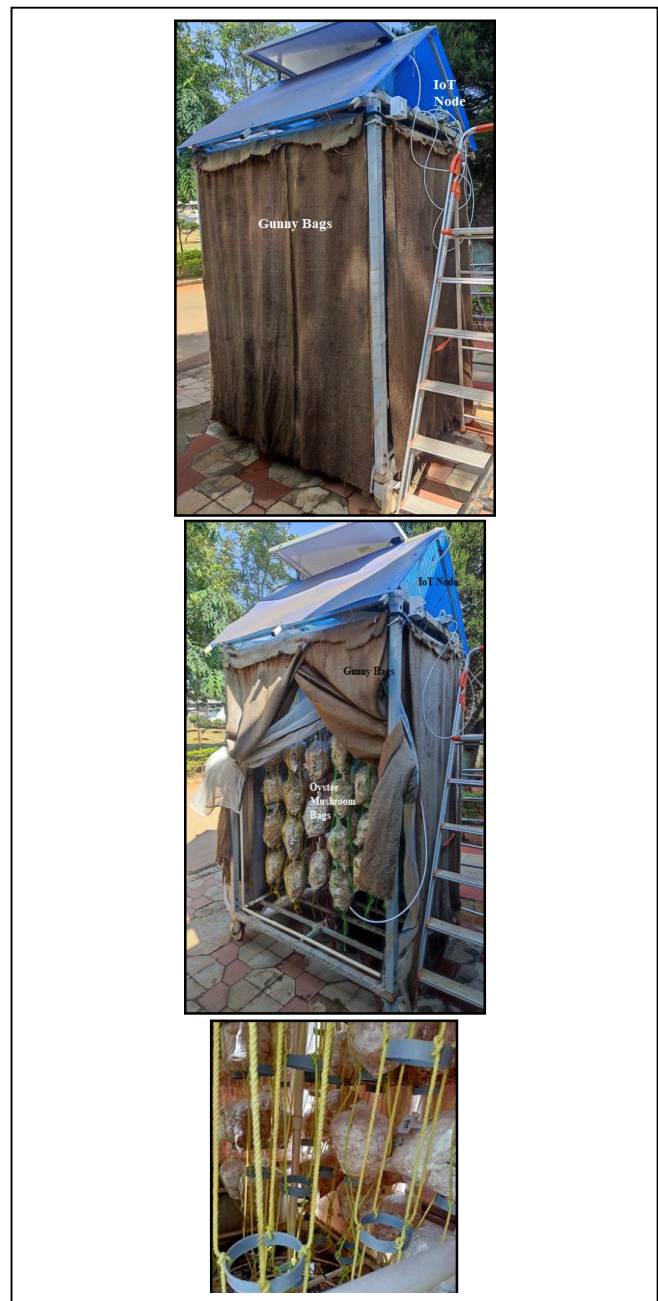


Fig. 5. Internal and external view of experimental setup of a mushroom unit.

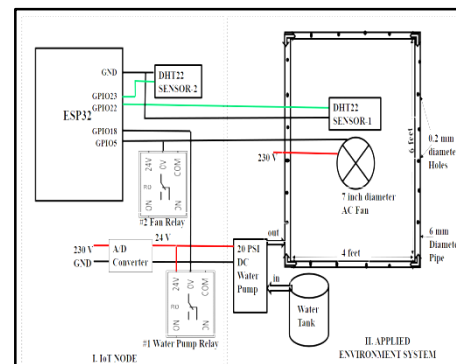


Fig. 6. IoT Node for installation.

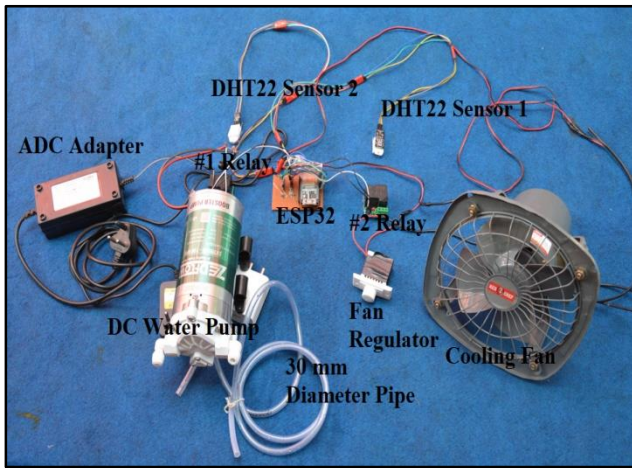


Fig. 7. IoT node for installation (model).

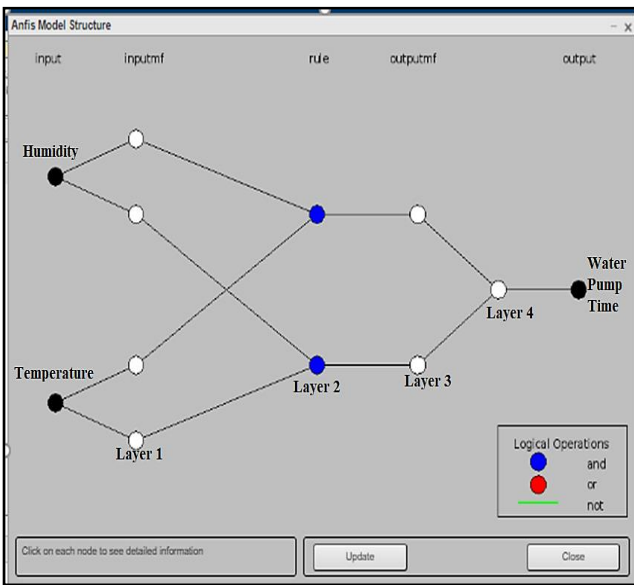


Fig. 8. ANFIS-1 architecture to predict water pump time.

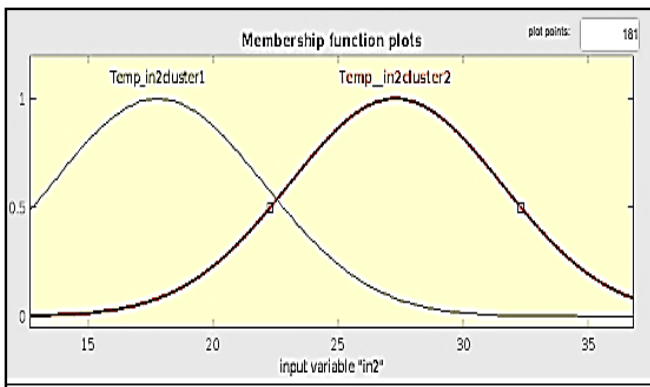


Fig. 9. ANFIS-1 membership function for input temperature.

Similarly, ANFIS-2 is implemented in the same way as ANFIS-1, with an expert dataset (with data points 14668) containing temperature, humidity, and fan time. The training error is reduced throughout 1,000 epochs until it is less than

2.28817. This implies that the ANFIS-2 system output is close to the desired training values.

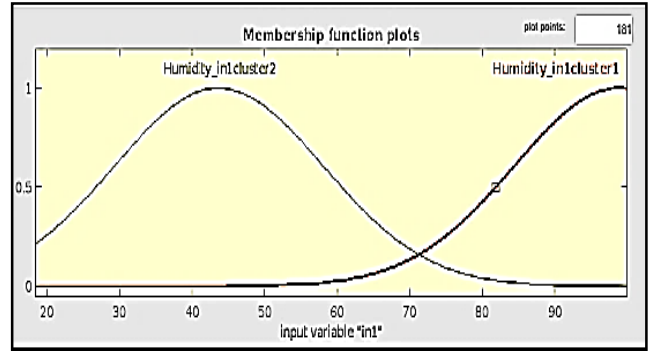


Fig. 10. ANFIS-1 membership function for input humidity.

C. Simulink Models for FIS, ANFIS and PID Controller

The dynamic models of PID, FIS and ANFIS controllers are designed in MATLAB/Simulink environment to control inside temperature and humidity of an oyster mushroom growing unit, as shown in Fig. 11. A primary dataset is collected while experimenting IoT prototype to control its temperature and humidity in real time. It is consisting of temperature, humidity, water pump time and fan time. It is used as an input to all Simulink models. In Simulink, first, the FIS Simulink model is implemented as per the required design details discussed. Secondly, the ANFIS Simulink model is implemented as discussed in previous section. Thirdly, PID Simulink model is implemented as per equation (6).

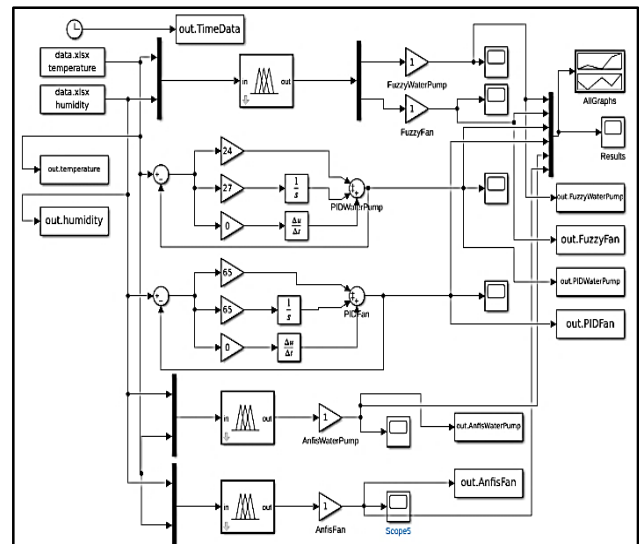


Fig. 11. Simulink models for FIS, ANFIS and PID Controller.

V. RESULTS AND DISCUSSION

In this section, firstly the results are presented and discussed for IoT based real time FIS controller, secondly the comparative study of FIS controller, ANFIS controller, and PID controller is discussed and presented, and lastly the cost analysis of IoT prototype is presented.

A. FIS Experimental Results and Discussion

The experimental results are obtained on implementing the IoT based prototype in an outdoor mushroom growing unit. To show the viability of the suggested FIS System, several experiments were carried out. The outcomes are the outputs of DHT22 sensor reading for temperature, humidity, ambient temperature, ambient humidity, and FIS calculated water pump time and fan time, transferred and updated on the website, www.thingspeak.com as shown in Fig. 12, Fig. 13, and Fig. 14. The date and timestamp for reading showed on website for user information. The real time results show the robustness of FIS based IoT prototype, which is able to maintain the required temperature, and humidity in an outdoor mushroom growing unit.

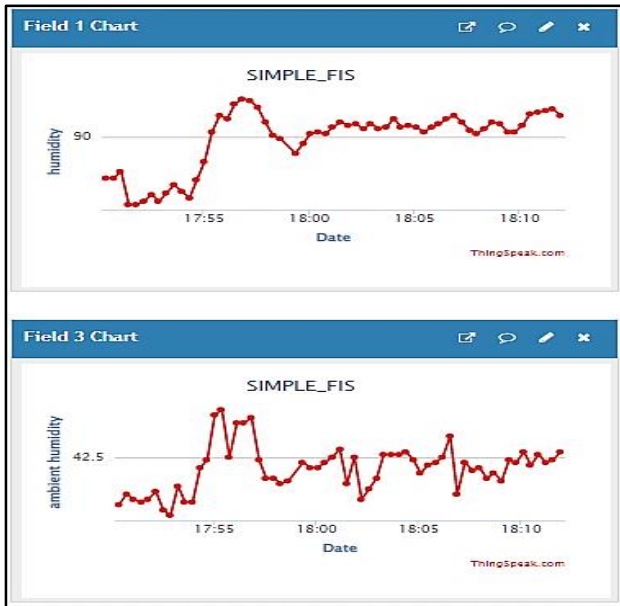


Fig. 12. Online visualization of humidity, and ambient humidity against time.

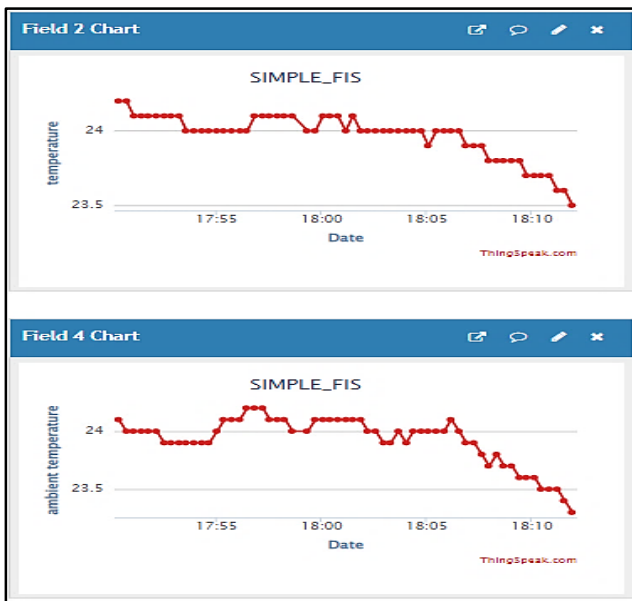


Fig. 13. Online visualization of temperature, ambient temperature against time.

Fig. 15 illustrates the calibrated humidity and ambient humidity sensor reading along with water pump time values of applied prototype obtained from the website, www.thingspeak.com in real time. It shows that, when humidity is below 70%, the water pump and fan switches ON, on the other hand when humidity rises above 70%, both remains off mode. This shows the water is used on requirement and playing a vital role in improving the water use as well. Similarly, Fig. 16 illustrates the calibrated temperature and ambient temperature sensor reading along with fan time values of applied prototype obtained from the website, www.thingspeak.com in real time. It shows that when temperature of an outdoor mushroom growing unit is not in range (above 27°C), then the FIS controller switches on the fan, until it comes in range. In addition when temperature is below 27°C, fan remains in switched off mode. This proves the robustness of the system.

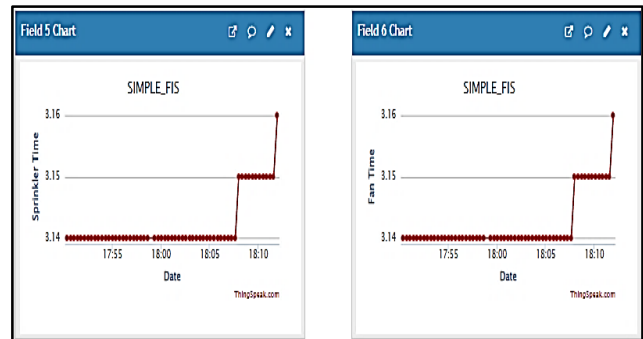


Fig. 14. Online visualization of water pump time, fan time against time.

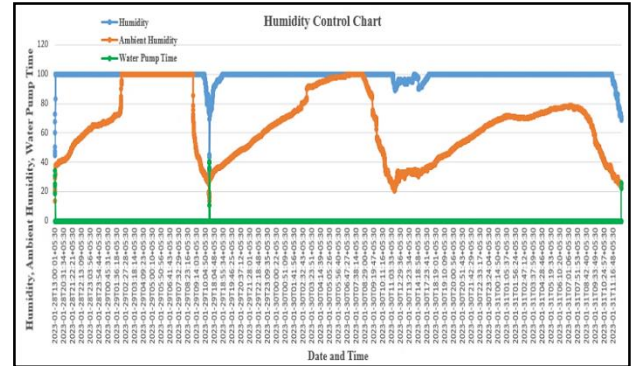


Fig. 15. Calibrated humidity and ambient humidity sensor reading along with water pump time values.

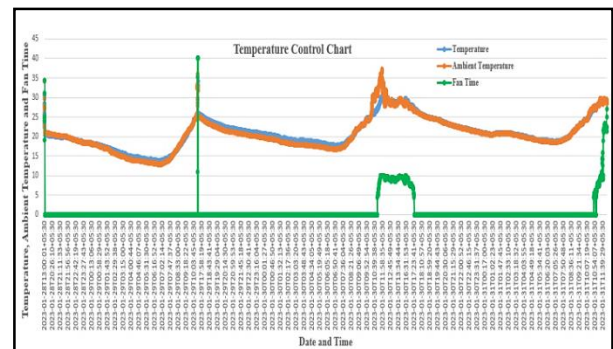


Fig. 16. Calibrated temperature and ambient temperature sensor reading along with fan time values.

B. Performance Evaluation of Simulink Models

ANFIS controller has the capability that can deal with nonlinear systems on the self-learning data. It is compared with FIS designed with human expertise knowledge and with a standard industrial PID controller with same system parameters. In PID controller there are only three parameters to adjust, whereas FLC has a lot of parameters to select like membership functions and its parameters, correct choice of rule base. The ANIFS controller self learns the data and designing neuro fuzzy system on training the data. The input data used is experimental data collected on implementing the IoT prototype for an outdoor oyster mushroom growing unit. It has timestamp, inside temperature and humidity value fields. The output of all Simulink models is water pump time and fan time, plotted in the graph shown in Fig 17.

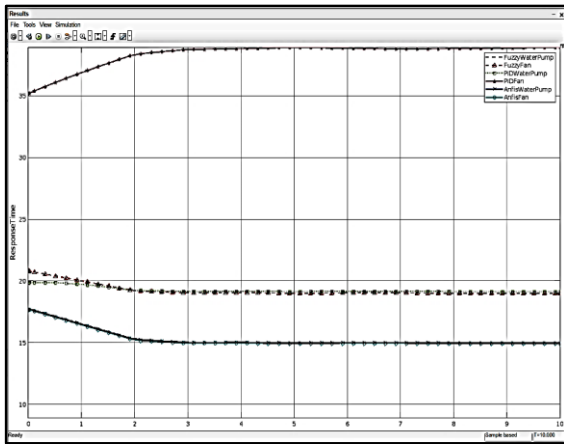


Fig. 17. Output of Simulink models.

All three Simulink models are compared and evaluated using four performance matrices, transient time, settling time, overshoot and peak time. The transient time is the output characteristic of a control system. After applying an input to the control system, the output takes a specific time to reach a steady state. Transient time is the length of time that the control system must respond in order for the transient state to stabilize. While calculating transient time, the parameters considered are settling time, maximum overshoot, and peak time, rise time [28]. Table II and III shows that ANFIS controller has performed better than the FIS and PID controller in terms of transient time, settling time, maximum overshoot and peak time on achieving optimum values.

TABLE II. PERFORMANCE EVALUATION FOR FIS, ANFIS AND PID CONTROLLER FOR WATER PUMP TIME

Performance Parameters	Parameter Values		
	FLC Controller	ANFIS Controller	PID Controller
Transient Time	2.9693	2.9441	7.2451
Settling Time	19.917	16.3742	19.5115
Settling Min	19.0171	14.9875	19.1456
Settling Max	20.8169	17.7610	19.8772
Overshoot	9.4640	8.5054	23.8212
Peak	20.8169	17.7610	19.8772

TABLE III. PERFORMANCE EVALUATION FOR FIS, ANFIS AND PID CONTROLLER FOR FAN TIME

Performance Parameters	Parameter Values		
	FLC Controller	ANFIS Controller	PID Controller
Transient Time	2.9693	8.7821	2.9441
Settling Time	19.917	37.0608	16.3742
Settling Min	19.0171	35.1824	14.9875
Settling Max	20.8169	38.9393	17.7610
Overshoot	9.4640	20	8.5054
Peak	20.8169	38.9393	17.7610

C. Cost Analysis

The list of components and their descriptions used in implementing the IoT prototype are shown in Table IV. Dollars are used to express the cost analysis. Because of variation in the exchange rate of the world market, these cost patterns may change time-to-time. It includes the cost of labor, value added tax, or delivery cost. It can be seen that the full prototype cost 40.46\$. This suggests an inexpensive gadget that can be used by farmers with minimum, available resources efficiently [29].

TABLE IV. COST ANALYSIS OF IMPLEMENTED DEVICE PROTOTYPE

Sr. No.	Component Name	Specifications	Quality	Price per Item	Total Price
1	ESP32	DC Power Source, built in Wi-Fi & Bluetooth	1	4.62\$	4.62\$
2	DHT22 Sensor	Operating Voltage- 5V, Temperature, Range: -40 to 80 °C error: +0.5°C, Humidity Range: 0 to 100% error: +-2%	2	2.42\$	4.84\$
3	Relay Optocoupler	Operating Voltage: 5 to 12V, 1 channel with optical coupler	2	2.42\$	4.84\$
4	FAN	7 inch diameter AC 230 V Fan	1	8.51\$	8.51\$
5	PMDC Diaphragm Motor	Operating Voltage: 12V to 24V, RPM: 40 to 3000rpm, Inlet PSI:20, Nominal Flow>=2 LPM, Working pressure: 100PSI, Power:80 Watt.	1	20.06\$	20.06\$
6	White Pipe	Plastic material, diameter=6mm	1	0.36\$	2.19\$
7	4 Elbow connectors	Plastic material	4	0.073\$	0.29\$
8	T connector	Plastic material	1	0.073\$	0.073\$
Total Price of IoT Prototype in Dollars				40.46\$	

VI. CONCLUSION

A novel Internet of Things-based smart environment monitoring and control system for an outdoor oyster mushroom growing unit is presented in this paper along with a low-cost autonomous sensor prototype. A real working prototype was developed using fuzzy inference system (FIS). The purpose of this effort was to empower farmers to monitor and control temperature and humidity automatically for an oyster mushroom, to increase its yield. The applied prototype used two DHT22 sensors to measure inside and outside temperature and humidity of unit, a water pump to sprinkle the adequate amount of water to maintain humidity, a cooling fan to maintain temperature, and a Wi-Fi module to make internet access to the collected data. The data, collected on the web server, were thoroughly observed and analyzed. The FIS controller is reliable and robust. The data is used to design and implement adaptive neuro fuzzy inference system (ANFIS) in MATLAB/Simulink to improve the performance of controller.

The ANFIS controller is compared with FIS and PID controller in MATLAB/Simulink. The performance evaluation results of ANFIS controller is better than FIS and PID controller in terms of transient time, settling time, maximum overshoot and peak time. In future, the applied low-cost system can be studied, observed, and analyzed with ANFIS controller design. In addition, the presented study focused on small-scale mushroom cultivation, the proposed ANFIS controller can be studied for large-scale mushroom production.

REFERENCES

- [1] Jegadeesh Raman, Seul-Ki Lee, Ji-Hoon Im, Min-Ji Oh, Youn-Lee Oh, and Kab-Yeul Jang, "Current prospects of mushroom production and industrial growth in India," *Journal of Mushrooms*, vol 16, no 4, pp 239-249, ISSN 1738-0294, December 2018.
- [2] Dhanaraju M, Chenniappan P, Ramalingam K, Pazhanivelan S, Kaliaperumal R, "Smart Farming: Internet of Things (IoT)-Based Sustainable Agriculture. *Agriculture*," vol 12, no 10, 2022.
- [3] Cikarge G.P., Arifin F., "Oyster mushroom humidity control based on fuzzy logic by using Arduino ATmega238 microcontroller," *J. Phys. Conf. Ser.* 12, pp. 1140, 2018.
- [4] Alhanafy T., Zaghlool F., El Din Moustafa A., "Neuro fuzzy modeling scheme for the prediction of air pollution," *J. Am. Sci.* 6 (12), 605–6012, 2010. [New and Renewable Energy Authority, Ministry of Electricity and Energy, 2005. Wind Atlas for Egypt Measurements and Modeling 1991-2005, Cairo, Egypt, 2010]
- [5] Mahmud M. A., Buyamin S., Mokji M. M., Abidin M. Z., "Internet of things based smart environmental monitoring for mushroom cultivation," *Indonesian Journal of Electrical Engineering and Computer Science*, 10(3), 847-852, 2018.
- [6] Thong-un N. and Wongsaraj W., "Productivity enhancement using low-cost smart wireless programmable logic controllers: A case study of an oyster mushroom farm," *Computers and Electronics in Agriculture*, 195, 106798, 2022.
- [7] Ariffin M. A. M., Ramli M. I., Amin M. N. M., Ismail M., Zainol, Z., Ahmad N. D., Jamil N., "Automatic climate control for mushroom cultivation using IoT approach," In 2020 IEEE 10th International Conference on System Engineering and Technology (ICSET) (pp. 123-128). IEEE, November 2020.
- [8] Sihombing P., Astuti T. P., Sitompul D., "Microcontroller based automatic temperature control for oyster mushroom plants," In *Journal of Physics: Conference Series*, Vol. 978, No. 1, pp. 012031. IOP Publishing, March 2018.
- [9] Chiochan O., Saokaew A., Boonchieng E., "IOT for smart farm: A case study of the Lingzhi mushroom farm at Maejo University," In 2017 14th International Joint Conference on Computer Science and Software Engineering (JCSSE), pp. 1-6, IEEE, July 2017.
- [10] Marzuki A., and Ying S. Y., "Environmental monitoring and controlling system for mushroom farm with online interface," *International Journal of Computer Science & Information Technology (IJCSIT)*, Vol 9, 2017.
- [11] Yin H., Yi W., Hu D., "Computer vision and machine learning applied in the mushroom industry: A critical review," *Computers and Electronics in Agriculture*, 198, 107015, 2022.
- [12] Koutb M., El-Rabaie N., Awad H., Hameed I.A., "Environmental control for plants using intelligent control systems." In: *Proceedings of Artificial Intelligence in Agriculture (AIA'04)*, IFAC, Cairo, pp. 101–106, 2004.
- [13] Lafont F., Balmat J.F., "Optimized fuzzy control of a greenhouse." *Fuzzy Sets Syst.* 128, 47–59, 2002.
- [14] Márquez-Vera, Marco A., Ramos-Fernández, Julio C., Cerecero-Natale, Luis F., Lafont, Frédéric, Balmat, Jean-Francois, Esparza-Villanueva, Jorge I., "Temperature control in a MISO greenhouse by inverting its fuzzy model," *Comput. Electron. Agric.*, 124, 168–174, 2016.
- [15] Mote T., Lokhande S., "Temperature control system using ANFIS," *Int. J. Soft Comput. Eng.* 2, 156–161, 2012.
- [16] Revathi S., Sivakumaran N., "Fuzzy based temperature control of greenhouse," *IFAC-PapersOnLine* 49 (1), 549–554, 2016.
- [17] Xu F., Chen J., Zhang L., Zhan H., "Self-tuning fuzzy logic control of greenhouse temperature using real coded genetic algorithm," In: *Proceedings of the 9th International Conference on Control, Automation, Robotics and Vision*, IEEE, Singapore, pp. 1–6, 2006.
- [18] Fourati F., Chtourou M., "A greenhouse control with feed-forward and recurrent neural networks," *Simul. Model. Pract. Theory* 15 (8), 1016–1028, 2004.
- [19] Coelho J., de Moura Oliveira P., Cunha J., "Greenhouse air temperature predictive control using the particle swarm optimisation algorithm," *Comput. Electron. Agric.* 49, 330–344, 2005.
- [20] Mohamed S., and Hameed I. A., "A GA-based adaptive neuro-fuzzy controller for greenhouse climate control system," *Alexandria Engineering Journal*, 57(2), 773-779, 2008.
- [21] Atia D. M., and El-madany H. T., "Analysis and design of greenhouse temperature control using adaptive neuro-fuzzy inference system. *Journal of Electrical Systems and Information Technology*, 4(1), 34-48, 2017.
- [22] Oubehar H., Selmani A., Ed-Dahhak A., Lachhab, A., Archidi, M. E. H., & Bouchikhi, B. (2020). ANFIS-based climate controller for computerized greenhouse system. *Advances in Science, Technology and Engineering Systems Journal*, 5(1), 08-12, 2020.
- [23] Hernández-Salazar J. A., Hernández-Rodríguez D., Hernández-Cruz R. A., Ramos-Fernández J. C., Márquez-Vera M. A., Trejo-Macotela F. R., "Estimation of the evapotranspiration using ANFIS algorithm for agricultural production in greenhouse," In 2019 IEEE International Conference on Applied Science and Advanced Technology (iCASAT) (pp. 1-5). IEEE, November 2019.
- [24] Qiuying Z., Jianwei J., Qingji L., Rui H., "Application of ANFIS for modelling and simulation of the greenhouse environment," In 2010 The 2nd International Conference on Industrial Mechatronics and Automation, Vol. 1, pp. 29-32, IEEE, May 2010.
- [25] Khuntia S. R. and Panda, S., "Simulation study for automatic generation control of a multi-area power system by ANFIS approach," *Applied soft computing*, 12(1), 333-341, 2012.
- [26] Hamidane H., El Faiz S., Rkik I., El Khayat M., Guerbaoui M., Ed-Dhhak A., Lachhab A., "Application analysis of ANFIS strategy for greenhouse climate parameters prediction: Internal temperature and internal relative humidity case of study," In *E3S Web of Conferences*, Vol. 297. EDP Sciences, 2021.
- [27] Dantas A. D. O. D. S., Dantas A. F. O. D. A., Campos J. T. L., de Almeida Neto D. L., Dórea, C. E. T., "PID control for electric vehicles subject to control and speed signal constraints," *Journal of Control Science and Engineering*, 2018.
- [28] Altbawi S. M. A., Mokhtar A. S. B., Jumani T. A., Khan I., Hamadneh N. N., Khan A. "Optimal design of Fractional order PID controller based

- Automatic voltage regulator system using gradient-based optimization algorithm. *Journal of King Saud University-Engineering Sciences*, 2021.
- [29] Abba S, Wadumi Namkusong J, Lee J-A, Liz Crespo M., "Design and Performance Evaluation of a Low-Cost Autonomous Sensor Interface for a Smart IoT-Based Irrigation Monitoring and Control System," *Sensors* Vol 19, no 17, pp 3643, 2019.

Hybrid Particle Swarm Optimization-based Modeling of Wireless Sensor Network Coverage Optimization

Guangyue Kou*, Guoheng Wei

Department of Information Security, Naval University of Engineering, Hubei 430000, Wuhan, China

Abstract—To address the problem of insufficient coverage of WSN and poor network coverage in obstacle environments, the study proposes an improved particle swarm optimization (PSO) combined with a hybrid grey wolf algorithm. The speed and position of the PSO particle's search for superiority are enhanced through the guiding nature of the superior wolf in the grey wolf optimization (GWO), thus the convergence speed and search precision are improved. Based on this, the study applies the improved PSO to a wireless sensor networks (WSN) coverage optimization model and uses model comparison to test the effectiveness and superiority of the algorithm. According to the results, the node network coverage of PSO, genetic algorithm (GA), data envelopment analysis (DEA), GWO, and grey wolf particle swarm optimization (GWPSO) reach 85.97%, 87.24%, 88.76%, 89.31%, and 91.05% respectively in the trapezoidal obstacle environment. And the node network coverage of the research-designed GWPSO algorithm reaches the highest value of its kind. This shows that the research-designed GWPSO has superior performance in the optimization control of sensor coverage deployment compared with similar algorithms. The design provides a new path for optimizing wireless sensor node network coverage.

Keywords—Particle swarm optimization; wireless sensor networks; network coverage; grey wolf optimization; grey wolf particle swarm optimization

I. INTRODUCTION

As a communication transmission technology under the development of modern network technology, wireless sensor networks (WSN) can freely connect and combine a large number of sensor nodes through wireless communication, forming a communication network. It integrates three information functions through information collection module, information transmission module, and information processing module to achieve coverage and integrated information processing [1-3]. So far, in order to improve the coverage effect of wireless sensor networks, a variety of different types of intelligent algorithms have been used as optimization tools. Among them, the particle swarm optimization algorithm, as an algorithm with strong practicability and robustness, has also received many adaptive improvements in application [4-5]. However, particle swarm optimization (PSO) itself has certain flaws. PSO has the problem of local optimal solutions, which is easily affected by initial values, resulting in inaccurate search; PSO is sensitive to parameter settings and requires multiple experiments to obtain suitable parameter combinations, making parameter tuning difficult; The current research is mostly limited to the improvement of PS itself, lacking research on the combination of PSO algorithm and

other optimization algorithms. Therefore, it is necessary to introduce other algorithms to improve the PSO algorithm and enhance its practicality in WSN coverage optimization [6-8]. By introducing the grey wolf optimization (GWO) and combining it with the PSO for wireless sensor network coverage optimization, it can effectively avoid the local optimal solution problem of the PSO algorithm and improve the accuracy and stability of the search. The research will design and implement an adaptive algorithm for wireless sensor network coverage optimization based on GWO and PSO, effectively improving its optimization effect in practical application scenarios. At the same time, experimental verification will be conducted to further enhance its effectiveness and practicality.

II. RELATED WORK

The hybrid PSO model, an improvement of the particle swarm algorithm, has been gaining ground in various fields in recent years. Şenel F A's team proposes a hybrid model that combines the PSO with GWO, which uses the particles of GWO to replace the relatively underperforming particles of PSO, and then applies the model to leather nested industrial technology problems. After evaluation by the researchers, this model has a performance advantage, being able to obtain the optimal solution faster with fewer iterations than its swarm and social spider counterparts [9]. Chen S's team proposes a new hybrid PSO algorithm model to predict pollutant concentration in air pollution detection. This model combines PSO with a support vector machine (SVM) and uses the pollutant influencing factors as the main model input variables. This hybrid PSO model has superior performance compared to similar models with the same variable elements [10]. Corazza M's team proposes a particle swarm hybrid heuristic algorithm for the portfolio decision problem, which uses a penalty function to redefine the portfolio problem as an unconstrained problem and uses adaptive updates in the optimization process of the unconstrained penalty parameters. This algorithm performs superior to PSO with constant penalty parameters and is more efficient overall [11]. In their study of lateral loading problems for pile-like structures, Khari M et al. proposed a hybrid PSO model that integrates artificial neural networks with particle swarm algorithms, which can effectively predict the lateral deflection of pile-like structures. The results of 183 simulations conducted by the researchers show that the model has higher accuracy in predicting the lateral deflection of pile-like structures compared to similar models, while the systematic error is smaller and it shows higher performance on both the training and test sets.[12] The Sohoul A N team combined the particle swarm algorithm with

a genetic algorithm to form a new evolutionary hybrid PSO and applied the algorithm to the modeling of geological models. This algorithm is applied to the modeling of geological models and geological exploration. The method uses a particle swarm algorithm for magnetic data improvement and a genetic algorithm for model parameter estimation. The algorithm can offer valuable results for estimating model parameters under a 25% noise level [13].

Khalaf O I applied the honeybee algorithm to wireless sensor coverage optimization and compared the results with those of a genetic algorithm. The results show that compared to the genetic algorithm, the honeybee-based wireless sensor coverage optimization has better optimal coverage and consumes fewer resources in the computing process [14]. Cao L et al. proposed a WSN coverage strategy based on the social spider optimization algorithm, which decomposes the combined optimization problem by building and WSN model. The insufficient search capability and convergence speed of the social spider algorithm are improved and finally combined to form an optimization model. The results show that the model is effective in preventing blind spots and redundant spots in the network coverage [15]. Hoffmann R's team proposes a meta-cellular automata approach that solves the optimal wireless sensor coverage problem with smaller sensor tiles to achieve a 2D spatial coverage, which in turn forms a sensor-centered pixel envelope. The results show that the model rules formed by this method can evolve to a more stable optimal coverage state and allow more time for model evolution after the optimal coverage is found.[16]. Li Q's team developed a mathematical model to improve the low overall coverage of wireless sensors and designed a mobile node scheme to improve the coverage optimization of the target area, which can effectively enhance the optimal coverage problem in the detection area. The results show that the strategy designed in the study can effectively enhance the network coverage and prolong the network service time [17]. ZainEldin H's team proposed a dynamic deployment technology based on a genetic algorithm and applied it to the optimization of WSN coverage, which is used to reduce the overlapping area between adjacent nodes by optimizing the minimum quantity of nodes, thus forming the coverage effect. The results of the study show that the designed method is compatible with the proposed method. The results of the study show that the method designed in the study has higher stability compared to other methods [18].

III. WSN COVERAGE OPTIMIZATION MODEL CONSTRUCTION BASED ON GWPSO HYBRID ALGORITHM

A. PSO Optimization based on the Standard GWO

WSN is a distributed large-scale network, mainly composed of micro-nodes that can sense and process information and communication capabilities, and through a decentralized and self-organizing form of network, its network structure mainly consists of aggregation nodes, sensors, networks, etc. WSN on the target environment, such as temperature, humidity, and image information is collected and processed, and transmitted to the sensor terminal device, for the need of information. The WSN collects and processes information such as temperature, humidity, and images from

the target environment and transmits it to the sensor terminals to serve the users who need the information. Multiple sensor nodes are placed in the target area, which collects temperature, humidity, and image information and sends it to the gateway or aggregation node via multi-hop routing. The WSN architecture is shown in Fig. 1.

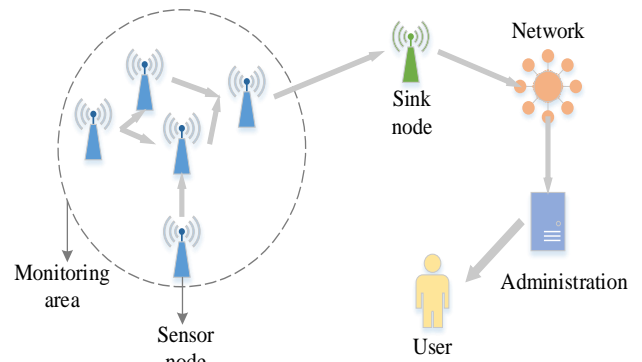


Fig. 1. WSN STRUCTURE.

Typically, a WSN node consists of a sensing unit, an energy unit, a processing unit, and a communication device, all of which work together to sense, collect and transmit target data. The sensing unit is responsible for converting the sensed analogue signal into a digital signal, which consists of sensors and A/D converters; the processing unit processes and compresses the collected data; the communication unit is responsible for data transmission and exchange of control information in the network; and the energy unit is responsible for providing energy to the other units, which are usually powered by micro batteries. The WSN node structure is shown in Fig. 2.

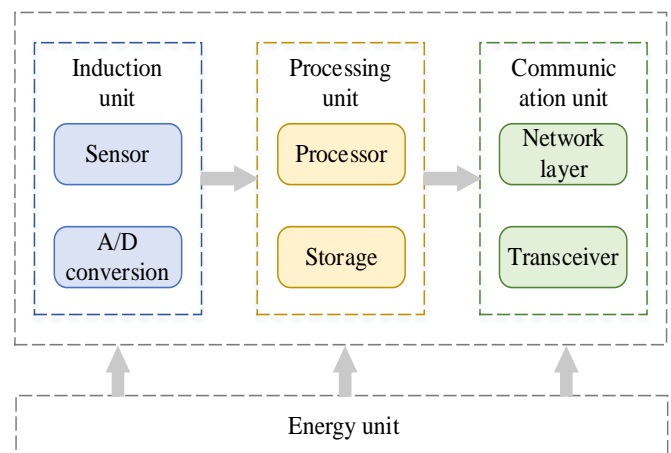


Fig. 2. WSN NODE STRUCTURE.

Suppose there are n sensor nodes in WSN, and the set is $S = \{s_1, s_2, \dots, s_i, \dots, s_n\}$, these nodes are identical and all have a radius of r , and the target detection area is a rectangle with an area of Z m². This grid monitoring area is transformed into Z a small rectangular grid of equal size whose geometric centre represents the monitoring position of the wireless sensor node in the target area. A monitoring action

is successful when the range between the target point and any node shall not be greater than the monitoring radius of the node. The set of monitoring target points is $M = \{m_1, m_2, \dots, m_j, \dots, m_Z\}$, the two-dimensional spatial coordinates of s_i in the set are (x_i, y_i) , the two-dimensional spatial coordinates of m_j are (x_j, y_j) , and the Euclidean distance between two nodes is shown in equation (1).

$$d(s_i, m_j) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (1)$$

The joint probability of all sensor nodes denoted as s_{all}, s_{all} to the target monitoring node m_j is shown in equation (2).

$$C_p(s_{all}, m_j) = 1 - \prod_{i=1}^n (1 - p_{cov}(s_i, m_j)) \quad (2)$$

In equation (2), P_{cov} represents the probability of a node sensing a target monitoring point s_i, m_j . Calculate the joint sensing probability of all target points, and the altogether joint sensing probability of target points is the coverage area, and the coverage rate C_r is as in equation (3).

$$C_r = \frac{\sum_{j=1}^Z C_p(s_{all}, m_j)}{Z} \quad (3)$$

A prerequisite for the self-organisation of sensor nodes to form a WSN is that the network remains connected. The nodes in the study have a sensing radius of r and a maximum communication distance of $2r$. When the range between nodes s_i and s_j does not exceed the sensing length, the two nodes are adjacent and the edge between nodes is 1. When the range between s_i and s_j exceeds the sensing radius, the two nodes are not adjacent and the edge between nodes is 0. Accordingly, the nodes' corresponding adjacency matrix AM is constructed and the connectivity of the network is judged using AM . The matrix N is shown in equation (4).

$$N = AM + AM^2 + \dots + AM^{n-1} \quad (4)$$

In equation (4), n represents the number of sensors, determining whether the elements in this matrix are all 1, if yes, the network is connected, otherwise the network is not connected.

The GWO imitates the hunting mechanism of grey wolves and has the advantage of being plain, flexible, and scalable, and uses fewer parameters in the algorithm. The mathematical

model of the algorithm simulates a wolf pack divided into four classes α, β, δ and ω , with a structure similar to that of a pyramid, as shown in Fig. 3.

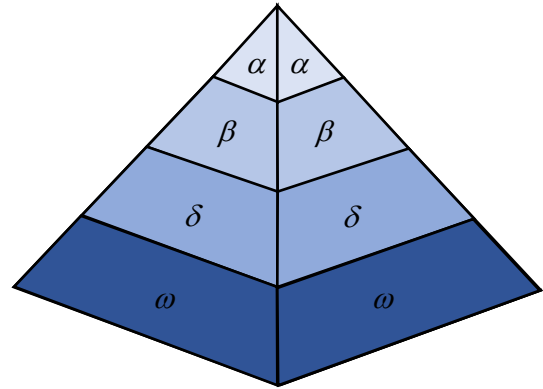


Fig. 3. RANKING STRUCTURE OF WOLVES.

The wolves are ranked according to the fitness value of individual grey wolves, and the top three grey wolves in the pack are ranked in the α, β and δ levels respectively. α has the highest rank and indicates the current optimal solution. ω The grey wolf individuals with the highest rank are the candidate in this group. ω In the iteration of the algorithm, the grey wolves in the first three levels are responsible for guiding the grey wolves in the ω level to search for prey, and the grey wolves in the ω level improve their fitness value by searching for prey. Assuming that the actual location of the prey is unknown to individual grey wolves during the hunting process, the wolves with the highest to lowest ranks of α, β and δ are closest to the prey, so the wolves in the ω layer can surround the prey according to the positions of the wolves in the α, β and δ layers, and keep approaching the prey and finally find the prey. ω The distances between the wolves in the, and α, β, δ layers are shown in equation (5).

$$\begin{cases} D_\alpha = C_1 * X_\alpha(t) - X_\omega(t) \\ D_\beta = C_2 * X_\beta(t) - X_\omega(t) \\ D_\delta = C_3 * X_\delta(t) - X_\omega(t) \end{cases} \quad (5)$$

In equation (5), D_α, D_β and D_δ represent the distances between α, β and δ and ω respectively, $X_\alpha(t), X_\beta(t), X_\delta(t)$ and $X_\omega(t)$ are the positions of α, β, δ and respectively, and C_1, C_2 and C_3 represent the orientation variables of ω when the layer wolves move towards α, β and respectively. δ, ω After calculating the distance between the layer wolves

and the positions of the α , β and δ layer wolves during the hunt, the layer wolves kept approaching them in certain steps respectively and finally reached the predetermined position. The position of the ω wolf was updated as shown in equation (6).

$$\begin{cases} X_1 = X_\alpha - A_1 * D_\alpha \\ X_2 = X_\beta - A_2 * D_\beta \\ X_3 = X_\delta - A_3 * D_\delta \end{cases} \quad (6)$$

In equation (6), X_1 , X_2 and X_3 indicate the position of the wolf in the ω layer when it is guided by the wolves in the α , β and δ layers, respectively, and t indicates the current iterations. A_1 , A_2 , A_3 indicate the step length of the ω layer wolf as it approaches the prey under the guidance of the α , β and δ layers, respectively. When, $|A_1| < 1$ ω wolves will conduct a fine search around the prey, and when $|A_1| > 1$, ω wolves will expand their search around the prey. A_1 The formulae for A_2 and A_3 are shown in equation (7).

$$\begin{cases} A_1 = 2a * rand - a \\ A_2 = 2a * rand - a \\ A_3 = 2a * rand - a \end{cases} \quad (7)$$

In equation (7), a is the convergence factor, which represents the iterative process of decreasing from 2 to 0. The convergence factor a is calculated by equation (8).

$$a = 2 - 2 \left(\frac{t}{t_{\max}} \right) \quad (8)$$

t_{\max} The GWO algorithm generates the initial wolf pack, divides the pack into four classes: α , β , δ and ω , gauges the range between individual grey wolves and their prey, then updates their respective positions according to the measured lengths, with each individual grey wolf in the pack representing a solution that is continuously updated during the search process. The GWO process is shown in Fig. 4.

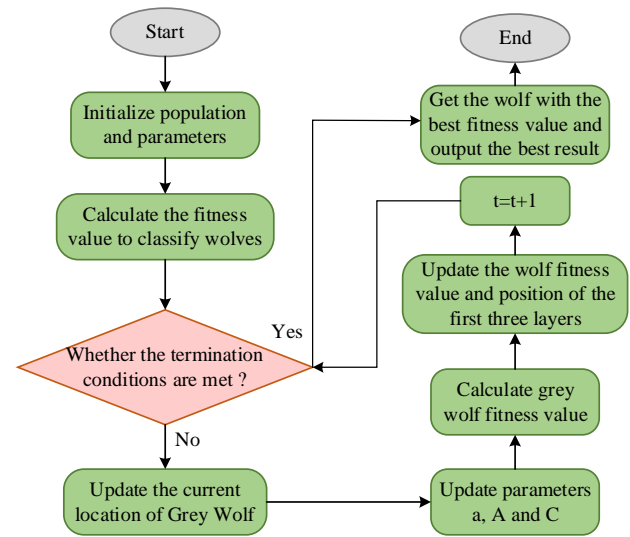


Fig. 4. FLOW OF GWO.

B. WSN Coverage Optimization Model for the GWPSO Hybrid Optimization Algorithm

The PSO always moves in the direction of the optimal individual's position, so its convergence velocity is relatively fast but the ability to balance the global search is still deficient, which leads to the inability of the algorithm to precisely seek the global optimal solution when solving complex optimization problems; GWO does not learn from the experience of others when searching for the optimal solution, so it is easy to ripe untimely. To address the shortcomings of both algorithms, the DEA algorithm is incorporated into PSO, and at the beginning, the chaos multi-way learning strategy is used to improve the population variance, and the convergence factor is dynamically adjusted to consider the global and local optimization. The properties of chaotic mapping can be able to properly enrich the variety of the initial population so that the particles can find the optimal solution, and the study uses Tent mapping to create the initial population [19-20]. Multi-way learning strategy can generate corresponding solutions by evaluating upper and lower-bound solutions and original solutions; the optimal solution of fitness value is selected from these solutions. The improved differential evolution PSO uses a mixed multidirectional learning strategy, according to which a multidirectional population is generated, the individuals of the generated multidirectional chaotic population are compared with the individuals of the original chaotic population in terms of their fitness values, and the individuals with the best fitness values are set as the initial population.

Assuming that the population size is N and the spatial dimension of it is D , a chaotic sequence is generated in the space using the Tent chaos

$$W = \{W_j, j = 1, 2, \dots, D\}$$

mapping

and $W_j = \{W_{i,j}, i = 1, 2, \dots, N\}$. The Tent chaos mapping function is shown in equation (9).

$$W_{i+1,j} = \begin{cases} Z_{i,j} / 0.65, & Z_{i,j} < 0.65 \\ (1 - W_{i,j}) / 0.35, & Z_{i,j} \geq 0.65 \end{cases} \quad (9)$$

$$a = -2 * \frac{\delta^2}{\delta_{\max}^2} \cos\left(\frac{\pi t}{2t_{\max}}\right) \quad (12)$$

The chaotic sequence generated by the chaotic mapping is mapped to the solution space to obtain the population

$$Y_j = \{Y_i, i = 1, 2, \dots, N\}$$

, $Y_i = \{Y_{i,j}, j = 1, 2, \dots, D\}$, and the population

individuals $Y_{i,j}$ denoted as shown in equation (10).

$$Y_{i,j} = Y_{\min,j} + Y_{i,j} (Y_{\max,j} - Y_{\min,j}) \quad (10)$$

In equation (10), $Y_{\min,j}$ and $Y_{\max,j}$ are the bounds on the particle finding solution, and $Y_{i,j}$ is the value of the i th particle in the space corresponding to the j th dimension. The multidirectional populations OY_j and OY_i , MY_j and MY_i are calculated as shown in equation (11).

$$\begin{cases} OY_{i,j} = Y_{\min,j} + Y_{\max,j} - Y_{i,j} \\ MY_{i,j} = Y_{\max,j} - Y_{\min,j} + Y_{i,j} \end{cases} \quad (11)$$

The fitness values of the primitive population and the multi-way population individuals are further calculated, and the particles with more favourable positions are selected from the population individuals based on the fitness values. The value of the coefficient A changes with the distance control parameter a during the iterative process, so setting the distance control parameter a to a reasonable value can effectively provide a solution to the balance between the speed of particle population search and the accuracy of particle local search. In the particle search process, the distance control parameter a needs to be set to a larger value in the first stage to expand the search range, which is beneficial to the particle search. In the later stage, the distance control parameter a needs to be set to a smaller value to concentrate the particle population around the optimal solution for fine searching. The linearly decreasing distance control parameter a cannot be adapted to the actual solving situation. To address this drawback, a cosine convergence factor strategy incorporating state coefficients is proposed to effectively take into account the overall optimization efficiency of the algorithm. Under this strategy, the distance control parameter a is non-linearly decreasing and its value is dynamically adjusted according to the properties of the random variables. With this strategy, the algorithm will search more vigorously at the initial stage of the iteration, and at the final stage of the iteration the particles will focus on the fine search around the optimal value, increasing the probability of finding the global optimum. The dynamic adjustment strategy for the convergence factor is shown in equation (12).

In equation (12), δ denotes the particle state coefficient, t

is the current iteration and t_{\max} is the maximum iteration. The study combines the convergence factor adjustment strategy of state coefficients and cosine transform, which effectively improves the speed of global particle search. The smaller change in the convergence factor at the end of the iteration is beneficial to the local fine search of the particle, thus improving the accuracy of the optimal solution. The GWO algorithm mainly adjusts its own position by combining the obtained position of individual grey wolves with the relationship between the first three levels of optimal solutions in the pack, enabling the exchange of information between the two. By introducing the idea of updating the position information in the GWO algorithm, the PSO's search capability is optimized so that the particles in space can expand the search space and enhance the search effort, thus finding the optimal solution more efficiently and accurately

[21]. The updated formula for the particles V_{ij} and X_{ij} after the introduction of the GWO idea is shown in equation (13).

$$\begin{cases} V_{ij}(t+1) = \omega V_{ij}(t) + c_1 r_1 (\omega_1 X_1(t) + \omega_2 X_2(t) + \omega_3 X_3(t)) \\ \quad + c_2 r_2 (p_{best}(t) - X_{ij}(t)) \\ X_{ij}(t+1) = X_{ij}(t) + V_{ij}(t+1) \end{cases} \quad (13)$$

In equation (13), c_1 represents the cognitive learning factor, which describes how much the finding of an optimal solution by an individual particle affects the finding of an

optimal solution by all particles in the space; c_2 represents the social learning factor, which describes how much the finding of an optimal solution by a population of particles affects the algorithm. c_1 Larger values indicate that particles are more

likely to concentrate locally, and larger values of c_2 indicate that particles are more likely to find a locally optimal solution

early and converge on that solution. r_1 and r_2 are random

numbers in the range [0,1]. ω_1 , ω_2 and ω_3 denote the inertia weight coefficients of the grey wolf. To take into account the global and local optimality finding capacity of the particles, the grey wolf inertia coefficients are improved as in equation (14).

$$\begin{cases} \omega_1 = \frac{|X_1|}{|X_1 + X_2 + X_3|} \\ \omega_2 = \frac{|X_2|}{|X_1 + X_2 + X_3|} \\ \omega_3 = \frac{|X_3|}{|X_1 + X_2 + X_3|} \end{cases} \quad (14)$$

When searching for the optimal value, the particle will learn from the current global optimum. When the difference between the current value and the global optimum is large, the learning of the particle will lead to an error and the particle will sink into the local optimum. If the global historical optimal solution approaches the current optimal solution, using the perturbation strategy will increase the range between the particle and the optimal solution, so the perturbation strategy should be used for particles that fall into the local optimum or perform poorly. As the 'early' particles are located closer to the optimal solution in some dimensions of space, external forces are applied to these particles to move them from their current position and proceed with the search. To address the problem of large fluctuations in the particle

population, the perturbation strategy is used to limit the perturbation operation to a distance of no more than 20%. The formula for updating the position of a particle after the perturbation is shown in equation (15).

$$X_{ij}(t+1) = r_1 V_{ij}(t+1) + (1 - 0.2r_2) X_{ij}(t) \quad (15)$$

In equation (15) r_1 and r_2 are random numbers in the range [-1,1]. Applying GWPSO hybrid optimization algorithm to the optimal deployment of node coverage in WSN, by using the coverage function as the fitness value of the algorithm. The beginning of the algorithm introduces a chaotic multi-way learning strategy to initialize the population and combines the state coefficients to improve the convergence factor using the cosine variation principle, thus enabling the algorithm to gain an improvement in its optimization-seeking capability. The inertia weight coefficients of the grey wolf are improved to update the position and speed of the particles, and finally, the speed and position of them are perturbed to improve the population diversity and thus the search accuracy of the particles, which effectively improves its search capability. The optimal fitness value at the end of the algorithm iteration is the global optimal solution. The flow of the algorithm is shown in Fig. 5.

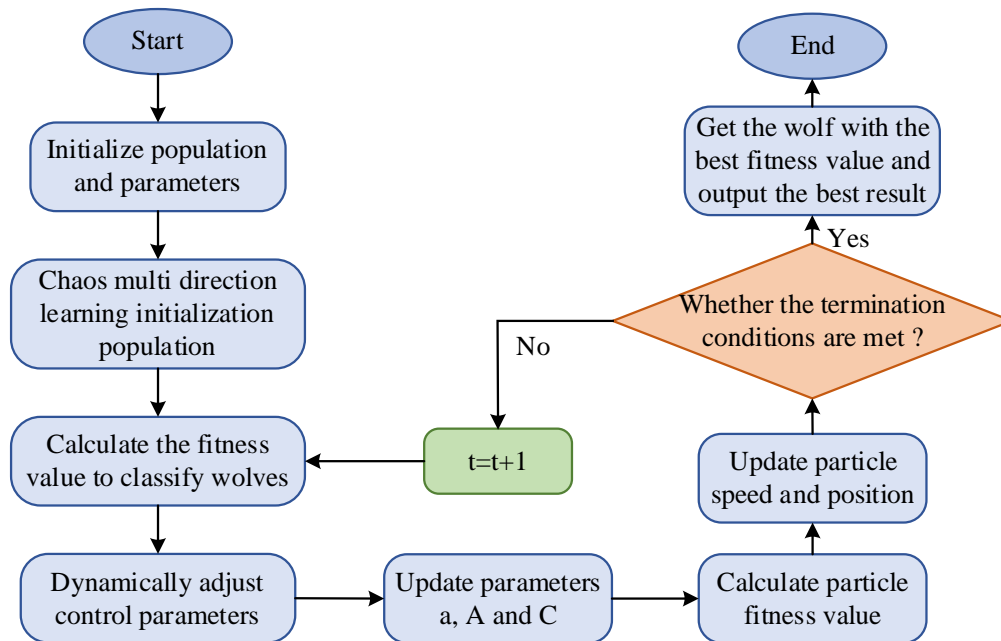


Fig. 5. FLOW OF GWPSO.

IV. ANALYSIS OF WSN COVERAGE OPTIMIZATION RESULTS BASED ON THE GWPSO HYBRID OPTIMIZATION ALGORITHM

The superiority of the GWPSO algorithm was demonstrated through simulation experiments in the MATLAB R2016a environment. Three different unimodal benchmark test functions and three different multimodal benchmark test functions were selected to test the convergence of the five algorithms. The population size in the test was 30, with 500 iterations. Any test function was independently run 50 times to record its average value. The study demonstrates the performance of the GWPSO hybrid optimization algorithm and its advantages through simulation experiments. Six functions are used to test the convergence function of the algorithm and to compare the performance with PSO, GA, DEA, and GWO algorithms. The four algorithms are used to optimise the deployment of WSN node coverage in an obstacle-free environment and a trapezoidal obstacle environment respectively, and finally, the results obtained are analysed. There are three single-peak-based test functions and three multi-peak-based test functions among the six selected test functions, and the optimal values in the GWPSO test theory are all 0. The test functions are shown in Table I.

The study compares the convergence of the PSO, GA, DEA, and GWO algorithms and the study's proposed GWPSO hybrid optimization algorithm under the test functions, and the algorithm's convergence under F1, F2, F3 and F4 is compared

as shown in Fig. 6.

In Fig. 6, the five algorithms converge gradually with an increasing number of iterations on the four functions, with the PSO, DEA, and GA algorithms showing poor convergence performance and the GWPSO algorithm showing the best convergence on the four functions. The convergence of the algorithms on F5 and F6 is shown in Fig. 7.

The advantageous convergence function of the GWPSO owing to the chaotic multidirectional learning strategy that improves the initial population space dynamically adjusts the control parameters, and uses the optimization-seeking property of the GWO algorithm to expand the particle's global search range in the pre-optimization phase. The use of the perturbation strategy effectively prevents the particles from sinking into the local optimum and significantly enhances the search precision of the particles, thus effectively improving the particle search capability. Thirty-five WSN nodes were deployed in a 50m x 50m square region with a sensing radius of 5m and a communication radius of 10m, $N = 50$ and $t = 30$. After the initial locations of the nodes were deployed, the nodes were unequally spread, and there was a large amount of coverage redundancy as the initial locations were randomly selected. Five algorithms were used to optimise the node coverage deployment and the coverage results are shown in Fig. 8.

TABLE I. TEST FUNCTION

ID	Function	Expression	Type
F1	Sphere	$f(x) = \sum_{i=1}^D x_i^2$	Unimodal
F2	Schwefel2.22	$f(x) = \sum_{i=1}^D x_i + \prod_{i=1}^D x_i $	Unimodal
F3	Rosenbrock	$f(x) = \sum_{i=1}^{n-1} \left(100(x_{i+1} - x_i^2)^2 + (x_i - 1)^2 \right)$	Unimodal
F4	Rastrigin	$f(x) = \sum_{i=1}^D \left[x_i^2 - 10 \cos(2\pi x_i) + 10 \right]$	Multimodal
F5	Griewank	$f(x) = \frac{1}{4000} \sum_{i=1}^D x_i^2 - \prod_{i=1}^D \cos\left(\frac{x_i}{\sqrt{i}}\right) + 1$	Multimodal
F6	Ackley	$f(x) = -20 \exp\left(-0.2 \sqrt{\frac{1}{D} \sum_{i=1}^D x_i^2}\right) - \exp\left(\frac{1}{D} \sum_{i=1}^D \cos(2\pi x_i)\right) + 20 + e$	Multimodal

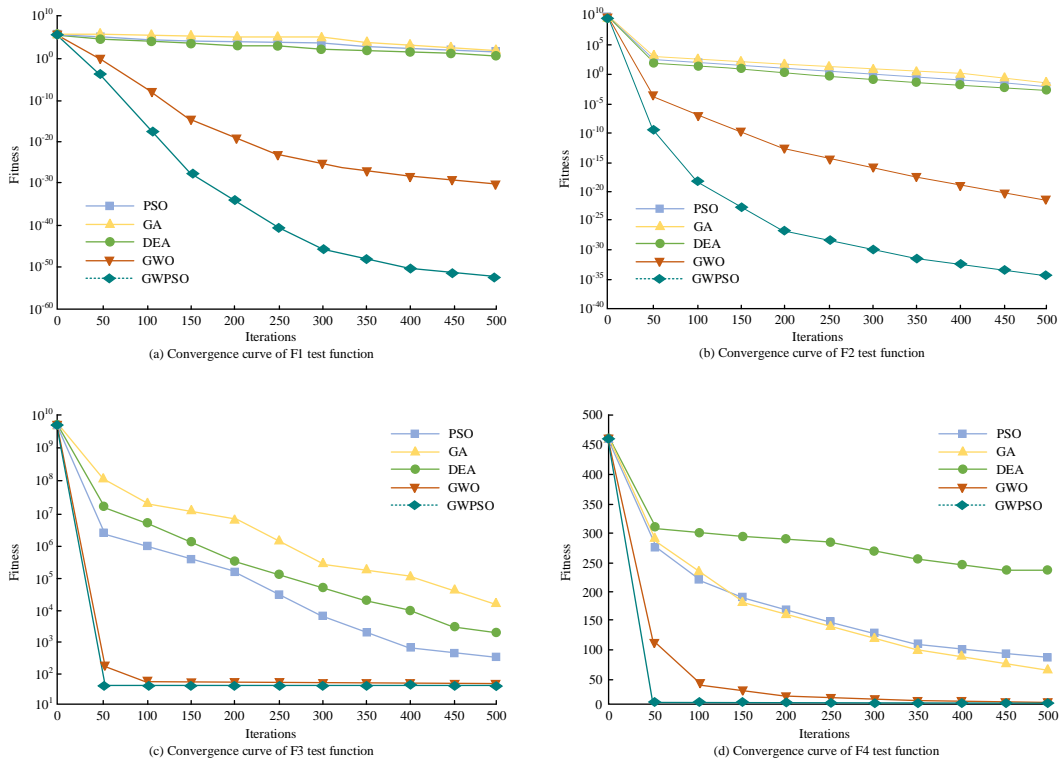


Fig. 6. CONVERGENCE CURVE OF F1, F2, F3 AND F4 TEST FUNCTIONS.

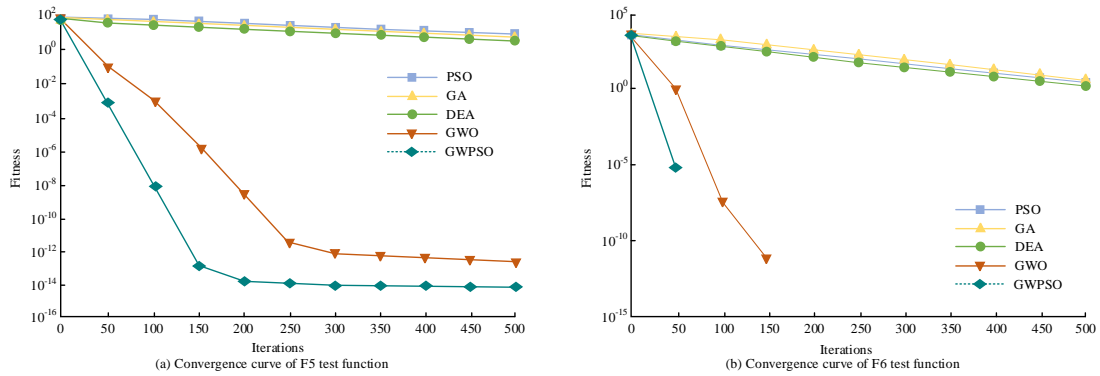


Fig. 7. CONVERGENCE CURVE OF F5 AND F6 TEST FUNCTIONS.

In Fig. 8, the network coverage was all improved after the node coverage deployment was optimized by the algorithms. The node network coverage after optimization by the PSO, GA, DEA, GWO, and GWPSO algorithms reached 86.75%, 88.24%, 89.54%, 90.48%, and 94.62% respectively. The node network coverage after optimization by the GWPSO algorithm was the highest among all algorithms and its optimization of node network coverage was the best, resulting in a significant coverage improvement. To further validate its availability, the study placed a trapezoidal obstacle in a 50m x 50m square monitoring area, which has an area of 500m². A population size of 50 was set and 25 sensing nodes were deployed, of which 2 were fixed nodes and the rest were mobile nodes. The maximum sensing radius of the mobile nodes is 5m and the maximum communication range is 10m, while the maximum sensing radius of the fixed nodes is 7.5m and the maximum communication range is 15m. Five algorithms were used to

optimize the coverage of the sensing nodes in the region, and the results are shown in Fig. 9.

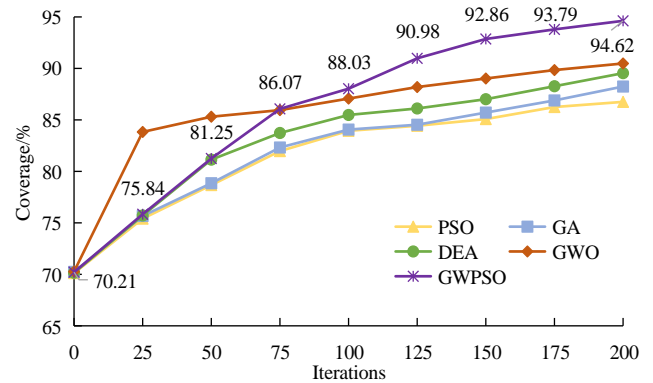


Fig. 8. COVERAGE RESULTS IN BARRIER-FREE ENVIRONMENT.

VI. CONCLUSION

To solve the problems of insufficient coverage of WSN and poor coverage in obstacle environments, the study combines the GWO with the PSO algorithm, which in turn forms an optimization search algorithm with higher search accuracy and faster convergence. The study adopts the algorithm in an applicative design, applies it to a wireless sensor network coverage optimization model, and finally analyses the application of the model by way of model comparison and application validation. Five experimental models have been used for the optimization of WSN. The results demonstrate that the five algorithms tested converge gradually with an increasing number of iterations on six functions, and the GWPSO algorithm converges best on all functions. In the comparison of network coverage optimization results, the PSO, GA, DEA, GWO, and GWPSO algorithms achieved 86.75%, 88.24%, 89.54%, 90.48%, and 94.62% of node network coverage after optimization, respectively. The GWPSO algorithm had the highest optimized network coverage. In the obstacle environment, the node network coverage of PSO, GA, DEA, GWO, and GWPSO algorithms reached 85.97%, 87.24%, 88.76%, 89.31%, and 91.05% respectively. The optimized network coverage of the GWPSO algorithm was also the highest. This shows that the GWPSO network coverage optimization algorithm designed in the study has a superior performance and is more practical for the optimal control of sensor coverage deployment.

REFERENCES

- [1] Abdulkarem M, Samsudin K, Rokhani F Z, et al. Wireless sensor network for structural health monitoring: a contemporary review of technologies, challenges, and future direction. *Structural Health Monitoring*, 2020, 19(3): 693-735.
- [2] Wei X, Guo H, Wang X, et al. Reliable data collection techniques in underwater wireless sensor networks: A survey. *IEEE Communications Surveys & Tutorials*, 2021, 24(1): 404-431.
- [3] Sah D K, Amgoth T. Renewable energy harvesting schemes in wireless sensor networks: a survey. *Information Fusion*, 2020, 63: 223-247.
- [4] Zhang Y. Coverage optimization and simulation of wireless sensor networks based on particle swarm optimization. *International Journal of Wireless Information Networks*, 2020, 27(2): 307-316.
- [5] Saheb S I, Khan K U R, Bindu C S. A Hybrid Modified Ant Colony Optimization-Particle Swarm Optimization Algorithm for Optimal Node Positioning and Routing in Wireless Sensor Networks. *International journal of electrical and computer engineering systems*, 2022, 13(7): 515-523.
- [6] Su B, Lin Y, Wang J, et al. Sewage treatment system for improving energy efficiency based on particle swarm optimization algorithm. *Energy Reports*, 2022, 8: 8701-8708.
- [7] Keserwani P K, Govil M C, Pilli E S, Govil P. A smart anomaly-based intrusion detection system for the Internet of Things (IoT) network using the GWO-PSO-RF model. *Journal of Reliable Intelligent Environments*, 2021, 7(1): 3-21.
- [8] Camacho-Villalón C L, Dorigo M, Stützle T. PSO-X: A component-based framework for the automatic design of particle swarm optimization algorithms. *IEEE Transactions on Evolutionary Computation*, 2021, 26(3): 402-416.
- [9] Şenel F A, Gökçe F, Yüksel A S, et al. A novel hybrid PSO-GWO algorithm for optimization problems. *Engineering with Computers*, 2019, 35(4): 1359-1373.
- [10] Chen S, Wang J, Zhang H. A hybrid PSO-SVM model based on a clustering algorithm for short-term atmospheric pollutant concentration forecasting. *Technological Forecasting and Social Change*, 2019, 146:

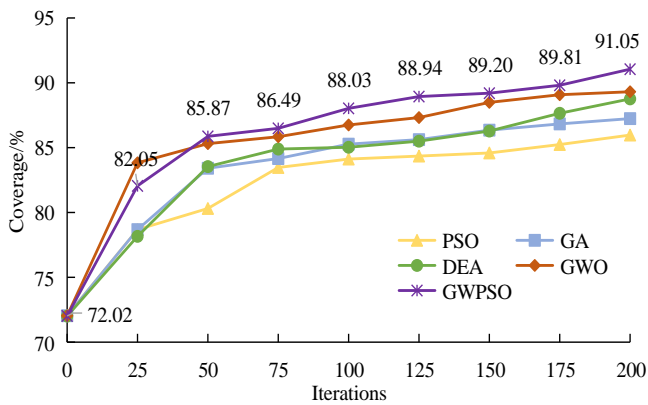


Fig. 9. COVERAGE RESULTS IN A TRAPEZOIDAL OBSTACLE ENVIRONMENT.

In Fig. 9, the network coverage in the trapezoidal obstacle environment was all improved after the algorithm was optimized for node coverage deployment. The node network coverage in the trapezoidal obstacle environment reached 85.97%, 87.24%, 88.76%, 89.31%, and 91.05% after optimization by the PSO, GA, DEA, GWO, and GWPSO algorithms respectively. The node network coverage after optimization by the GWPSO algorithm was the highest among all algorithms and its optimization of node network coverage was the best, resulting in marked upgradation in coverage. Because the number of sensor nodes in the trapezoidal obstacle environment was 10 less than the number of sensors in the barrier-free environment, the overall node network coverage after algorithm optimization was worse than that in the barrier-free environment, and the algorithm's optimization of node network coverage was also worse than that in the barrier-free environment. The results demonstrate that the GWPSO algorithm has the most significant optimization effect among all algorithms in both the obstacle-free and trapezoidal obstacle environments, fully verifying that the algorithm has superior performance in the optimal control of sensor coverage deployment, and providing an effective path for the optimization of WSN node network coverage.

V. DISCUSSION

The research aims to solve the problem of insufficient coverage of wireless sensor networks and poor coverage effect in obstacle environments. By combining the Grey Wolf algorithm and PSO algorithm, this study designed a GWPSO wireless sensor network coverage optimization algorithm and applied it to the sensor network coverage optimization model. The research results show that the GWPSO algorithm has the best convergence performance on all functions, and it achieves the best results in optimizing node network coverage, and also has the best coverage effect in obstacle environments. This shows that the GWPSO algorithm has better search accuracy and convergence speed, and has a significant application effect in the coverage optimization model of wireless sensor networks, with higher practicability. This research result provides effective algorithm support for the deployment and optimization of future wireless sensor networks, and can better adapt to complex real application scenarios. Future research based on this algorithm can further optimize its performance and enhance its applicability in application fields.

- 41-54.
- [11] Corazza M, di Tollo G, Fasano G, et al. A novel hybrid PSO-based metaheuristic for costly portfolio selection problems. *Annals of Operations Research*, 2021, 304(1): 109-137.
- [12] Khari M, Jahed Armaghani D, Dehghanbanadaki A. Prediction of lateral deflection of small-scale piles using hybrid PSO-ANN model. *Arabian Journal for Science and Engineering*, 2020, 45(5): 3499-3509.
- [13] Sohoulı A N, Molhem H, Zare-Dehnavi N. Hybrid PSO-GA algorithm for estimation of magnetic anomaly parameters due to simple geometric structures.. *Pure and Applied Geophysics*, 2022, 179(6): 2231-2254.
- [14] Khalaf O I, Abdulsahib G M, Sabbar B M. Optimization of wireless sensor network coverage using the Bee Algorithm. *J. Inf. Sci. Eng.*, 2020, 36(2): 377-386.
- [15] Cao L, Yue Y, Cai Y, et al. A novel coverage optimization strategy for heterogeneous wireless sensor networks based on connectivity and reliability. *IEEE Access*, 2021, 9: 18424-18442.
- [16] Hoffmann R, Désérable D, Seređyński F. Cellular automata rules solving the wireless sensor network coverage problem. *Natural Computing*, 2022, 21(3): 417-447.
- [17] Li Q, Liu N. Monitoring area coverage optimization algorithm based on nodes perceptual mathematical model in wireless sensor networks. *Computer Communications*, 2020, 155: 227-234.
- [18] ZainEldin H, Badawy M, Elhosseini M, et al. An improved dynamic deployment technique based-on-genetic algorithm (IDDT-GA) for maximizing coverage in wireless sensor networks. *Journal of Ambient Intelligence and Humanized Computing*, 2020, 11(10): 4177-4194.
- [19] Shaheen M A M, Hasanien H M, Alkuhayli A. A novel hybrid GWO-PSO optimization technique for optimal reactive power dispatch problem solution. *Ain Shams Engineering Journal*, 2021, 12(1): 621-630.
- [20] Senthil Kumar A M, Krishnamoorthy P, Soubaylu S, Venugopal J K, Marimuthu K. An Efficient Task Scheduling Using GWO-PSO Algorithm in a Cloud Computing Environment//*Proceedings of International Conference on Intelligent Computing, Information and Control Systems*. Springer, Singapore, 2021: 751-761.
- [21] Gul F, Rahiman W, Alhady S S, Ali A, Mir I, Jalil A. Meta-heuristic approach for solving multi-objective path planning for autonomous guided robot using PSO-GWO optimization algorithm with evolutionary programming. *Journal of Ambient Intelligence and Humanized Computing*, 2021, 12(7): 7873-7890.

Effect of Multi-SVC Installation for Loss Control in Power System using Multi-Computational Techniques

N. Balasubramaniam¹, N. A. M. Kamari^{2*}, I. Musirin^{3*}, A. A. Ibrahim⁴

Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Malaysia^{1,2,4}

Institute of Power Engineering (IPE), Universiti Tenaga Nasional, 43000 Kajang, Malaysia¹

School of Electrical Engineering-College of Engineering, Universiti Teknologi MARA, (UiTM), 40450 Shah Alam, Selangor, Malaysia³

Abstract—Flexible AC Transmission Systems (FACTS) play a vital role in minimizing the power losses and improving voltage profile in power transmission system. These increase the real power transfer capacity of the system. However, optimal location of sizing of the FACTS devices determines the extent of benefits provided by the FACTS devices to the transmission system. Non-optimal solution in terms of the location and sizing may possibly lead to under-compensation or over-compensation phenomena. Thus, a robust optimization is a priori for optimal solution achievement. This paper presents a study on the effect on multi static VAR compensators (SVC) installation for loss control in power system using evolutionary programming (EP), artificial immune system (AIS) and immune evolutionary programming (IEP). The objective is to minimize the real power loss transmission and improve the voltage profile of the transmission power system. The study reveals that installation of multi-units SVC significantly reduces the power loss and increases the voltage profile of the system, validated on the IEEE 30-Bus Reliability Test System (RTS).

Keywords—Flexible AC Transmission Systems (FACTS); Shunt VARs Compensators (SVCs); Evolutionary Programming (EP); Artificial Immune System (AIS); Immune Evolutionary Programming (IEP)

I. INTRODUCTION

The world electricity demand has been steadily increasing over the past few decades due to various factors such as population growth, urbanization, economic development, and technological advancements [1]. Conventional approach such as construction of new power plant and transmission lines to meet the increasing demand of electricity is not a feasible option due to many reasons such as high cost, environmental concerns, technical and time constraints. One of the vital ways to optimize the current system is by reducing the loss in the power system which can be achieved by injecting or retrieving the reactive power with the assistance of FACTS. Installation of FACTS devices can be one of the popular initiatives.

The concept of FACTS was first introduced by Hingorani in 1998 [2]. The working principle of FACTS is to enable the system electric parameters to change fast and flexibly while maintaining the security, stability and reliability of power system; thus, optimizing the existing resources in reducing power loss and cost, while improving the efficiency of the power grid operation [3]. It is important to understand that

FACTS devices confined several compensation devices such as unified power flow controller (UPFC), static VAR compensator (SVC), thyristor-controlled series compensator (TCSC), and static synchronous compensator (STATCOM). SVC is considered as a popular compensating device in power system. SVC is a parallel connected device which can act as variable capacitor or variable inductor.

The important uses of SVC are voltage stabilization of weak networks, reducing transmission losses, increasing power transfer capacity, increasing the small disturbance damping, improving voltage stability and removing power fluctuations [4]. SVC is chosen in this work based on its functionality. Optimal placement and sizing remain as a challenge in application of SVCs in voltage stability enhancement [5],[6]. Several optimization techniques have been invented to achieve the optimal solution for SVC installation for the purpose of minimizing the loss in power system or controlling the voltage level in a system within the acceptable limit determined by IEEE or IET standards. Otherwise, a power system will operate under low voltage level which in turn affecting the life time of a transmission cable in the system.

Heuristic optimization techniques have become an important approach in solving complex which is difficult to be solved using traditional approach [6],[7]. Heuristic optimization technique has been adopted in determining the optimization of FACTS devices for power system performance improvement. EP was used to optimize the size of SVC for minimization of loss and voltage profile improvement [8]. EP and AIS were used for SVC location and sizing optimization in IEEE 30-Bus RTS [9]. This application indicates that both EP and AIS is robust in achieving the optimal solution for SVC installation in power system.

On the other hand, improved version of traditional optimization techniques has also been proposed. Among the important techniques that can be highlighted, is a novel improved differential evolutionary (IDE) algorithm which is applied to optimize SVC and TCSC location and sizing for reactive power management in IEEE Bus-30 RTS, IEEE-57 RTS and IEEE-118 RTS [10]. Improved particle swarm in [11] is successfully applied in solving multi-objectives problems. However, the application dealt with the available transfer capability (ATC) study. Other important work that can be highlighted is the work conducted [12] where SVC and

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TCSC were used as the compensating devices. Gravitational search algorithm (GSA) is proposed for the loadability enhancement of the power system under different loading conditions by determining the optimal placement of different TCSC and SVC [13]. Another work conducted using whale optimization technique in [14] can be considered useful involving SVC and TCSC installation. Thus, a critical review may lead to an efficient decision in any compensation effort in power system.

This paper presents effects of multi-SVC installation for loss control in power system using multi-computational techniques. In this study, EP, AIS and Immune EP (IEP) were applied to identify the locations and sizing of SVC installation in controlling the transmission loss in power system. Controlling transmission loss in power systems is important as it enables optimal voltage control, reactive power compensation, and power flow regulation. By strategically placing SVCs, voltage stability is maintained, transmission losses are minimized, and system efficiency is improved, leading to reliable and secure operation. Results validated on the IEEE 30-Bus RTS revealed that all the techniques are comparable for loss control scheme in power system.

This paper is organized as follows. The objectives and problem formulations are established in Section II. Section III describes the optimization techniques used in detail. Section IV presents the test system used in the work. Section V presents the simulation results and discussions. Finally, Section VI concludes the paper with recommendations.

II. OBJECTIVE AND PROBLEM FORMULATION

Loss minimization is a vital remedial action applied in power system planning and operation. Transmission loss is proportionally translated to monetary loss as not all electricity generated is delivered to the customers. Compensation scheme such as installation of SVC can greatly reduce losses in the system. This research holds significant importance as its main objective is to study the effect of installing multi SVCs for loss control in power system using multi-computational intelligence techniques. The optimization of SVC location and sizing plays a crucial role in achieving this objective. By formulating the problem in terms of power loss minimization, this study addresses a critical aspect of enhancing power system efficiency and sustainability, thereby contributing to the advancement of power grid operations and control strategies.

The objective function, (OF) of this work is to minimize total loss in a transmission power system, which is mathematically represented by:

$$OF = \min \sum_{i=1}^n P_{Loss,i} \quad (1)$$

where n is number of buses in the system, and $P_{Loss,i}$ is power loss for line i which can be determined using (2), (3) and (4).

$$P_{Loss} = \sum_{i=1}^n \sum_{j=1}^n [\alpha_{ij}(P_i P_j + Q_i Q_j) + \beta_{ij}(Q_i P_j + P_i Q_j)] \quad (2)$$

$$\alpha_{ij} = \frac{r_{ij}}{v_i v_j} \cos(\delta_i - \delta_j) \quad (3)$$

$$\beta_{ij} = \frac{r_{ij}}{v_i v_j} \sin(\delta_i - \delta_j) \quad (4)$$

where

r_{ij} = line resistance between bus i and bus j

P_i and P_j = active power at bus i and bus j

Q_i and Q_j = reactive power at bus i and bus j

V_i and V_j = voltage magnitude

δ_i and δ_j = voltage angles

α_{ij} = active power loss factor

β_{ij} = reactive power loss factor

The objective function is subjected to voltage constraints and SVC location and sizing during the optimization process. The minimum voltage must be kept within the specified limits during the optimization process as indicated in (5).

$$0.95 \text{ p.u.} \leq V_i \leq 1.05 \text{ p.u.} \quad (5)$$

Electrical utilities maintain the voltage level to be in the range ± 5 from the nominal voltage level. SVC can be located at load bus only.

The sizing of the SVC is subjected to constraint as shown in (6).

$$0 \text{ MVar} \leq Q_{SVC} \leq 100 \text{ MVar} \quad (6)$$

Loss reduction percentage (LRP) and V_{\min} improvement percentage (VIP) are used for comparison. LRP and VIP are computed based on (7) and (8).

$$LRP = \frac{P_{Loss}(\text{pre_SVC}) - P_{Loss}(\text{post_SVC})}{P_{Loss}(\text{pre_SVC})} \quad (7)$$

$$VIP = \frac{V_{\min}(\text{post_SVC}) - V_{\min}(\text{pre_SVC})}{V_{\min}(\text{pre_SVC})} \quad (8)$$

III. OPTIMIZATION TECHNIQUES

Optimization technique is a collection of mathematical principles and methods used in solving a quantitative problem. Optimization technique is one of the most preferred and widely used techniques to solve SVC location and sizing optimization for minimization of transmission loss. In this study, three promising and evolving optimization techniques are applied, namely EP, AIS, IEP for location and sizing optimization of SVC for power loss reduction.

A. Evolutionary Programming

Evolutionary Programming (EP) is an artificial intelligence method inspired from natural selection process to find the global optimum of a complex problem. It was first invented by Lawrence J. Fogel in the US in 1960 [15]. The mechanics of EP algorithm is illustrated in Fig. 1.

Step 1: Initialization

The initialization process of EP begins with generating the control variables for optimal location and sizing of SVC using a uniformly distributed random number generator. 20

individuals (parents) are generated based on the control variables for the first iteration. In this case, the control variables will represent the locations and sizing of the SVC units. Apparently, the number of control variables or decision variables will be doubled of the number of SVC units to be installed into the system. During initialization, parameters such as: number of individuals, mutation step size and maximum number of iterations are specified. The total loss of the system before optimization, $P_{Loss (pre_SVC)}$ is calculated as the reference value. The individuals that violate the requirements and constraints are subsequently exterminated from the population pool.

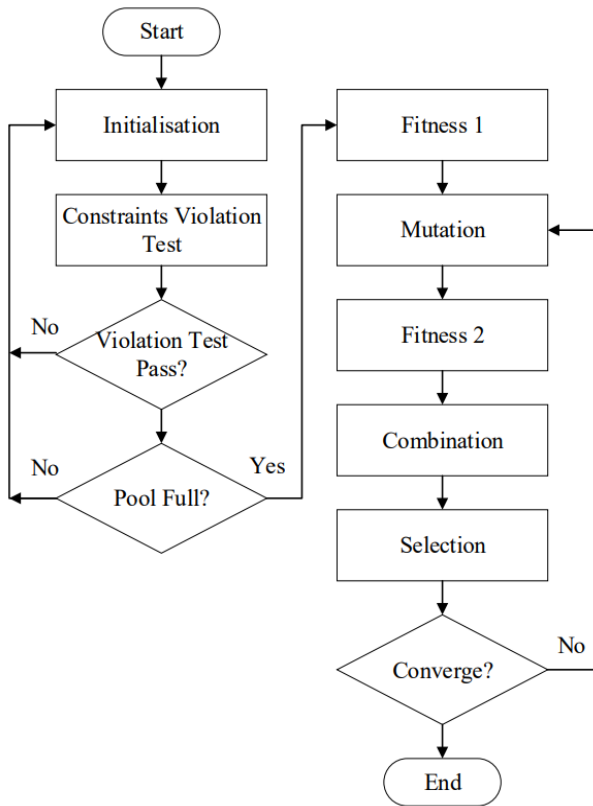


Fig. 1. Flow chart of EP algorithm.

Step 2: Fitness 1 Calculation

Load flow programs are performed to calculate the fitness value which is the real power loss, $P_{Loss (post_SVC)}$. If $P_{Loss (post_SVC)} < P_{Loss (pre_SVC)}$, and fulfils the other constraints specified, they will be accepted into the initial population pool. The general matrix for the initial population, X is given by (9).

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1q} & f_1 \\ x_{21} & x_{22} & \dots & x_{2q} & f_2 \\ \vdots & \vdots & \dots & \vdots & \vdots \\ x_{p1} & x_{p2} & \dots & x_{pq} & f_p \end{bmatrix} \quad (9)$$

where:

p = population size

q = no. of variable

f = fitness of the individual (parent)

Step 3: Mutation

Mutation is a process to breed offspring. The individuals (parents) in the population pool are mutated to breed offspring using the Gaussian mutation operator [16]–[18]. The Gaussian mutation equation is given in (10).

$$x_{i+m,j} = x_{i,j} + N \left(0, \beta (x_{jmax} - x_{jmin}) \left(\frac{f_i}{f_{max}} \right) \right) \quad (10)$$

where

$x_{i+m,j}$ = offspring (mutated parent)

$x_{i,j}$ = parent

N = Gaussian random variable

β = mutation scale $0 < \beta < 1$

x_{jmax} = maximum value of parent

x_{jmin} = minimum value of parent

f_i = fitness of the i^{th} random number

f_{max} = maximum fitness

Step 4: Fitness 2 Calculation

Fitness 2 calculation is performed by running the load flow again, using the offsprings bred during the mutation process. The matrix for the offspring population, X_{off} is given by (11).

$$X_{off} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \dots & \alpha_{1q} & F_1 \\ \alpha_{21} & \alpha_{22} & \dots & \alpha_{2q} & F_2 \\ \vdots & \vdots & \dots & \vdots & \vdots \\ \alpha_{p1} & \alpha_{p2} & \dots & \alpha_{pq} & F_n \end{bmatrix} \quad (11)$$

where

n = population size

m = no. of variable

F = fitness of the offspring

Step 5: Combination Process

The parent matrix and the offspring matrix are then combined in a cascaded form as in (12).

$$X_{combined} = \begin{bmatrix} X \\ X_{off} \end{bmatrix} \quad (12)$$

Step 6: Selection Process and Convergence Test

The individuals in matrix $X_{combined}$ is ranked in ascending order based on fitness value. 20 best individuals from matrix $X_{combined}$ are selected for the next iteration. New individuals are identified for the next iteration process. In this case, the new individuals will be equipped together with the corresponding fitness value for the next iteration or evolution. However, if the new individuals do not bring together the corresponding fitness values, Fitness 1 calculation needs to be conducted. A convergence test is used to check if the optimal solution has been achieved. Otherwise, Step 2 through Step 4

will be repeated until the convergence criterion is met or the iteration cycle reaches the maximum value set. EP algorithm converges when the difference between the maximum and minimum fitness values is 0.00001 presented mathematically in (13).

$$P_{Loss(max)} - P_{Loss(min)} \leq 0.00001 \quad (13)$$

That ends the EP process.

B. Artificial Immune System

Artificial Immune System (AIS) technique is inspired by biological immune system and has been used for computational models in solving complex real-world problems. The algorithms in artificial immune system adapt the immune system features of learning and memory to solve a problem. The evolution of AIS has its roots from the work of Farmer, Packard and Perelson [19]. The AIS flowchart is presented in Fig. 2.

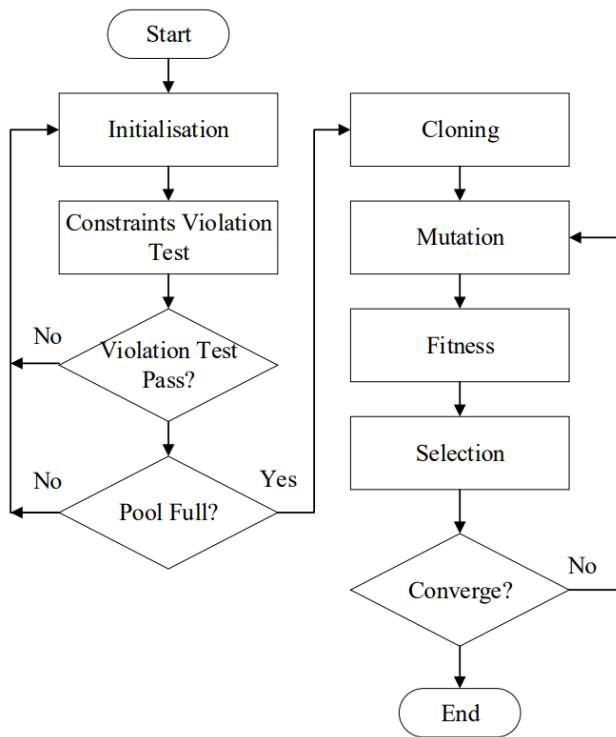


Fig. 2. Flowchart of AIS algorithm.

Step 1: Initialization

The initialization process of AIS begins with generating the control variables for optimal SVC using a uniformly distributed random number generator. 20 individuals (parents) are initially generated based on the control variables for the first iteration. During initialization, parameters such as: number of individuals, mutation step size and maximum number of iterations were to be specified. The total loss of the system before optimization, $P_{Loss(pre_SVC)}$ is calculated as the reference value. The individuals that violate the requirements and constraints are subsequently exterminated from the population.

Step 2: Parent Fitness Calculation

Load flow programs is performed to calculate the fitness value which is real power loss, $P_{Loss(post_SVC)}$. If $P_{Loss(post_SVC)} < P_{Loss(pre_SVC)}$, and fulfils the other constraints specified, they are accepted into the initial population pool. The general matrix for the initial population, X is given by (9).

Step 3: Cloning Process

The individuals in the initial pool, which are referred as parents, are cloned with a factor of 10 as suggested [20], [21]. The population size increases 10 folds after cloning. The general cloned matrix is given in (14) where k is the cloning factor.

$$X_{clone} = \begin{bmatrix} \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1q} & f_1 \\ x_{21} & x_{22} & \dots & x_{2q} & f_2 \\ \vdots & \vdots & \dots & \vdots & \vdots \\ x_{p1} & x_{p2} & \dots & x_{pq} & f_p \end{bmatrix} \\ \vdots \\ \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} & f_1 \\ x_{21} & x_{22} & \dots & x_{2q} & f_2 \\ \vdots & \vdots & \dots & \vdots & \vdots \\ x_{p1} & x_{p2} & \dots & x_{pq} & f_p \end{bmatrix} \end{bmatrix} \quad (14)$$

Step 4: Mutation

Mutation is a process to produce offspring. The individuals of the cloned population, X_{clone} are mutated to breed offspring. Mutation equation in (10) is adapted.

Step 5: Offspring Fitness Calculation

Then, load flow analysis is performed to determine the fitness of the offspring. The matrix for the offspring population, X_{cloned_off} is given by (15).

$$X_{cloned_off} = \begin{bmatrix} \begin{bmatrix} \alpha_{11} & \alpha_{12} & \dots & \alpha_{1q} & F_1 \\ \alpha_{21} & \alpha_{22} & \dots & \alpha_{2q} & F_2 \\ \vdots & \vdots & \dots & \vdots & \vdots \\ \alpha_{p1} & \alpha_{p2} & \dots & \alpha_{pq} & F_p \end{bmatrix} \\ \vdots \\ \begin{bmatrix} \alpha_{11} & \alpha_{12} & \dots & \alpha_{1q} & F_1 \\ \alpha_{21} & \alpha_{22} & \dots & \alpha_{2q} & F_2 \\ \vdots & \vdots & \dots & \vdots & \vdots \\ \alpha_{p1} & \alpha_{p2} & \dots & \alpha_{pq} & F_p \end{bmatrix} \end{bmatrix} \quad (15)$$

where

p = population size

q = no. of variable

F = fitness of the offspring

k = cloning factor

Step 6: Selection Process and Convergence Test

Selection process is conducted to identify the survivors among the fittest. In this case, the individuals in matrix X_{cloned_off} are ranked in ascending order based on fitness value. For this study, the individuals are ranked based on the lowest fitness value since the objective function is

minimization of total transmission loss. 20 best individuals from the matrix X_{cloned_off} are selected for the next iteration. A convergence test is used to check if the optimal solution has been achieved. Otherwise, Step 2 through Step 5 will be repeated until the convergence criterion is met or the iteration cycle reaches the maximum value set. AIS algorithm converges when the difference between the maximum and minimum fitness values is 0.00001 as presented in (13). That ends the AIS process.

C. Immune Evolutionary Programming

Immune Evolutionary Programming (IEP) is derived by integrating the traditional EP and AIS. The IEP flowchart is presented in Fig. 3.

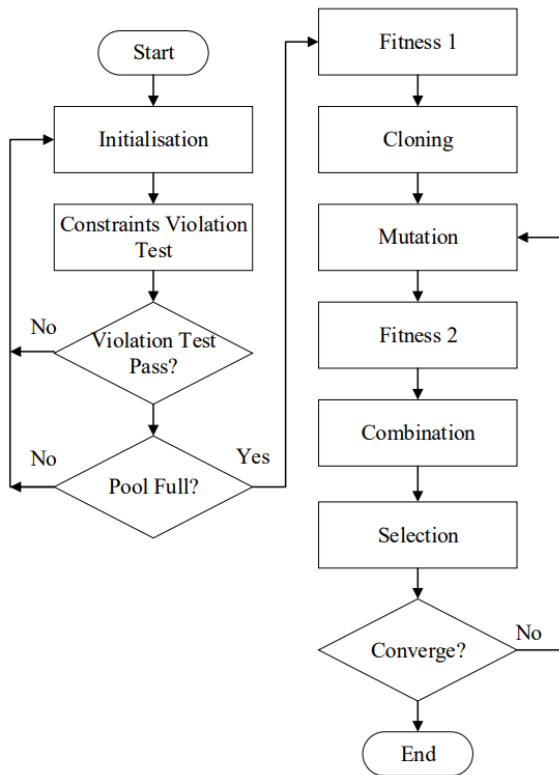


Fig. 3. Flowchart of IEP algorithm.

Step 1: Initialization

The initialization process of EP begins with generating the control variables for optimal SVC using a uniformly distributed random number generator. 20 individuals (parents) are generated based on the control variables first iteration. During initialization, parameters such as: number of individuals, mutation step size and maximum number of iterations were to be specified. The total loss of the system before optimization, $P_{Loss(pre_SVC)}$ is calculated as the reference value. The individuals that violate the requirements and constraints are subsequently exterminated from the population.

Step 2: Fitness 1 Calculation

Load flow programs are run to calculate the fitness value which is real power loss, $P_{Loss(post_SVC)}$. If $P_{Loss(post_SVC)} < P_{Loss(pre_SVC)}$, and fulfils the other constraints specified, they will be accepted into the initial population pool. The general matrix for the initial population, X is given by (9).

Step 3: Cloning

The individuals in the initial pool which are referred as parents are cloned with a factor of k as in (14).

Step 4: Mutation

Mutation is a process to produce offspring. The individuals in the cloned population pool are mutated to breed offspring. The Gaussian mutation equation in (10) is adapted.

Step 5: Fitness 2 Calculation

Then, load flow analysis is performed to determine the fitness of the offspring. The matrix for the offspring population, X_{cloned_off} is obtained as shown in (15).

Step 6: Combination Process

The parent matrix and the offspring matrix are then combined in a cascaded form. If the parent matrix and the offspring matrix are represented by (9) and (15), respectively, then the combined matrix, C , has the form as in (16).

$$X_{combined} = \begin{bmatrix} X \\ X_{cloned_off} \end{bmatrix} \quad (16)$$

Step 7: Selection Process and Convergence Test

The individuals in matrix $X_{combined}$ are ranked in ascending order based on fitness value. 20 best individuals from matrix $X_{combined}$ are selected for the next iteration. A convergence test is used to check if the optimal solution has been achieved. Otherwise, Step 2 through Step 4 will be repeated until the convergence criterion is met or the iteration cycle reaches the maximum value set. IEP algorithm converges when the difference between the maximum and minimum fitness values is 0.00001 as presented in (13).

That ends the IEP process.

IV. TEST SYSTEM

The single line diagram of IEEE 30-Bus RTS used in this study [22] is shown Fig. 4, depicts the configuration of the power system. This system consists of five generators located at Bus 2, Bus 5, Bus 8, Bus 11, and Bus 13. There is a slack bus located at Bus 1 which serves as the reference point for voltage and frequency. There are 24 load buses in the system. The system is interconnected through a total of 41 bus interconnecting lines, forming a complex network. This power system topology is used for identifying and analyzing optimum location and sizing of SVC installation in controlling the transmission loss in power system.

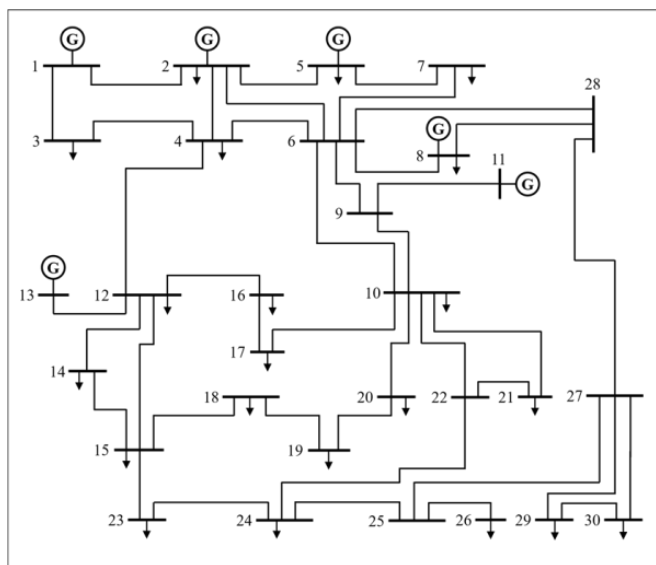


Fig. 4. IEEE 30-Bus reliability test system.

V. RESULTS AND DISCUSSIONS

This section presents the results of multi-SVC installation for loss control in power system using multi-computational techniques.

A. Bus Category Identification

Test was performed on IEEE 30-Bus RTS to identify the weak and strong buses of this system. An increasing reactive power load, Q_d was subjected to each of the load bus in the system and the corresponding voltage at the bus is recorded until the system collapsed. The results are presented in Fig. 1. From the figure, buses 26, 29 and 30 are identified as the weak buses indicated by their low maximum loadability value, $Q_{d,max}$ of each bus. For instance, the $Q_{d,max}$ for Bus 26 is 30 MVAR with its corresponding voltage 0.6997 p.u.. Other weak buses can be referred to the same figure. The identified strong buses for this system are buses 6, 4 and 3 due to maximum loadability of each bus. The $Q_{d,max}$ for all the three strong buses are 200 MVAR. The summary of all the details of weak and strong buses are tabulated in Table I.

B. Multi SVCs Installation

In this study, EP, AIS and IEP are validated on IEEE 30-Bus RTS to determine the effect of SVC installation on power loss and voltage profile of the system. In this study, three scenarios have been considered as follows:

- Scenario 1: Single SVC installation.
- Scenario 2: 2 units of SVC installation.
- Scenario 3: 3 units of SVC installation.

Error! Reference source not found. TABLE 2 tabulates the implementation scope of the multi-SVC installation on IEEE 30-Bus RTS. These are the scenarios studied to evaluate

the proposed optimization algorithm in finding the optimal location and sizing of SVCs.

1) *Scenario 1: Single SVC installation:* This section discusses the optimization results of single SVC installation in the attempt to minimize the P_{Loss} of the system. All together 6 buses were subjected to reactive power load; 3 weak buses (Bus 26, 29, 30) and 3 strong buses (Bus 6, 4, 3).

III presents the results for single SVC installation involving weak buses at Buses 26, 29 and 30 and strong buses involving Buses 6, 4 and 3. In general, all techniques managed to reduce the power loss in the system. For instance, when Bus 26 was subjected to 10 MVAR, the installation of single SVC managed to reduce the loss from 18.230 MW to 17.820 MW, solved using EP. The LRP is 2.249%. When the load is increased to 30 MVar, loss was reduced from 26.109 MW to 17.542, where the LRP is 32.815%. AIS and IEP also managed to achieve these results, which imply that all the three techniques are comparable. Generally, the values of LRP increase as the reactive power loading is increased regardless of any optimization technique. The details can be referred to the same table.

Table IV presents V_{min} and VIP before and after the single SVC installation. When Bus 26 was subjected to 10 MVAR, the installation of single SVC managed to increase the V_{min} of IEEE 30-Bus RTS from 0.940 p.u. to 0.957 p.u., solved using EP. The VIP is 1.841%.

When the load is increased to 30 MVAR, the V_{min} increased from 0.691 p.u. to 0.973 p.u., where the VIP is 40.799%. AIS and IEP also managed to achieve these results. Generally, the values of VIP increase as the reactive power loading is increased regardless of any optimization technique. More details can be referred to the same table.

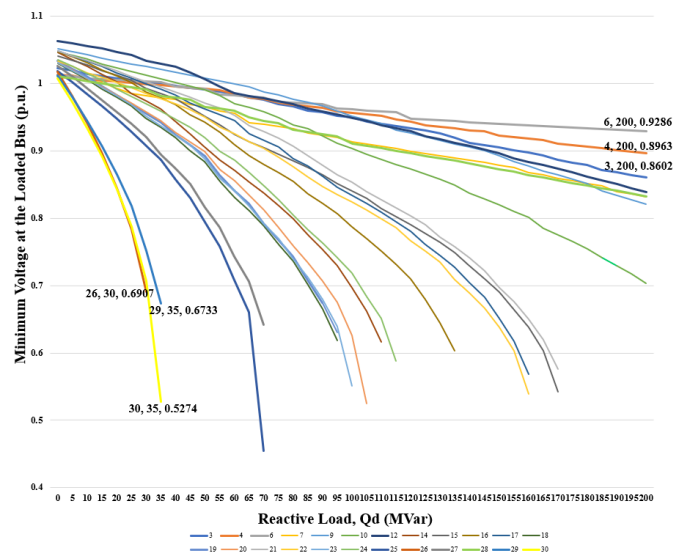


Fig. 5. Minimum voltage profile of IEEE 30-Bus RTS with load variation.

TABLE I. SUMMARY OF 3 WEAKEST AND 3 STRONGEST BUSES IN IEEE 30-BUS RTS

Bus category	Bus Number	Reactive Load (MVar)	Voltage at loaded bus(p.u.)
Weak	26	30	0.6907
	30	35	0.5274
	29	35	0.6733
Strong	6	200	0.9286
	4	200	0.8963
	3	200	0.8602

TABLE II. IMPLEMENTATION SCOPE

Scenario	SVC	Bus Category	Bus Subjected to Q_d Load
1	1	Weak	26, 29 ,30
	1	Strong	6,4,3
2	2	Weak	26, 29 ,30
	2	Strong	6,4,3
3	3	Weak	26, 29 ,30
	3	Strong	6,4,3

TABLE III. P_{Loss} AND LRP OF SINGLE SVC OPTIMIZATION

Bus	Q_d (MVar)	Pre SVC P_{Loss} (MW)	Single SVC Post Installation					
			EP		AIS		IEP	
			P_{Loss} (MW)	LRP (%)	P_{Loss} (MW)	LRP (%)	P_{Loss} (MW)	LRP (%)
26	10	18.230	17.820	2.249	17.820	2.249	17.820	2.249
	20	20.252	17.573	13.227	17.573	13.227	17.573	13.227
	30	26.109	17.542	32.815	17.542	32.815	17.542	32.815
29	10	18.116	17.559	3.080	17.559	3.080	17.559	3.080
	20	19.386	17.562	9.406	17.562	9.406	17.562	9.406
	30	22.441	17.571	21.704	17.571	21.704	17.571	21.704
30	10	18.109	17.753	1.969	17.753	1.969	17.753	1.969
	20	19.548	17.550	10.222	17.552	10.215	17.552	10.215
	30	23.442	17.732	24.360	17.552	25.124	17.732	24.360
6	50	18.017	17.603	2.297	17.603	2.297	17.603	2.297
	100	19.139	17.608	8.001	18.022	5.838	18.022	5.838
	150	20.568	19.041	7.424	19.041	7.424	19.041	7.424
4	50	18.265	17.479	4.301	17.479	4.301	17.479	4.301
	100	19.838	17.626	11.148	17.626	11.148	17.626	11.148
	150	22.431	18.359	18.153	18.359	18.153	18.359	18.153
3	50	18.529	17.508	5.511	17.508	5.511	17.508	5.511
	100	20.724	17.764	14.282	17.764	14.282	17.764	14.282
	150	24.463	18.533	24.243	18.533	24.243	18.533	24.243

TABLE IV. V_{min} AND VIP OF SINGLE SVC OPTIMIZATION

Bus	Q_d (MVar)	Pre SVC V_{min} (p.u.)	Single SVC Post Installation					
			EP		AIS		IEP	
			V_{min} (p.u.)	VIP(%)	V_{min} (p.u.)	VIP(%)	V_{min} (p.u.)	VIP(%)
26	10	0.940	0.957	1.841	0.957	1.841	0.957	1.841
	20	0.845	1.006	19.124	1.006	19.124	1.006	19.124
	30	0.691	0.973	40.799	0.973	40.799	0.973	40.799
29	10	0.944	0.951	0.774	0.951	0.774	0.951	0.774
	20	0.865	1.008	16.461	1.008	16.461	1.008	16.461
	30	0.752	1.007	33.838	1.007	33.838	1.007	33.838
30	10	0.933	0.953	2.230	0.953	2.230	0.953	2.230
	20	0.844	1.007	19.282	1.007	19.353	1.007	19.353
	30	0.707	1.006	42.241	0.997	40.996	1.006	42.241
6	50	0.978	0.994	1.615	0.987	0.910	0.994	1.615
	100	0.950	0.966	1.694	0.982	3.357	0.966	1.705
	150	0.931	0.954	2.437	0.954	2.437	0.954	2.437
4	50	0.986	0.996	0.994	0.989	0.243	0.996	0.994
	100	0.956	0.964	0.847	0.966	0.962	0.964	0.847
	150	0.923	0.952	3.208	0.952	3.208	0.952	3.208
3	50	0.987	0.991	0.355	0.992	0.506	0.991	0.355
	100	0.949	0.952	0.305	0.954	0.495	0.952	0.305
	150	0.905	0.956	5.634	0.956	5.634	0.956	5.634

TABLE V. P_{Loss} AND LRP OF 2 SVCs OPTIMIZATION

Bus	Q_d (MVar)	Pre SVC P_{Loss} (MW)	2 SVCs Post Installation					
			EP		AIS		IEP	
			P_{Loss} (MW)	LRP (%)	P_{Loss} (MW)	LRP (%)	P_{Loss} (MW)	LRP (%)
26	10	18.230	17.799	2.362	17.806	2.324	17.799	2.362
	20	20.252	17.638	12.906	17.638	12.905	17.638	12.906
	30	26.109	17.663	32.352	17.663	32.352	17.663	32.352
29	10	18.116	17.595	2.880	17.595	2.880	17.595	2.880
	20	19.386	17.672	8.837	17.864	7.849	17.673	8.837
	30	22.441	17.885	20.304	17.571	21.704	17.885	20.303
30	10	18.109	17.775	1.843	17.769	1.879	17.775	1.843
	20	19.548	17.576	10.091	17.576	10.091	17.576	10.091
	30	23.442	17.664	24.649	17.664	24.649	17.664	24.649
6	50	18.017	17.520	2.754	17.520	2.754	17.520	2.754
	100	19.139	18.115	5.351	18.365	4.045	18.115	5.351
	150	20.568	18.999	7.627	19.141	6.937	18.999	7.627
4	50	18.265	17.480	4.296	17.622	3.519	17.480	4.296
	100	19.838	17.572	11.423	17.572	11.423	17.572	11.423
	150	22.431	17.929	20.071	17.929	20.071	17.929	20.071
3	50	18.529	17.615	4.932	17.615	4.931	17.615	4.931
	100	20.724	17.926	13.503	17.926	13.503	17.926	13.503
	150	24.463	18.467	24.510	18.628	23.853	18.467	24.510

TABLE VI. V_{min} AND VIP OF 2 SVCs OPTIMIZATION

Bus	Q_d (MVar)	Pre SVC V_{min} (p.u.)	2 SVCs Post Installation					
			EP		AIS		IEP	
			$V_{min}(p.u.)$	VIP(%)	$V_{min}(p.u.)$	$V_{min}(p.u.)$	VIP(%)	$V_{min}(p.u.)$
26	10	0.940	0.953	1.458	0.953	1.405	0.953	1.458
	20	0.845	1.008	19.313	1.010	19.586	1.008	19.313
	30	0.691	0.955	38.193	1.006	45.635	0.955	38.193
29	10	0.944	0.983	4.144	0.959	1.664	0.983	4.144
	20	0.865	0.991	14.507	1.005	16.114	0.991	14.507
	30	0.752	1.009	34.157	1.010	34.237	1.009	34.157
30	10	0.933	0.971	4.107	0.960	2.917	0.971	4.107
	20	0.844	1.008	19.495	0.996	17.978	1.008	19.495
	30	0.707	1.010	42.877	1.009	42.764	1.010	42.877
6	50	0.978	0.9969	1.922	0.9804	0.235	0.9969	1.922
	100	0.950	0.9843	3.589	0.965	1.558	0.9843	3.589
	150	0.931	0.9653	3.651	0.9832	5.573	0.9653	3.651
4	50	0.986	0.9988	1.267	1.0001	1.399	0.9988	1.267
	100	0.956	0.9813	2.614	0.9669	1.108	0.9813	2.614
	150	0.923	0.9528	3.262	0.9642	4.498	0.9528	3.262
3	50	0.987	1.0088	2.188	0.9896	0.243	1.0088	2.188
	100	0.949	0.9613	1.264	0.955	0.600	0.9613	1.264
	150	0.905	0.9918	9.567	0.9598	6.032	0.9918	9.567

2) *Scenario 2: 2 SVCs installation:* Table V presents the results for 2 SVCs installation involving weak buses and strong buses. In general, all techniques managed to reduce the power loss in the system with 2 SVCs installation. For instance, when Bus 26 was subjected to 30 MVAR, the installation of 2 SVCs managed to reduce the loss from 26.109 MW to 17.663 MW, solved using EP. The LRP is 32.352%. AIS and IEP also managed to achieve similar results. On the other hand, when strong buses (Bus 6, 4, 3) were subjected to 50 MVAR, the installation of 2SVCs managed to reduce the losses, solved using all the three techniques. However, the LRP in the range of 2.5% to 5% only. This implies that SVC installation reduces the loss in the power system greatly when weak buses are subjected to reactive power load compared to strong buses.

Tale VI presents V_{min} and VIP before and after the 2 SVCs installation. Overall, 2 SVCs installation increases the V_{min} in both weak buses and strong buses regardless the optimization techniques applied. For instance, when Bus 30 is subjected to 30 MVAR, V_{min} is increased from 0.707 p.u. to 1.010 p.u., solved using EP. The VIP is 42.877%. AIS and IEP also managed to achieve VIP in the similar range. Details on other buses can be referred to Table VI.

3) *Scenario 3: 3 SVCs installation:* Table VII presents the results for 3 SVCs installation involving weak buses and strong buses. 3 SVCs installation reduced loss in the system regardless the techniques applied. When Bus 30 is subjected to 30 MVAR, the loss was reduced from 26.109 MW to 19.140 MW which implies a LRP of 26.695% solving with EP. For the same scenario the LRP was 32.815% for single SVC installation and 32.352% for 2 SVCs installation. Similar results were observed with AIS and IEP. These results indicate, installation of multi-SVC not necessarily further reduces the loss of the power system. Based on the results, a maximum of 2 SVCs installation is recommended. However, other constraints of the power system need to considered. The details can be referred Table VII.

Table VIII presents V_{min} and VIP before and after the 3 SVCs installation. Overall, 3 SVCs installation increases the V_{min} in both weak buses and strong buses regardless of the optimization techniques applied. The best VIP was recorded when Bus 30 was subjected to 30 MVAR. The V_{min} was increased from 0.691 p.u. to 1.010 p.u. solving using EP. The VIP is 46.228%. AIS and IEP also managed to achieve same results. Results for other buses can be referred to Table VIII.

TABLE VII. P_{Loss} AND LRP OF 3 SVCs INSTALLATION

Bus	Q_d (MVar)	Pre SVC P_{Loss} (MW)	3 SVCs Post Installation					
			EP		AIS		IEP	
			P_{Loss} (MW)	LRP (%)	P_{Loss} (MW)	LRP (%)	P_{Loss} (MW)	LRP (%)
26	10	18.230	17.922	1.688	17.871	1.967	17.922	1.688
	20	20.252	18.005	11.095	17.638	12.905	18.005	11.093
	30	26.109	19.140	26.695	18.756	28.162	19.140	26.693
29	10	18.116	17.579	2.969	17.579	2.968	17.579	2.968
	20	19.386	17.517	9.638	17.550	9.470	17.517	9.638
	30	22.441	18.553	17.327	17.885	20.303	18.553	17.326
30	10	18.109	17.533	3.181	17.623	2.686	17.533	3.181
	20	19.548	17.585	10.043	17.583	10.056	17.585	10.043
	30	23.442	17.526	25.237	17.654	24.692	17.526	25.237
6	50	18.017	17.515	2.783	17.515	2.783	17.515	2.783
	100	19.139	17.716	7.435	17.878	6.590	17.716	7.435
	150	20.568	18.382	10.629	17.539	14.727	18.382	10.629
4	50	18.265	17.582	3.742	17.621	3.525	17.582	3.742
	100	19.838	17.663	10.964	17.663	10.964	17.663	10.964
	150	22.431	17.804	20.629	17.804	20.629	17.804	20.629
3	50	18.529	17.518	5.457	17.898	3.408	17.518	5.457
	100	20.724	18.118	12.573	18.118	12.573	18.118	12.573
	150	24.463	18.175	25.705	18.293	25.221	18.175	25.705

TABLE VIII. V_{min} AND VIP OF 3 SVCs INSTALLATION

Bus	Q_d (MVar)	Pre SVC V_{min} (p.u.)	3 SVCs Post Installation					
			EP		AIS		IEP	
			V_{min} (p.u.)	VIP(%)	V_{min} (p.u.)	V_{min} (p.u.)	VIP(%)	V_{min} (p.u.)
26	10	0.940	0.953	1.458	0.971	3.310	0.953	1.458
	20	0.845	1.010	19.597	1.008	19.408	1.010	19.597
	30	0.691	1.010	46.228	1.010	46.228	1.010	46.228
29	10	0.944	1.006	6.560	0.963	2.077	1.006	6.560
	20	0.865	0.959	10.843	0.993	14.819	0.959	10.843
	30	0.752	1.010	34.237	1.010	34.237	1.010	34.237
30	10	0.933	0.952	2.059	1.008	8.053	0.952	2.059
	20	0.844	0.955	13.119	1.008	19.448	0.955	13.119
	30	0.707	0.959	35.649	1.010	42.877	0.959	35.649
6	50	0.978	1.001	2.351	0.995	1.748	1.001	2.351
	100	0.950	0.972	2.315	1.003	5.578	0.972	2.315
	150	0.931	0.984	5.659	0.967	3.812	0.984	5.659
4	50	0.986	1.003	1.673	0.996	1.004	1.003	1.673
	100	0.956	0.979	2.342	0.986	3.074	0.979	2.342
	150	0.923	0.999	8.302	0.959	3.923	0.999	8.302
3	50	0.987	1.006	1.935	0.998	1.074	1.006	1.935
	100	0.949	0.965	1.664	0.974	2.549	0.965	1.664
	150	0.905	0.976	7.855	1.001	10.561	0.976	7.855

TABLE IX. LOCATION AND SIZING OF SINGLE SVC INSTALLATION

Bus	Q_d (MVar) Max	OT	Single SVC Installation		
			Location 1	Sizing 1 (MVar)	LRP (%)
26	30	EP	26	31.161	32.815
		AIS	26	31.159	32.815
		IEP	26	31.161	32.815
29	30	EP	26	31.161	32.815
		AIS	29	35.691	33.838
		IEP	29	35.691	33.838
30	30	EP	30	24.405	24.360
		AIS	30	33.207	25.124
		IEP	30	24.405	24.360
6	150	EP	4	94.770	7.4240
		AIS	4	94.774	7.4240
		IEP	4	94.774	7.4240
4	150	EP	4	94.776	18.153
		AIS	4	94.775	18.153
		IEP	4	94.776	18.153
3	150	EP	3	99.874	24.243
		AIS	3	90.464	18.242
		IEP	3	90.465	18.242

C. Location and Sizing of SVCs

The installation of SVCs into the system as the initiative to reduce the total power loss will require the optimal locations and sizing. The multi-SVC locations and sizing details for all the three scenarios are tabulated in Tables IX to XI.

Scenario 1: Location and sizing of single SVC: The results for Scenario 1 are tabulated in Table IX. Only location and sizing of single SVC for $Q_{d,max}$ for each bus are shown to simplify the results. For instance, when Bus 26 is subjected to 30 MVAR, the single SVC to be installed at Bus 26 of a 31.161 MVAR for a LRP of 32.815%, solved by EP. AIS and IEP also solved the same location for SVC installation and same range of SVC sizing, which implies that all the three techniques are comparable. Details of single SVC location and sizing when other buses are subjected to $Q_{d,max}$ can be referred to Table IX.

1) Scenario 2: Location and sizing of 2 SVCs: The results for Scenario 2 are tabulated in Table X. Only location and sizing of 2 SVCs for $Q_{d,max}$ for each bus are shown for simplification purpose. For instance, when Bus 26 is subjected to 30 MVAR, the 2 SVCs to be installed are at Bus 28 (27.535 MVAR) and Bus 26 (27.893 MVAR) for a LRP of 32.352%, solved by EP. The total SVC sizing was 55.428 MVAR. AIS and IEP also solved the same location for SVC installation and

same range of SVC sizing, which implies that all the three techniques are comparable.

However, it was observed the sizing of single SVC is much lower for the same scenario compared to total SVC sizing when 2 SVCs installation was opted. In this case, single SVC and 2 SVCs installations has same range of LRP. This implies, multi-SVC is not always an option to reduce loss in the system. Other factors such as installation cost, maintenance cost and accessibility need to be considered before opting for multi-SVC installation. Details of 2 SVCs location and sizing when other buses are subjected to $Q_{d,max}$ can be referred to Table X.

2) Scenario 3: Location and sizing of 3 SVCs: The results for Scenario 3 are tabulated in Table XI. Only location and sizing of 3 SVCs for $Q_{d,max}$ for each bus are shown for simplification purpose. For instance, when Bus 26 is subjected to 30 MVAR, the 3 SVCs to be installed are at Bus 10 (35.094 MVAR), Bus 16 (59.106 MVAR) and Bus 26 (41.203 MVAR) for a LRP of 26.695%, solved by EP. The total SVC sizing was 135.403 MVAR. IEP also solved the same location and sizing while AIS solved different location and sizing as shown in the same table.

TABLE X. LOCATION AND SIZING OF 2 SVCs INSTALLATION

Bus	Q_d (MVar) Max	OT	2 SVCs Installation					
			Location 1	Sizing 1 (MVar)	Location 2	Sizing 2 (MVar)	Total Sizing (MVar)	LRP (%)
26	30	EP	28	27.535	26	27.893	55.428	32.352
		AIS	28	27.534	26	27.891	55.425	32.352
		IEP	28	27.535	26	27.893	55.428	32.352
29	30	EP	3	44.272	29	46.766	91.038	20.304
		AIS	5	55.284	29	35.691	90.975	21.704
		IEP	3	44.277	29	46.771	91.048	20.303
30	30	EP	30	24.405	25	13.645	38.050	24.649
		AIS	30	24.403	25	13.643	38.046	24.649
		IEP	30	24.405	25	13.645	38.050	24.649
6	150	EP	28	38.985	9	69.217	108.202	7.6270
		AIS	4	94.773	3	50.068	144.841	6.9370
		IEP	28	38.985	9	69.217	108.202	7.6270
4	150	EP	4	94.776	3	50.071	144.847	20.071
		AIS	4	94.774	3	50.068	144.842	20.071
		IEP	4	94.776	3	50.071	144.847	20.071
3	150	EP	3	99.873	23	12.221	112.095	24.510
		AIS	5	10.998	3	97.245	108.243	23.853
		IEP	28	27.535	26	27.893	55.428	32.352

TABLE XI. LOCATION AND SIZING OF 3 SVCs INSTALLATION

Bus	Q_d (MVar) Max	OT	3 SVCs Installation							
			Location 1	Sizing 1	Location 2	Sizing 2	Location 3	Sizing 3	Total Sizing	LRP
26	30	EP	10	35.094	16	59.106	26	41.203	135.403	26.695
		AIS	4	51.876	2	56.146	26	51.689	159.710	28.162
		IEP	10	35.099	16	59.109	26	41.206	135.414	26.693
29	30	EP	3	92.551	29	46.659	9	46.018	185.228	17.327
		AIS	3	44.277	29	46.771	11	44.591	135.639	20.303
		IEP	3	92.558	29	46.664	9	46.023	185.244	17.326
30	30	EP	22	5.1940	27	7.1640	30	26.992	39.349	25.237
		AIS	30	24.403	25	13.642	13	60.099	98.143	24.692
		IEP	22	5.1940	27	7.1640	30	26.992	39.349	25.237
6	150	EP	4	84.149	12	42.380	10	71.345	197.874	10.629
		AIS	6	82.832	6	98.791	8	23.357	204.980	14.727
		IEP	4	84.155	12	42.386	10	71.351	197.892	10.629
4	150	EP	4	94.776	3	50.071	12	27.708	172.555	20.629
		AIS	4	94.774	3	50.068	12	27.706	172.548	20.629
		IEP	4	94.776	3	50.071	12	27.708	172.555	20.629
3	150	EP	4	80.912	28	4.5520	3	82.972	168.437	25.705
		AIS	6	53.351	3	99.870	23	12.220	165.441	25.221
		IEP	4	80.912	28	4.5520	3	82.972	168.437	25.705

On the other hand, it was observed the sizing of single SVC and 2 SVCs are much lower for the same scenario compared to total SVC sizing when 3 SVCs installation was opted. In this case, single SVC and 2 SVCs installations have higher LRP compared to 3 SVCs. This implies, multi-SVC is not necessarily an option to obtain the highest LRP in the system. Based on the results, installation of 3 SVCs is not recommended as the LRP achieved is lower compared to single SVC and 2 SVCs. Other factors such as installation cost, maintenance cost and accessibility need to be considered before opting for multi-SVC installation. Details of 3 SVCs location and sizing when other buses are subjected to $Q_{d,max}$ can be referred to Table XI.

VI. CONCLUSION

Based on the key findings of this study, it can be concluded that the three optimization techniques, namely EP, AIS and IEP are effective solutions for addressing the complex task of optimal location and sizing of multi-SVC installation in the IEEE 30-Bus RTS power system. The work successfully explored the optimal positions, sizes, and number of SVCs while considering network operational constraints and SVC limitations, ultimately aiming to reduce total active power loss.

Findings of this study have broader implications for the field of power system optimization and control. It contributes to advancing the understanding of SVC installation for enhancing power system performance using multi-computational intelligence techniques. It also showcases the effectiveness of EP, AIS and IEP in tackling large-scale technical challenges and highlights their potential for addressing similar optimization problems in other power system scenarios.

In summary, this work demonstrates the efficacy of EP, AIS, and IEP in solving the optimal location and sizing problem of multi-SVC allocation. These results provide valuable insights for power system optimization and have broader implications for improving power grid performance, reliability, and efficiency.

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REFERENCES

- [1] W. Wu and Y. Lin, "The impact of rapid urbanization on residential energy consumption in China," *PLoS One*, vol. 17, no. 7 July, Jul. 2022, doi: 10.1371/journal.pone.0270226.
- [2] N. G. Hingorani, "Flexible ac transmission," *IEEE Spectr*, vol. 30, no. 4, pp. 40–45, 1993, doi: 10.1109/6.206621.
- [3] L. Jiankun, C. Jing, and Q. Zhen, "Comparative analysis of FACTS devices based on the comprehensive evaluation index system", *MATEC Web of Conferences*. 95. 15002. 10.1051/mateconf/20179515002.
- [4] M. A. Kamarposhti, H. Shokouhandeh, I. Colak, S. S. Band, and K. Eguchi, "Optimal Location of FACTS Devices in Order to Simultaneously Improving Transmission Losses and Stability Margin Using Artificial Bee Colony Algorithm," *IEEE Access*, vol. 9, pp. 125920–125929, 2021, doi: 10.1109/ACCESS.2021.3108687.
- [5] R. Sirjani, A. Mohamed, and H. Shareef, "Optimal Placement and Sizing of Shunt FACTS Devices in Power Systems Using Heuristic Optimization Techniques: a Comprehensive Survey", *Przeglad Elektrotechniczny*, Vol 88 Issue (10 B), 335–341, 2012.
- [6] A. al Ahmad and R. Sirjani, "Optimal placement and sizing of multi-type FACTS devices in power systems using metaheuristic optimisation techniques: An updated review," *Ain Shams Engineering Journal*, vol. 11, no. 3. Ain Shams University, pp. 611–628, Sep. 01, 2020. doi: 10.1016/j.asej.2019.10.013.
- [7] A. M. Shaheen, S. R. Spea, S. M. Farrag, and M. A. Abido, "A review of meta-heuristic algorithms for reactive power planning problem," *Ain Shams Engineering Journal*, vol. 9, no. 2. Ain Shams University, pp. 215–231, Jun. 01, 2018. doi: 10.1016/j.asej.2015.12.003.
- [8] N. Rul, H. Abdullah, and M. M. Othman, "Transmission Loss Minimisation and SVC Installation Cost using Evolutionary Programming," 2009. [Online]. Available: <https://www.researchgate.net/publication/261713740>.
- [9] S. Jelani *et al.*, "Multi-Heuristic Based Technique in Multi-SVCs Installation Scheme for Loss Control in Transmission System," 2021.
- [10] L. Kumar, M. K. Kar, and S. Kumar, "Reactive Power Management of Transmission Network Using Evolutionary Techniques," *Journal of Electrical Engineering & Technology*, vol. 18, no. 1, pp. 123–145, 2023, doi: 10.1007/s42835-022-01185-1.
- [11] W. Liu, X. Yang, T. Zhang, and A. Abu-Siada, "Multi-objective Optimal Allocation of TCSC for Power Systems with Wind Power Considering Load Randomness," *Journal of Electrical Engineering & Technology*, vol. 18, no. 2, pp. 765–777, 2023, doi: 10.1007/s42835-022-01233-w.
- [12] J. G. Jamnani and M. Pandya, "Coordination of SVC and TCSC for management of power flow by particle swarm optimization," in *Energy Procedia*, Elsevier Ltd, 2019, pp. 321–326. doi: 10.1016/j.egypro.2018.11.149.
- [13] B. Bhattacharyya and S. Kumar, "Loadability enhancement with FACTS devices using gravitational search algorithm," *International Journal of Electrical Power & Energy Systems*, vol. 78, pp. 470–479, 2016, doi: <https://doi.org/10.1016/j.ijepes.2015.11.114>.
- [14] S. Raj and B. Bhattacharyya, "Optimal placement of TCSC and SVC for reactive power planning using Whale optimization algorithm," *Swarm Evol Comput*, vol. 40, pp. 131–143, Jun. 2018, doi: 10.1016/j.swevo.2017.12.008.
- [15] De Jong, Kenneth & Fogel, David & Schwefel, Hans-Paul. (1997). *A history of evolutionary computation*.
- [16] K. T. Lan and C. H. Lan, "Notes on the distinction of gaussian and cauchy mutations," in *Proceedings - 8th International Conference on Intelligent Systems Design and Applications, ISDA 2008*, 2008, pp. 272–277. doi: 10.1109/ISDA.2008.237.
- [17] T. Jun and Z. Xiaojuan, "Particle swarm optimization with adaptive mutation," in *2009 WASE International Conference on Information Engineering, ICIE 2009*, 2009, pp. 234–237. doi: 10.1109/ICIE.2009.59.
- [18] Y. Peng, Y. Xiang, and Y. Zhong, "Quantum-behaved particle swarm optimization algorithm with Lévy mutated global best position," in *Proceedings of the 2013 International Conference on Intelligent Control and Information Processing, ICICIP 2013*, 2013, pp. 529–534. doi: 10.1109/ICICIP.2013.6568132.

- [19] J. D. Farmer, N. H. Packard, and A. S. Perelson, "The immune system, adaptation, and machine learning," *Physica D*, vol. 22, no. 1, pp. 187–204, 1986, doi: [https://doi.org/10.1016/0167-2789\(86\)90240-X](https://doi.org/10.1016/0167-2789(86)90240-X).
- [20] T. K. A. Rahman, S. I. Suliman, and I. Musirin, "Artificial Immune-Based Optimization Technique for Solving Economic Dispatch in Power System," in *Neural Nets*, B. Apolloni, M. Marinaro, G. Nicosia, and R. Tagliaferri, Eds., Berlin, Heidelberg: Springer Berlin Heidelberg, 2006, pp. 338–345.
- [21] T. K. A. Rahman *et al.*, "Clonal Selection-Based Artificial Immune System Optimization Technique for Solving Economic Dispatch in Power System," 2005.
- [22] P. K. Hota and A. P. Naik, "Analytical Review of Power Flow Tracing in Deregulated Power System," *American Journal of Electrical and Electronic Engineering*, vol. 4, no. 3, pp. 92–101, 2016, doi: [10.12691/ajece-4-3-4](https://doi.org/10.12691/ajece-4-3-4).

Economic Development Efficiency Based on Tobit Model: Guided by Sustainable Development

Ming Liu

Department of Business and Accounting, Henan Open University, Zhengzhou, 450000, China

Abstract—At present, in resource-based regions in China, it has been seriously restricted in the harmonious growth of green economy (GE) and environment. To find and solve the problems that affect the quality of regional GE development, the study took Xinjiang, a resource-based province, as the research object. With the data of 14 prefectures and cities in Xinjiang from 2017 to 2022, an evaluation model for the efficiency of GE development based on DEA-Tobit was constructed. Data envelopment analysis (DEA) measures the spatial autocorrelation and distribution characteristics of GE development efficiency in various prefectures and cities in Xinjiang. The influencing factors were analyzed by using Tobit model. From the empirical results, there are obvious differences in the spatial distribution of GE development among various prefectures and cities in Xinjiang. The average value is 0.7289, the highest value is 1, and the lowest value is 0.3684, with a difference of 0.6316. The efficiency values of GE in the seven regions R1, R2, R4, R6, R7, R9, and R13 have reached 1, and DEA is effective. Based on the global and local Moran index, it can be seen that there is no obvious spatial correlation between the development efficiency of green economy in the cities and cities of Xinjiang, and the absolute value of its coefficient is not more than 0.5. From the results of the Tobit model, there are still areas for raising the efficiency of GE development in most regions of Xinjiang. Based on the established DEA-Tobit GE development efficiency evaluation model, this study proposes targeted development strategies for improving the efficiency of GE development in Xinjiang.

Keywords—Tobit model; DEA; economic development efficiency; Moran index

I. INTRODUCTION

The coordination and win-win situation of "economic growth" and "resources and environment" is the essence of green development. Improving the quality of economic development and enhancing the GE efficiency is the way to achieve that. [1]. Currently, green development is promising direction of development. The proposal of this concept can not only solve the relationship between humans and nature, but also apply the concept to people's daily lives. This has played a positive role in establishing a resource saving and environmental friendly society. This has achieved the harmonious development of the economy, society, and ecological environment [2]. Along with the sustained and rapid growth of economy, the ecological environment has also deteriorated. This has restricted the harmonious development of the economy and environment in countries, especially in resource-based regions. However, in the current researches, there are few systematic researches on the efficiency of GE development in specific provinces. In the northwest frontier of China is Xinjiang, a province with harsh natural environmental

conditions and a low economic development. Ecological and environmental problems occur consequently. This has restricted the high-quality development of Xinjiang's economy [3,4]. Therefore, achieving green transformation and development in Xinjiang is an inevitable requirement for achieving sustainable development. Since there are few research results on green economy development efficiency in Xinjiang, taking it as the main body of research and carrying out detailed research from prefecture-prefecture level can enrich the field of green economy development efficiency in this region. Based on the double carbon background, this study applies the green related theory to the reality of green economy development in Xinjiang, which can expand the research ideas in this field. In addition, the research mainly constructs two empirical models. They are the DEA model of non-expected output and the Tobit spatial measurement model respectively; and the representative indicators of Xinjiang region are selected. This experiment not only measured the development efficiency of green economy in this region, but also innovatively conducted a further comparative analysis of its spatial distribution characteristics. The research combines measurement methods, spatial distribution rules and influencing factors to make the research results more convincing. Since the improvement of the development efficiency of green economy is a long-term development process, its input and output have a certain lag, which will also have a certain impact on the measurement results. This is what future research needs to improve as much as possible.

This study takes the green development of various states in Xinjiang as the research object, including five parts. At the beginning of the article, the first part mainly introduces the research background, significance, current situation and methods of the development efficiency of green economy. The second part describes the theoretical basis of green economy development and literature review. Respectively from the foreign and domestic two levels to comb and summarize. The third part is the method design of economic development efficiency measurement. It is mainly divided into two sections. The first section is to preliminarily screen the evaluation indicators of green economic development efficiency and establish a DEA model to calculate the corresponding green development efficiency value. The second section further extracts the effective indicators and constructs the evaluation model of green economy development efficiency based on Tobit. The fourth part is the empirical analysis of green economy development efficiency in Xinjiang from 2017 to 2019. The corresponding data were collected, and the spatial panel Tobit regression model was established to analyze the influence degree of the seven indicators on the green

development efficiency in Xinjiang. The last part is based on the empirical analysis results, and puts forward specific suggestions for the green development of Xinjiang.

II. RELATED WORKS

With the economic development and living standard improvement, natural environmental pollution is also increasing. Therefore, the GE has gradually become the hot issue of many researchers at home and abroad, and has been studied in various aspects. Scholars such as Ohene Arsare have evaluated the energy efficiency of African countries and its determinants through bootstrap truncated regression. The study showed that economic development and technological progress had a positive influence on energy efficiency in African countries [5]. Researchers such as Mikhno analyzed environmental impact factors on other quality of life indicators and the main trends and issues that had emerged since the introduction of the "GE". Research has proven that with the extensive development of the economy, the per capita GDP has significantly decreased [6]. Wang et al. constructed a coupling coordination degree evaluation method with entropy weight. Quantitative analysis was conducted on the sustainable development trend and subsystem coupling of regional GE. Research has shown that the model is feasible for the development of regional GE [7]. A heterogeneous stochastic frontier model was used to measure China's GE efficiency by researchers such as Qin. The GE efficiency in China was unsatisfactory, and regional heterogeneity was significant [8]. GE efficiency and regional differences of 11 cities in Zhejiang were measured with the non-radial DEA model of the Malmquist index by Lu et al. From the research, the main factors affecting the urban GE efficiency in Zhejiang were industrial structure, environment, and urbanization degree [9].

Scholars such as Zhao measured the air pollution control by adopting the proportion of air pollutant emissions to GDP. This study has effectively verified the relevance among air pollution, technology, investment, and GE development [10]. Zheng and other researchers based on the super-efficient DEA framework. It incorporated non expected output into the measurement index of regional economic development with a non-radial distance function. This study showed that the influence of financial aggregation on local GE had a non-linear threshold feature [11]. Lebedeva et al. compared existing GE assessment methods. The study found that current methods were mainly used to measure the "greening" of the economy [12]. To raise the efficiency of urban GE planning, researchers such as Liu have constructed a model based on an improved genetic algorithm. From the research results, the model has a high calculation accuracy and can be adopted in the design of urban greening planning [13]. Rutskiy and other experts have constructed a regression model based on empirical correlation. This model defined the impact of GE factors on manufacturing productivity. The research results showed that pollution control equipment and factory investment had a significant positive impact on the GE manufacturing industry [14].

To sum up, predecessors usually compare efficiency measurements based on a single structured data indicator system, while there are few researches on the major reasons influencing the efficiency of GE development. In addition, the

systematic and comprehensive efficiency analysis for specific provinces is also absent. Therefore, this study is aimed at specific provinces and regions, using Tobit model and DEA to measure the reasons influencing the efficiency of GE development in the province, thereby providing practical suggestions for these factors.

III. ECONOMIC DEVELOPMENT EFFICIENCY BASED ON TOBIT MODEL

A. Preliminary Selection of Evaluation Indicators for the Efficiency of GE Development

The term "GE" was proposed by the famous British economist Pearce. It believes that the GE is an economic development model that both human and nature can bear [15]. Moreover, this model will not cause ecological and social imbalances due to economic growth, nor will it restrict the constant growth of economy due to the depletion of natural resources. With the introduction of GE, many methods have been developed to measure the efficiency. However, there is currently no complete indicator system for the efficiency of GE development. Based on massive relevant achievements on green development, combined with the actual situation and data of various states and cities, the study screened the issues that affecting the efficiency of GE. For the establishment of an indicator system, it is first necessary to follow the principles shown in Fig. 1.

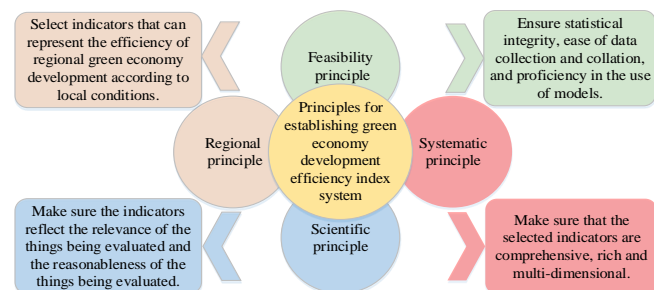


Fig. 1. Principles of establishing GE development efficiency index system.

In Fig. 1, the selection of this indicator requires four principles in order. The first is the principle of feasibility. The foundation of model implementation is data. When selecting indicators, it is necessary to consider whether the statistical data is complete, the difficulty of data collection, the proficiency in using models, and the feasibility of the results. The second is the systematic principle. The evaluation of the efficiency of the GE development involves multiple aspects such as resources, environment, and economy. Therefore, when selecting indicators, it is necessary to ensure that they are comprehensive, rich, and multidimensional. To make the calculation results more objective and reasonable, different indicators should be selected from multiple aspects to avoid interference with the evaluation results. Then there is the regional principle. When constructing an indicator system, it is needed to select GE development efficiency indicators that can represent different regions based on the economic level, cultural and geographical environment, and other conditions of different regions. Finally, there is the principle of scientificity. In constructing an indicator system, science should be taken as the basis. The selected indicators should be able to reflect the

relationship between the evaluated things, while ensuring the rationality of the evaluation results of the model. With the principle of indicator selection, the research preliminarily

divides the efficiency of GE development into three categories of indicators, as shown in Fig. 2.

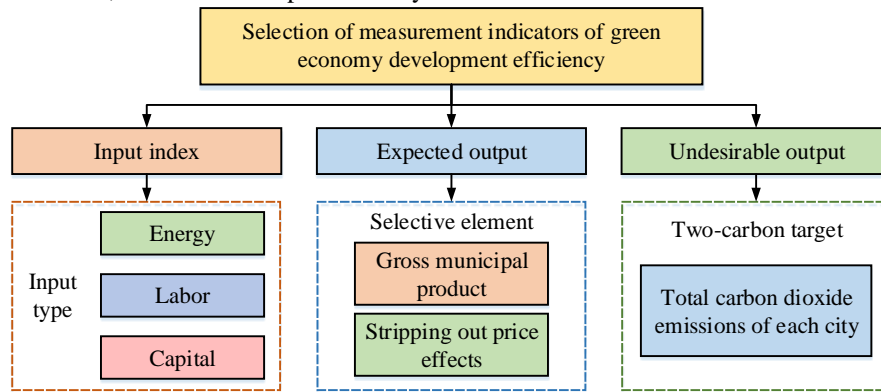


Fig. 2. Selection of measurement indicators of GE development efficiency.

In Fig. 2, the selection of investment indicators generally focuses on capital, labor, and energy inputs. Based on the availability and scientificity of data, capital investment is usually the amount of fixed assets investment of the whole society in each city. Energy input refers to the consumption of energy by enterprises or industries above designated size. Labor input is the total population of each city. In the current government work report, it is mentioned that efforts should be made to achieve the dual carbon goal and optimize the industrial and energy structure [16]. Therefore, the research takes the CO₂ emissions of each city as an unexpected output.

DEA is a relatively effective method for measuring efficiency values [17]. Measurement models consist of two broad categories, namely radial and non-radial, and angular and non-angular. Due to the fact that traditional DEA models do not take into account the slack issues caused by inputs and outputs, there may be a certain degree of calculation bias due to the existence of unexpected outputs when measuring efficiency values. Non-radial and non-angular DEA-SBM models were put forward to solve this issue [18]. The model considers the problem of relaxation variables and improves the accuracy of efficiency. The study compared various models and data collection, and ultimately selected the DEA model with unexpected outputs. The calculation expression of the DEA model for undesired outputs is shown in Equation (1).

$$\rho^* = \min \frac{1 - \frac{1}{w} \sum_{i=1}^w \frac{s_i^-}{x_{i0}}}{1 + \frac{1}{s_1 + s_2} \left(\sum_{r=1}^{s_1} \frac{s_r^g}{y_{r0}^g} + \sum_{r=1}^{s_2} \frac{s_r^b}{y_{r0}^b} \right)} \quad (1)$$

In Equation (1), ρ^* represents the efficiency value of GE development s_1, w, s_2 represents the total of elements of expected output, input, and undesired output, respectively. s^-, s^g, s^b are the relaxation variables of expected output, non-expected output, and input, respectively. x, y^g, y^b is input value, expected output value, and non-expected output value, and their respective calculation expressions are shown in Equation (2).

$$s.t. = \begin{cases} x_0 = X\lambda + s^- \\ y_0^g = Y^g\lambda - s^g \\ y_0^b = Y^b\lambda + s^b \\ s^- \geq 0, s^g \geq 0, s^b \geq 0, \lambda \geq 0 \end{cases} \quad (2)$$

In Equation (2), λ represents the weight vector. X, Y^g, Y^b represents a matrix composed of unexpected outputs, inputs, and expected outputs, respectively. The spatial autocorrelation test can reflect the overall distribution among regions. The spatial distribution characteristics of natural and ecological factors and their interrelationships can be measured by the spatial autocorrelation coefficient [19]. Moran's I coefficient and Geary's c coefficient are main indices for spatial autocorrelation analysis [20]. The global and the local Moran index are used to organise a spatial analysis of the GE development efficiency of each city, and judges whether the northern objects have a certain degree of agglomeration in space. The spatial correlation between a region and all regions can be reflected by the global Moran index. And it also can be applied to test the spatial dependence, spatial patchiness, and the degree of dispersion of gradients among all elements of the space as a whole. The calculation expression is expressed in Equation (3).

$$I = \frac{n \sum_{a=1}^n \sum_{b=1}^n \varpi_{ab} (x_a - \bar{x})(x_b - \bar{x})}{n \sum_{a=1}^n \sum_{b=1}^n \varpi_{ab} (x_a - \bar{x})(x_b - \bar{x})} = \frac{n \sum_{a=1}^n \sum_{b=1}^n \varpi_{ab} (x_a - \bar{x})(x_b - \bar{x})}{s^2 n \sum_{a=1}^n \sum_{b=1}^n \varpi_{ab}} \quad (3)$$

In Equation (3), x_a, x_b represents the observed values of a, b respectively. \bar{x} represents the average value observed in all regions. The spatial weight is ϖ , and n represents the number of samples. When Moran index $I > 0$, it indicates that the development efficiency of GE has a positive spatial correlation, and the greater the I value, the stronger the correlation. When the Moran index is $I = 0$, it indicates that the efficiency value is randomly distributed in space. The significance test of its spatial autocorrelation is performed

using the standardized statistic $Z(I)$, and its calculation expression is shown in Equation (4).

$$Z(I) = \frac{I - E(I)}{\sqrt{VAR(I)}} \quad (4)$$

In Equation (4), $E(I), VAR(I)$ represents the variance and expected value of the global Moran index, respectively. The local spatial autocorrelation analysis is performed using the local Moran index to reflect the relevance between a certain area and its surroundings. The calculation expression is shown in Equation (5).

$$I_i = \frac{x_a - \bar{x}}{s^2} \sum_{b=1}^n \omega_{ab} (x_b - \bar{x}) \quad (5)$$

The parameter meaning in Equation (5) is the same as the global Moran index, and the significance level is also tested using $Z(I)$.

B. Construction of Evaluation Model for GE Development Efficiency Based on Tobit

After preliminary screening of evaluation indicators for the efficiency of GE development, it is also necessary to focus on the actual GE development in the study area, guided by sustainable development, and conduct in-depth research on its various influencing factors. Based on the preliminary indicator selection of GE development, the study expanded it, and combined with the actual green development situation in Xinjiang, the specific indicators selected are shown in Fig. 3.

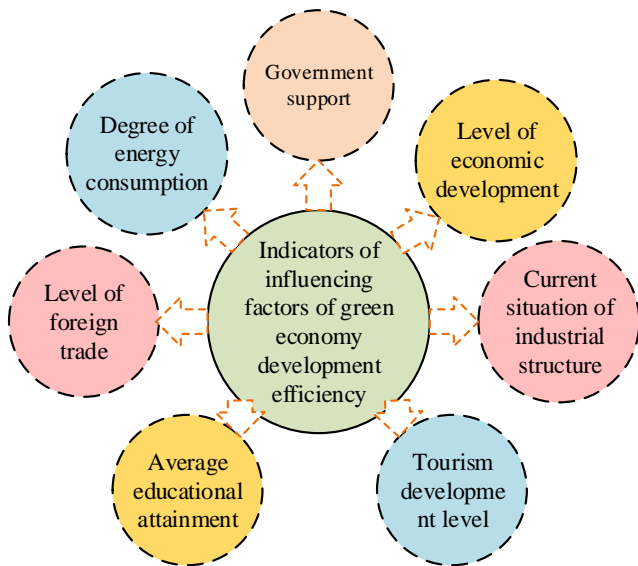


Fig. 3. Selection of influencing factors of GE development efficiency.

In Fig. 3, the study selected seven representative indicators as specific evaluation indicators for the standard of green development in Xinjiang. These include government support, economic development level, current industrial structure, tourism development level, average education level, foreign trade level, and energy consumption level that play an important role in Xinjiang's development. Tobit model is a generalization of Probit regression model proposed by economist James Tobin. It refers to an econometric model with hidden variables, although continuously distributed at positive values, still contain a portion of observations with a positive value of 0 [21]. The model uses the maximum likelihood method for estimation. In parameter estimation, this can better avoid bias or inconsistency issues. The model expression is shown in Equation (6).

$$r_i = \begin{cases} v_i \beta + \varepsilon, & r_i > 0 \\ 0, & r_i \leq 0 \end{cases} \quad (6)$$

In Equation (6), v_i represents the explanatory variable. r_i is the interpreted variable. β represents a regression parameter. ε represents a random perturbation term. Before figuring out the issues influencing the efficiency of GE development in various cities in Xinjiang, it was clear that the explained variable value was in the range of 0-1, so the Tobit model was used as the analysis method in the study. The efficiency of GE development is used as the explanatory variable, and the statistical yearbooks or bulletins of different cities in Xinjiang are used as the data source for studying the explanatory variable. According to the Tobit model, the resulting regression equation is constructed as shown in Equation (7).

$$Y_{gh} = \beta_1 X_{1gh} + \beta_2 X_{2gh} + \beta_3 X_{3gh} + \beta_4 X_{4gh} + \beta_5 X_{5gh} + \beta_6 X_{6gh} + \beta_7 X_{7gh} + \varepsilon \quad (7)$$

In Equation (7), $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7$ represents the parameter to be evaluated. g represents the city of Xinjiang, and h represents the year. The explanatory variables and the interpreted variables are expressed in Table I.

TABLE I. EXPLAINED VARIABLE VERSUS INTERPRETED VARIABLE

Statistical variable	Index name	Variable	Meaning
Explained variable	Efficiency of GE development	Y	Efficiency of GE development
Interpreted variable	Government support	X_1	Share of General Public Budget expenditure in GDP (%)
	Level of economic development	X_2	Per capita gross regional product (yuan)
	Current situation of industrial structure	X_3	Proportion of output value of secondary industry in GDP (%)
	Tourism development level	X_4	Share of tourism revenue in GDP (%)
	Average educational attainment	X_5	Proportion of the total number of students in school to the total population of the District (%)
	Level of foreign trade	X_6	Total imports and exports as a percentage of GDP
	Degree of energy consumption	X_7	Energy consumption per unit of GDP (10,000 tons of standard coal / 10,000 yuan)

There are contradictions and incompatibilities among various factors in the indicator system, so the study conducts dimensionless quantitative processing on the values of the original indicators. Since most of the indicators are benefit based, the linear standardization method is used for processing. Equation is the standardized calculation of positive indicators (8).

$$X_{ij} = \frac{x_{ij} - m_j}{M_j - m_j} \quad (8)$$

In Equation (8), j represents the selected indicators. i represents each city. X_{ij} is the value of the j indicator i region after standardization. x_{ij} represents the original value. M_j, m_j represents the maximum and minimum values of the j index during the sample period. The standardized calculation of inverse indicators is expressed in Equation (9).

$$X'_{ij} = \frac{M_j - x_{ij}}{M_j - m_j} \quad (9)$$

Then, each indicator is weighted. Entropy method can avoid the interference of subjective factors and the importance of indicators is taken as the basis for weighting. Therefore, the research mainly uses entropy method to work out the proportion of specific indicators in the indicator system. It assumes that there is an indicator data matrix composed of m evaluation objects and n evaluation indicators. The higher the degree of dispersion of data, the lower the value of information entropy, and the greater the corresponding weight. Due to the standardization of some indicator values, the data may be small or even negative. Therefore, to ensure convenient and uniform calculation, its standardized values will be translated. The calculation expression is shown in Equation (10).

$$x'_{ij} = H + x_{ij} \quad (10)$$

In Equation (10), H represents the magnitude of the indicator shift, typically taking a value of 1. The weight of an indicator can be determined with entropy method. It represents a measure of uncertainty, and a smaller value indicates a higher

degree of variation. The more information offered by that, the more the weight it occupies. The calculation expression of the ratio of the market value of the i land under the j th indicator in this indicator is shown in Equation (11).

$$p_{ij} = x'_{ij} / \sum_{i=1}^n x'_{ij} \quad (11)$$

In Equation (11), p_{ij} represents the proportion of x'_{ij} . However, after the indicator is standardized, a value of 0 may appear during processing. Therefore, the study shifted the entire processed data to the right by 0.0001 units to make the 0 value after standardization meaningful. Then determine the information entropy value of the j index, as shown in Equation (12).

$$a_j = -k \sum_{i=1}^n y_{ij} \ln p_{ij} \quad (12)$$

In Equation (12), a_j represents the information entropy value of each indicator. n represents the sample number of each indicator. k represents a constant, which is related to the number of samples n , as shown in Equation (13).

$$k = 1 / \ln n \quad (13)$$

Information entropy a_j can be used to measure the information utility value of the j th indicator. When the information is completely out of order, $a_j = 1$. At this time, the utility value d_j of the indicator of a_j for comprehensive evaluation is 0. The relationship between the information usage value a_j of the indicator and the information entropy d_j of the indicator is expressed in Equation (14).

$$d_j = 1 - a_j \quad (14)$$

In Equation (14), $j = 1, 2, \dots, p$. When using the entropy to calculate the weight of each evaluation index, the higher the coefficient in the evaluation, the greater the importance of the evaluation. On the contrary, the importance of evaluation will

be smaller. The weight expression of the j index is obtained in Equation (15).

$$w_j = d_j / \sum_{j=1}^n d_j \quad (15)$$

According to the weights of various indicators, it needs to build corresponding for the standardized values of various indicators of data, and then the linear weighting method is used to calculate the sum of efficiency values.

IV. AN EMPIRICAL ANALYSIS OF THE EFFICIENCY OF GE DEVELOPMENT

After preprocessing the collected data, based on the non-expected output DEA model proposed in the study, the GE development efficiency of four prefecture-level cities, five regions, and five autonomous prefectures in Xinjiang were measured by MATLAB R2017b software. In the experiment, these 14 prefectures and cities in Xinjiang were named R1-R14. Their calculation results are shown in Fig. 4.

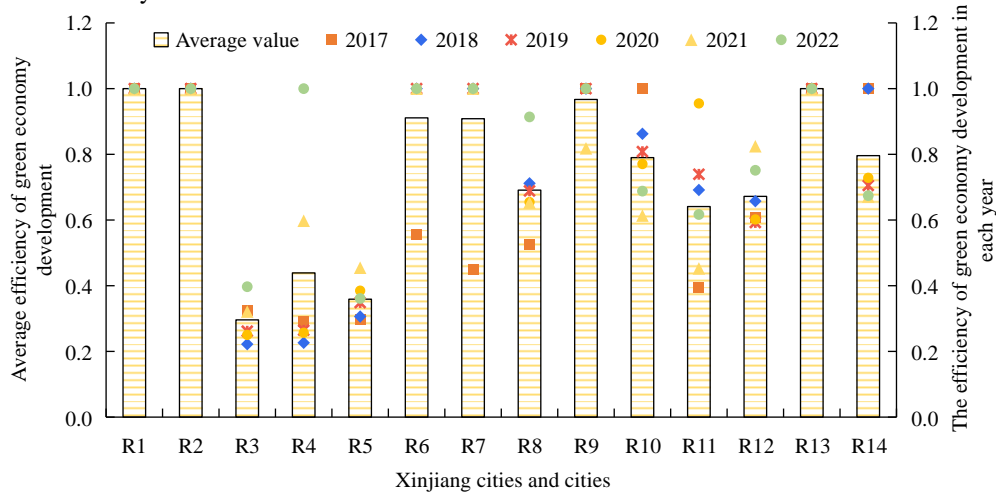


Fig. 4. GE development efficiency of 14 prefectures and cities in Xinjiang from 2017-2022.

From Fig. 4 it is clear that the spatial distribution of GE development in various prefectures and cities in Xinjiang varied greatly. The average value was 0.7289; the highest and the lowest value was 1 and 0.3684, respectively, with a difference of 0.6316. From the measurement results, the GE efficiency values of the seven regions R1, R2, R4, R6, R7, R9, and R13 had reached 1, and their DEAs were effective. In

2017-2019, only four regions, R1, R2, R9, and R13, achieved an average value of GE development above 0.9. The average value of GE development efficiency in northern, southern, eastern, and entire Xinjiang based on the measured GE development efficiency of each prefecture and city in Xinjiang are calculated and expressed in Fig. 5.

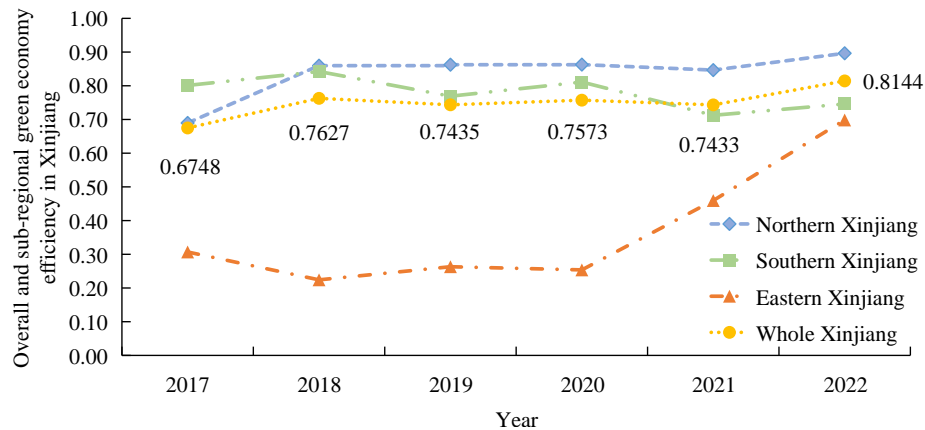


Fig. 5. Change trend of GE efficiency in Xinjiang as a whole and sub-region during 2017-2022.

From Fig. 5 it is clear that the overall efficiency of GE development in Northern Xinjiang was on the rise, with an average value of about 0.7796. The fluctuation trend of the efficiency of GE development in Southern Xinjiang was obvious, with an average value of about 0.7783, which was at a relatively stable medium to high stage. The efficiency of GE development in Eastern Xinjiang continued to rise after 2020,

with an average value of 0.4272. From 2019 to 2022, the efficiency of GE development in the entire Xinjiang region had a relatively stable trend of change, with a slow upward trend. This indicates that optimization has been done in industrial organization and the transformation of its development mode has been effective. In the experiment, Eviews software was used to obtain the GE development efficiency values of 14

prefectures and cities in Xinjiang in 2022, and a broken line chart reflecting their fluctuation trend was obtained, as shown

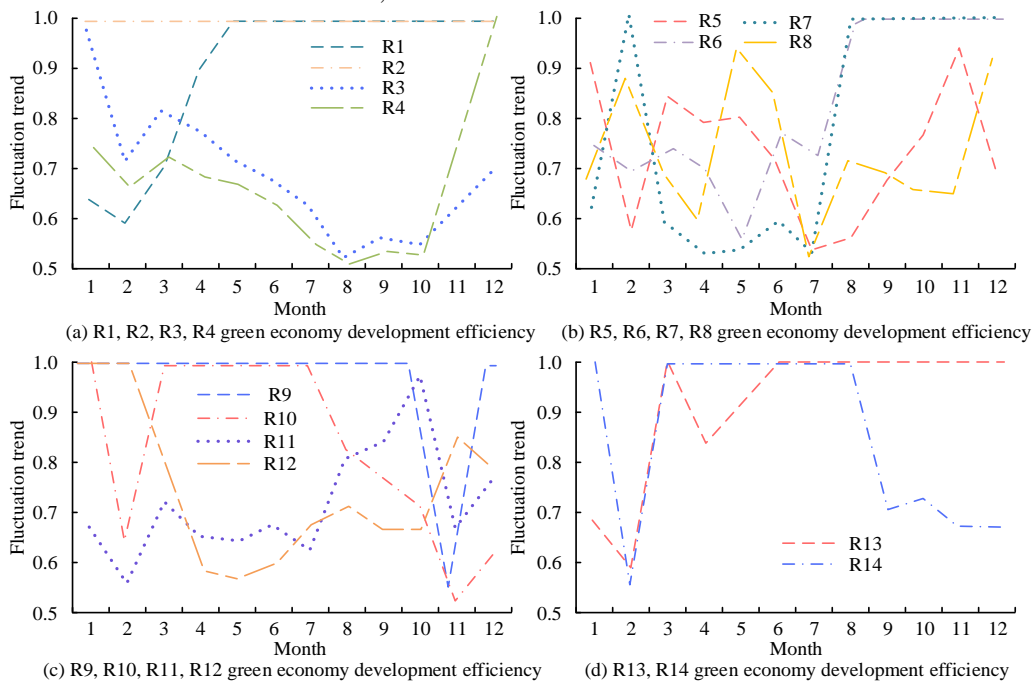


Fig. 6. Trend types of GE development efficiency in Xinjiang cities and cities in 2022.

From Fig. 6(a), GE development efficiency of R1 was of a fluctuating and rising type. That of R2 was stable. That of R3 and R4 was continuously fluctuating. From Fig. 6(b), GE development efficiency of R5, R6, R7, and R8 were the type of first decreasing and then increasing, fluctuating and rising, continuously fluctuating, and first decreasing and then increasing, respectively. From Fig. 6(c), GE development efficiency of R9, R10, R11, and R12 were respectively stable, fluctuating, decreasing first, then rising, and continuously fluctuating. From Fig. 6(c), GE development efficiency of R13 and R14 were respectively fluctuating upward type and fluctuating downward type. Among them, the development of resources, economy, and environment in stable regions was relatively balanced. However, fluctuating and declining regions were due to excessive urging of economic development, leading to resource waste and environmental pollution. This has led to a slide in the overall efficiency of the region's GE. The experiment used Stata15 software and combined with calculations to obtain the global Moran index measurement results of GE development efficiency in various states and cities in Xinjiang, see Table II.

TABLE II. MORAN INDEX AND TTS TEST IN XINJIANG FROM 2017 TO 2022

Year	I	$sd(I)$	z	$p-value^*$
2017	-0.113	0.181	-0.199	0.421
2018	0.320	0.174	2.287	0.011
2019	0.294	0.175	2.115	0.017
2020	0.319	0.175	2.264	0.012
2021	0.089	0.178	0.932	0.176

in Fig. 6.

2022	-0.044	0.173	0.187	0.426
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From Table II, in 2018, 2019, and 2020, the GE development efficiency of various prefectures and cities in Xinjiang showed a relatively strong positive correlation. The correlation I was 0.320, 0.294, and 0.319, respectively. The spatial correlation in other years was significant. Through calculation, the local Moran index of GE development efficiency in various prefectures and cities in Xinjiang can be obtained. As shown in Fig. 7, the local Moran index test results and scatter plot for 2022 are shown.

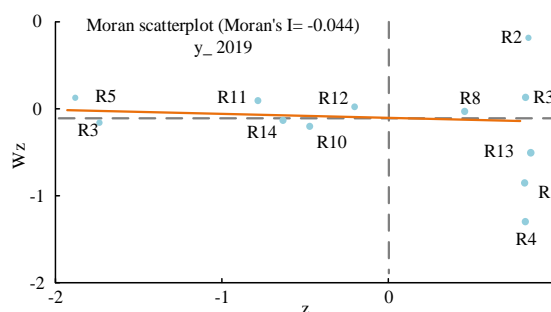


Fig. 7. Scatter plot of local Moran index in 2022.

From Fig. 7, in 2022, most of the autocorrelations of the 14 prefectures and cities in Xinjiang did not pass the assist test, and only a few regions had significant local spatial correlations. Based on the overall and local Moran indexes, there is no significant spatial correlation between the efficiency of GE development in various prefectures and cities in Xinjiang. The experiment conducted statistical processing on seven specific evaluation index data of GE development

efficiency in Xinjiang from 2017 to 2022, and the results are shown in Figure 8.

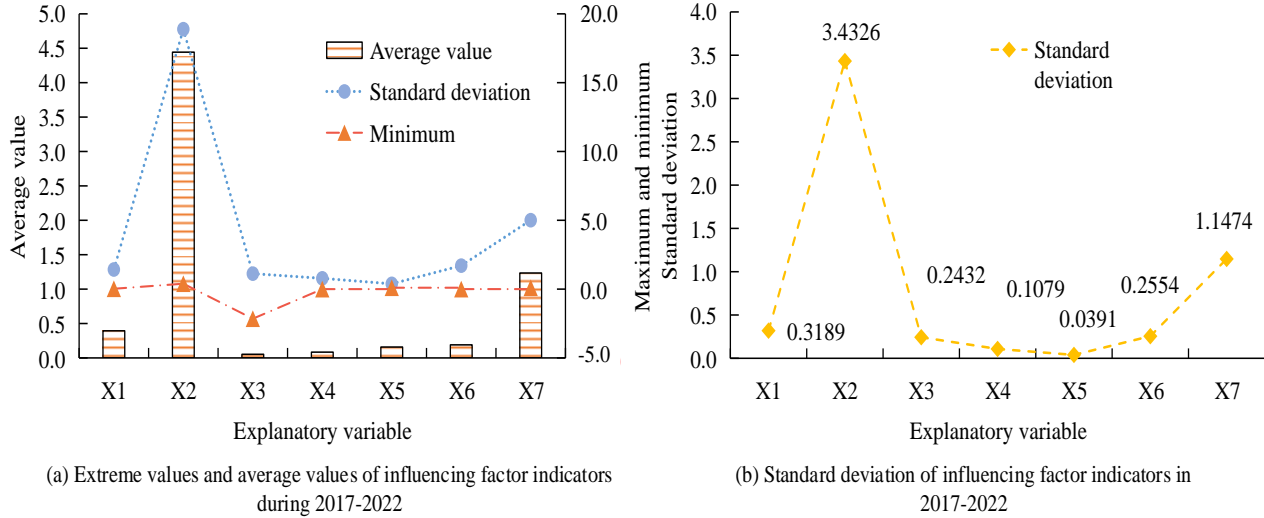


Fig. 8. Statistics of influencing factors of Xinjiang GE development efficiency from 2017-2022.

From Fig. 8 (a), among the seven GE development efficiency evaluation indicators, the average value of X_2 was the largest. This indicates that the contribution rate of GDP per capita is the highest, at 4.44. The average value of X_3 was the smallest, 0.0527, and its minimum value was negative. From Fig. 8(b), X_2 had the largest standard deviation of

3.4326. The standard deviation of DD was the smallest, 0.0391. Before conducting regression analysis on the data of the above indicators, correlation analysis and correlation significance test shall be conducted for each explanatory variable. This can avoid multiple collinearity problems between variables, as shown in Table III.

TABLE III. CORRELATION COEFFICIENTS OF EACH VARIABLE

Variable	X_1	X_2	X_3	X_4	X_5	X_6	X_7
X_1	1.000	0.186*	0.002	0.011*	0.220*	-0.012	-0.459*
X_2	0.186*	1.000	-0.010**	-0.058**	0.162*	0.025**	-0.195*
X_3	0.002	-0.010**	1.000	-0.098**	0.024	0.074*	0.103
X_4	0.011*	-0.058**	-0.098**	1.000	-0.101	0.013*	-0.036**
X_5	0.220*	0.162*	0.024	-0.101	1.000	-0.140*	0.096
X_6	-0.012	0.025**	0.074*	0.013*	-0.140*	1.000	-0.050*
X_7	-0.459*	-0.195*	0.103	-0.036**	0.096	-0.050*	1.000

Note: * and ** mean a significance level of 5% and 10%, respectively.

From Table III, even though the correlation between the two variables was significant, the correlation coefficient between each explanatory variable was small, and the absolute value of the coefficient was below 0.5. This implies that the probability of causing multicollinearity problems among

various explanatory variables is low. The experiment used Eviews 8.0 software to establish a Tobit model based on the relevant data of GE development efficiency indicators in Xinjiang and various regions from 2017 to 2022. Table IV is the regression results.

TABLE IV. REGRESSION RESULTS OF TOBIT MODEL

Explanatory variable	Northern Xinjiang	Southern Xinjiang	Eastern Xinjiang	Whole Xinjiang
ε	0.6993*	0.8480*	0.9368*	0.7741*
X_1	-0.3992	-0.1383**	-1.7892*	-0.1283**
X_2	-0.0108	0.0035	0.5073*	-0.0032
X_3	-0.3552	0.1578*	0.0376	0.0054
X_4	0.0913	1.2268	0.0239	-0.2882**
X_5	2.3485*	0.0184	-0.3553	0.8976**
X_6	0.0192	0.2973	-2.9941*	0.1227**
X_7	-0.0864*	-0.1238*	-0.0463	-0.0987*

Note: * and ** mean a significance level of 5% and 10%, respectively.

In Table IV, based on the analysis of the entire Xinjiang region, there was a significant correlation between the GE development efficiency and X_1 , X_4 , X_5 , X_6 , X_7 . The correlation values were -0.1283 **, -0.2882 **, 0.8976 **, 0.1227 **, -0.0987 *. Among them, there was a negative correlation with X_1 , X_4 , and X_7 . This indicates that government support, tourism development level, and energy consumption level have restrained the efficiency of Xinjiang's GE development. Average education level and foreign trade level promote the efficiency of GE development. From a regional perspective, the value of GE development in northern Xinjiang was significantly positively correlated with X_5 , and significantly negatively correlated with X_7 . The value of GE development in South Xinjiang was significantly positively correlated with X_3 , and negatively correlated with X_1 and X_7 . The value of GE development in Eastern Xinjiang was significantly positively correlated with X_2 , and significantly negatively correlated with X_1 and X_6 . Overall, there is significant room for improving the efficiency of GE development in most regions of Xinjiang.

V. CONCLUSION

This study took Xinjiang, a typical resource rich province, as the research object, and built a GE development efficiency evaluation index model based on DEA-Tobit to achieve sustainable green development of economy, resources and environment. The study used this model to calculate the efficiency of GE development in 14 prefectures and cities in Xinjiang from 2017 to 2020. At the same time, the autocorrelation relationship and spatial distribution characteristics were analyzed in depth. The research showed that there were obvious differences in the spatial distribution of GE development among various prefectures and cities in Xinjiang. The average value was 0.7289; the highest value was 1; the lowest value is 0.3684, with a difference of 0.6316. The GE efficiency value of the seven regions R1, R2, R4, R6, R7, R9, and R13 has reached 1, and their DEA were effective. Based on the overall and local Moran indexes, there was no obvious spatial correlation between the efficiency of GE development in various prefectures and cities in Xinjiang. The absolute values of their coefficients did not exceed 0.5.

According to the regression results obtained from the Tobit model, X_5 and X_6 had a great promoting effect on the efficiency of GE development in Xinjiang. X_1 has not played a positive role in the efficiency of Xinjiang's GE development, indicating that the relevant policies of the government were lagging behind. X_4 had an inhibitory influence on the efficiency of Xinjiang's GE development. This indicates that during its development, it has caused a certain degree of ecological damage. X_7 would inhibit the rise of the efficiency of GE development. Based on the results of the study, it is recommended to first increase the support of the local government in Xinjiang, optimize the industrial structure of Xinjiang as soon as possible, and promote energy development efficiency. In addition, it is necessary to strengthen investment in education in Xinjiang, do a good job in energy saving and emission reduction, and promote the overall efficiency of GE development in Xinjiang according to local conditions.

REFERENCES

- [1] A. V. Agbedahin, "Sustainable development, education for sustainable development, and the 2030 agenda for sustainable development: emergence, efficacy, eminence, and future," *Sustainable Development*, vol. 27, no. 4, pp. 669-680, 2019.
- [2] C. Qiqi, W. Jinghua, and S. Yufeng, "Theoretical basis and level evaluation of Tobacco planting and green agriculture: a Case Study in Henan Province, China," *Tobacco Regulatory Science*, vol. 7, no. 5, pp. 2777-2793, 2021.
- [3] J. S. Finley, "Tabula rasa: Han settler colonialism and frontier genocide in "re-educated" Xinjiang," *HAU: Journal of Ethnographic Theory*, vol. 12, no. 2, pp. 341-356, 2022.
- [4] Z. Zhang, and K. P. Paudel, "Small-Scale forest cooperative management of the grain for green program in Xinjiang, China: A SWOT-ANP Analysis," *Small-Scale Forestry*, vol. 20, no. 2, pp. 221-233, 2021.
- [5] K. Ohene-Asare, E. N. Tetteh, and E. L. Asuah, "Total factor energy efficiency and economic development in Africa," *Energy Efficiency*, vol. 13, no. 6, pp. 1177-1194, 2020.
- [6] I. Mikhno, V. Koval, G. Shvets, and O. Garmatiuk, "Green economy in sustainable development and improvement of resource efficiency," *Central European Business Review*, vol. 1, pp. 99-113, 2022.
- [7] M. Wang, X. Zhao, Q. Gong, and Z. Ji, "Measurement of regional green economy sustainable development ability based on entropy weight-topsis-coupling coordination degree—a case study in Shandong Province, China," *Sustainability*, vol. 11, no. 1, pp. 2-18, 2019.

- [8] X. Qin, J. Wang, Y. Liu, "Efficiency measurement and inefficiency environmental factors of China's green economy," *Prague Economic Papers*, vol. 1, pp. 25-57, 2022.
- [9] Y. Lu, B. Cao, Y. Hua, et al., "Efficiency measurement of green regional development and its influencing factors: an improved data envelopment analysis framework," *Sustainability*, vol. 12, no. 11, pp. 3-23, 2020.
- [10] M. Zhao, F. Liu, Y. Song, G. Jiangbo, "Impact of air pollution regulation and technological investment on sustainable development of green economy in eastern China: empirical analysis with panel data approach," *Sustainability*, vol. 12, no. 8, pp. 2-18, 2020.
- [11] Y. Zheng, S. Chen, N. Wang, "Does financial agglomeration enhance regional green economy development? Evidence from China," *Green Finance*, vol. 2, no. 2, pp. 173-196, 2020.
- [12] M. Lebedeva, "Comparative analysis of methods for assessing the transition to a green economy," *Vestnik Volgogradskogo Gosudarstvennogo Universiteta Ekonomika*, vol. 3, pp. 109-122, 2020.
- [13] T. Liu, B. Xin, F. Wu, "Urban green economic planning based on improved genetic algorithm and machine learning," *Journal of Intelligent and Fuzzy Systems*, vol. 40, no. 4, pp. 7309-7322, 2021.
- [14] V. N. Rutskiy, M. V. Osipenko, "Green economy as a labor productivity factor in the manufacturing industry of European Union Countries," *Finansovyy zhurnal-Financial Journal*, vol. 4, pp. 69-84, 2020.
- [15] K. Sakai, M. A. Hassan, C. S. Vairappan, Y. Shirai, "Promotion of a green economy with the palm oil industry for biodiversity conservation: A touchstone toward a sustainable bioindustry," *Journal of Bioscience and Bioengineering*, vol. 133, no. 5, pp. 414-424, 2022.
- [16] T. Jiang, Y. Yu, A. Jahanger, D. Balsalobre-Lorente, "Structural emissions reduction of China's power and heating industry under the goal of "double carbon": A perspective from input-output analysis," *Sustainable Production and Consumption*, vol. 31, pp. 346-356, 2022.
- [17] J. Lozić, "Application of data envelopment analysis in information and communication technologies," *Tehnički glasnik*, vol. 16, no. 1, pp. 129-134, 2022.
- [18] H. Jung, K. Lee, "Efficiency analysis of security management system of affiliates of conglomerate using DEA-SBM model," *Journal of the Korea Institute of Information Security & Cryptology*, vol. 32, no. 2, pp. 341-353, 2022.
- [19] J. Mur, "A simple test of spatial autocorrelation for centered variables," *Revista Economía*, vol. 44, pp. 41-55, 2021.
- [20] G. Tepanosyan, L. Sahakyan, C. Zhang, A. Saghatelyan, "The application of Local Moran's I to identify spatial clusters and hot spots of Pb, Mo and Ti in urban soils of Yerevan," *Applied Geochemistry*, vol. 104, pp. 116-123, 2019.
- [21] M. D. Amore, S. Murtinu, "Tobit models in strategy research: Critical issues and applications," *Global Strategy Journal*, vol. 11, no. 3, pp. 331-355, 2021.

A Proposed Approach for Motif Finding Problem Solved on Heterogeneous Cluster with Best Scheduling Algorithm

Abdullah Barghash, Ahmed Harbaoui

Department of Computer Science, King Abdulaziz University, Jeddah, KSA

Abstract—The Motif Finding Problem (MFP) is the problem of finding patterns in sequences of DNA. This paper discusses and presents an enhanced scheduling approach to solve the motif problem on the Heterogeneous Cluster by making a comparison between exact algorithms. The method that was followed is to analyze several exact algorithms, compare them within specific points to measure, and improve performance by comparing the number of devices and peripheral units used in every situation and running time in every method. Our experimental results show that the use of the scheduling approach that use different algorithms on Heterogeneous Cluster make a significant difference in the speed of completing the problem and in a shorter record time with less resources, and that this proposed approach is more effective than the traditional method of distributing tasks to solve the motif problem.

Keywords—Motif finding problem; scheduling algorithm; heterogeneous; high-performance computing

I. INTRODUCTION

Motif finding is a well-known problem in bioinformatics that involves identifying patterns or motifs within a set of DNA or protein sequences [1]. These motifs, which can be as short as a few base pairs or amino acids, can provide important insights into the function and regulation of genes and proteins [2]. The motif finding problem is computationally intensive, as it requires analyzing large datasets and generating many potential motif candidates. To accelerate the motif finding process, researchers have increasingly turned to high-performance computing (HPC) techniques, which involve the use of specialized hardware and software tools to distribute and parallelize the computational workload [3]. Within this paper, we present our proposed approach, which not only improves time performance but also requires fewer resources, making it a valuable contribution to the field.

HPC clusters can be constructed with a variety of computing resources, including Central Processing Units (CPUs), Graphics Processing Units (GPUs), Many Integrated Core (MIC) Architecture, and other computing resources. As the domain of processors continues to evolve, that will lead to more heterogeneity among them.

One HPC approach for solving the motif finding problem is the use of CPUs and GPUs [4, 5]. By using CPUs and GPUs in combination, researchers can harness the power of both types of processing units to analyze large datasets and search more efficiently for motifs.

Das and Dai [6] proposed another HPC approach where the use of many integrated core (MIC) architectures, such as Intel's

Xeon Phi. MIC architectures are designed to provide high levels of parallelism and are well-suited for tasks that can be easily parallelized, such as motif finding. Zymbler and Kraeva [7] explained that by using MIC architectures, researchers can further increase the computational power available for solving the motif finding problem by following the proposed algorithm which showed high scalability, especially in the case of high computational load due to greater motif length.

Durbin et al. [8] found that effective use of HPC techniques for motif finding requires the implementation of appropriate scheduling strategies. Scheduling strategies determine how the computational workload is distributed among the available processing units and can significantly impact the efficiency of the motif finding process. For example, a scheduling strategy may involve dividing the dataset into smaller chunks and distributing them among the available CPUs, GPUs and MICs for parallel processing. Alternatively, Jones and Pevzner [9] determined that scheduling strategy may involve using machine learning techniques to optimize the allocation of computational resources.

HPC users may not always fully utilize the resources available to them on a cluster. This can be due to a variety of factors, including a lack of knowledge about the cluster's capabilities, the complexity of the HPC environment, limited time and resources, insufficient data, incorrect configuration, and inefficient algorithms. To overcome these challenges and fully utilize a cluster in their experiments, HPC users can seek support from experts, optimize their algorithms and data processing pipelines, and allocate sufficient resources. Additionally, HPC users can take advantage of cluster management tools and techniques, such as job scheduling and resource allocation, to better utilize the cluster's resources and improve the efficiency of their experiments. By addressing these challenges, HPC users can effectively leverage the power of HPC to solve complex problems and advance their research. Due to the difficulty of installing programs, as most software packages are not available by default for this environment, and the programs must be improved to take advantage of the capabilities of this device and match its high specifications, the same problems and challenges may be present through the administrator's view of the high-performance computer system. But, as software engineering advances, these problems are overcome by allowing software to optimize how it operates in a HPC environment. Another problem that is encountered from the point of view of the system administrator is that most users use by default one type of available resource, and this leads to a long waiting time in the queue for it to be released

for use by another user. This problem can be overcome by enabling scheduling algorithm that will direct users through different channels from resources to reduce waiting time in queue.

The effectiveness of using various types of resources in a heterogeneous environment depends on the parallel approaches chosen by the developer. The implementation of a scheduling strategy is a crucial aspect of performance. However, HPC users often utilize only one computing resource at a time for their experiments due to their expectations and behaviors. This paper presents a modified scheduling strategy for the planted motif finding problem that can achieve significant performance while using fewer computational resources.

II. MOTIF FINDING PROBLEM AND ALGORITHMS

The Motif-Finding problem (MFP) is the problem of finding patterns in sequences of DNA. Finding the common patterns in sequences is challenging as the DNA is a huge set [10]. This common pattern is called Motif and is usually a short segment that occurs frequently, see Fig. 1. These patterns considered a scientific interest in bioinformatics domain and those Motifs can be correspond to sequences of DNA that control the activation of specific genes [11]. MFP discovery algorithms can be classified into three categories based on its variants as Simple Motifs Search (SMS), Edited Motif Search (EMS) and Planted (l,d)-Motif Search (PMS)[12, 13]. This paper will consider (PMS) exact algorithms due to its high complexity [12] which makes it suitable to be solved on HPC systems as MFP is well known to be computationally intensive problem [14]. To detect a Motif of length L with allowed mutation d and all possible L -mers (4^L) is compared for all possible Motifs of length L and a sequence with size N we will get $(N - L + 1)$ using Brute-Force Algorithm. We will present our parameters same as used in [14, 15] and for such intensive resources computations could be implemented using heterogeneous platforms [4], [16]-[21] and for our experiment it will be conducted on a cluster containing CPUs, GPUs and MIC. The DNA constructed of nucleotides which is cytosine [C], guanine [G], adenine [A] or thymine [T] and can be represented using the regular expression in (1). The length L and its possible L -mers represented in (2). The sequence set on (3) and the *match* function used to compare Motifs A and B each of them has a size L represented on (4) the i _{th} position is represented where $A_i B_i$ for A and B Motifs. The counting of existence of L -mer in T sequences done by using *score* function shown in (5).

Motif finding problem can be solved in many algorithms that researchers have investigated in the past two decades [12, 13] and these algorithms are influenced by the length and the allowed mutations [6]. Some techniques are using variants of brute force algorithm that requires hundreds of hours. Faheem et al. [15] proposed an algorithm that can benefit from different architectures to split the MFP into smaller sub problems that can be solved on heterogeneous architectures with minimal communications. They proposed a speed-based scheduling algorithm to split the work and they proved that the problem is a data parallel problem given that they are using only brute force algorithm which may not be the most suitable algorithm for such problem; also it's hard to for a normal user to reserve a full cluster due to the fact that most of HPC centers

are a shared resource and they apply some resource limitation per user.

A Brute Force Algorithm solves this problem by considering all possible sets all 4^l possible l -mers. Compute the total distance of each l -mer in that set from all other l -mers in all t sequences. The correct Motif is the one with the smallest distances along all other l -mers. The running time of this algorithm is $O(4^l nt)$. To find a motif of $l = 11$ is about 5 hours and longer motifs cannot be processed in a reasonable amount of time [4]. Although the execution time of the brute force algorithm is clearly too long to solve the challenge problem, but it's of the exact algorithms that never fail to find the motif [4, 12].

The original Brute Force can be improved to be an upgraded version of Brute-Force algorithm called "SKIP Brute-Force" (SKIP BF) [4, 5, 22] as proven by Faheem [4] by using a grid computing and the enhanced version of Skip Brute Force has better execution time. This approach can be implemented in parallel on different compute resources as done by M. Al-Qutt et al. [5]. They implement the Skip Brute Force and solve MFP on CPU, GPU and MIC and the parallel version of their solution has significant execution time. The core enhancement on this SKIP BF Algorithm (Fig. 2) is to skip all iterations that won't lead to a correct solution. The algorithm behaves as Brute-Force algorithm by generating all possible 4^l l -mers then a generated l -mer of length L with d permitted mutations is considered matched if at least $(L - d) + 1$ identical positions at both are matched. Then the algorithm starts looking to the next sequence and excludes any unmatched l -mers from the search for the next sequence [5, 23]. SKIP BF leads to a better running time against the original Brute-Force Algorithm by skipping those irrelevant iterations and it's shown a high speedup performance on hardware accelerators like FPGA and shown a good chance for parallelization due to its fact of repetitive nature [22]. The complexity of this algorithm is $O(4^l nt)$ at its worst case [4].

The other algorithm to solve MFP was proposed by [3] called Recursive Brute Force Algorithm (RBF) and simply considered a searching technique that aims to search among the highest occurrence of the patterns of length L in set of characters and in some cases this algorithm allow us to accept the result of allowed mutation which means a non-exact match which is valid for MFP. RBF shown good time performance but its required a huge memory to be implemented using parallel methods as shown by Marwa Radad et al. [16, 25]. Memory allocation for recursive algorithms is major point and for RBF proposed by [24] they use the static memory allocation technique to avoid memory management and it was implemented in two phases- the initialization phase begins with candidate initialization as shown in Fig. 4; then test the candidate's list to search for possible candidates. Then extend the target for a good Motif and all motifs that have grater mutations than d are called bad candidates. The second phase is candidate generation phase and the extension and addition phase. RBF algorithm use a parallelization layer and distribute the workload using parallel paradigms MPI (Fig. 3). The search is finished in (level 1) with no expansion in time of $O(4^l nt)$. It has same complexity as the original Brute Force Algorithm [16].

Nikolaos et al. [28] introduced a parallel algorithm aimed at

efficient Top-k Motif Discovery in Weighted Networks. Their approach demonstrated commendable scalability and speedup, especially with an increase in the number of CPU cores. In a separate study, Theepalakshmi et al. [29] developed an enhanced solution for planted motif by applying the Freezing FireFly (FFF) algorithm. Their method outperformed existing state-of-the-art optimization algorithms in terms of time efficiency. Despite these advancements, this paper will primarily concentrate on the work referenced as [4], [5], [15], [16] given that the same platform was used for our experimental procedures.

$$V \rightarrow A|C|G|T \quad (1)$$

$$\text{Possible } L_{mers} \rightarrow V^l \quad (2)$$

$$S = \{s_1, s_2, \dots, s_T\} \quad (3)$$

$$\text{match}(A, B, l, d) = \begin{cases} 1, & l - d \geq \sum_i \begin{cases} 1, & A_i = B_i \\ 0, & \text{else} \end{cases} \\ 0, & \text{else} \end{cases} \quad (4)$$

$$\text{score}(L_{mers}, S, d) = \sum_{i=1}^T \sum_{k=0}^{N-l+1} \text{match}(L_{mer}, s_i[k, \dots, k+l], l, d) \quad (5)$$

$$\text{motif} = \{m \mid m = \text{MAX} (\text{score}(L_{mer}, S, m) \forall L_{mer} \in \text{Possible } L_{mers})\} \quad (6)$$

Input
N=45
T=5
d=2
L=10

0 5 10 15 20 25 30 35 40 45
agcaatcgccgattccggttaaagcctgcctcgctagctcgaagctg
ggctctgcgtgcatcgctaagctagcaaccgctagcatgcgctagcct
gattcgaataggcaaacgcacgaagtccgttaaagctagcatcgatcg
gctagctagcactattccggttttagcgatccgcctagccagagagatc
ccgctcgatcgtagcggatcgctagcatttccgttatccgtgcatagcg

Output

0 5 10 15 20 25 30 35 40 45
agcaatcgcc**CGTATTCCGT**taaagcctgcctcgctagctcgaagctg
GGTCTTGCGTgcatcgctaagctagcaaccgctagcatgcgctagcct
gattcgaataggcaaacgc**CGAAGTCCGT**taaagctagcatcgatcg
gctagctagc**ACTATTCCGT**tttagcgatccgcctagccagagagatc
ccgctcgatcgtagcggatcgctagcatt**CGTTATCCGT**gcatagcg

Fig. 1. Example of founded planted motif-[10, 2].

III. PERFORMANCE ANALYSIS OF MOTIF FINDING ALGORITHMS ON DIFFERENT ARCHITECTURES

To evaluate the performance of HPC for solving planted motif finding problems, we conducted a series of experiments using CPUs, GPUs, and MIC architectures. The experiments were designed to compare the performance of different algorithms on each type of resource. We used three different exact algorithms for solving the planted motif finding problem: Brute Force (BF), Skip Brute Force (SBF) and Recursive Brute Force (RBF).

```

1. for L = 0 to 4L_motifSize - 1 do % examine all possible l-mers
2.     for Ti = 1 to t_sequences do % loop on all t sequences
3.         motif_found = 0;
4.         current_score = d_mutations;
5.         for W = 1 to n_seqSize-l_motifSize+1 do % loop on
           all windows
6.             dist = compute_distance ( L , W);
7.             if dist <= current_score
8.                 solution.motif = Li; % this can be the motif
9.                 solution.posit(Ti) = W; % save its position
10.                motif_found = 1; % a suspected motif was
                    found
11.                current_score = dist;
12.                if Ti = t_sequences % we reached the
                    last sequence
13.                    solution_found = 1;
14.                end
15.                %% break; %% (dows not guarantee to find best
                    solution)
16.            end
17.            if motif_found == 0
18.                break; % Skip that Li, it is not the Motif
19.            end
20.        end
21.    end
22.    if solution_found
23.        break;
24.    end
25. end
    
```

Fig. 2. Pseudo code algorithm for SBF.

For the experiments, we used a Synthetic DNA sequences [13] as database with a data parameters that proposed by Pevzner [14] for Planted (l, d) Motif where the input sequences of size $N = 600$ each from the set of alphabets (1) and a motif M of size $l = 15$ and $d = 4$ allowed mutation.

For the CPU experiments, we used a cluster that with a limited recourses per user of eight nodes, each equipped with two Intel Xeon processors. For the GPU experiments, we used a cluster of 2 nodes, each equipped with one NVIDIA GPGPU K20 graphics card. For the MIC experiments, we used a cluster of two nodes, each equipped with one Intel Xeon Phi 7250 processor. We measured the performance of the algorithms by running time in seconds that reflected the time required to complete the planted motif finding process.

Examining the results in Table I gives an indication of the improvement in total run time with different algorithms. For instance, implementing the three algorithms using one regular node with OpenMP will reduce the run time from 11368 seconds for brute force algorithm on a single regular node to 2343 seconds for skip brute force algorithm with a speedup factor of 4.8 and recursive brute force algorithm run time 420 seconds that's comes with a speed factor of 28.2 to the original brute force algorithm run time while using eight regular nodes, will reduce the run time for brute force algorithm from 1416 seconds on pure 8 regular nodes to 73 seconds for skip brute force algorithm with a speedup factor of 19.3 and recursive brute force algorithm run time 40 seconds that's comes with a speed factor of 35.4 to the original brute force algorithm run time. For MIC and GPU, architectures are designed to

TABLE I. MFP RESULTS WITH DIFFERENT ARCHITECTURES

Trial No.	Platform	BF Results (sec)	Skip Results (sec)	RBF Results (sec)
1	1 Regular node (OpenMP)	11368	2343	420
2	1 Regular node (MPI+OpenMP)	11303	538	400
3	2 Regular node (MPI+OpenMP)	5627	273	120
4	4 Regular node (MPI+OpenMP)	2821	140	70
5	8 Regular node (MPI+OpenMP)	1416	73	40
6	MIC	11287	541	Not supported
7	GPU	10614	540	Not supported

```

1. Input:
2. l; d; t; S[1...,t]
3. Output:
4. ActualMotif [1..., x]
5. Score [1...,x]
6. BEGIN
7.   Allocate CandidateMotifs [ $4^{d+1}/RANKS^d$ ] [L]
8.   CandidateMotifs ← Provision ( $4^{d+1}/RANKS$ ) Motif each of
   length d+1.
9.   ForEach motif in CandidateMotifs
10.  BEGIN
11.    ForEach seq in S
12.    BEGIN
13.      ForEach window in seq:
14.      BEGIN
15.        If (mismatch (motif, window) < d)
16.        BEGIN
17.          MatchCount++;
18.          Break;
19.        END
20.      END
21.      If MatchCount == n and Len (Motif) < L
22.        CandidateMotifs ←
        ProvisionNewMotifs (Motif)
23.      Else if MatchCount == n and len (Motif) == L
24.        Actual Motif ← Append (Motif)
25.    END
26.  END
27.  Return (ActualMotifs, Score (ActualMotifs))
28. END

```

Fig. 3. Pseudo code MPI algorithm for RBF.

that can be easily parallelized. They are not well-suited for tasks that require sequential execution or complex control flow that use recursive function calls. Therefore, parallel recursive algorithms are generally not supported on MIC architectures or GPUs while results show that skip brute force algorithm has better running time than original brute force algorithm with speed up factor 5.9 to GPU and 20.8 for MIC.

The results of the experiments showed that the performance of the algorithms varied significantly depending on the type of resource and the algorithm deployed on each one of them. Overall, the GPU and MIC architectures outperformed the CPU architecture in terms of running time in some algorithms while CPU has better running time for recursive brute force algorithm, these results will provide valuable insights into the performance of different algorithms on different types of resources and will help to identify the most effective algorithm for each architecture and generate the assign map Table II. We will be able to optimize the use of computational resources in Table I and II to improve the scheduling strategy efficiency of the motif finding process in detail in the coming section.

TABLE II. ASSIGNED ALGORITHM TO EACH TYPE OF ARCHITECTURE

Architecture	Assigned Algorithm
CPU	RBF
GPU	SBF
MIC	SBF

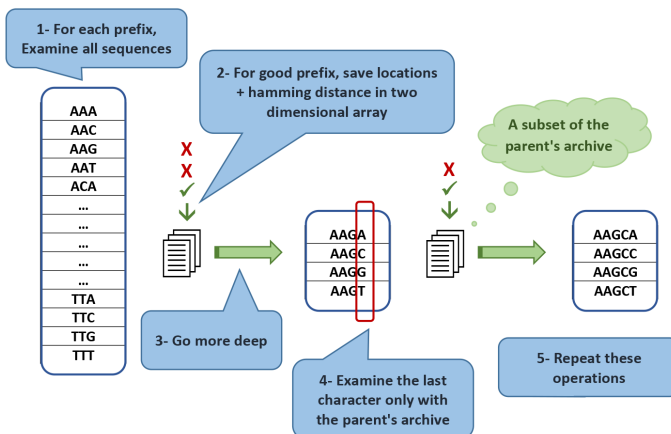


Fig. 4. RBF steps to find candidate motif.

IV. SCHEDULING STRATEGY AND PROPOSED APPROACH

A scheduling strategy is a plan or approach for distributing computational tasks among the available resources in a HPC environment. In the context of motif finding, a scheduling strategy involve dividing the dataset into smaller chunks and distributing them among the available CPUs, GPUs, and MICs for parallel processing. There are several approaches that can be used to develop a scheduling strategy for solving motif finding problems on HPC systems that have different types of computing nodes.

HPC systems are typically shared resources among multiple users, each with their own research goals and computational needs. In this context, it is often the case that one user cannot fully utilize the entire cluster for their own use and must share the resources with other users. This can lead to a lack of access to the resources that a user needs for their research, or to longer wait times for access to the resources. Furthermore, HPC users often rely on only one type of computing resource, such as CPU or GPU, for their experiments which can lead to underutilization of other resources and less efficient use of the available resources.

provide high levels of parallelism and well-suited for tasks

A scheduling strategy can help to mitigate these issues by more efficiently allocating the resources of the HPC system among the different users and their tasks. By using a scheduling strategy that takes into account the characteristics of the tasks and the available resources, it is possible to improve the overall performance of the HPC system and increase the number of users that can be accommodated on the system.

We use a Task-based scheduling strategy that assigns tasks to the computing node that is most suitable for solving them based on the best performed algorithm from previous results. These types of strategies are often used to optimize the performance of HPC systems by ensuring that tasks are executed on the most appropriate computing resources [26].

We have developed a scheduling strategy that can be used to divide tasks based on the best-performed algorithm for solving the motif finding problem on CPUs, GPUs, and MICs with similar approach described in [15], [27]. The PBS script used to construct the scheduler and designed to optimize the performance of HPC systems by selecting the best algorithm for each task on each type of resource based on its performance, then will divide the workload among other computing resources as shown in Fig. 5. The scheduler can help to ensure that tasks are executed efficiently and accurately, improving the overall performance of the system. In addition, the PBS script can be easily modified to support new algorithms or to adapt to changes in the characteristics of the data, making it a flexible and versatile tool for solving the motif finding problem on HPC systems with different types of resources.

V. EXPERIMENT RESULTS AND VALIDATION

After running the scheduler on a heterogeneous cluster consisting of CPUs, GPUs, and MICs, we obtained the following results.

TABLE III. RESULTS OF THE PREVIOUS PAPERS

Platform	CPU Ratio %	CUDA Ratio %	MIC Ratio %	Results
1 Regular Node+ 1 CUDA+1 MIC	40.321	29.867	29.812	2330.11
2 Regular Node+ 1 CUDA+1 MIC	69.250	15.389	15.361	1978.20
4 Regular Node+ 1 CUDA+1 MIC	79.427	10.296	10.277	1533.72
8 Regular Node+ 1 CUDA+1 MIC	86.549	6.732	6.719	1056.87

TABLE IV. RESULTS OF THE PROPOSED APPROACH

Platform	CPU Ratio %	CUDA Ratio %	MIC Ratio %	Result
1 Regular Node+ 1 CUDA+1 MIC	40.321	29.867	29.812	363
2 Regular Node+ 1 CUDA+1 MIC	69.250	15.389	15.361	182
4 Regular Node+ 1 CUDA+1 MIC	79.427	10.296	10.277	121
8 Regular Node+ 1 CUDA+1 MIC	86.549	6.732	6.719	77

The scheduler was able to effectively divide the tasks based on the best-performed algorithm for each type of resource, resulting in an overall improvement in the performance of the system. With more resources that selected the more workload, is assigned as the case for CPU as shown in Table I.

```

1. PROGRAM MotifScheduler
2. Input : S[1, ..., T]
3. Input : L
4. Input : d
5. Input : Matrix M
6. BEGIN
7.  $t[t_1, \dots, t_p] \leftarrow$  load single task execution time for architectures
8.  $t_{min} \leftarrow \text{MIN}_{i=1}^p (t_i) * 4^L$ ; find the smallest run time
9. Assign smallest run time to the best performed algorithm from Matrix M
10. FOR  $i=1$  to  $p$ 
11.   IF  $t_i \leq t_{min}$  THEN
12.      $R_i \leftarrow 4^L / t_i$ ; find the weight of each architecture
13.   ELSE
14.      $R_i \leftarrow 0$ ; this architecture is very slow and will be ignored
15.   END
16. END
17.  $R_{total} \leftarrow R_1 + R_2 + \dots + R_p$ ; sum the weights
18.  $R_u \leftarrow 4^L / R_{total}$ ; find the tasks assigned to each weight unit
   offset = 0
   start $_i$  = 0
19. FOR  $i = 1$  to  $p$ 
20.    $C_i = R_i * R_u$ ; tasks assigned to architecture
   start $_i = \text{start}_i + \text{offset}$ ; determine the start index of tasks
   end $_i = \text{start}_i + C_i - 1$ ; determine the end index of tasks
   offset =  $C_i$ 
21.   Score $_i \leftarrow \text{SPAWN Algorithm}_i(S, L, d, C_i, \text{start}_i, \text{end}_i)$ 
22. END
23. return  $\text{MAX}_{i=1}^p (\text{Score}_i)$ ; find the motif of highest occurrence
24. END

```

Fig. 5. Pseudo code of scheduling algorithm to assign workload to architecture.

TABLE V. COMPARISON BETWEEN RESULTS

Platform	Previous Results	Our Results	Speed up
1 Regular Node+ 1 CUDA+1 MIC	2330.11	363	6.42
2 Regular Node+ 1 CUDA+1 MIC	1978.20	182	10.87
4 Regular Node+ 1 CUDA+1 MIC	1533.72	121	12.68
8 Regular Node+ 1 CUDA+1 MIC	1056.87	77	13.73

By comparing our results with Table III from [15] that use the same cluster we can see with one Regular Node, one CUDA and one MIC, our approach managed to finish in 363 second instead of 2330 seconds with speedup factor 6.4 and by using 8 Regular Node, 1 CUDA and 1 MIC, as this is the maximum user limitation for the user in the cluster we gain a speedup factor 13.7 in total time of 77 seconds while in Table III its required full capacity that consist of 265 Regular Node to gain total performance of 54.91 seconds.

A comparison of our results in Table IV with those presented in Table III from study [15] shows that our approach was able to achieve a significant improvement in performance. Using a configuration of one Regular Node, one CUDA Node, and one MIC Node, our approach was able to complete the planted motif finding problem in 363 seconds, compared to

2330 seconds in Table III. This resulted in a speedup factor of 6.4. Additionally, by using a configuration of 8 Regular Node, 1 CUDA Node, and 1 MIC Node, which is the maximum user limitation for our cluster, we were able to achieve a speedup factor of 13.7 in a total time of 77 seconds as shown in Table V. This is compared to the full capacity configuration of 265 Regular Node in Table III which took 54.91 seconds. The chart in the Fig. 6 illustrates a comparison between previous studies and the proposed approach.

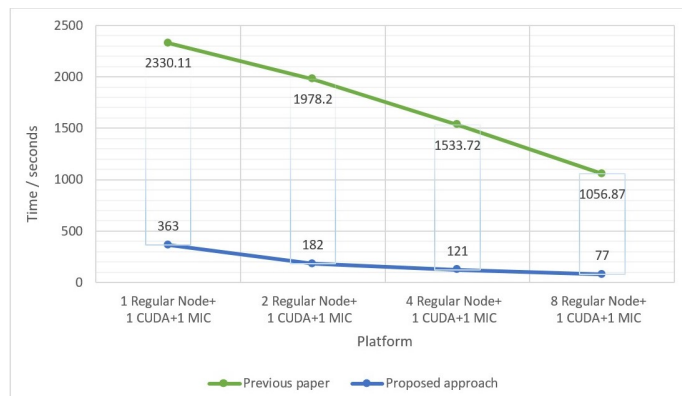


Fig. 6. Comparison between previous studies and the proposed approach.

These results demonstrate the effectiveness of our approach in achieving improved performance in motif finding problem on heterogeneous cluster. Hence, it can be seen that the waiting time has become significantly less, because the distribution of users by placing them in different channels to use the resources makes the available resources larger and does not require a large launch time to make them available to the new user.

VI. CONCLUSION

In this paper, we propose a scheduling algorithm to make better use of the heterogeneous cluster. It is based on the idea of dividing tasks on multiple types of resources available on the HPC. The results of this algorithm were compared with previous results, but they were using only one type of resource, which caused a burden and took a longer time to solve the problem.

Overall, the use of the scheduler resulted in a significant improvement in the performance of the system for solving the motif finding problem on a heterogeneous cluster with different algorithms. The scheduler was able to effectively select the best-performed algorithm for each type of resource, resulting in an efficient and accurate solution to the problem with much more less resources.

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REFERENCES

[1] P. A. Pevzner, Computational Molecular Biology: An Algorithmic Approach. 2000. doi: 10.7551/mitpress/2022.001.0001.

[2] M. Soskine and D. S. Tawfik, "Mutational effects and the evolution of new protein functions," *Nat Rev Genet*, vol. 11, no. 8, Art. no. 8, Aug. 2010, doi: 10.1038/nrg2808.

[3] W. Kim, M. Li, J. Wang, and Y. Pan, "Biological network motif detection and evaluation," *BMC Systems Biology*, vol. 5, no. 3, p. S5, Dec. 2011, doi: 10.1186/1752-0509-5-S3-S5.

[4] H. M. Faheem, "Accelerating motif finding problem using grid computing with enhanced Brute Force," in 2010 The 12th International Conference on Advanced Communication Technology (ICACT), Feb. 2010, vol. 1, pp. 197–202.

[5] H. Khaled, M. Al-Qutt, R. El-Gohary, H. Faheem, I. Katib, and nayif al-johani, *Accelerating Motif Finding Problem Using Skip Brute- Force on CPUs and GPU's Architectures*. 2017.

[6] M. K. Das and H.-K. Dai, "A survey of DNA motif finding algorithms," *BMC Bioinformatics*, vol. 8, no. S7, p. S21, Dec. 2007, doi: 10.1186/1471-2105-8-S7-S21.

[7] M. L. Zymbler and Ya. A. Kraeva, "Discovery of Time Series Motifs on Intel Many-Core Systems," *Lobachevskii J Math*, vol. 40, no. 12, pp. 2124–2132, Dec. 2019, doi: 10.1134/S199508021912014X.

[8] R. Durbin, S. R. Eddy, A. Krogh, and G. Mitchison, *Biological Sequence Analysis: Probabilistic Models of Proteins and Nucleic Acids*, 1st ed. Cambridge University Press, 1998. doi: 10.1017/CBO9780511790492.

[9] N. C. Jones and P. Pevzner, *An introduction to bioinformatics algorithms*. Cambridge, MA: MIT Press, 2004.

[10] P. F. Stadler, M. E. M. T. Walter, M. Hernandez-Rosales, and M. M. Brigido, Eds., *Advances in Bioinformatics and Computational Biology: 14th Brazilian Symposium on Bioinformatics, BSB 2021, Virtual Event, November 22–26, 2021, Proceedings*, vol. 13063. Cham: Springer International Publishing, 2021. doi: 10.1007/978-3-030-91814-9.

[11] D. Edwards, J. Stajich, and D. Hansen, Eds., *Bioinformatics*. New York, NY: Springer, 2009. doi: 10.1007/978-0-387-92738-1.

[12] S. Mohanty, P. K. Pattnaik, A. A. Al-Absi, and D.-K. Kang, "A Review on Planted (l, d) Motif Discovery Algorithms for Medical Diagnose," *Sensors (Basel)*, vol. 22, no. 3, p. 1204, Feb. 2022, doi: 10.3390/s22031204.

[13] F. A. Hashim, M. S. Mabrouk, and W. Al-Atabany, "Review of Different Sequence Motif Finding Algorithms," *Avicenna J Med Biotechnol*, vol. 11, no. 2, pp. 130–148, 2019.

[14] P. A. Pevzner and S. H. Sze, "Combinatorial approaches to finding subtle signals in DNA sequences," *Proc Int Conf Intell Syst Mol Biol*, vol. 8, pp. 269–278, 2000.

[15] H. M. Faheem, B. Koenig-Riez, M. Fayeze, I. Katib, and N. Al-Johani, "Solving the Motif Finding Problem on a Heterogeneous Cluster using CPUs, GPUs, and MIC Architectures".

[16] M. A. Radad, N. A. El-Fishawy, and H. M. Faheem, "Implementation of Recursive Brute Force for Solving Motif Finding Problem on Multi-Core," *Int. J. Syst. Biol. Biomed. Tech.*, vol. 2, no. 3, pp. 1–18, Jul. 2013, doi: 10.4018/ijssbt.2013070101.

[17] S. J. Park, D. R. Shires, and B. J. Henz, "Coprocessor Computing with FPGA and GPU," in 2008 DoD HPCMP Users Group Conference, Jul. 2008, pp. 366–370. doi: 10.1109/DoD.HPCMP.UGC.2008.69.

[18] M. Showerman et al., "QP: A Heterogeneous Multi-Accelerator Cluster".

[19] D. B. Thomas, L. Howes, and W. Luk, "A comparison of CPUs, GPUs, FPGAs, and massively parallel processor arrays for random number generation," in *Proceedings of the ACM/SIGDA international symposium on Field programmable gate arrays*, New York, NY, USA, Feb. 2009, pp. 63–72. doi: 10.1145/1508128.1508139.

[20] K. Underwood, "FPGAs vs. CPUs: trends in peak floating-point performance," in *Proceedings of the 2004 ACM/SIGDA 12th international symposium on Field programmable gate arrays*, Monterey California USA, Feb. 2004, pp. 171–180. doi: 10.1145/968280.968305.

[21] H. Khaled, H. E. D. M. Faheem, and R. El Gohary, "Design and implementation of a hybrid MPI-CUDA model for the Smith-Waterman algorithm," *Int J Data Min Bioinform*, vol. 12, no. 3, pp. 313–327, 2015, doi: 10.1504/ijdbm.2015.069710.

[22] Y. Farouk, T. ElDeeb, and H. Faheem, "Massively Parallelized DNA Motif Search on FPGA," in *Bioinformatics - Trends and Methodologies*, M. A. Mahdavi, Ed. InTech, 2011. doi: 10.5772/23578.

- [23] P. Perera and R. Ragel, "Accelerating motif finding in DNA sequences with multicore CPUs," in 2013 IEEE 8th International Conference on Industrial and Information Systems, Dec. 2013, pp. 242–247. doi: 10.1109/ICIInfS.2013.6731989.
- [24] H. Khaled, "Enhancing Recursive Brute Force Algorithm with Static Memory Allocation: Solving Motif Finding Problem as a Case Study," in 2019 14th International Conference on Computer Engineering and Systems (ICCES), Dec. 2019, pp. 66–70. doi: 10.1109/ICCES48960.2019.9068158.
- [25] M. A.Radad, N. A. El-fishawy, and H. M. Faheem, "Enhancing Parallel Recursive Brute Force Algorithm for Motif Finding," *IJCA*, vol. 86, no. 3, pp. 15–22, Jan. 2014, doi: 10.5120/14965-3143.
- [26] O. Sinnen, *Task Scheduling for Parallel Systems*, 1st edition. Hoboken, N.J: Wiley-Interscience, 2007.
- [27] H. M.Faheem and B. König-Ries, "A New Scheduling Strategy for Solving the Motif Finding Problem on Heterogeneous Architectures," *IJCA*, vol. 101, no. 5, pp. 27–31, Sep. 2014, doi: 10.5120/17685-8543.
- [28] A. Papadopoulos and N. Koutounidis, "Parallel Top-K Motif Discovery in Weighted Networks," Available SSRN 4418674, 2023.
- [29] P. Theepalakshmi and U. S. Reddy, "Freezing firefly algorithm for efficient planted (l, d) motif search," *Med. Biol. Eng. Comput.*, vol. 60, no. 2, pp. 511–530, 2022.

Fruit Classification using Colorized Depth Images

Dhong Fhel K. Gom-os
Department of Computer Science
University of the Philippines Cebu
Cebu, Philippines 6000

Abstract—Fruit classification is a computer vision task that aims to classify fruit classes correctly, given an image. Nearly all fruit classification studies have used RGB color images as inputs, a few have used costly hyperspectral images, and a few classical ML-based have used colorized depth images. Depth images have apparent benefits such as invariance to lighting, less storage requirement, better foreground-background separation, and more pronounced curvature details and object edge discontinuities. However, the use of depth images in CNN-based fruit classification remains unexplored. The purpose of this study is to investigate the use of colorized depth images in fruit classification with four CNN models, namely, AlexNet, GoogleNet, ResNet101, and VGG16, and compare their performance and computational efficiency, as well as the impact of transfer learning. Depth images of apple, orange, mango, banana and rambutan (*Nephelium Lappaceum*) were manually collected using a depth sensor with sub-millimeter accuracy and subjected to jet, uniform, and inverse colorization to produce three sets of dataset. Results show that depth images can be used to train CNN models for fruit classification with ResNet101 achieving the best accuracy of 96% on the inverse dataset. It achieved 100% accuracy after transfer learning. GoogleNet showed the most significant improvement after transfer learning on the uniform dataset, at 12.27%. It also exhibited the lowest training and inference times. The results show the potential use of depth images for fruit classification and similar computer vision tasks.

Keywords—Fruit classification; depth image; depth colorization; CNN; transfer learning

I. INTRODUCTION

The depth output of a depth sensor is converted into a three-dimensional RGB image to provide a colorized depth image. To create colorized images, specific colorization procedures are used to the depth data. A colorized depth image stores the depth information per pixel as opposed to a color image, which typically stores red, green, and blue intensity values per pixel. As a result, in a colorized depth image, the intensity of each pixel indicates how far an object is from the camera. Depth image is also known as range image.

The use of colorized depth images has continuously gained attention in the research community. They are used in soybean canopy analysis through 3D point clouds [1], action recognition [2], human posture analysis [3], 3D semantic segmentation [4], object recognition [5], and kangaroo detection [6]. In these studies, depth images were used either exclusively or in combination with RGB through fusion. These studies have shown that colorized depth images are helpful for solving complex computer vision problems.

Certain colorized depth-image characteristics are beneficial for both simple and complex computer-vision problems. For example, depth images are good at separating 3D objects from

the horizontal plane [4], which is beneficial for object detection. They can provide an outline of the strong discontinuities at the edges of an object, which is advantageous for object classification [5]. Curvature information is also more prevalent in depth images than in color images [5]. In addition, they require less storage than colored images (see Table II). They are more useful in edge cases of machine learning problems [7], such as differentiating between a hotdog food and a hotdog balloon. They are also invariant to extreme variations in lighting conditions and scale [7]. However, it is widely known that depth images require a lot of pre-processing as opposed to color images because of their tendency to contain missing depths [5], as well as their low contrast property [6]. Additional processing is required to improve the contrast and accuracy in highly complex and wide-area applications.

For less complex and more constrained applications such as fruit image classification, the benefits of using depth images can be leveraged. Fruit image classification is a computer vision task in which fruit images are classified according to their class. Here, it is assumed that the images do not contain more than one class of fruit. Applications for fruit image classification include supermarket self-checkouts and fruit sorting in factories.

Several studies on fruit image classification have been conducted. However, most of these studies used color images as inputs. Only a few studies have explored the use of depth images for fruit classification. In particular, one study [8] trained six machine learning algorithms, including Sequential Minimum Optimization (SMO), k-nearest neighbors (KNN), bagging based on REPTree, Decision Trees (DT), and Random Forests (RF) in the Waikato Environment for Knowledge Analysis (Weka) using visual features from color images and object shape representations from depth images. The shape descriptors extracted from the depth images include compactness, symmetry, local convexity, smoothness, and image moments. The results showed that RF trained on a combination of scalable color and edge histogram descriptors yielded the best performance at 99% accuracy. The problem with this classical approach is the need to perform segmentation in color images and manually extract features from the depth images. Depth images cannot be processed without their corresponding color images.

Another study [9] used depth images to render a 3D point cloud of fruits for classification. Similar to [8], [9] developed a multi-feature classification framework utilizing both color and depth images. It uses a color layout descriptor, viewpoint feature histogram, and point feature histogram as descriptors in the classification problem. Similarly, this approach is labor intensive and requires manual extraction of features from

images.

Based on [8] and [9], depth images can be beneficial for fruit-image classification. However, no study has explored the use of depth images yet, particularly in CNN-based fruit classification. Therefore, the goal of this study is to explore the use of purely depth images based on simple colorization techniques in fruit classification using CNN. The researcher used three different types of depth images, namely color-jet, uniform, and inverse hue colorization, and compared the performance of each type in four CNN models, namely, AlexNet, GoogleNet, ResNet101 and VGG16. The effect of transfer learning on the type of depth image with the lowest error rate in each CNN model was also investigated. Because depth sensors are gaining popularity in the sensor market, it would be beneficial to explore the use of depth images in computer vision problems, particularly in fruit classification.

The remainder of this paper is organized as follows. After the introduction, Section II discusses the background of the study. Section III discusses the methodology of the study. The findings are presented in Section IV followed by future work and conclusions in Sections V and VI, respectively.

II. BACKGROUND

A. Fruit Classification

Fruit image classification is the process of identifying a specific type of fruit in an image. This task is typically performed using convolutional neural networks (CNNs), a type of deep learning model that has become dominant in various computer vision tasks. CNNs are trained on large datasets of labeled images and learn to recognize features that are relevant to the task of fruit classification. The trained model can then be used to classify new images of fruits based on learned features.

Almost all studies tackling fruit classification using CNN use RGB color images as their dataset, except for a few that use hyper-spectral images. Hyperspectral images are captured using expensive hyper-spectral imaging which is a technique that collects and processes information from across the electromagnetic spectrum to obtain the spectrum for each pixel in an image of a scene. Table I shows a summary of the dataset types used in training the CNN models for fruit classification from 2015. [10] summarized the CNN-based fruit classification studies conducted from 2015 to 2020. This summary was manually checked by the researcher, and the outcome was plotted in the table mentioned above. For 2021-2023, the researcher manually searched the Scopus database using the keyword "fruit classification" for relevant papers. As shown in Table I, there is only one paper [11] that used the other type of dataset, i.e. hyper-spectral, from 2015-2020 and another one [12] in 2022. Evidently, the research community on fruit classification has extensively used RGB color images, and has not substantially explored other image types, including depth images.

The most popular benchmarks used for fruit classification are ImageNet, VegFru [13] and Fruit 360 [14]. ImageNet is a large visual database designed for use in visual object recognition software. It contains over 14 million images that have been hand-annotated to indicate what objects are pictured, and bounding boxes are provided in at least one million

TABLE I. NUMBER OF CNN-BASED FRUIT CLASSIFICATION STUDIES PER DATA TYPE

Year	Color (RGB)	Other (Hyper-spectral)
2015-2020	20	1
2021	27	0
2022	29	1
2023*	5	0

images. VegFru is a domain-specific dataset for fine-grained visual categorization of vegetables and fruits based on their eating characteristics. Each image in the dataset contained at least one edible part of vegetables or fruits with the same cooking usage, and all images were labeled hierarchically. It is closely related to the daily lives of people and is aimed at domestic cooking and food management. Fruit 360 is a dataset of images containing fruits. It is a high-quality dataset that includes 131 fruits and vegetables. The images are color (RGB) and 100 pixels \times 100 pixels in size, with three values for each pixel. It contains a total of 90,380 images, with 67,692 images in the training dataset and 22,688 images in the test dataset.

Similar to other computer vision tasks, fruit classification tasks extensively use color images, perhaps because of ubiquitous color sensors. However, RGB images obtained from color sensors have issues when used in fruit classification. There is a high rate of misclassification of fruits that are of similar colors, such as avocado and watermelon, banana and papaya, orange and carrot, as shown in [15]; passion fruit and blackberries, red grapes and passion fruits in [16]; and peach and apple red, pear and apple green, and pomegranate and apple in [14]. It was also found in [17] that shape feature also resulted in high misclassification between apples and oranges. A similar result was found in [18] which suggested that the color feature alone does not provide a good classification outcome. One very recent study [19] used MobileNetV2 with attention module in the classification. The attention module worked well in non-smoothed fruits but provided low precision in smoothed fruits like orange (at 81.75%). The researcher argues that it might be beneficial to explore other types of images for fruit classification, one that is independent of color. This is especially because fruit classification task is constrained and not complex, where special imaging sensors such as a depth sensor can easily be set up.

B. Depth Sensing

Depth sensing refers to the process of measuring the distance between a device and an object. Depth-sensing cameras are used for this purpose, and they automatically detect the presence and measure the distance of an object within its field of view. There are three types of depth-sensing cameras based on their method of calculating depth: (a) structured light and coded light, (b) stereo depth, and (c) time of flight and LIDAR [20].

(a) is a type of technology that uses projected light, usually infrared light, in the scene for a sensor to obtain its pattern and estimate its depth. This type of technology is the best indoors and within a short range. However, it is vulnerable to interference from nearby devices that emit infrared light. As opposed to (a), which uses projected light, (b) uses any light to

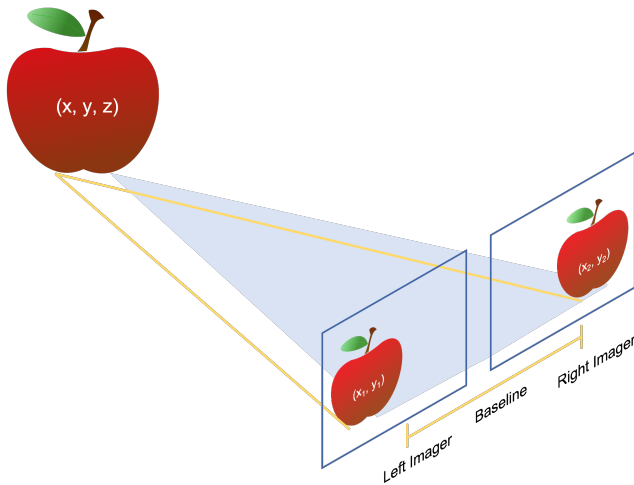


Fig. 1. Basic principle of stereo vision.

estimate depth but uses two sensors at a small distance apart. This technology works well both indoors and outdoor. Fig. 1 shows the basic operation of the stereo vision system. Similar to (a), (c) also emits light in the scene and calculates the time it returns to the sensor by which the depth is computed. As in (a), it is vulnerable to interference and is not ideal for outdoor conditions. The most common depth sensor uses a stereo vision mechanism for depth sensing. The depth sensor used in this study was a stereo-vision camera.

C. Depth Colorization

Depth colorization is a subset of image colorization [21] which is the process of estimating RGB colors for grayscale images to enhance perceptual quality. In the context of depth images, a grayscale image is a 2D depth map, where each pixel contains depth measurements from the depth sensor. Depth colorization is a method that adds colors to a depth map. This involves compression and coding [22]. It is not yet as developed as in compression and encoding in color images, but the ultimate goal is essentially the same: efficient storage, reduced artifacts, and reduced system bandwidth. To achieve this goal, various approaches have been developed. [23] suggested that there are two primary categories of representing colorized depth images, namely, hand-crafted depth colorization and ML-based depth colorization.

Some hand-crafted approaches include depth-to-surface normals [5], geocentric embedding (a.k.a. HHA encoding) [24], rendered mesh [25], quadtree decomposition & plane approximation [26], color-jet [27], and uniform and inverse colorization [22].

The surface normals [5] approach uses two cross-multiplied orthogonal tangent vectors and is normalized using the Euclidean norm, but introduces a recursive median filter to estimate the missing depth values and a bilateral filter to reduce noise. The geometric embedding approach encodes the height above ground and the angle with gravity for each pixel on top of the horizontal disparity [24]. The rendered mesh approach [25] first performs tabletop segmentation to extract the relevant depth map, missing depth values are filled in,

the mesh is extracted from the point cloud, and the mesh is re-projected to a canonical camera pose. All the three approaches are computationally expensive. Despite this, they only result in minimal to no improvement in some benchmarks for object recognition tasks. The quadtree decomposition and plane approximation approaches [26] achieved a low bit rate. However, this approach requires proprietary software for encoding and decoding and does not take advantage of the hardware acceleration modules present in modern computers.

A more advanced colorization technique, ML-based depth colorization, was developed in [23]. It uses a CNN architecture that is pre-trained on ImageNet. However, despite the use of neural networks, the results show that the model did not significantly improve the classification accuracy compared to color-jet and surface normals [27]. In fact, it performs worse in some models and benchmarks. It can be deduced from [23] that the encoding used does not significantly impact performance and high accuracy in computer vision tasks is still achievable even with a simple colorization approach.

It is for this reason that simple colorization approaches have been adopted in this study, namely, color-jet [27], uniform and inverse colorization [22].

1) *Color-Jet*: This is a common approach in depth colorization [27] where depth data is applied with a jet colormap to transform it from a single channel to a three-channel 2D depth image. This approach was found to be effective and computationally inexpensive and was shown to outperform HHA for object recognition. In this approach, the depth values are first normalized between 0 and 255, and then a jet color map is applied to the one-channel image to make it a three-channel image. A jet is a colormap [28] used for data visualization. It is a rainbow map that is commonly used to create false color images. Typically, the depth image is derived for each pixel (i, j) by mapping the distance to color values ranging from red (near) over green to blue (far). Sometimes, this mapping is reversed, i.e., blue is near, which is the case in this study.

2) *Uniform and Inverse Colorization*: [22] also developed a similar approach to [27] which uses the Hue colorspace with 6 gradations and 1529 discrete levels. It has two variations: uniform and inverse. The former directly encodes the depth value whereas the latter encodes the disparity value (reciprocal of the depth value). The latter is suitable for closer distances because it can capture finer details and information. The equations below show the mapping between the normalized depth (d_n) to the Red (p_r), Green (p_g) and Blue (p_b) channels respectively in case of uniform colorization.

$$d_n = \frac{d - d_{min}}{d_{max} - d_{min}}$$

$$p_r = \begin{cases} 255, & 0 \leq d_n \leq 255 \cup 1275 < d_n \leq 1529 \\ 255 - d_n, & 255 < d_n \leq 510 \\ 0, & 510 < d_n \leq 1020 \\ d_n - 1020, & 1020 < d_n < 1275 \end{cases}$$

$$p_g = \begin{cases} d_n, & 0 < d_n \leq 255 \\ 255, & 255 < d_n \leq 510 \\ 765 - d_n, & 510 < d_n \leq 765 \\ 0, & 765 < d_n \leq 1529 \end{cases}$$

$$p_b = \begin{cases} d_n, & 0 < d_n \leq 765 \\ d_n - 765, & 765 < d_n \leq 1020 \\ 255, & 510 < 1020 \leq 1275 \\ 1529 - d_n, & 1275 < d_n \leq 1529 \end{cases}$$

In case of inverse colorization, the mapping is done on the disparity value ($disp$) which is the reciprocal of depth.

$$disp = \frac{1}{d}, disp_{min} = \frac{1}{d_{min}}, disp_{max} = \frac{1}{d_{max}}$$

$$d_n = \frac{disp - disp_{min}}{disp_{max} - disp_{min}}$$

It is imperative that a simple and computationally efficient colorization approach be employed especially for real-time classification.

D. CNN Models

Convolutional neural networks (CNNs) is a deep learning network that automatically learns from visual data. In contrast to classical machine learning algorithms, CNN offers end-to-end model development without the need to manually extract features. CNN models learn patterns from input data via the convolution and pooling of multidimensional matrices. Four common models were considered in this study: AlexNet, VGG16, GoogleNet, and ResNet101.

1) *AlexNet*: AlexNet [29] is a convolutional neural network (CNN) architecture that was introduced in 2012 by Alex Krizhevsky, Ilya Sutskever, and Geoffrey Hinton. It was designed to compete in the ImageNet Large-Scale Visual Recognition Challenge (ILSVRC) and achieved a significant improvement in accuracy over previous methods. AlexNet consists of five convolutional layers and three fully connected layers, with multiple convolutional kernels extracting features from the images. The architecture also includes max-pooling layers and ReLU activation functions to improve performance. AlexNet's success in ILSVRC helped popularize deep learning and CNNs, leading to many more papers and applications in computer vision.

2) *GoogleNet*: GoogleNet [30], also known as Inception v1, is a convolutional neural network architecture that was introduced in 2014 by researchers at Google. The architecture was designed to improve the performance of neural networks by making them deeper while avoiding the complications that arise with an increasing number of layers. GoogleNet uses a unique architecture called the inception module that consists of multiple convolutional layers with different filter sizes and pooling operations. The Inception module allows the network to capture features at different scales and resolutions, thereby improving its ability to recognize objects in images. GoogleNet also includes auxiliary classifiers that help combat the vanishing gradient problem and improve training performance.

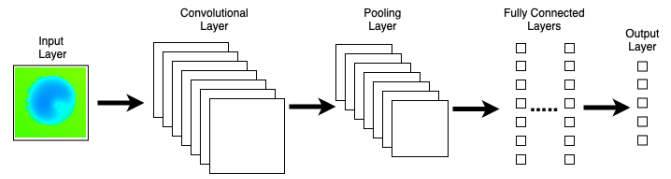


Fig. 2. General CNN architecture with depth image input.

3) *ResNet101*: ResNet101 [31] is a convolutional neural network architecture that was introduced in 2015 by researchers in Microsoft. The architecture is 101 layers deep and includes a unique feature called the “identity shortcut connection,” which allows the model to skip one or more layers. This approach helps to combat the vanishing gradient problem and allows the network to be deeper without sacrificing its performance. ResNet101 was designed to improve the accuracy of image classification tasks and it achieved high performance on the ImageNet dataset at the time of its introduction. The architecture has since been widely used and studied in the field of computer vision.

4) *VGG16*: VGG16 [32] is a convolutional neural network architecture introduced in 2014 by researchers at the University of Oxford. The architecture is unique in that it has only 16 layers with weights, as opposed to relying on a large number of hyper-parameters. VGG16 was designed to improve the accuracy of image recognition tasks and it achieved high performance on the ImageNet dataset at the time of its introduction. The architecture consists of five blocks of convolutional layers, each followed by a max-pooling layer, and three fully connected layers. The convolutional layers use small 3×3 filters, which help to reduce the number of parameters in the model.

E. Transfer Learning

Transfer learning is a machine learning technique that involves reusing a pre-trained model as the starting point for a new model on a different task. The pre-trained model has already been trained on a large dataset and has learned to recognize a wide range of features. By using the pre-trained model as a starting point, we can save time and computational resources that would otherwise be required to train a new model from scratch. Transfer learning is particularly useful when we have limited data for the new task, as the pre-trained model can provide a good starting point for learning the new task. Transfer learning has become a popular technique in deep learning, and it has been used in a wide range of applications, including image classification, object detection, and natural language processing. By leveraging the knowledge learned from pre-trained models, we can improve the performance of our models and reduce the time and resources required for training.

III. MATERIALS AND METHODS

The general architecture of the CNN model in this study is illustrated in Fig. 2.

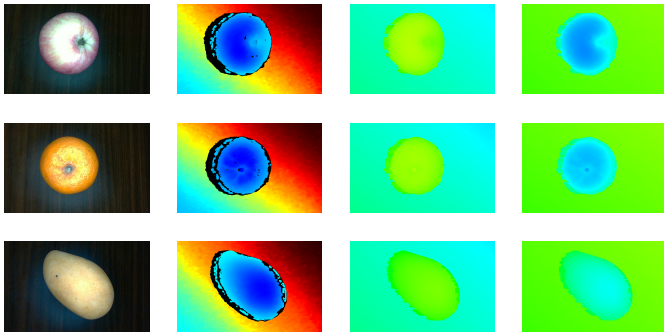


Fig. 3. Dataset samples: (left-right) RGB, jet (D1), uniform (D2), inverse (D3).

A. Dataset

In this study, there was a need to gather depth images of fruits from scratch. A depth camera based on stereo vision matching, Intel RealSense D405, was used to collect depth images in an indoor environment at an 848×480 resolution (30 fps). This depth camera is ideal for close-range applications, providing sub-millimeter accuracy to capture small features in an object that is suitable for this study. It was attached to a tripod ~ 10 cm from the platform, and the surroundings were artificially lit with a 14 W LED ring light at 1600 lumens. The camera was placed in the middle of the ring light for even lighting. Fig. 3 shows a set of dataset samples with RGB and depth images in three colorization: jet, uniform and inverse.

One important aspect of this study is the choice of colorization for the depth images. Based on [23], there is no significant benefit from using computationally expensive approaches, as there is no evidence that this translates to high performance. Therefore, three simple colorization approaches were used. The researcher refers to these as D1, D2, and D3 for the color-jet, uniform, and inverse colorization, respectively. These datasets have one-on-one correspondence in samples, i.e., each sample in each dataset was taken at the same time, with the same fruit object and resolution, just a different colorization. In this way, we can also make fair comparisons of the performance of the three colorization methods.

The fruits considered in this study were apple, orange, mango, banana, and rambutan (*Nephelium Lappaceum*). These fruits were selected for the following reasons: (a) apples and oranges are different in color and similar in shape; (b) mangoes and bananas are similar in color and different in shape, and apples and rambutans are similar in color and have different shapes and textures.

B. Post-Processing Filters

To improve the depth quality and accuracy, the depth data from the depth camera underwent a series of post-processing filters before colorization, except for jet. Both the uniform and inverse colorized depth images underwent a series of filters, namely, decimation, spatial, temporal, and hole filling. Depth-to-disparity transformation and vice versa are required for certain filters.

Fig. 4 presents a summary of the post-processing filters used for each dataset. A decimation filter was used to minimize

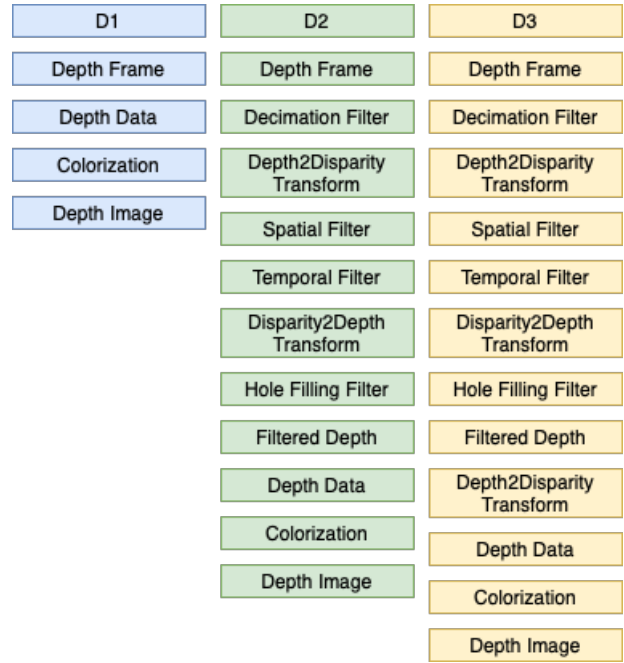


Fig. 4. The post-processing pipeline for each dataset.

TABLE II. FILE SIZE STATISTICS (IN BYTES)

	Min/Max	Mean	Median	Mode
D1	111,255/187,947	153,930	162,560	152,809
D2	76,041/111,565	96,124	99,273	93,907
D3	68,367/110,659	88,971	90,198	89,373
RGB	659,071/836,928	759,140	762,023	722,643

depth scene complexity. This was achieved by running an $N \times N$ median filter. A spatial filter was used to perform a 1D edge-preserving filter using a high-order domain transform in both the horizontal and vertical directions. A temporal filter was applied to enhance the persistence of depth data by pixel value manipulation over a number of previous frames. This is done by implementing a single pass on the data and updating the depth values while keeping track of the historical values. The hole-filling filter is intended to complete missing depth values and is performed by selecting neighborhood pixels to replace the missing depth.

After colorization, the depth images were saved using the PNG format, a type of lossless compression. Table II summarizes the statistics of the sizes of the different depth images, including their corresponding RGB color images in bytes. As shown, the inverse colorization requires the least storage among the three datasets used in this study. Generally, depth images require less storage than RGB images do. The RGB color image was almost 10 times the size of the inverse depth image. This is one benefit of using depth images over color images in computer vision tasks.

C. Experimental Flow

The activities of this study include data preprocessing, data augmentation, data splitting, training and validation, and performance evaluation as shown in Fig. 5. Each step is described in the following subsections.

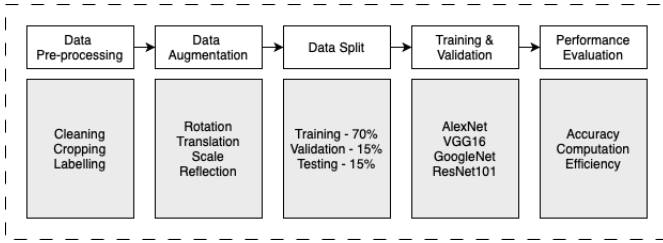


Fig. 5. Flowchart of data processing and analysis.

TABLE III. DATASET DISTRIBUTION PER CLASS IN EACH DATASET TYPE

	Raw	Cleaned	Augmented	Cleaned + Augmented
apple	1,068	456	1,368	1,824
banana	1,057	534	1,068	1,602
mango	1,075	861	861	1,722
orange	1,077	301	1,204	1,505
rambutan	1,066	882	882	1,764
	5,343	3,034	5,383	8,417

1) *Data Pre-processing*: A total of 5,343 depth images were collected for each dataset type. However, all these cannot be used because some are extremely noisy such as images with large regions with missing depths. To clean the dataset, a MATLAB program was developed to display and manually check each image in color and depth formats. As a result of the cleaning process, there are only 3,034 valid samples in the dataset, as shown in Table III. Orange and mango produced the most and least number of invalid samples, respectively.

After the dataset was cleaned, the images were cropped ~ 80 pixels from the left border because of invalid depth [33]. Consequently, the dimensions of the image were reduced. This is a known issue for stereo vision algorithms that utilize the left imager as a reference because of the non-overlapping region in the camera's field of view.

2) *Data Augmentation*: Because the resulting dataset was reduced after cleaning, there was a need to perform data augmentation to increase the sample size. Transformations used in data augmentation include rotation, translation, scaling, and reflection. It is important to note that exactly the same augmentation was performed on the same depth image of each type to ensure uniformity across the different dataset. For instance, the same transformation is applied to sample image X across D1, D2, and D3. This ensures uniform transformation across depth images and provides fairer performance comparisons later. The dataset (both the cleaned and augmented) now totals 8,417 per type, i.e., 25,251 depth images across all three datasets.

3) *Data Split*: To avoid possible overfitting in model training, the dataset was augmented and divided into 70% training, 15% validation, and 15% testing. To provide better and fairer comparisons across types, the split was performed uniformly across types and evenly between the cleaned and augmented samples, i.e., each split contained a proportional distribution of cleaned and augmented samples. To do this, each sample in the cleaned and augmented dataset was numbered sequentially, and a MATLAB program was developed to uniformly and evenly divide the dataset.

4) *Training and Validation*: Model training was performed after the dataset was processed and split. The CNN models used in the training were AlexNet, VGG16, GoogleNet, and ResNet101, with a batch size of 32 and an epoch of 20. The Adam optimizer was used, and the loss type was the categorical cross-entropy. The training was run using the TensorFlow framework on Macbook Pro M2 with 16GB memory, 8 CPU, and 10 GPU cores. Prior to training, the images were rescaled between 0 and 1 and resized to 224×224 for AlexNet and 227×227 for the rest. In addition, a random seed was set, and TensorFlow op was enabled for deterministic output. A total of 12 training sessions were performed, i.e., four models were trained for each dataset. Retraining of the best-performing dataset per model was performed to determine the effect of transfer learning.

5) *Performance Metrics and Evaluation*: To evaluate the performance of the trained model, we ran the trained models on the test dataset and utilized standard performance measures. The metrics used in this study were the average per-class accuracy (A), precision (P), recall (R), macro-average F1-score ($F1_M$), weighted-average F1-score ($F1_\mu$), Kappa score (k), training time, and inference time. A confusion matrix was derived from each model after testing to compute the metrics.

$$A = \frac{\sum_{a=1}^L \frac{tp_a + tn_a}{tp_a + tn_a + fp_a + fn_a}}{L}$$

$$P = \frac{\sum_{a=1}^L \frac{tp_a}{tp_a + fp_a}}{L}$$

$$R = \frac{\sum_{a=1}^L \frac{tp_a}{tp_a + fn_a}}{L}$$

where tp_a , tn_a , fp_a , and fn_a represent true positive, true negative, false positive and false negative for class a .

$$F1_M = \frac{1}{|L|} \sum_{a \in L} F1_a$$

$$F1_\mu = \frac{1}{\sum_{a \in L} Supp(a)} \sum F1_a \times Supp(a)$$

where $Supp(a)$ denotes the number of samples in class a , and $F1_a$ is the F1-score of class a

$$F1_a = 2 \times \frac{P_a \times R_a}{P_a + R_a}$$

where P_a and R_a are precision and recall for class a respectively.

$$k = \frac{p_0 - p_e}{1 - p_e}$$

where p_0 is the observed agreement ratio and p_e is the hypothetical probability of change agreement. k is a statistical measure of inter-rater agreement for categorical data.

Training and inference times are the times required for the model to train and test, respectively. These are important metrics for verifying the calculation efficiency of models trained on depth images.

IV. RESULTS AND DISCUSSION

This section presents and discusses the findings of this study. Here, the researcher aims to demonstrate the performance of the models trained using different datasets. First, the performance by model with the use of the three datasets during training and validation is discussed, followed by the performance of each model by dataset. Subsequently, the performance of each trained model on the test dataset is presented. The calculation efficiency of each model is also discussed. Finally, the effect of transfer learning on model performance is presented.

A. Comparison of Performance during Training and Validation

In this section, the performances of the model in terms of training and validation accuracy and loss are compared. A desirable CNN model should rapidly improve accuracy and maintain stability as the number of epochs increases. Fig. 6 shows the training and validation performance of each model on the three datasets. With AlexNet, the training performance for all datasets showed a rapid and stable trend. This was also evident from the training loss trend of the model. Its validation accuracy was slightly lower than that of D2, showing an early increase as opposed to D1 and D3. Both D1 and D3 tended to oscillate in their validation performances during the early epochs. GoogleNet had a slower increase in training accuracy compared to AlexNet in all three datasets, although it stabilized well in later epochs. Its validation performance was more stable than that of AlexNet, even at earlier epochs. Compared with GoogleNet, ResNet101 showed a more rapid increase in training accuracy, but was still slower than AlexNet. It also exhibited a stable trend as the number of epochs increased. However, it showed very unstable validation performance across the three datasets. VGG16 has a better training performance than GoogleNet, particularly for D1. Its validation performance is comparable to that of GoogleNet, which registered high validation at earlier epochs and stabilized onwards. It showed the most stable validation performance for all datasets among all models.

Next, we look at the performance of the models by dataset as shown in Fig. 7. On D1, we can see that the quickest to rapidly increase in training accuracy is AlexNet followed by VGG16 and ResNet101. GoogleNet is the slowest. Both GoogleNet and VGG16 performs well in the validation set with more stability compared with the other two. ResNet101 is the worst to perform in the validation set with very unstable trend. Only VGG16 has stable trend in the validation loss compared to the rest with ResNet101 being the worst. In terms of D2, AlexNet still leads in terms of rapid increase in training accuracy with GoogleNet still trailing behind the rest. ResNet101 still has the worst validation performance. The validation loss of GoogleNet tend to be more stable in D2. In terms of D3, AlexNet still is the quickest to rapidly increase in training accuracy still with GoogleNet the worst. The trend of validation accuracy of ResNet101 still oscillate. We can say

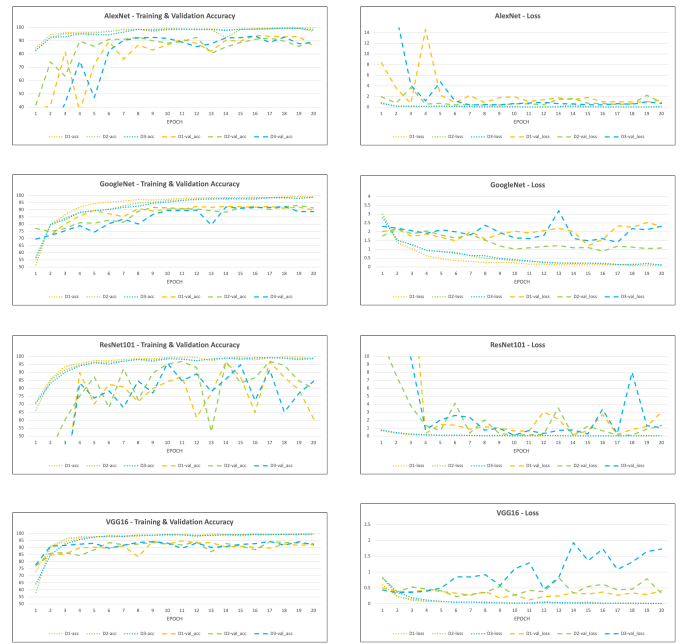


Fig. 6. Training & validation accuracy and loss by model.

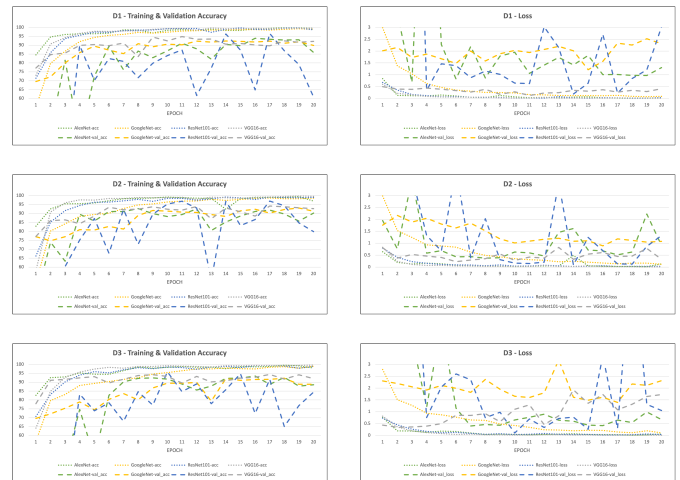


Fig. 7. Training & validation accuracy and loss by dataset.

that all models perform well in the training set across the three datasets but the validation performance of ResNet101 which is quite unstable.

B. Comparison of Performance on the Test Dataset

In this section, the performances of the models on the test datasets are presented. Table IV summarizes the performance measures for each model using different datasets. It can be observed that ResNet101 has the best performance across the three datasets and in all performance metrics. It had the highest accuracy, precision, recall, kappa-score, $F1_M$ and $F1_\mu$ on D3, followed by D2 and D1. On D1, it was followed by VGG16 and GoogleNet with AlexNet, with the poorest performance in all metrics. It has the lowest performance, with an average per-class accuracy of 0.76 and k of 0.7. Note that D1 did not

pass through the post-processing pipeline, which may have contributed to this result. In terms of D2, ResNet101 was followed by VGG16 and AlexNet, with GoogleNet performing the worst. It should be noted that AlexNet and GoogleNet had the same accuracy, precision, and recall values. They only differ in terms of k , $F1_M$ and $F1_\mu$ with AlexNet higher by 0.01 only. In terms of D3, next to ResNet101 are VGG16 and AlexNet, with GoogleNet trailing behind. It can be seen that VGG16 performs the second best overall with ResNet101. Overall, all models performed well in the three test datasets, except for AlexNet on D1, which registered $< 80\%$ across all metrics. The top dataset is D3, which is based on inverse colorization and registered 96% accuracy using ResNet101.

C. Training and Inference Duration

In this section, the computational efficiency of these models is discussed. The number of CNN parameters and the computational complexity are vital for the development of deep-learning applications. These variables contribute to the training and inference durations of the CNN models. An ideal CNN model is one that is less complex, yet produces good results at low training and inference times.

The number of layers and parameters in each CNN model, including the FLOPs, is listed in Table V. These variables define a complex CNN structure. The deeper the layers in a network, the more complex image processing properties that it can perform. Consequently, the hardware requirements for processing are greater. In essence, computational efficiency is determined by the amount of layers in the network and the training time, whereas computational difficulty is evaluated by the number of network parameters and FLOPs. The training and inference times of the models were also presented.

The AlexNet model has only 11 layers, which is the smallest among all the models considered in this study. It also had the lowest number of FLOPs. However, it did not have the lowest training time. It was only next to GoogleNet across all three datasets. This is due to the number of parameters, which is 60M compared with 6.8M of GoogleNet. Notably, VGG16 had the longest training time compared to ResNet101. Both also had approximately the same inference time. This can be attributed to the number of parameters VGG16 has including its massive amount of FLOPs. Among all three datasets, D3 requires the least amount of computation using GoogleNet in both training and inference with 41.07 and 0.53 minutes for training and inference, respectively. Note that D3 required the least storage which may have contributed to this outcome.

D. Transfer Learning

The researcher compared the accuracy of the four models with and without transfer learning. Only the dataset with the best accuracy during training from scratch for each model was chosen for the transfer learning experiment. D2 was used for AlexNet, GoogleNet, and VGG16, whereas D3 was used for ResNet101. The weights of the four models trained on ImageNet dataset were used.

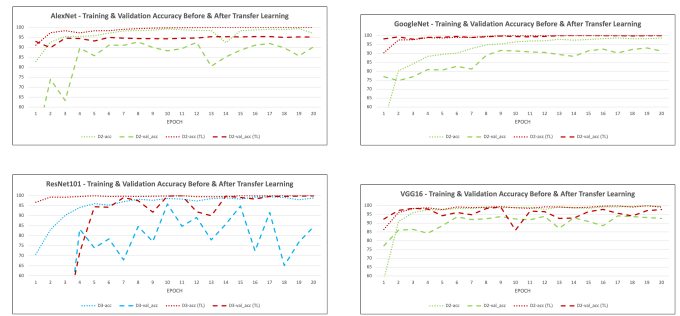


Fig. 8. Training & validation accuracy before and after transfer learning.

Fig. 8 shows the accuracy trend of each of the four models with and without transfer learning. The red lines indicate the accuracy of the model with transfer learning, and the other color indicates the accuracy without transfer learning. It is evident that the training accuracy of each model rapidly increased at earlier epochs with transfer learning compared to the accuracy without transfer learning. It also has a more stable rate than without transfer learning. It can be observed that the training accuracy is considerably higher with transfer learning, particularly for AlexNet, GoogleNet, and ResNet101. The training accuracy for VGG16 remained unchanged in later epochs.

In terms of validation accuracy, Fig. 8 shows a better overall performance in all models. Of note is ResNet101, which registered a more stable validation performance with fewer oscillations compared with no transfer learning. Both AlexNet and GoogleNet had very stable validation performances compared with no transfer learning and even with transfer learning for the ResNet101 and VGG16 models. Remarkably, GoogleNet's validation accuracy with transfer learning surpassed its training accuracy without transfer learning. These results indicate that transfer learning substantially increases both the training and validation accuracy of the CNN models. The extent of improvement varied from model to model.

To understand the effect of transfer learning on the four CNN models, the researcher gathered statistics on the training, validation, and testing performance of these models. The results are listed in Table VI. Here, the difference in accuracy is between the best accuracy with and without transfer learning. The increment, on the other hand, is the ratio between the accuracy difference and the accuracy of the CNN model without transfer learning. This measures the improvement provided by the use of transfer learning.

As shown in Table VI, GoogleNet exhibited the highest improvement in all aspects, including training, validation, and testing. It had the highest improvement in testing and the lowest improvement in training. This indicates that the novel GoogleNet architecture is suitable for applying transfer learning using depth images. It should be noted that its training accuracy has already reached 100% with the use of transfer learning. VGG16 was next to GoogleNet, with the highest improvement in the test dataset. This is despite having the lowest increase in training accuracy. It should be noted that VGG16 already has a high accuracy rate, even without transfer

TABLE IV. PERFORMANCE OF THE DIFFERENT CNN MODELS ON THE THREE DATASETS

	D1						D2						D3					
	A	P	R	k	$F1_M$	$F1_\mu$	A	P	R	k	$F1_M$	$F1_\mu$	A	P	R	k	$F1_M$	$F1_\mu$
AlexNet	0.76	0.78	0.75	0.70	0.75	0.76	0.89	0.9	0.88	0.87	0.88	0.89	0.87	0.86	0.86	0.83	0.86	0.87
GoogleNet	0.87	0.88	0.86	0.83	0.85	0.86	0.89	0.90	0.88	0.86	0.87	0.88	0.86	0.86	0.85	0.83	0.84	0.85
ResNet101	0.91	0.91	0.91	0.89	0.90	0.91	0.95	0.95	0.95	0.94	0.95	0.95	0.96	0.96	0.96	0.95	0.96	0.96
VGG16	0.90	0.89	0.90	0.87	0.89	0.90	0.91	0.91	0.90	0.88	0.90	0.90	0.88	0.88	0.87	0.85	0.87	0.88

TABLE V. TRAINING AND INFERENCE DURATION (MINUTES)

	Layers	No. of Parameters (M)	FLOPs (M)	D1		D2		D3	
				Training	Inference	Training	Inference	Training	Inference
				AlexNet	11	60	727	84.92	0.70
GoogleNet	87	6.8	2000	42.68	0.57	41.18	0.55	41.07	0.53
ResNet101	101	44	7600	199.58	0.95	199.00	0.95	198.67	0.97
VGG16	16	138	16000	215.90	0.97	211.87	0.97	221.38	0.95

TABLE VI. EFFECT ON MODEL ACCURACY BEFORE AND AFTER TRANSFER LEARNING

	Dataset	Training Accuracy Difference (%)	Validation Accuracy Difference (%)	Test Accuracy Difference (%)	Training Increment (%)	Validation Increment (%)	Test Increment (%)
AlexNet	D2	0.56	2.70	3.46	0.56	2.91	3.89
GoogleNet	D2	1.37	6.98	10.92	1.39	7.50	12.27
ResNet101	D3	0.66	4.13	4.00	0.66	4.31	4.17
VGG16	D2	0.03	5.00	8.13	0.03	5.31	8.93

learning. AlexNet registered the least improvement in both validation and test datasets. This is an indication that the traditional CNN structure has no significant effect in testing accuracy. In addition, its architecture was less affected by transfer learning. AlexNet, GoogleNet, and ResNet101 achieved 100% training accuracy with transfer learning. These findings are consistent with the belief that the two nonlinear structures of GoogleNet and ResNet are more suitable for certain classes of inputs, i.e., the accuracy increases as the image classes change. On the other hand, the single-channel classic CNN architectures of AlexNet and VGG16 are thought to be costlier for varying inputs.

The different CNN models respond differently to transfer learning due to their diverse structures. In addition, there is a large difference in terms of the dataset used to train the parameters of these models for transfer learning, i.e., ImageNet, and the actual dataset used in the classification problem, i.e. colored depth images. Overall, it was shown that transfer learning can significantly affect the classification accuracy of colored depth images of fruits. This is despite the fact that the pre-trained models were not previously trained on depth images. The extent of improvement depended on the model structure.

V. LIMITATIONS AND FUTURE WORK

This study has shown that it is possible to use colored depth images in fruit classification with a high rate of accuracy, aided by CNN and transfer learning. However, this study is limited in multiple aspects, such as the dataset used and CNN models considered. The dataset used in this study was limited, with only five classes. In future work, this can be increased to include other types of fruits, including those that are very similar in form, shape, color, and texture. Only four CNN models are used in this study. Future work could include other models, such as MobileNetV2, as well as other colorization approaches. It is also useful to explore the fusion of RGB and colored depth images in fruit classification problems.

VI. CONCLUSION

In this study, the researcher investigated the use of colored depth images in CNN-based fruit classification using AlexNet, GoogleNet, ResNet101 and VGG16 and examined their performance and the impact of transfer learning application. The primary findings are as follows: (1) All four models performed well during training and validation with both GoogleNet and VGG16 having desirable trends in all of the three datasets. ResNet101 is the least ideal. (2) ResNet101 exhibited the best test accuracy with 96% rate on D3, 95% on D2 and 91% on D1. AlexNet performed the least on D1 at 76%. (3) The post-processing filters applied to D2 and D3 contributed to the performance of the models. (4) Transfer learning considerably improved the performance of the models with GoogleNet registering the largest increase on the test set at 12.27%. (5) Transfer learning could provide better validation performance in ResNet101 whose validation performance was very unstable without transfer learning.

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REFERENCES

- [1] X. Ma, K. Zhu, H. Guan, J. Feng, S. Yu, and G. Liu, "High-Throughput Phenotyping Analysis of Potted Soybean Plants Using Colorized Depth Images Based on A Proximal Platform," Remote Sensing, vol. 11, no. 9, Art. no. 9, Jan. 2019, doi: 10.3390/rs11091085.
- [2] Y. Htet, T. T. Zin, H. Tamura, K. Kondo and E. Chosa, "Action Recognition System for Senior Citizens Using Depth Image Colorization," 2022 IEEE 4th Global Conference on Life Sciences and Technologies (LifeTech), Osaka, Japan, 2022, pp. 494-495, doi: 10.1109/LifeTech53646.2022.9754900.

- [3] A. Abobakr, D. Nahavandi, J. Iskander, M. Hossny, S. Nahavandi and M. Smets, "RGB-D human posture analysis for ergonomie studies using deep convolutional neural network," 2017 IEEE International Conference on Systems, Man, and Cybernetics (SMC), Banff, AB, Canada, 2017, pp. 2885-2890, doi: 10.1109/SMC.2017.8123065.
- [4] T. Amemiya and T. Tasaki, "Design of Class in Unknown Object Segmentation Focusing on 3D Object Detection in Depth Image," 2021 IEEE/SICE International Symposium on System Integration (SII), Iwaki, Fukushima, Japan, 2021, pp. 706-707, doi: 10.1109/IEEECONF49454.2021.9382606.
- [5] A. Aakerberg, K. Nasrollahi, C. B. Rasmussen, and T. B. Moeslund, "Depth Value Pre-Processing for Accurate Transfer Learning Based RGB-D Object Recognition," International Joint Conference on Computational Intelligence, pp. 121-128, 2017, doi: 10.5220/0006511501210128.
- [6] K. Saleh, M. Hossny, and S. Nahavandi, "Effective Vehicle-Based Kangaroo Detection for Collision Warning Systems Using Region-Based Convolutional Networks," Sensors, vol. 18, no. 6, Art. no. 6, Jun. 2018, doi: 10.3390/s18061913.
- [7] I. RealSense, "What does depth bring to Machine Learning?," Intel® RealSense™ Depth and Tracking Cameras, May 02, 2019. <https://www.intelrealsense.com/machine-learning-and-depth-cameras/> (accessed Apr. 13, 2023).
- [8] L. Jiang, A. Koch, S. A. Scherer, and A. Zell, "Multi-class fruit classification using RGB-D data for indoor robots," in 2013 IEEE International Conference on Robotics and Biomimetics (ROBIO), Shenzhen, China: IEEE, Dec. 2013, pp. 587-592. doi: 10.1109/ROBIO.2013.6739523.
- [9] M. E. Rachmawati, M. I. Supriana, and D. M. L. Khodra, "Toward a New Approach in Fruit Recognition using Hybrid RGBD Features and Fruit Hierarchy Property," 2017.
- [10] C. C. Ukwuoma, Q. Zhiguang, M. B. Bin Heyat, L. Ali, Z. Almaspoor, and H. N. Monday, "Recent Advancements in Fruit Detection and Classification Using Deep Learning Techniques," Mathematical Problems in Engineering, vol. 2022, p. e9210947, Jan. 2022, doi: 10.1155/2022/9210947.
- [11] J. Steinbrener, K. Posch, and R. Leitner, "Hyperspectral fruit and vegetable classification using convolutional neural networks," Computers and Electronics in Agriculture, vol. 162, pp. 364-372, Jul. 2019, doi: 10.1016/j.compag.2019.04.019.
- [12] T. Arumuga Maria Devi and P. Darwin, "Hyper Spectral Fruit Image Classification for Deep Learning Approaches and Neural Network Techniques," International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, vol. 30, no. 3, pp. 357-383, 2022, doi: 10.1142/S0218488522400116.
- [13] S. Hou, Y. Feng, and Z. Wang, "VegFru: A Domain-Specific Dataset for Fine-Grained Visual Categorization," in 2017 IEEE International Conference on Computer Vision (ICCV), Venice: IEEE, Oct. 2017, pp. 541-549. doi: 10.1109/ICCV.2017.66.
- [14] H. Mureşan and M. Oltean, "Fruit recognition from images using deep learning," Acta Universitatis Sapientiae, Informatica, vol. 10, no. 1, pp. 26-42, Aug. 2018, doi: 10.2478/ausi-2018-0002.
- [15] M. S. Hossain, M. Al-Hammadi, and G. Muhammad, "Automatic Fruit Classification Using Deep Learning for Industrial Applications," IEEE Trans. Ind. Inf., vol. 15, no. 2, pp. 1027-1034, Feb. 2019, doi: 10.1109/TII.2018.2875149.
- [16] Y. Zhang, S. Wang, G. Ji, and P. Phillips, "Fruit classification using computer vision and feedforward neural network," Journal of Food Engineering, vol. 143, pp. 167-177, Dec. 2014, doi: 10.1016/j.jfoodeng.2014.07.001.
- [17] H. M. Zawbaa, M. Hazman, M. Abbas, and A. E. Hassanien, "Automatic fruit classification using random forest algorithm," in 2014 14th International Conference on Hybrid Intelligent Systems, Kuwait, Kuwait: IEEE, Dec. 2014, pp. 164-168. doi: 10.1109/HIS.2014.7086191.
- [18] J. L. Rojas-Aranda, J. I. Nunez-Varela, J. C. Cuevas-Tello, and G. Rangel-Ramirez, "Fruit Classification for Retail Stores Using Deep Learning," in Pattern Recognition, K. M. Figueroa Mora, J. Anzures Marín, J. Cerda, J. A. Carrasco-Ochoa, J. F. Martínez-Trinidad, and J. A. Olvera-López, Eds., in Lecture Notes in Computer Science. Cham: Springer International Publishing, 2020, pp. 3-13. doi: 10.1007/978-3-030-49076-8_1.
- [19] T. B. Shahi, C. Sitaula, A. Neupane, and W. Guo, "Fruit classification using attention-based MobileNetV2 for industrial applications," PLoS ONE, vol. 17, no. 2 February, 2022, doi: 10.1371/journal.pone.0264586.
- [20] I. RealSense, "Beginner's guide to depth (Updated)," Intel® RealSense™ Depth and Tracking Cameras, Jul. 16, 2019. <https://www.intelrealsense.com/beginners-guide-to-depth/> (accessed Apr. 13, 2023).
- [21] S. Anwar, M. Tahir, C. Li, A. Mian, F. S. Khan, and A. W. Muzaffar, "Image Colorization: A Survey and Dataset." arXiv, Jan. 26, 2022. Accessed: Apr. 22, 2023. [Online]. Available: <http://arxiv.org/abs/2008.10774>
- [22] "Depth image compression by colorization for Intel® RealSense™ Depth Cameras," Intel® RealSense™ Developer Documentation. <https://dev.intelrealsense.com/docs/depth-image-compression-by-colorization-for-intel-realsense-depth-cameras> (accessed Apr. 13, 2023).
- [23] F. M. Carlucci, P. Russo and B. Caputo, "(DE) 2 CO: Deep Depth Colorization," in IEEE Robotics and Automation Letters, vol. 3, no. 3, pp. 2386-2393, July 2018, doi: 10.1109/LRA.2018.2812225.
- [24] S. Gupta, R. Girshick, P. Arbeláez, and J. Malik, "Learning Rich Features from RGB-D Images for Object Detection and Segmentation," in Computer Vision – ECCV 2014, D. Fleet, T. Pajdla, B. Schiele, and T. Tuytelaars, Eds., in Lecture Notes in Computer Science. Cham: Springer International Publishing, 2014, pp. 345-360. doi: 10.1007/978-3-319-10584-0_23.
- [25] M. Schwarz, H. Schulz, and S. Behnke, "RGB-D object recognition and pose estimation based on pre-trained convolutional neural network features," in 2015 IEEE International Conference on Robotics and Automation (ICRA), Seattle, WA, USA: IEEE, May 2015, pp. 1329-1335. doi: 10.1109/ICRA.2015.7139363.
- [26] Y. Morvan, D. Farin, and P. H. N. de With, "Novel coding technique for depth images using quadtree decomposition and plane approximation," presented at the Visual Communications and Image Processing 2005, Beijing, China, Beijing, China, Jul. 2005, p. 59603I. doi: 10.1117/12.631647.
- [27] A. Eitel, J. T. Springenberg, L. Spinello, M. Riedmiller and W. Burgard, "Multimodal deep learning for robust RGB-D object recognition," 2015 IEEE/RISJ International Conference on Intelligent Robots and Systems (IROS), Hamburg, Germany, 2015, pp. 681-687, doi: 10.1109/IROS.2015.7353446.
- [28] G. Ulander Voltaire, "Influence of different colormaps on the perceptual interpretation of numerical values produced by a self-organizing feature map." 2021. Accessed: Apr. 22, 2023. [Online]. Available: <https://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-296348>
- [29] A. Krizhevsky, I. Sutskever, and G. E. Hinton, "ImageNet Classification with Deep Convolutional Neural Networks," in Advances in Neural Information Processing Systems, Curran Associates, Inc., 2012. Accessed: Apr. 24, 2023. [Online]. Available: https://papers.nips.cc/paper_files/paper/2012/hash/c399862d3b9d6b76c8436e924a68c45b-Abstract.html
- [30] C. Szegedy et al., "Going deeper with convolutions," 2015 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Boston, MA, USA, 2015, pp. 1-9, doi: 10.1109/CVPR.2015.7298594.
- [31] K. He, X. Zhang, S. Ren and J. Sun, "Deep Residual Learning for Image Recognition," 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Las Vegas, NV, USA, 2016, pp. 770-778, doi: 10.1109/CVPR.2016.90.
- [32] K. Simonyan and A. Zisserman, "Very Deep Convolutional Networks for Large-Scale Image Recognition." arXiv, Apr. 10, 2015. doi: 10.48550/arXiv.1409.1556.
- [33] "Intel RealSense D400 series product family Datasheet," Intel® RealSense™ Developer Documentation. [Online]. Available: <https://dev.intelrealsense.com/docs/intel-realsense-d400-series-product-family-datasheet>. [Accessed: 14-Apr-2023].

From Phishing Behavior Analysis and Feature Selection to Enhance Prediction Rate in Phishing Detection

Asmaa Reda Omar, Shereen Taie, Masoud E. Shaheen
Computer Science Department,
Faculty of Computers and Information,
Fayoum University, Fayoum 63514, Egypt

Abstract—Phishing incidents have captured the attention of security experts and end users in recent years as they have become more frequent, widespread, and sophisticated. The researchers offered a variety of strategies for detecting phishing attacks. Over time, these approaches suffer from insufficient performance and the inability to identify zero attacks. One of the limitations with these methods is that phishing techniques are constantly evolving, and the proposed methods are not keeping up, making it a hard nut to crack. The objective of this research is to develop a URL phishing detection model that can demonstrate its robustness against constantly changing attacks. One of the most significant contributions of this paper is the selection of a novel combination of features based on literal and recent phishing behavior analysis. This makes the model competent sufficient to recognize zero attacks and able to adjust to changes in phishing attacks. Furthermore, eleven machine learning classification techniques are utilized for classification tasks and comparative objectives. Moreover, three datasets with different instance distributions were constructed at different times for the model's initial construction and evaluation. Several experiments were carried out to investigate and evaluate the proposed model's performance, effectiveness, and robustness. The experiments' findings demonstrated that the GaussianNB method is the most durable, capable of maintaining performance even in the absence of retraining. Additionally, the LightGBM, Random Forest, and GradientBoost algorithms had the highest levels of performance, which they were able to maintain by routinely retraining the model with newer types of attacks. Models that employed these three suggested algorithms outperformed other current detection models with an average accuracy of about 99.7%, making them promising.

Keywords—Gradient boosting; light GBM; machine learning; phishing; phishing URL; random forest

I. INTRODUCTION

Phishing is a crime to steal personal data and financial account credentials by employing social engineering and technical deception. This type of attack leads victims to deal with counterfeit websites and fool them into believing that they are legitimate and trusted ones by using deceptive e-messages with deceptive e-addresses. These sites trick recipients into revealing extensive financial and personal information, leading to significant aggregate identity theft and financial losses. These attacks could also instill malware onto victims' computers to directly steal credentials, often using systems that intercept victims' account data, user names, and passwords, or misdirect consumers to counterfeit websites [9]. Phishing is a significant

threat to Internet users. It also causes pecuniary loss and reputational impairment to the targets, like universities, companies, charities, and government entities. The first phishing attack was on E-Gold in June 2001 [25]. Although it was not considered successful, it planted a vital seed, and it established the basics of how phishers would operate going forward and still do, in large part, today. Phishers in late 2003 registered many domains that looked like legitimate sites such as eBay and PayPal. By the beginning of 2004, they were achieving considerable success that included attacks on banking sites. Since then, they have improved their methods to be more sophisticated, but they all still work on the same basic concept, which has proven to be quite effective. Phishing attacks result in a colossal loss of sensitive/personal information and even funds whose total amount could be billions of dollars in one year [31].

Since the beginning of 2020, the Anti-Phishing Working Group¹ (APWG) was tracking between 68,000 and 94,000 attacks each month. In the fourth quarter of 2021, APWG saw 888,585 attacks, which was the previous high. March 2022 had the highest monthly total in APWG's reporting history with 384,291 attacks. APWG recorded a total of 1,025,968 phishing attacks in the first quarter of 2022. This quarter's phishing activity was the worst that the APWG has ever recorded, and it was also the first time that the quarterly total exceeded one million. The number of phishing attacks has more than tripled every year.[8] According to studies on the user experiences of phishing attacks [33], [20], computer users are susceptible to phishing for the following reasons: Users improve their confidence and vulnerability as a result of decreasing their chances of falling victim to a phishing attack. Additionally, they lack a thorough understanding of URLs, are unaware of trustworthy websites, and are unable to view the complete URL of a web page because of redirectors or hidden URLs. They do not have much time to check the URL or access certain online pages mistakenly. They are unable to discriminate between legitimate and phishing web pages. Regardless of how important caution and experience are to the user, it is not entirely possible to prevent users from being caught in phishing attacks using their expertise. Technological advancement has provided phishers with better tools to launch dangerous and sophisticated attacks, making even the savviest internet users vulnerable. [18] For instance, Examining URLs carefully and avoiding sites that do not have

¹<https://apwg.org/>

an SSL certificate have been one of the main recommendations for avoiding phishing sites for many years. A website that has "HTTPS" in the URL is one that is secured by the HTTPS encryption protocol and has an SSL certificate. This method, however, is no longer effective for identifying suspicious websites. According to APWG's report [9], SSL was used by 84 percent of the phishing sites that were examined in the fourth quarter of 2020. This with quarterly increases of about 3%. To increase the success of phishing attacks, attackers have considered end-user personality traits, particularly the ability to deceive experienced users. A spear phishing attack is one that targets a specific organization, business, or individual. This type of attack is not typically carried out by random attackers, but rather by criminals seeking financial gain, trade secrets, or military information. Furthermore, some active attackers constantly innovate and learn how to circumvent new defensive methods, causing attacks to evolve on a daily basis and luring victims into gaining access to their accounts and financial information.

Since 2004, researchers have been working to combat phishing, which has become such a severe menace that it has caused significant damage. As the term 'phishing' revealed on DBLP² (Digital Bibliography & Library Project), the number of research articles released about detecting phishing attacks increases year after year. Phishing attacks exploit human users' weaknesses, and attackers are always devising new strategies to avoid detection. As a result, additional assistance systems are required to secure the systems/users. As decision support tools for users, software-based approaches are preferred. These approaches are classified as list-based, search engine-based, visual similarity-based, and machine learning-based. In dealing with phishing attacks, the machine learning-based strategy is the most successful. All researchers work for the same objectives: high detection accuracy, detection stability, fast detection, zero-day detection, language independence, and real-time detection. There are however some drawbacks that researchers must contend with, such as restricted datasets and the requirement for up-to-date information as phishing strategies evolve; additional features are difficult to obtain, slow, third-party dependant, and time consuming. As a result, certain machine learning systems need a significant amount of computing to acquire and calculate the features of diverse sources. In addition, the solution must be constantly improved to deal with changes in attack technique.[18] On the attacker's side, the technologies' support to attackers allows them to effortlessly deceive the victims. Consequently, phishing is one of the most persistent and rapidly growing online threats; identifying phishing attacks is one of the ongoing issues, and the hunt for a better solution continues.

This paper proposes new models for detecting URL phishing using a new set of fourteen robustness features. These features were chosen after observing the most recent and previous phishing attacks and focusing on URL phishing detection models and the literature features in order to consider the most important features and build a robust classification model that can deal with ever-evolving attacks. Furthermore, three new datasets were created at various points in time, one for building the model and the others for testing and measuring the model's performance and robustness. Eleven different

machine learning algorithms were evaluated to determine the model's best classification performance. Several experiments were carried out in order to assess the models. The main contributions of this paper are as follows:

- Introducing a novel combination of phishing URL detection features based on observations of old and recent phishing attacks. To the best of our knowledge, this is the first paper to analyze such criteria while constructing a feature set for the phishing detection system. The main objective of this approach is to ascertain how the phishing feature set can be sufficiently integrated into an effective countermeasure that can handle constantly changing attacks.
- Implementing a phishing URL detection model that is difficult for attackers to avoid and outperform other existing detection models. The proposed model could maintain its performance and detect any phishing URL whether it came from the pretrained or new datasets, even if the trained dataset was outdated, making it a promising solution for the phishing detection problem.
- Developing a robustness test utilizing three new URL datasets (phishing / genuine) gathered at different times over a three-year period to assess the performance of the proposed model.
- Examining the effect of retraining on model performance to emphasize the importance of regular model retraining for newer types of attacks, as well as having a robustness feature for dealing with constantly evolving attacks.

The remainder of this paper is organized as follows; the next section provides a literature review. Our methodology is proposed in Section III. Section IV highlights the experiments and evaluations of our proposed model. Section V concludes this paper, along with future work and directions.

II. RELATED WORK

Various methods and approaches have been investigated in order to understand and address phishing attacks. There are two types of phishing attack detection methods: user education-based and software-based. User education-based approaches try to improve users' ability to detect phishing attacks. These approaches teach people how to distinguish between authentic and phishing websites and emails. Software-based approaches are preferred as decision support systems for the user; these approaches are further classified into four types: blacklisting, visual similarity, machine learning, and hybrid methods. The widely used approaches to detect phishing websites is those based on machine learning. Classification, one of the primary areas of machine learning algorithms, is a widely used strategy for detecting phishing websites. The four stages of classification are typically preprocessing, feature generation, feature selection, and classification. The primary issue of classification algorithms is improving accuracy. Improving each categorization process may result in increased overall accuracy. In this section, we will concentrate on the most relevant and significant publications, as well as the existing methodologies for detecting phishing attacks that have been proposed in the literature.

²<https://dblp.org/>

Authors at [10] examined three important machine learning classifiers, Artificial Neuron Network (ANN), K-Nearest Neighbor (K-NN), and Decision Tree (C4.5), to cast with Random Forest Classifiers (RFC) in order to present a prototype for detecting phishing attacks on a website using the machine learning algorithm. According to the study, RFC outperforms other classifiers in terms of detection accuracy, scoring 97.33%. 4898 legitimate and 6157 phished websites were used in the experiment, and the researchers came to the conclusion that adding more variables to the process will increase the detection accuracy.

In this research [32], the authors employ a machine learning technique to handle the phishing problem, producing a model that uses 30 different features for phishing identification with three different algorithms: Random Forest RF, Support Vector Machine SVM, and classification tree CT. They create five alternative classification situations, including each algorithm alone, the combination of AND Techniques, and the combination of OR Techniques. The experiment results reveal that the Classification Trees technique has the most effectiveness in predicting whether a URL is secure or not, with an accuracy of 90% across a set of website links.

Authors at [21] examine different machine learning algorithms, including K-Nearest Neighbors (KNN), Decision Tree (DT), Support Vector Machines (SVM), Logistic Regression (LR), Random Forest (RF), and Extra Trees, to determine the best technique for detecting phishing websites. After comparing all of these techniques, authors decided that the Random Forest Classifier is the best for Phishing Website Detection. The authors at [27] compared the use of Random Forest, probabilistic neural networks, and XGBOOST in detecting Phishing and discovered that XGBOOST produced the best results in terms of MCC, F.score, and accuracy. This research [22] examines hyperlinks in HTML source code to detect phishing websites. Authors present a novel phishing detection approach that is client-side, language-independent, and achieves more than 98.4% accuracy when the Logistic Regression algorithm is used.

Authors at [7] propose a machine learning-based detection model and compare various algorithms. They also used various feature selection tools to select the most valuable features in 20 of the 48 features. According to their conclusion, Random Forest is the most effective classifier to use because it detected a phishing attack with 98.11 accuracy in 2.44 seconds. Fifteen features from various classes were chosen in this paper [34]. Five machine learning classifiers were tested, and it was discovered that random forest had the highest detection accuracy (94.79%). This study investigates the importance of each feature class and all potential combinations of feature classes. Authors in this research [19] created a phishing detection approach that only requires nine lexical features to detect phishing attacks. Their dataset contains 11964 instances of legitimate and phishing URLs. They tested their approach on various machine learning classifiers, including Random Forest, k-Nearest-Neighbor, support vector machine, and logistic regression, and found that the Random Forest algorithm had the highest accuracy of 99.57%. The authors claim that their approach's main contributions are third-party independence, real-time detection, detection of new websites, and use of limited features.

The authors of this paper [29] show that a machine learning model trained on old datasets can perform well when tested on those same old datasets, but when tested on new datasets, using the same features in both cases, its performance noticeably degrades. They also show that SVM is the most resistant to the new tactics employed by the current phishing attacks among the widely used machine learning algorithms. With the newly created dataset, their experimental findings revealed that Random Forest is the most effective strategy among all methods that were tested, including Support Vector Machines (SVM), k-Nearest Neighbors (kNN), Naive Bayes (NB), and Logistic Regression (LR).

Authors at [11] identify an effective machine learning approach for phishing URLs detection based on precision, false-positive rate, and false-negative rate. To ascertain the classification accuracy in phishing detection, different classifiers including Random Forest, Linear SVM, SVM Polynomial Kernel, and SVM Sigmoid Kernel were used. With an accuracy of about 97.42%, the result showed that Random Forest outperformed the other three machine learning algorithms. For similar purposes, six distinct machine learning classification techniques are used to identify phishing websites in this study [23]. The Gradient Boost Classifier had the best possible accuracy of 94.75%, while the Random Forest Classifier got the highest possible accuracy of 97.17%. Provisioning accuracy for the Decision Tree classifier is 94.69%. In contrast, SVM has a provisioning accuracy of 56.04%, KNN has a provisioning accuracy of 60.45%, and Logistic Regression has a provisioning accuracy of 92.76%.

Authors of [6] investigated the predictive performance of a number of machine learning techniques, such as Random Forests (RF), Logistic Regression (LR), Classification and Regression Trees (CART), Neural Networks (NNet), Support Vector Machines (SVM), Bayesian Additive Regression Trees (BART), and other models of AI algorithm. Based on their comparison results, the Gradient Boosting Classifier and Random Forest Classifier had the highest accuracy. Using a dataset from a phishing website called "phishing.csv," authors in this article [14] examined the accuracy of XGBoost Classifier, Decision Tree Classifier, Random Forest Classifier, SVM Classifier, KNN Model, Logistic Regression Model, and AdaBoost Classifier methods. XGBoost Classifier & Random Forest Classifier had better accuracy according to their results, even after applying SMOTE and PCA Techniques to the dataset to account for accuracy discrepancies.

This study [16] suggests a hybrid feature-based anti-phishing technique that only uses client-side URL and hyperlink data to extract features. In order to conduct experiments utilizing well-known machine learning classification algorithms, they also create a new dataset. Their test results demonstrate that the suggested phishing detection method is superior than conventional methods, with a detection accuracy of 99.17% using the XG Boost technique. Random Forest, Decision Tree, Light GBM, Logistic Regression, and Support Vector Machine methods are compared in this study [5] to evaluate and choose the best classification algorithm for the phishing problem. Their findings demonstrate that the Light GBM algorithm delivered the greatest results.

Considering the feature selection, the authors of this research [30] discuss the efficacy of two feature selection

methods, Omitting Redundant (FSOR) and Filtering Method (FSFM), in detecting Phishing Websites and compare the efficacy of three different machine learning algorithms: Naive Bayes (NB), Multilayer Perceptron (MLP), and Random Forest (RF). According to their empirical data, the optimized Random Forest (RFPT) classifier with feature selection by the FSFM outperforms all other strategies. Moreover, a framework for feature selection was described by the authors at [13], [12]. They presented an empirical hybrid framework with two stages that takes into account the filter and wrapper method. Those researches involve applying models with optimized (hyperparameter) parameters, such as Artificial Neural Network, XGBoost Classifier, and Random Forest Classifier, on two phishing datasets. The outcomes demonstrated that the XGBoost Classifier performed better than other classifiers.

Authors In this paper [26], proposed a strategy to identify the critical features by combining correlation and recursive feature elimination. The first scenario combines power predictive score correlation and recursive feature elimination, and the second scenario combines the maximal information coefficient correlation and recursive feature deletion. The third scenario combines recursive feature removal and Spearman correlation. According to their experimental findings, even with the lowest feature subset, all three scenarios from the combined findings of the offered approaches reach a high level of accuracy. Additionally, they discovered that Random Forest (RF) performs more accurately in identifying phishing websites.

A systematic review of phishing detection systems based on machine learning was carried out at [17]. The authors noted that studies that include more features have higher performance findings, studies that contain more features are more often used, and runtime performance was overlooked by most systems. In [15], the authors conducted a similar systematic review on machine learning-based phishing detection systems. They ranked classifiers based on the number of studies that used them. However, their conclusion is based solely on the statistical analysis of the studies under consideration. Moreover, the authors of [4] provide a systematic review of existing studies concentrating on Machine Learning and Deep Learning based phishing website detection in order to identify the major gaps and provide appropriate solutions. Their findings show that the imbalanced dataset use, issues with appropriate feature selection techniques, source selection, train-test split ratios, dataset size, inclusion and exclusion of website features, and run-time analysis are the main contributors to these flaws. Moreover, the results show that Random Forest, in the vast majority of peer-reviewed research articles, has the best overall accuracy.

In summary, the majority of the studies reviewed in this paper concentrate on the classification phase. Well-known machine learning algorithms like KNN, SVM, XGBoost Classifier, Decision Tree, Logistic Regression (LR), and Random Forest were used in the majority of the research. The Random Forest and the XGBoost Classifier algorithms are consistently yielding the best performance results when they were compared to other algorithms. The other part of the previous works is worked on feature selection phase through evolutionary and metaheuristic algorithms, and also some authors proposed hybrid feature selection models. The feature

set can be derived from a variety of sources, including the page source, search engine, URL, website traffic, and DNS. High detection accuracy, detection stability, quick detection, zero-day detection, language independence, and real-time detection are the universal goals shared by all researchers.

Additionally, these methods have a number of limitations that must be addressed in order to detect phishing URLs. To begin, the limited datasets and the requirement for updated datasets as phishing techniques develop; the majority of the work has employed preclassified and smaller datasets, which do not produce exact efficiency and precision when applied to great and real-world datasets. Additionally these approaches suffer from insufficient performance and the inability to identify zero attacks over time; as phishing techniques are always evolving, and the proposed methods are not keeping up. Second, the previously extracted features are comprehensive, with the limitation that such extraction requires a significant amount of time. Third, certain approaches used statistical methods to choose relevant features, while others proposed their own features; researchers often did not consider how their features can be defeated. Although these strategies have been effectively implemented in various approaches, they generate inaccurate results when domain knowledge is not amplified. Fourth, the previous methodologies offered lack advanced evaluation measures; the majority of the offered solutions don't concentrate at robustness and accuracy over time. To improve the classification accuracy of phishing websites, our suggested methodology concentrated on the feature selection phase as well as the classification phase. Furthermore, various datasets gathered over time and various experiments are used to test the model's performance and robustness.

Phishing incurs significant financial costs and can harm a company's, government entity's, or university's reputation. It also harms the systems of web hosts, email providers who must protect users from phishing spam, and responders tasked with defending networks and users. The number of phishing attacks discovered is constantly increasing. Phishing remains one of the most persistent and rapidly evolving online threats. As a result, the search for a better solution to overcome the limitations of existing solutions continues.

III. METHODOLOGY

A. Datasets

There are no benchmark datasets for detecting phishing websites. This is due to the limited lifespan of phishing websites and the inability of content-based analysis to exploit dead URLs. Furthermore, the majority of datasets are restricted to experimental feature values with no URL references. This prevents datasets from being reproduced or tested with different features. Moreover, the authors of this study [18] noticed a decline in performance when previous methods were evaluated on a current dataset, even after retraining. This drop in performance highlights the necessity of using a broad, high-quality, and up-to-date dataset when creating models. It is critical to have a robust model that can deal with constantly shifting attacks. Training classification algorithms on one dataset and then testing on a different recent one is one strategy to assess the robustness of the detection model.

As a result, three URL datasets (phishing and legitimate URLs) were collected over a three-year period. The first dataset (24,200 URLs) was collected in June 2020 for use in model building (training and initial testing), followed by the second (16,028 URLs) and the third (15,974 URLs) in October 2021 and January 2022, respectively. Both datasets will be used later to test the model’s robustness without and with retraining. The classification of these datasets is displayed in Tables I, II, III.

Legitimate webpage URLs are gathered from Alexa³, University of New Brunswick open databases⁴, and Mendeley Data repository⁵. For Alexa it only recommends top-ranked domains without mentioning sub-domains or paths. As a result, for the diversity of URLs, those lists cannot be used directly, especially when features such as subdomains and paths are used. To address this issue and provide a realistic dataset, the collected domains are used as seeds for crawling 10 URLs per domain. It was then processed through to remove duplicate and domain-only URLs, allowing for more representative samples. Phishtank is used to collect phishing URLs. All duplicate and defunct URLs are deleted during preprocessing of the collected URLs, and a maximum of 10 URLs with the same domain name are preserved.

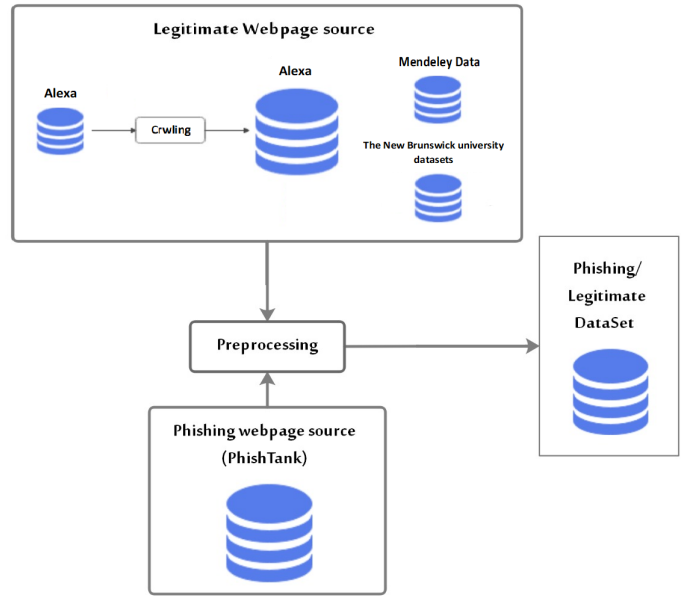


Fig. 1. Dataset construction process.

TABLE I. DATASET 1 (24,200 URLs) JUNE 2020

Database	Number of instances	Phishing/legitimate
PhishTank dataset	4,010 out of 6,233	Phishing
Alexa top-ranked websites	2,019 ended with 20,190	Legitimate

TABLE II. DATASET 2 (16,028 URLs) OCTOBER 2021

Database	Number of instances	Phishing/legitimate
PhishTank dataset	2,652 out of 4,862	Phishing
Alexa top-ranked websites	1,000 ended with 10,000	Legitimate
Mendeley data	3367	Legitimate

TABLE III. DATASET 3 (15,974 URLs) JANUARY 2022

Database	Number of instances	Phishing/legitimate
PhishTank dataset	2,659 out of 4,312	Phishing
the New Brunswick university datasets	2315	Legitimate
Alexa top-ranked websites	1,100 ended 11,000	Legitimate

B. Preprocessing

After collecting each dataset, it must be prepared for the feature extraction procedure. As soon as the dataset is collected, the preparation procedure begins. Three datasets and three distinct preparation processes have been completed. After gathering the dataset, the next stage is data preprocessing, which involves:

1. Eliminating redundant URLs and ensuring there are no intersections between the URLs in the three datasets.
2. Filtering all URLs to avoid broken URLs to ensure that the required accurate features are extracted during the feature extraction procedure.

It is important to note that using a fresh dataset is necessary because the majority of URLs provided by PhishTank or other providers won’t likely be active for three months or less. The collected phishing URLs were 4,010 out of 6,233 in the first dataset, 2,659 out of 4,312 in the second dataset, and 2,652 out of 4,862 in the third dataset. For the legitimate URLs, to ensure there are no redundancies, the URLs were collected with different ranking values. As a result, we obtained three distinct datasets. The general procedure used to create the dataset is shown in Fig. 1. The dataset is now ready for the next stage.

C. Feature Selection

The process of feature selection is crucial because correctly chosen features can improve classifier performance, while poorly chosen features can have the opposite effect. Feature selection is frequently accomplished by extracting as many features as possible and weighting them statistically in order to select the most weighted and vital aspects. This procedure generates dataset-dependent features that result in the best model performance. This performance, however, is not permanent because the features gradually lose significance and weight with time and a use of new datasets. This method of selection is one of the primary causes of the reduction in performance observed by prior works when their models were tested on new datasets. As a result, selecting robust features is a key goal to ensure that the classification model’s performance is maintained over time. A feature or collection of features

³<https://www.alexa.com/>

⁴<https://www.unb.ca/cic/datasets/url-2016.html>

⁵<https://data.mendeley.com/datasets/c2gw7fy2j4/3>

is considered robust if a phisher is unable to readily build a phishing website with features that mimic those of a reliable website.

In the next subsection, a phishing newest behavior is evaluated to serve as a guide in the selection process in order to identify a robust feature collection and efficiently detect phishing attacks. It is based on the most recent APWG reports as well as the most recent annual study of the scope and distribution of phishing by Interisel Consulting Group⁶. This part aims to increase understanding of the rate at which phishing is evolving, gather and assess the most recent phishing attack characteristics, and pinpoint which characteristics suggest more effective ways to combat phishing. Furthermore, it recommends which vulnerable features should be changed or ignored, as well as which additional phishing features are necessary.

1) Phishing Behaviour: In regard to phishing and how it has evolved, phishers always develop and vary their methods and approaches in order to avoid being detected and enticing victims. Thus, phishing is a significant hazard to millions of consumers, and it remains one of the most rapidly growing and persistent online threats confronting today's businesses. [1] So, staying up to date on the latest phishing strategies and phisher habits will keep us one step ahead of phishing attacks.

According to the authors of this report [28], the average lifetime of a phishing attack from start to the last victim is only 21 hours. Moreover, the Anti-Phishing Working Group's Global Phishing Survey [3], indicates that when victims begin accessing phishing sites, antiphishing entities take an average of 8 hours and 44 minutes to detect the attack. During this time, 63% of victims are exploited before the attack is detected and stopped. Therefore, in order to detect zero phishing attacks, you must not rely only on phishing blacklists. Additionally, you must work with a fresh dataset to ensure that you have the necessary features before the URL expires.

According to the data in [1], many phishing sites go undiscovered for days, if not months, allowing them to carry out their attacks. Around 78% of malicious sites were identified during the first year of registration, and 22% of phishing domains were older than a year. According to the authors of [1], the majority of malicious domains are used for phishing within the first three days of registration, while some domains are used within 14 days. Phishers typically employ them quickly to escape discovery. Some phishers recently waited more than 90 days after registering their domains to move out of the new domain status, which earns low reputation scores from security and anti-spam firms. According to their findings, 17% of maliciously registered domains were not used within 90 days of registration. **In this instance, the "Domain age" feature is still a good option from this standpoint.**

According to [24], 42% of phishing domains are compromised, and 58% of them have malicious registrations. Furthermore, the authors of [1] showed that 61% of the 99,412 domains utilized for phishing during their study period were maliciously registered, with the remaining 39% classed as compromised. In contrast to phishing that occurs on compromised (hacked) domains held by innocent parties, maliciously

registered domains are domain names registered by phishers to conduct phishing sites. According to the authors of a recent Interisel Consulting Group analysis [2], phishers hosted more attacks on compromised sites than malicious domains (a 53:47 ratio). This is consistent with the idea that hacked hostnames are appealing to phishers since they are more difficult to detect.

Many malicious domains have distinguishing features that may be utilized to rapidly and accurately detect them. In the event of hacked domains, however, it has legitimate features that will result in a high percentage of false-negative rates. To address this issue, we must distinguish between hacked and legitimate domains. We have principally based on three aspects, from the most recent common and best practices in the field: **1. A WHOIS-based feature (the domain's age), 2. An engine-based feature (web traffic), and 3. A feature based on HTML (if it has fake forms, broken hyperlinks, or foreign hyperlinks). All of these factors can be used to distinguish between legitimate and compromised domains.**

The majority of phishing attacks target just a few domain registries, domain registrars, and hosting companies.[24] About 9% of Phishing happens at a small number of providers that provide subdomain services [1]. As a member of the APWG, RiskIQ continuously analyzes the domain name system for instances of phishing. They discovered that out of the 6,153 distinct phishing URLs submitted to the APWG's eCrime Exchange in Q4 2020, 3,598 were hosted on unique second-level domains and 15 more were hosted on unique IP addresses without domains.[9]

In addition, Axur (an APWG member company) discovered that 63 percent of phishing domain names lacked a catchy keyword or contained or imitated brand names (like "accountupdate" or "sale"). In Q2 of 2020, it was 58%, while in 2019, it was 33%. To be clear, phishers aim to escape detection by utilizing generic terms instead of brand names in their selected domain names since telltale words in domain names are easier for defenders to locate.[9] Instead, phishers attempt to fool Internet users by taking advantage of the fact that characters in different language scripts may be virtually (or entirely) identical, allowing the phisher to impersonate a brand name. Phishers do employ them on occasion, though, since they can mislead the human eye and avoid detection by security tools that do not identify the words they are designed to represent [8].

In certain situations, **lexically-based characteristics, such as equal or hexadecimal in the URL and digits in the domain name**, might be used as a warning sign for phisher deceit. Moreover, a good signal for a phishing URL may be found in **the WHOIS-based feature; Registrar Name**, which phishers hide to avoid being blacklisted. Furthermore, the usage of subdomains that lead to phishing URLs is also indicated by **URL-based characteristics including URL length, host length, path length, and the number of dots in the URL.**

According to [9] several deception strategies phishers use to deceive consumers include encryption designed. In Q4 2020, 84 percent of phishing sites used SSL/TLS certificates, up 3 percent quarter over quarter, and 10% year over year. Furthermore, they discovered that 89 percent of the certificates used in phishing were Domain Valid "DV" certificates; these are routinely offered for free, and because they do not need

⁶<https://www.interisle.net/index.html>

human authentication, simply the domain name being used, they provide the lowest type of certificate validation. **In this case, the https/http check is not a sign of a phishing attack.** however, with a little motivation, we can still take use of this feature and try to leverage this clue to provide a low false-positive rate.

Based on these indications, fourteen features are in a great position to detect and prevent the bulk of phishing that occurs on maliciously and compromised domains. The structure, content, behavior, and URL of phishing websites have been considered. The selection of these features is one of the paper's main contributions. A novel fourteen-feature combination was presented to improve the detection accuracy of phishing URLs and verify resilience to deal with ever-evolving attacks.

D. Feature Extraction

This phase extracts features from the URL dataset. The extracted features are categorized as HTML-Based, URL-Based, Lexical-Based, WHOIS-Based, and Engine-Based Features, for a total of 14 features.

A data collector script was created. APIs are used for features that rely on a third party, such as WHOIS and Engine function. HTML parsing was necessary for the HTML features. Other features, such as URL and Lexical, were extracted quickly. Next the extraction and storage of these features for each URL, literature-based heuristics were employed to construct the feature vector, as illustrated below. To produce the labeled dataset, each URL needs its own feature vector. The feature vector corresponding to each URL is specified as $F = F1, F2, F3, \dots, F14$. Each attribute generates a value in the form of 1 or 0, with 1 indicating phishing and 0 indicating legitimate. Finally, the feature vectors were stored by the script into the database to be used later in the classification stage.

URL-BASED FEATURES:

- Feature 1 (F1): URL length
Although some phishers employ the accessible URL shortening tool, others continue to use the lengthy URL in the address bar to conceal the brand or company name. Legitimate URLs are often short in order to be easily remembered. Many phishing URLs, on the other hand, are lengthier since they rely on clicking on the phishing URL, and the phisher usually hides the redirected information in that long URL. URLs that are longer than 54 characters are given 1 (phishing), otherwise 0 (legitimate).
- Feature 2 (F2): Sub-domain
The URL of the majority of phishing websites has more than two subdomains. Each domain is separated by a dot (.), and it is uncommon to see more than one subdomain in the URL of a legitimate site. So, URLs with more than three dots are assigned 1 (phishing), otherwise 0 (legitimate).
- Feature 3 (F3): Secure Connection
Although it is simple to obtain a free SSL certificate from free sources such as Let's Encrypt, some phishers continue to avoid utilizing the HTTPS protocol. With a little drive, we can still make use of this feature. A

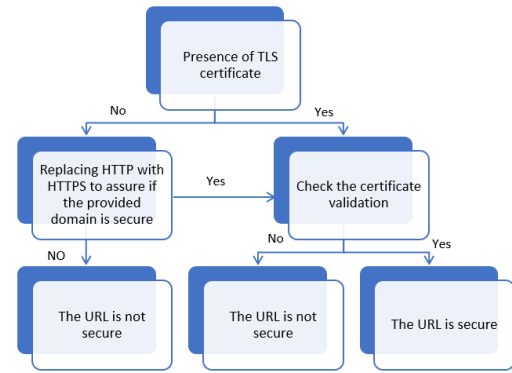


Fig. 2. Flowchart for secure connection check.

flowchart for the security check was shown in Fig. 2. Simultaneously, the vast majority of trustworthy websites are secure. Furthermore, even if the supplied URL is not secure, the URL is tested after replacing HTTP with HTTPS to determine whether the provided domain is safe or not, resulting in a more accurate extraction by lowering the false-positive and false-negative rate. Furthermore, for each domain having a certificate, we validate the certificate. Depending on whether the certificate is genuine, the value assigned to this feature is 1 (phishing) or 0 (legitimate).

- Feature 4 (F4): Host Length
Like URL length, genuine URLs are frequently short in order to be easily remembered and swiftly published, but phishing URLs are longer in order to conceal the identity of the site. So, URLs with host length more than 20 characters are allocated 1 (phishing), else 0 (legitimate).
- Feature 5 (F5): Path Length
The same as URL and host length, should not be too lengthy to ensure that the whole URL is not too long as a result. So, URLs with path length more than 35 characters are assigned 1 (phishing), otherwise 0 (legitimate).

HTML-BASED FEATURES:

- Feature 6 (F6): Fake Form
Following HTML processing, look for the page form. Assume the page has forms with external actions. In such instances, it is a fake form since it is most likely a phishing form that takes data and transmits it to an external processing website. So, depending on whether the page contains external form activities or not, the value assigned to this feature is 1 (phishing) or 0 (Legitimate).
- Feature 7 (F7): Broken Hyperlinks
The majority of phishers are just interested in one page that they are releasing. Most likely, most of the hyperlinks on the website are broken, thus if we discover that the majority of the hyperlinks are broken, it is an indication that the URL may be a phishing

URL. So, if the percentage of broken hyperlinks is greater than 25%, the feature is assigned 1 (phishing), otherwise it is assigned 0. (Legitimate).

- Feature 8 (F8): Foreign Hyperlinks
To prevent having broken hyperlinks on the website, most phishing pages use external functional URLs. So, if we discover that the majority of the hyperlinks are foreign, it is a strong sign that the URL is a phishing URL. If the percentage of foreign hyperlinks is more than 50%, the characteristic is assigned 1 (phishing), otherwise it is assigned 0. (Legitimate).

LEXICAL-BASED FEATURES:

- Feature 9 (F9): Equal
Because “=” is utilized to obtain input from the end-user, most professional websites are no longer used due to the risk of data sniffing. It is preferable to avoid URLs with this complex and hazardous lexical character by assigning 1 (phishing) to URLs with “=” else 0 (Legitimate).
- Feature10 (F10): Hexadecimal
Because URL encoding substitutes unsafe ASCII characters with “%” followed by two hexadecimal numbers, it is best to avoid using “%” in URLs such that URLs containing “%” symbols have a value of 1 (phishing) otherwise 0. (Legitimate).
- Feature11 (F11): Digit
Domains with numerals are perplexing. Furthermore, professional websites do not use domain names that include digits, and many phishers utilize numbers to fool end-users, such as naming the domain apple.com instead of apple.com. If the IP address is present in the URL, it is a malicious URL, and it will be allocated 1; otherwise, it is a genuine URL, and it will be assigned 0.

WHOIS-BASED FEATURES:

- Feature12 (F12): Host Age
The normal procedure for registering a domain is to register domain and then construct the website as rich as possible, which will take some time. The founder begins to declare and publicize the URL, or does not announce at all and instead relies on search engines such as Google to do so. On the contrary, most phishers register a domain and utilize it rapidly in order to evade discovery. As a result, it is preferable to avoid domains with an age of less than 90 days by assigning it 1 (phishing) else 0 (Legitimate).
- Feature13 (F13): Registrar Name
The registrar is the entity where the domain name is registered. According to the Internet Corporation for Assigned Names and Numbers (ICANN), there were over a thousand ICANN-accredited registrars globally by the middle of 2017, with the number steadily rising. Unless they hide it for any reason, we can determine who owns most domains. If you get a URL as an announcement with an unknown registrant name, it is most likely a phishing URL and will be assigned 1 (phishing), else 0 (no phishing) (Legitimate).

ENGINE-BASED FEATURES:

- Feature14 (F14): Web traffic
The web traffic, which can be collected from the Alexa database, is the total number of users who have visited a URL or webpage. Assume the website is among the top 500 thousand. In such instances, unless it is hacked to be used as a phishing website, it is difficult to be a phishing website. The likelihood of a phishing website growing as its popularity decreases. As a result, URLs with a rank more than 500 thousand are allocated 1 (phishing), while others are assigned 0. (Legitimate).

E. Classification Phase

In this phase, eleven classification algorithms; which were found to be the most adaptable in phishing websites detection, including Random Forest (RF), Gradient Boosting (GBoost), LightGBM (LGBM), Support Vector Machines (SVM), Logistic Regression (LR), k-nearest neighbors (KNN), Gaussian Naive Bayes(GaussianNB), CatBoost, Decision Tree (DT), Linear Discriminant Analysis (LDA), and Quadratic Discriminant Analysis (QDA), are used for classification activities and comparison purposes.

IV. EXPERIMENTAL AND EVALUATION

A. Evaluation Criteria

To evaluate the effectiveness of the proposed model, there are numerous assessment tools available. Calculating the accuracy rates will be accurate and efficient due to the used binary datasets. In order to assess how accurate our model is, we pay attention to its correctness.

Accuracy (A): It measures the overall percentage of predictions that come true as in Eq. (1).

$$Accuracy(A) = \frac{TP + TN}{TP + TN + FP + FN} \quad (1)$$

Properly identified cases are denoted by the letters TP, correctly rejected instances by the letters TN, incorrectly identified instances by the letter FP, and wrongly rejected instances by the letters FN.

Moreover, security is paramount in the world of cybersecurity since phishing attempts can cause significant harm to end users. Therefore, the key goal is to protect users from phishing attacks and drastically reduce misclassification to avoid any challenges faced by the user when utilizing services. Consequently, we include Precision, Recall, and F1-Score in our evaluation.

Precision evaluates the proportion of occurrences properly identified as phishing compared to all instances identified as phishing as in Eq. (2).

$$Precision = \frac{TP}{TP + FP} \quad (2)$$

Recall: It measures the proportion of phishing incidents that are accurately identified compared to all phishing incidents as in Eq. (3).

$$Recall = \frac{TP}{TP + FN} \quad (3)$$

F1-Score: It is a weighted average of Precision and Recall as in (4).

$$F1_Score = \frac{2 * Precision * Recall}{Precision + Recall} \quad (4)$$

B. Experiments and Results

Two stages of the experiments were carried out. The first step is to assess the classifiers and choose the algorithm that performs the best. The robustness and generalizability of the proposed models are evaluated in the second stage by training the model on recent datasets without retraining it. It also conducts additional experiments to investigate the impact of retraining on model performance by testing the model with a recent dataset after retraining. Each of these stages will be thoroughly illustrated in the following subsections.

1) *Releasing the Best Classification Algorithm:* These experiments aim to determine the classification process' best performing algorithm. Random Forest (RF), Gradient Boosting (GBoost), LightGBM (LGBM), Support Vector Machines (SVM), Logistic Regression (LR), k-nearest neighbors (KNN), Gaussian Naive Bayes(GaussianNB), CatBoost, Decision Tree, Linear Discriminant Analysis (LDA), and Quadratic Discriminant Analysis (QDA) algorithms are trained and tested on the first dataset; 24,200 phishing and legitimate URLs, as shown in Table II. The dataset is randomly split into 90% and 10% of the samples for the training set and testing set, respectively. On the training set, a randomized cross-validation (10-fold) search was performed with a maximum of 1000 iterations. These algorithms' classification results after 10, 100, and 1000 iterations are shown in Table IV. All algorithms

TABLE IV. PERFORMANCE OF THE CLASSIFIERS USING 10, 100, AND 1000 ITERATIONS

Algorithm	10 iterations	100 iterations	1000 iterations
RF	99.63	99.71	99.79
GBoost	99.42	99.67	99.84
LGBM	99.67	99.84	99.84
SVM	96.66	96.87	96.99
LR	96.28	96.82	97.07
KNN	99.42	99.42	99.59
GaussianNB	98.06	98.47	98.76
CatBoost	95.83	96.49	96.82
DT	96.16	96.61	96.61
LDA	95.87	96.32	96.94
QDA	83.80	84.88	85.95

improved in performance as the number of iterations increased, as can be shown. The best performance for the LightGBM and Decision Tree algorithms was achieved after 100 iterations and

TABLE V. THE BEST PERFORMANCE OF THE CLASSIFIERS

Algorithm	Accuracy	Precision	Recall	F1-score
RF	99.79	1.00	1.00	1.00
GBoost	99.84	1.00	1.00	1.00
LGBM	99.84	1.00	0.99	1.00
SVM	96.99	0.94	0.95	0.94
LR	97.07	0.95	0.92	0.94
KNN	99.59	1.00	0.99	0.99
GaussianNB	98.76	0.97	0.90	0.98
CatBoost	96.82	0.95	0.93	0.94
DT	96.61	0.94	0.93	0.94
LDA	96.94	0.96	0.91	0.94
QDA	85.95	0.43	0.50	0.46

remained constant after 1000 iterations. The results also show a performance competition among RF, LGBM, and GBoost classifiers. To the best of our knowledge, they outperform currently available state-of-the-art phishing detection systems designed and reach the best performance with nearly identical results. The highest accuracy of the classifiers is shown in Table V, and Fig. 3.

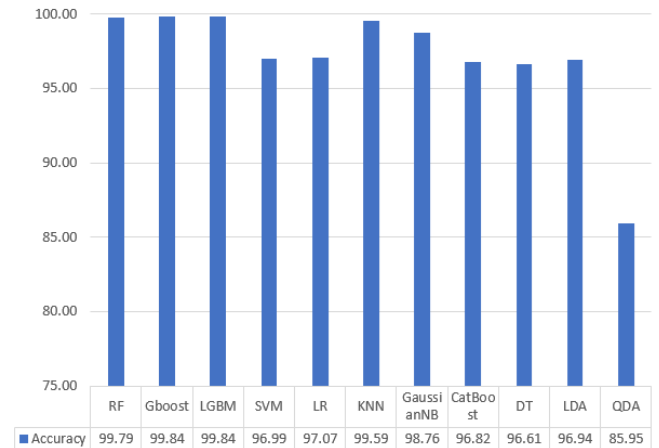


Fig. 3. The best classifier's accuracy.

2) *Future Attacks:* The goal of these experiments is to ensure that we have a robust model that can deal with ever-changing attacks. One method is to train the model on one dataset and then test it on a different, more recent one. As a result, two new datasets were used in these experiments. As shown in Tables II and III, we referred to them as the second and the third datasets.

These experiments were carried out in three steps:

- 1- Measuring model performance with new attacks.
- 2- Investigating the impact of retraining on model performance.
- 3- Emphasizing the significance of the model's regular retraining.

a) *Measuring Model Performance with New Attacks:* The first stage is to evaluate the model's performance with the new attacks, which is done by evaluating the suggested models with the second and third datasets, using all models demonstrated in the prior section. Table VI present the findings. According to the results, most of the classifiers' performance is slightly lower than in the previous experiment, with the exception of the CatBoost and DT algorithms, which both have slightly higher performance. Given that these datasets were not used in the training set, that each dataset is unique with no common URLs, and they were gathered over a three-year period, these findings could be considered good. Furthermore, the results show a decrease in performance for both the KNN and LightGBM algorithms. In terms of best performance, the second dataset indicated a competition amongst three classifiers: Gaussian NB, Random Forest, and Gradient Boost. Furthermore, the Gaussian NB classifier performs better with

TABLE VI. PERFORMANCE OF CLASSIFIERS ON THE SECOND, AND THE THIRD DATASETS

Algorithm	On the second dataset	On the third dataset
RF	98.5	98
GBoost	98.51	97.9
LGBM	95.7	83.5
SVM	95.8	95.7
LR	95.98	96.3
KNN	93.795	91
GaussianNB	98.5	98.67
CatBoost	97	97.1
DT	97	97.1
LDA	96	95.5
QDA	83.4	83.5

the third dataset. Random Forest and Gradient Boost are placed second and third in terms of performance, respectively.

The model’s efficacy and robustness are ensured by the features and classification technique used. This experiment highlights the value of the features chosen for the classification models, demonstrating that they were more resilient to new attacks and that active phishers are unable to overcome them. It also shows that the Gaussian NB algorithm’s performance has held steady over time, implying that it is the most resilient to fresh phishing attack strategies. In a close race for second place, the Random Forest and Gradient Boost algorithms both performed well.

b) Investigating the Impact of Retraining on Model Performance: The second step in these experiments is to investigate the effect of retraining on the model performance, which is accomplished by testing the models again after they’ve been retrained with the new phishing attacks. The second dataset was divided into two parts: train and test. The model was then retrained with the new training set (90% of the second dataset), with the same set of features, and tested using the new testing set (the remaining 10% of the second dataset) and the third dataset. Table VII shows the classification results.

For the new testing set (the remaining 10% of the second dataset), all of the classifiers’ performance increased and was very near to the first findings released from the initial model, emphasizing the need of retraining operations in order to preserve model performance over time. LightGBM was the most significantly improved algorithm, with its performance dropping from 99.84% accuracy to 95.68% when tested on the new dataset without retraining and returning to 99.78% accuracy when tested again but after retraining on fresh phishing attacks. For the third dataset, most classifiers’ performance increased when compared to the results of the prior test with the same dataset without retraining, as shown in Table VI. LightGBM benefitted the most after retraining, increasing its accuracy from 83.5% to 95.57%, although it was not the best accuracy classifiers received. In terms of greatest accuracy, the GaussianNB Algorithm ranks first with around 98.46%, followed by both GradientBoost and Random Forest in second place with approximately 98.3%. Despite the modest decline in performance, the GaussianNB Algorithm maintained its performance from the start of the experiments. After retraining, the performance of the CatBoost, QDA, and DT algorithms all decreased.

This experiment emphasizes the need of retraining for algorithms like LightGBM, which lose performance while

TABLE VII. PERFORMANCE OF THE RETRAINED MODELS

Algorithm	On the new testing dataset	On the third dataset
RF	99.751	98.31
GBoost	99.727	98.3
LGBM	99.776	95.57
SVM	96.943	96.13
LR	96.619	96.47
KNN	99.528	94.31
GaussianNB	98.608	98.46
CatBoost	97.042	97
DT	98.423	88.79
LDA	96.396	95.84
QDA	85.235	83.43

TABLE VIII. PERFORMANCE OF THE RETRAINED MODEL ON THE NEW TESTING DATASET

Algorithm	Accuracy
RF	99.72
GBoost	99.72
LGBM	99.73
SVM	96.98
LR	96.62
KNN	99.59
GaussianNB	98.38
CatBoost	96.85
DT	96.98
LDA	96.21
QDA	84.77

dealing with fresh datasets without retraining. Algorithms such as Random Forest and GradientBoost can deal with new attacks with a minor reduction in performance; this is regarded a satisfactory outcome if they do not regularly retrain with fresh datasets, but they are able to retain performance after retraining. The GaussianNB algorithm is the most immune to new phishing attacks without retraining and can even function effectively while being retrained.

c) Emphasizing the Significance of the Model’s Regular Retraining: The third phase emphasizes the importance of continual model retraining for more current attack types. As indicated in previous findings; Table VII, the classifiers’ performance was as excellent as it was for the first model due to retraining the model using recent attacks from the same time period as the test set. To ensure this, the third dataset is separated into train and test sets. The model was then retrained with the new training set. The new testing set is then used to test it. The classification result is shown in Table VIII below. The performance of most classifiers has improved once again, like in the prior experiment. LightGBM classifier returns to top place in terms of accuracy, followed by Random Forest and GradientBoost at the second level. The third and fourth levels are occupied by KNN and GaussianNB, respectively.

When these results were compared to the previous test results for the third dataset without any retraining, it was discovered that all algorithms outperformed their previous performance with the exception of GaussianNB, CatBoost, and DecisionTree algorithms, whose performance had a slight slip after retraining. The same result was observed while testing the third dataset after retraining the model using a portion of the second dataset, except that DecisionTree method performance rose after retraining the model with recent attacks from the same time period. Fig. 4, 5 compare models performance with and without retraining.

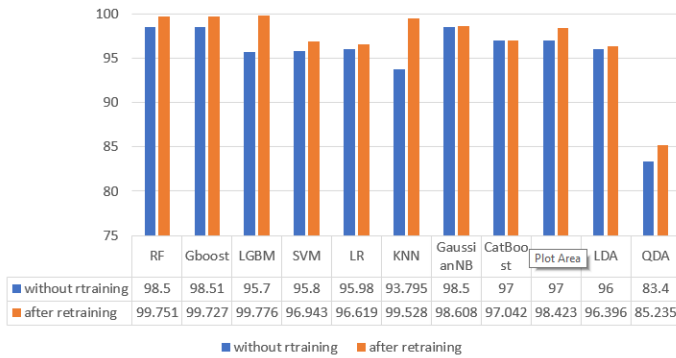


Fig. 4. The models performance on the second dataset with and without retraining.

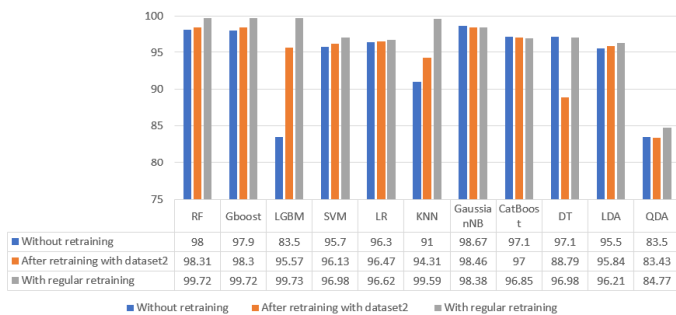


Fig. 5. The models performance on the third dataset with and without retraining.

These studies illustrate the need of having a diverse set of characteristics that can counter ever changing attacks. It also underlines the need of selecting a classification method that performs well with both previously trained and fresh datasets. Furthermore, to safeguard the model's performance, it should be retrained on a regular basis for newer sorts of attacks. Furthermore, these experiments demonstrated that the LightGBM, Random Forest, and GradientBoost algorithms performed the best and maintained their performance with regular retraining of the model with newer types of attacks. Furthermore, the GaussianNB method is the most resilient algorithm, capable of maintaining its performance even without retraining, and its performance is considered good in comparison to current best and common practices used in the field. These four proposed models demonstrate that it is tough for attackers to avoid, since it is capable of dealing with the ever-changing nature of phishing attacks. Furthermore, they outperform the other detection models currently available. To the best of our knowledge, these are the first detection models that have demonstrated their resilience and generalization by being assessed with fresh up-to-date datasets without and with retraining and indicating that they can sustain and continue to perform well.

V. CONCLUSION AND FUTURE WORK

Based on the observation of historical and contemporary phishing attacks, this article developed a unique combination of phishing URL detecting features which offered novel

detection models that used the proposed features in concert with a machine learning algorithm. Eleven alternative machine learning algorithms were examined for classification tasks and comparative objectives. For the initial model creation and the model evaluation, three datasets were created. These datasets were gathered over a three-year interval to guarantee the model's generalizability and resilience to new datasets and phishing attacks.

Through a variety of experiments, beginning with assessing the classifiers to pick the best-performing algorithm and ending with emphasizing the relevance of the model's frequent retraining, the model performance, generalization, and robustness were evaluated using appropriate evaluation metrics. Based on the experimental data, the key conclusion is that the suggested models; which utilize LightGBM, Random Forest, or GradientBoost algorithms, have the best performance with an average accuracy rate of 99.7%, outperforming all other model in the literature. Furthermore, when evaluated with newer datasets, Random Forest, and GradientBoost models comes in the second level after the GaussianNB model which is the most durable without retraining. Additionally, it demonstrated that these models are able to maintain its performance with regular retraining with newer types of attacks and with the same set of features, which is regarded an extraordinary achievement and a step forward in phishing detection technologies. Adapting various parallel processing approaches to lower the time necessary to extract the features is one potential future attempt. Furthermore, we intend to employ deep learning algorithms in a performance evaluation. Moreover, we plan to expand our work on social media platforms such as Facebook, Instagram, and others.

REFERENCES

- [1] Greg Aaron, Lyman Chapin, David Piscitello, and Dr. Colin Strutt. Phishing landscape 2020, a study of the scope and distribution of phishing, 13 October 2020.
- [2] Greg Aaron, Lyman Chapin, David Piscitello, and Dr. Colin Strutt. Phishing landscape 2022, a study of the scope and distribution of phishing, 19 July 2022.
- [3] Greg Aaron, iThreat Cyber Group, and Rod Rasmussen. Global phishing survey: trends and domain name use in 2016.
- [4] Kibreab Adane and Berhanu Beyene. Machine learning and deep learning based phishing websites detection: The current gaps and next directions. *Review of Computer Engineering Research*, 9(1):13–29, 2022.
- [5] SK Hasane Ahammad, Sunil D Kale, Gopal D Upadhye, Sandeep Dwarkanath Pande, E Venkatesh Babu, Amol V Dhumane, and Mr Dilip Kumar Jang Bahadur. Phishing url detection using machine learning methods. *Advances in Engineering Software*, 173:103288, 2022.
- [6] Ammar Almomani, Mohammad Alauthman, Mohd Taib Shatnawi, Mohammed Alweshah, Ayat Alosan, Waleed Alomoush, and Brij B Gupta. Phishing website detection with semantic features based on machine learning classifiers: A comparative study. *International Journal on Semantic Web and Information Systems (IJSWIS)*, 18(1):1–24, 2022.
- [7] Mohammad Almseidin, AlMaha Abu Zuraiq, Mouhammd Al-Kasassbeh, and Nidal Alnidami. Phishing detection based on machine learning and feature selection methods. 2019.
- [8] APWG. Phishing activity trends report (1st quarter 2022), 7 June 2022.
- [9] APWG. Phishing activity trends report (4th quarter 2020), 9 February 2021.
- [10] Abdul Basit, Maham Zafar, Abdul Rehman Javed, and Zunera Jalil. A novel ensemble machine learning method to detect phishing attack. In *2020 IEEE 23rd International Multi-topic Conference (INMIC)*, pages 1–5. IEEE, 2020.

- [11] Anuja Bhosale, Gayatri Gadas, Muskan Chavan, and Seema Hadke. Detection of phishing websites using machine learning. *International Journal of Advanced Research in Computer and Communication Engineering*, 6:490–494, 2022.
- [12] Pankaj Bhowmik and Pulak Chandra Bhowmik. A machine learning approach for phishing websites prediction with novel feature selection framework. In *Proceedings of International Conference on Fourth Industrial Revolution and Beyond 2021*, pages 357–370. Springer, 2022.
- [13] Pankaj Bhowmik, Md Sohrawordi, UA Ali, Pulak Chandra Bhowmik, et al. An empirical feature selection approach for phishing websites prediction with machine learning. In *International Conference on Bangabandhu and Digital Bangladesh*, pages 173–188. Springer, 2022.
- [14] Mr Swapnil S Chaudhari, Satish N Gujar, and Farhat Jummani. Detection of phishing web as an attack: A comprehensive analysis of machine learning algorithms on phishing dataset. *Journal of Engineering (IOSRJEN)*, 2022.
- [15] Avisha Das, Shahryar Baki, Ayman El Aassal, Rakesh Verma, and Arthur Dunbar. Sok: a comprehensive reexamination of phishing research from the security perspective. *IEEE Communications Surveys & Tutorials*, 22(1):671–708, 2019.
- [16] Sumitra Das Gupta, Khandaker Tayef Shahriar, Hamed Alqahtani, Dheyaaldin Alsalman, and Iqbal H Sarker. Modeling hybrid feature-based phishing websites detection using machine learning techniques. *Annals of Data Science*, pages 1–26, 2022.
- [17] Zuochao Dou, Issa Khalil, Abdallah Khreishah, Ala Al-Fuqaha, and Mohsen Guizani. Systematization of knowledge (sok): A systematic review of software-based web phishing detection. *IEEE Communications Surveys & Tutorials*, 19(4):2797–2819, 2017.
- [18] Ayman El Aassal, Shahryar Baki, Avisha Das, and Rakesh M. Verma. An in-depth benchmarking and evaluation of phishing detection research for security needs. *IEEE Access*, 8:22170–22192, 2020.
- [19] Brij B Gupta, Krishna Yadav, Imran Razzak, Konstantinos Psannis, Arcangelo Castiglione, and Xiaojun Chang. A novel approach for phishing urls detection using lexical based machine learning in a real-time environment. *Computer Communications*, 175:47–57, 2021.
- [20] Tzipora Halevi, Nasir D. Memon, and Oded Nov. Spear-phishing in the wild: A real-world study of personality, phishing self-efficacy and vulnerability to spear-phishing attacks. *Innovation Law & Policy eJournal*, 2015.
- [21] Sohrab Hossain, Dhiman Sarma, and Rana Joyti Chakma. Machine learning-based phishing attack detection. *International Journal of Advanced Computer Science and Applications*, 11(9), 2020.
- [22] Ankit Kumar Jain and Brij B Gupta. A machine learning based approach for phishing detection using hyperlinks information. *Journal of Ambient Intelligence and Humanized Computing*, 10(5):2015–2028, 2019.
- [23] SM Mahamudul Hasan, Nirjas Mohammad Jakilim, Forhad Rabbi, Rumel Rahman Pir, et al. Determining the most effective machine learning techniques for detecting phishing websites. In *Applications of Artificial Intelligence and Machine Learning*, pages 593–603. Springer, 2022.
- [24] Sourena Maroofi, Maciej Korczyński, Cristian Hesselman, Benoit Ampeau, and Andrzej Duda. Comar: Classification of compromised versus maliciously registered domains. In *2020 IEEE European Symposium on Security and Privacy (EuroS&P)*, pages 607–623. IEEE, 2020.
- [25] Michael Miller. *Is It Safe? Protecting Your Computer, Your Business, And Yourself Online*. Que Publishing; 1st edition (June 6, 2008), 1 January 2000.
- [26] Jimmy Moedjahedy, Arief Setyanto, Fawaz Khaled Alarfaj, and Mohammed Alreshoodi. Ccrfs: Combine correlation features selection for detecting phishing websites using machine learning. *Future Internet*, 14(8):229, 2022.
- [27] Hajara Musa, Bala Modi, Ismail Abdulkarim Adamu, Ali Ahmad Aminu, Hussaini Adamu, and Yahaya Ajiya. A comparative analysis of different feature set on the performance of different algorithms in phishing website detection. *International Journal of Artificial Intelligence and Applications (IJAAI)*, 10(3), 2019.
- [28] Adam Oest, Penghui Zhang, Brad Wardman, Eric Nunes, Jakob Burgis, Ali Zand, Kurt Thomas, Adam Doupé, and Gail-Joon Ahn. Sunrise to sunset: Analyzing the end-to-end life cycle and effectiveness of phishing attacks at scale. In *Proceedings of the 29th USENIX Security Symposium*, Proceedings of the 29th USENIX Security Symposium, pages 361–377. USENIX Association, 2020.
- [29] Manuel Sánchez-Paniagua, Eduardo Fidalgo, Víctor González-Castro, and Enrique Alegre. Impact of current phishing strategies in machine learning models for phishing detection. In *Computational Intelligence in Security for Information Systems Conference*, pages 87–96. Springer, 2019.
- [30] Shafaizal Shabudin, Nor Samsiah Sani, Khairul Akram Zainal Ariffin, and Mohd Aliff. Feature selection for phishing website classification. *International Journal of Advanced Computer Science and Applications*, 11(4), 2020.
- [31] Anjum N. Shaikh, Antesar M. Shabut, and M.A. Hossain. A literature review on phishing crime, prevention review and investigation of gaps. In *2016 10th International Conference on Software, Knowledge, Information Management and Applications (SKIMA)*, pages 9–15, 2016.
- [32] A Suryan, C Kumar, M Mehta, R Juneja, and A Sinha. Learning model for phishing website detection. *EAI Endorsed Transactions on Scalable Information Systems*, 7(27):e6–e6, 2020.
- [33] Melanie Volkamer, Karen Renaud, Benjamin Reinheimer, and Alexandra Kunz. User experiences of torpedo: Tooltip-powered phishing email detection. *Computers and Security*, 71:100–113, 2017.
- [34] Nur Sholihah Zaini, Deris Stiawan, Mohd Faizal Ab Razak, Ahmad Firdaus, Wan Isni Sofiah Wan Din, Shahreen Kasim, and Tole Sutikno. Phishing detection system using machine learning classifiers. *Indonesian Journal of Electrical Engineering and Computer Science*, 17(3), 2020.

Ensemble of Deep Learning Models for Multi-plant Disease Classification in Smart Farming

Hoang-Tu Vo, Luyl-Da Quach, Hoang Tran Ngoc
Software Engineering Department
FPT University, Cantho city, Vietnam

Abstract—Plant disease identification at an early stage plays a crucial role in ensuring efficient management of the diseases and crop protection. The occurrence of plant ailments can result in substantial reductions in both crop yield and quality, which may cause financial setbacks for farmers and lead to food shortages for consumers. Traditional methods of disease detection rely on visual observation, which can consume a significant amount of time, be a labor-intensive, and often be inaccurate. Automated disease detection systems, based on techniques for machine learning have the potential to greatly improve the precision and speed of disease detection. This article presents a model for classifying plant diseases that combines the output of two transfer learning models, EfficientNetB0 and MobileNetV2, to improve disease classification accuracy. The PlantVillage Dataset was used to train and test the model under consideration, which contains 54,305 photos of 38 different plant disease classes, achieving an accuracy rate of 99.77% in disease classification. The use of an ensemble of deep learning models in this study shows promising results, indicating that the technique can enhance the accuracy of plant disease classification. Besides, this study contributes to the development of accurate and reliable automated disease detection systems, thereby supporting sustainable agriculture and global food security.

Keywords—Ensemble learning; automated disease detection systems; transfer learning models; plant diseases

I. INTRODUCTION

Plants are susceptible to a variety of diseases, and this is particularly true in the Mekong Delta region of Vietnam and across the world. There are numerous factors that contribute to the development and spread of plant diseases, including weather conditions, soil health, and the presence of pests and pathogens [3]. The Mekong Delta, situated in the southwest of Vietnam, is also referred to as the Western Region, the humid and warm climate provides ideal conditions for the growth of many plant diseases, which can have significant economic and environmental impacts on local farmers and communities [41]. Similarly, in other parts of the world, plant diseases can be a major challenge for agriculture and food security, affecting yields and quality of crops. Therefore, it is crucial to monitor and manage plant diseases to prevent their spread and minimize their impact on plant health and food production. In recent times, there has been a growing interest in using machine learning (ML) and deep learning (DL) techniques to improve the early diagnosis of plant diseases. This involves developing algorithms that can analyze large datasets of plant images and detect early signs of disease, such as changes in leaf color or texture. These algorithms can be trained using labeled datasets of healthy and diseased plants, allowing them to identify

patterns and make accurate predictions about the health of a plant. By using these advanced techniques, researchers hope to enhance the precision and quickness of disease diagnosis, which could help farmers to take preventive measures and minimize crop losses. The study's primary contribution is to introduce a model for classifying plant diseases that combines the output of two transfer learning models, EfficientNetB0 and MobileNetV2, to improve disease classification accuracy.

II. RELATED WORKS

Numerous research studies have investigated the use of both traditional classification algorithms and advanced deep learning models in classifying plant leaf diseases. This indicates that there is an ongoing effort to develop more accurate and efficient methods for identifying and diagnosing diseases that affect plant leaves. The article [30] proposes ANN and SVM classifiers to identify and classify fungal diseases with an accuracy of 87% and 91.16%, respectively. This study [14] utilizes the Support Vector Machine (SVM) classifier for disease recognition, achieving an accuracy rate exceeding 90%. In the research [28] employs the SVM classification technique and involves the extraction of color and texture features, resulting in a classification accuracy of 88.89%. Through the extraction of features such as color, shape, and texture from images of healthy and unhealthy tomato plants and feeding them to a classification tree, the study [36] achieved a classification accuracy of 97.3% for six types of tomato images. The study [20] combines convolution neural networks (CNNs) and SVM method to extract features and classify rice leaf disease images, respectively. The research achieves a classification accuracy of 96.8%. The study [12] presents a fresh model for identifying plant leaf diseases, which employs a Deep CNN trained with an open dataset comprising 39 classes of images of plant leaves and their backgrounds. The research attains a classification accuracy of 96.46%. The paper [44] discusses the practicality of using CNN for classifying plant diseases in leaf images, resulting in an accuracy rate of 99.32%. The study [25] introduces a new approach to identifying rice diseases that utilizes deep CNN techniques, achieving an accuracy rate of 95.48%. The paper [48] presents a novel approach to classifying tomato leaf diseases using a deep CNN that incorporates an attention mechanism, achieving an accuracy rate of 99.24% on the tomato leaf diseases dataset. A compact CNN is suggested in this research [27] for the Tomato Disease identification task, achieving an F1 score of 99.70%. [43] The tomato diseases are accurately defined and classified using Convolutional Neural Network (CNN), achieving a success rate of 98.49%. In recent times,

transfer learning has gained widespread popularity and has been successful in solving several problems with significant achievements. Agriculture imaging tasks [32], [5], [26], [33], [31]; Medical imaging tasks [34], [2], [47], etc. To utilize the pretrained model for identifying plant diseases, this paper [49] presents the identification of apple leaf diseases with an accuracy of 93.71% using DenseNet-121. The study [16], the VGG16 deep learning model has been employed to achieve a 90% accuracy in identifying diseases in tea leaves. In this paper [45] employs the VGG16 model to identify diseased apple leaves with an accuracy of 90.4%. The identification of haploid and diploid maize seeds is achieved with an accuracy of 94.22% in this study [1] using the VGG-19 model. The classification of Tomato crop diseases is achieved in this paper [35] with an accuracy of 97.29% using VGG16 and 97.49% using AlexNet. The study [21] employed transfer learning with the plant village dataset to retrain the EfficientNet B7 deep architecture. Subsequently, down-sampling of collected features was performed using a Logistic Regression technique, which achieved a 98.7% accuracy. The research [13] involved tomato leaf disease detection, which was performed using Densenet-Xception, resulting in an accuracy of 97.10%. In this study [39], CNN models were employed to categorize diseases found in tomato plants, achieving an accuracy of 98.6% across 10 different disease classes. In the study [42], the success rate for tomato leaf disease recognition using VGG16, InceptionV3, and Resnet50 models were 99.62%, 99.75%, and 99.5%, respectively. The goal of this study [37] was for the purpose of diagnosing diseases present in tomato leaves by categorizing healthy and unhealthy tomato leaf photos using two pretrained CNNs, namely InceptionV3 and Inception ResNetV2. The study [22] achieved an accuracy of 99.22%. In this work, three CNN-based models (VGG-16, ResNet-152, and EfficientNet-B4) were proposed for the classification of tomato leaf diseases. The study found that the models reached accuracies of 93.75%, 97.27%, and 98%, respectively. With the utilization of a DenseNet model, the paper [6] achieved a classification accuracy of 99.9% in identifying tomato diseases. By leveraging MobileNetV2, the research [24] created an enhanced algorithm for recognizing apple leaf diseases and achieved an accuracy rate of 96.23%. In the research [4], the detection of tomato leaf diseases was performed using several models, with MobileNet achieving an accuracy rate of 94%, Xception at 95.32%, VGG16 at 93.35%, ResNet50 at 96.03%, DenseNet121 at 96.3%, and EfficientNetB5 at 99.07%.

III. TRANSFER LEARNING MODELS AND ENSEMBLE LEARNING

A. Transfer Learning Models

Transfer learning (TL) [29] is a technique in machine learning that improves the learning process by leveraging a pre-trained model for a new task. TL models are neural networks that have undergone training on a large dataset, typically used for tasks such as image recognition or natural language processing. These models are then adjusted and fine-tuned for a new task using a smaller dataset. The core principle behind transfer learning is based on the idea that a model capable of recognizing specific features in one domain can be repurposed to identify similar features in another domain. In recent times, various Deep Learning models, including EfficientNet, MobileNet, VGG, DenseNet, Xception, ResNet,

among others, have emerged victorious in the ILSVRC competitions. The ImageNet database, containing more than 1.4 million images for 1000 different classes, is the most widely utilized dataset for these competitions. The present research involves the combination of EfficientNetB0 and MobileNetV2 models for the classification of plant diseases.

B. Ensemble Learning

Ensemble learning (EL) [11] is a method that involves merging multiple separate models to achieve improved overall performance in terms of generalization. There are several types of ensemble models that can be used for this purpose, each with its own unique approach and set of advantages and disadvantages. One of the most common types of ensemble models is bagging [8], which stands for bootstrap aggregating. The Bagging technique consists of training multiple models on distinct subsets of data, followed by the amalgamation of their predictions through averaging or majority voting. This approach can diminish the variance of the models and enhance their general stability. Another popular ensemble method is boosting [10] [9], which involves sequentially training weak models and adjusting the weights of the training examples to focus on the most difficult cases. Boosting can be effective for improving the accuracy of the models and reducing bias. Stacking [46] is a more complex type of EL that involves training several models and then using another model, called a meta-model or a blender, to combine their predictions. Finally, decision fusion strategies based on deep ensemble models use deep learning methods to combine the results of several models, either in a hierarchical or parallel manner, to achieve better performance.

In our approach, we utilized two transfer Learning models (EfficientNetB0 [40] and MobileNetV2 [15] [38]) for the purpose of extracting deep features from the data provided. These deep features were then integrated together to form a single, high-dimensional feature vector. These features were then fed into a few dense layers for further processing and feature transformation. Finally, the resulting features were used to perform classification. This allowed us to leverage the complementary strengths of different deep networks and capture a richer representation of the input data compared to using a single deep network or traditional feature extraction methods. The outcomes demonstrate the proficiency of our method in leveraging the power of TL models for multi-plant disease classification.

IV. METHODOLOGY

A. Dataset and Data Preparation

The data set utilized in this research is PlantVillage dataset was first introduced at [17], [18]. The PlantVillage dataset comprises 54,305 images of leaves, both healthy and diseased, which have been categorized into 38 different groups based on their species and type of disease. The images include 14 types of crops and consist of 38 categories can be found in Table III. To train and evaluate the effectiveness of the suggested model, the dataset was divided into three separate groups, namely the training set, testing set, and validation set, in the proportion of 60:20:20. The distribution of the data set can be discovered in Fig. 1 and examples of plant disease

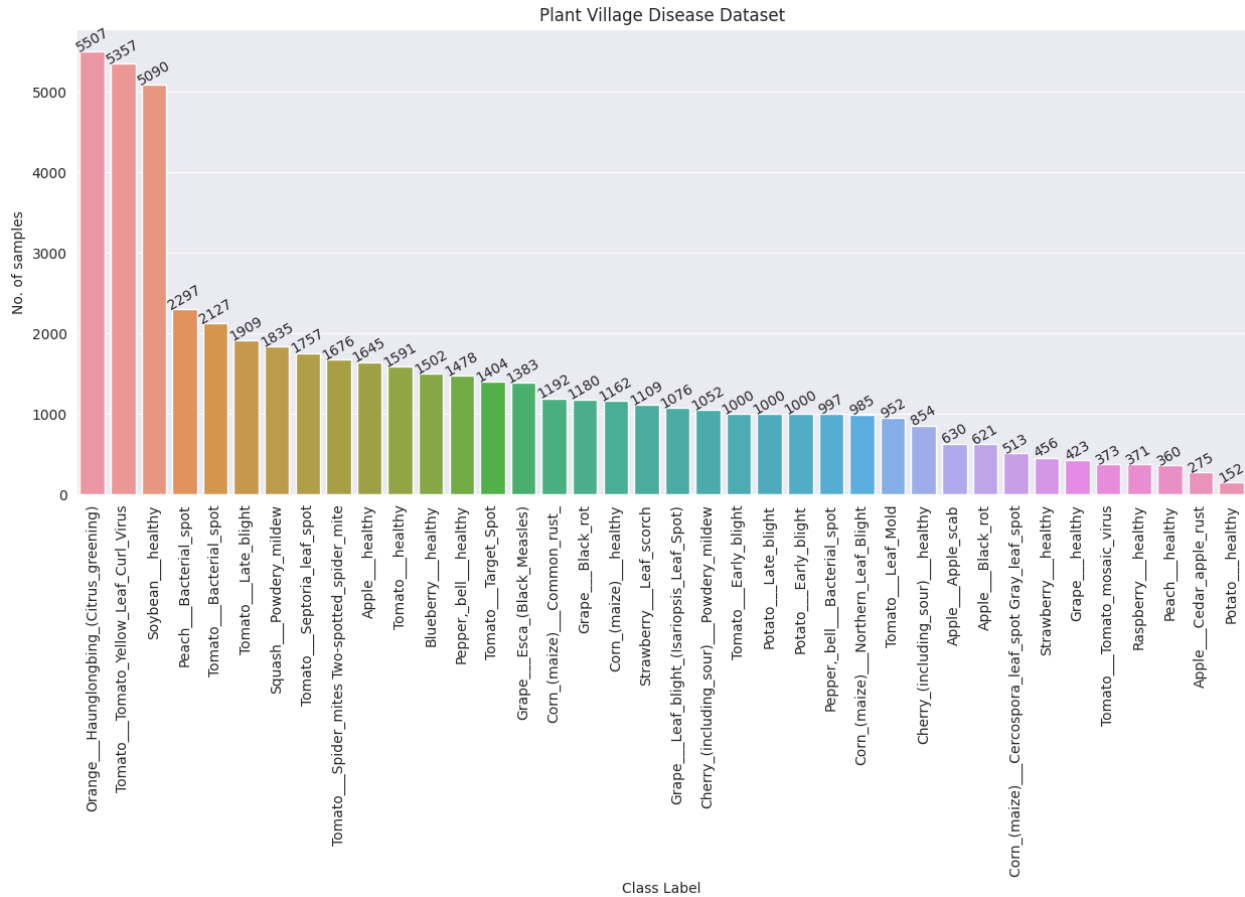


Fig. 1. A dataset distribution.

pictures from The PlantVillage dataset can be presented Fig. 2. Before the model training and evaluation, the datasets for training, validation, and testing will go through preprocessing techniques. These techniques consist of resizing the images to 224x224 and applying the image preprocessing function.

B. Proposed Model

In this research, we utilized two transfer Learning models (EfficientNetB0 [40] and MobileNetV2 [15] [38]) to extract deep features from the input data. These deep features were then concatenated together to create a feature vector. Then, these features were fed into a few dense layers for further processing and feature transformation. Finally, the resulting features were used to perform classification. The suggested model for plant disease classification can be seen in Fig. 3. The model has two main backbone networks, “EfficientNetB0” and “MobileNetV2,” both of which produce an output shape of (None, 1280). These output tensors are then processed by two separate batch normalization layers, and their outputs are concatenated together to form a (None, 2560) tensor. This concatenated tensor is then fed into a dense layer comprising of 256 units, followed by a dropout layer with a dropout rate of 0.5 to prevent overfitting. Finally, the output of the dropout layer is passed through another dense layer with 38 units, which produces the final output of the model. The overall count of parameters within the model is 6,983,177,

with 6,901,922 of them being trainable and the remaining 81,255 being non-trainable. The Architecture and Proposed model can be displayed in Fig. 4 and Table 1 showcases the representation of various information including layers of the model, the shape of each layer’s output, the count of trainable parameters in every layer, and the overall count of trainable parameters within the model. The proposed model also utilizes the technique of learning rate scheduling [23] during its training process. Learning rate scheduling is a technique that adjusts the learning rate, which controls the step size of the gradient descent optimization algorithm, during training. The purpose of this technique is to improve the convergence of the model by gradually reducing the learning rate over time. In this model, after two epochs, the learning rate has decreased by a factor of 0.5 to wait to adjust the learning rate if training accuracy does not improve. In order to address potential overfitting in the model, the regularization techniques used in this architecture assisting in avoiding overfitting and improve the model’s overall performance, which is important for many applications in the real world.

C. Model Evaluation Metrics

This study examined the effectiveness of DL models using a range of metrics, including Precision, Recall, F1-score, and Accuracy. Accuracy was employed to assess the overall performance of the models in predicting the target

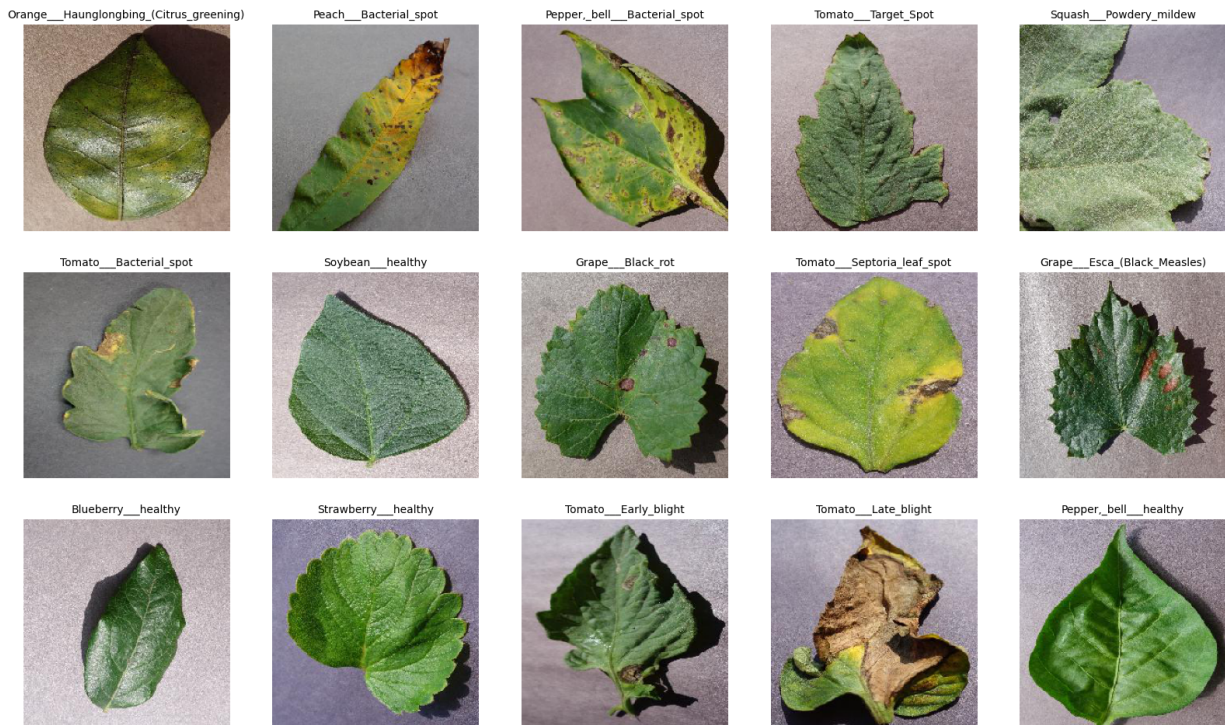


Fig. 2. Sample plant disease in plantVillage dataset.

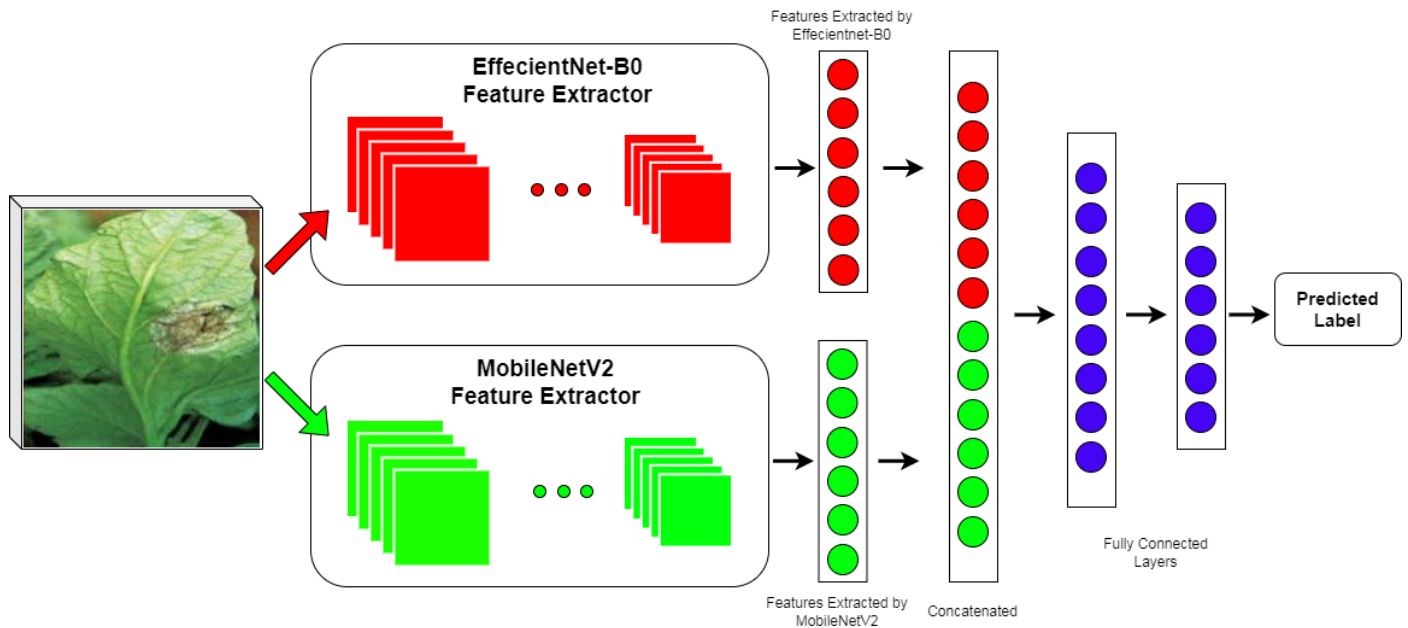


Fig. 3. Proposed model for plant disease classification.

variable. Precision measured the ratio of true positive results to all positive predictions, while recall measured the ratio of true positive predictions to all actual positive instances in the dataset. F1-score, which combines precision and recall, provided a balanced perspective on the model's performance, particularly in scenarios with imbalanced classes. By employing multiple evaluation metrics, we gained a comprehensive understanding of the model's performance and made well-

informed judgments regarding its effectiveness.

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (1)$$

$$Precision = \frac{TP}{TP + FP} \quad (2)$$

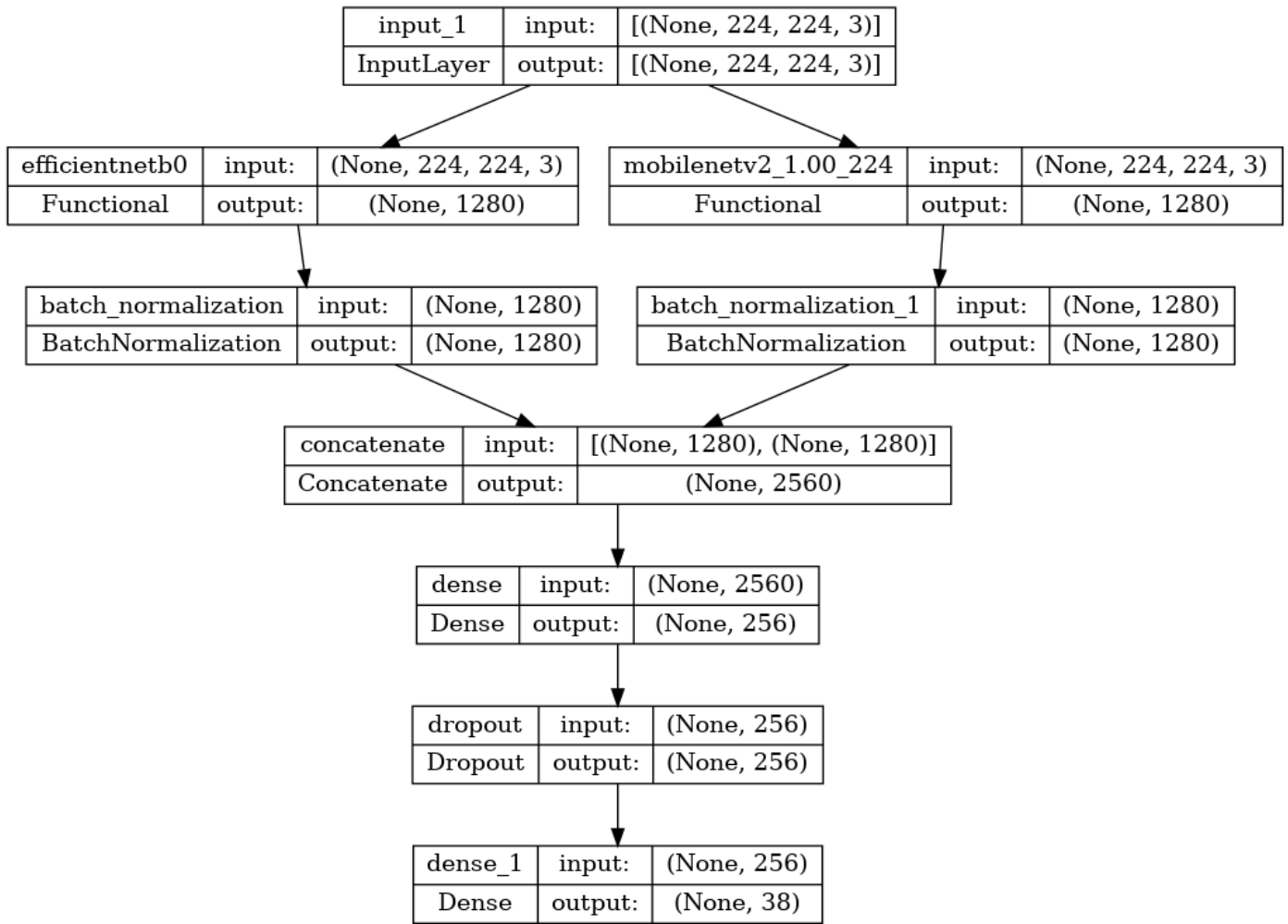


Fig. 4. The architecture of the suggested model is used in this study.

TABLE I. THE LAYERS OF PROPOSED MODEL

Layer (type)	Output Shape	Param #
input_1 (InputLayer)	[(None, 224, 224, 3)]	0
efficientnetb0 (Functional)	(None, 1280)	4049571
mobilenetv2_1.00_224 (Functional)	(None, 1280)	2257984
batch_normalization (BatchNormalization)	(None, 1280)	5120
batch_normalization_1 (BatchNormalization)	(None, 1280)	5120
concatenate (Concatenate)	(None, 2560)	0
dense (Dense)	(None, 256)	655616
dropout (Dropout)	(None, 256)	0
dense_1 (Dense)	(None, 38)	9766
Total params: 6,983,177		
Trainable params: 6,901,922		
Non-trainable params: 81,255		

$$Recall = \frac{TP}{TP + FN} \quad (3)$$

$$F_1 - Score = \frac{Precision * Recall}{Precision + Recall} \quad (4)$$

In which, TP: True Positive, TN: True Negative, FP: False Positive, FN: False Negative.

D. Results

Table II presents a comparative examination of the suggested model with modern methods on similar problems. The table includes the name of the plant, the quantity of categories, the number of pictures in the dataset, and the method used for detection along with the accuracy rate achieved. The PlantVillage dataset was used for both training and testing the recommended model, containing 54,305 photos of 38 different plant disease classes. According to the findings, the model that was suggested, which combines the output of two transfer learning models, EfficientNetB0, and MobileNetV2, achieved an accuracy rate of 99.77%, which outperformed all other methods listed in the table. According to the results, the suggested approach has the potential to substantially enhance the precision of plant disease classification and provide more reliable automated disease detection systems. The classification report presents the evaluation metrics for each class of plant disease, along with the support values for each class presented in Table III. The report shows that the model performs excellently, with most classes achieving perfect scores for evaluation metrics. The report provides useful insights into the model's capacity to identify and categorize various types of plant diseases. The confusion matrix of the suggested

model results is displayed in Fig. 5 and Fig. 6 presents the metrics that measure the proposed model's performance during both training and validation phases, which include loss and accuracy.

V. CONCLUSION

The presented study highlights the importance of timely identification of diseases that affect plants and the significant losses that can result from their unchecked spread. Traditional methods of disease detection are often inaccurate, time-consuming, and labor-intensive, making it difficult for farmers to efficiently manage their crops. The use of automated disease detection systems based on machine learning algorithms offers an excellent opportunity to improve the accuracy and speed of disease detection. The model for classifying plant diseases that have been suggested, which combines the outputs of two transfer learning models, EfficientNetB0 and MobileNetV2, has demonstrated an accuracy rate of 99.77% in disease classification, indicating its potential to provide more reliable automated disease detection systems.

Furthermore, this study's results offer promising indications that the use of an ensemble of DL models can significantly enhance the accuracy of plant disease classification. The development of more accurate and reliable automated disease detection systems is vital to support sustainable agriculture and global food security, making this study a valuable contribution to this field of research.

VI. FUTURE WORKS

There are several future works that can be pursued based on the findings of this study. First, the model can be tested on different datasets containing images of plant diseases to assess its robustness and generalizability. This will help to determine if the model can be applied to other crops and environments. Second, the model can be integrated into a real-time monitoring system to enable early detection and timely intervention. This will require the design of an easy-to-use interface that can be used by farmers and other stakeholders.

REFERENCES

- [1] Yahya Altuntaş, Zafer Cömert, and Adnan Fatih Kocamaz. Identification of haploid and diploid maize seeds using convolutional neural networks and a transfer learning approach. *Computers and Electronics in Agriculture*, 163:104874, 2019.
- [2] Laith Alzubaidi, Mohammed A Fadhel, Omran Al-Shamma, Jinglan Zhang, J Santamaría, Ye Duan, and Sameer R. Olewi. Towards a better understanding of transfer learning for medical imaging: a case study. *Applied Sciences*, 10(13):4523, 2020.
- [3] Kubilay Kurtulus Bastas. Impact of climate change on food security and plant disease. In *Microbial Biocontrol: Food Security and Post Harvest Management: Volume 2*, pages 1–22. Springer, 2022.
- [4] Mohan Bhandari, Tej Bahadur Shahi, Arjun Neupane, and Kerry Brian Walsh. Botanicx-ai: Identification of tomato leaf diseases using an explanation-driven deep-learning model. *Journal of Imaging*, 9(2):53, 2023.
- [5] Petra Bosilj, Erchan Aptoula, Tom Duckett, and Grzegorz Cielniak. Transfer learning between crop types for semantic segmentation of crops versus weeds in precision agriculture. *Journal of Field Robotics*, 37(1):7–19, 2020.
- [6] Mohamed Bouni, Badr Hssina, Khadija Douzi, Samira Douzi, et al. Impact of pretrained deep neural networks for tomato leaf disease prediction. *Journal of Electrical and Computer Engineering*, 2023, 2023.
- [7] Mohammed Brahimi, Kamel Boukhalfa, and Abdelouahab Moussaoui. Deep learning for tomato diseases: classification and symptoms visualization. *Applied Artificial Intelligence*, 31(4):299–315, 2017.
- [8] Leo Breiman. Bagging predictors. *Machine learning*, 24:123–140, 1996.
- [9] Leo Breiman. Arcing classifier (with discussion and a rejoinder by the author). *The annals of statistics*, 26(3):801–849, 1998.
- [10] Yoav Freund and Robert E Schapire. A decision-theoretic generalization of on-line learning and an application to boosting. In *Computational Learning Theory: Second European Conference, EuroCOLT'95 Barcelona, Spain, March 13–15, 1995 Proceedings 2*, pages 23–37. Springer, 1995.
- [11] Mudasir A Ganaie, Minghui Hu, AK Malik, M Tanveer, and PN Suganthan. Ensemble deep learning: A review. *Engineering Applications of Artificial Intelligence*, 115:105151, 2022.
- [12] G Geetharamani and Arun Pandian. Identification of plant leaf diseases using a nine-layer deep convolutional neural network. *Computers & Electrical Engineering*, 76:323–338, 2019.
- [13] Huiqun Hong, Jinfa Lin, and Fenghua Huang. Tomato disease detection and classification by deep learning. In *2020 International Conference on Big Data, Artificial Intelligence and Internet of Things Engineering (ICBAIE)*, pages 25–29. IEEE, 2020.
- [14] Selim Hossain, Rokeya Mumtahana Mou, Mohammed Mahedi Hasan, Sajib Chakraborty, and M Abdur Razzak. Recognition and detection of tea leaf's diseases using support vector machine. In *2018 IEEE 14th International Colloquium on Signal Processing & Its Applications (CSPA)*, pages 150–154. IEEE, 2018.
- [15] Andrew G Howard, Menglong Zhu, Bo Chen, Dmitry Kalenichenko, Weijun Wang, Tobias Weyand, Marco Andreetto, and Hartwig Adam. Mobilenets: Efficient convolutional neural networks for mobile vision applications. *arXiv preprint arXiv:1704.04861*, 2017.
- [16] Gensheng Hu, Haoyu Wu, Yan Zhang, and Mingzhu Wan. A low shot learning method for tea leaf's disease identification. *Computers and Electronics in Agriculture*, 163:104852, 2019.
- [17] David Hughes, Marcel Salathé, et al. An open access repository of images on plant health to enable the development of mobile disease diagnostics. *arXiv preprint arXiv:1511.08060*, 2015.
- [18] David P. Hughes and Marcel Salathé. An open access repository of images on plant health to enable the development of mobile disease diagnostics through machine learning and crowdsourcing. *CoRR*, abs/1511.08060, 2015.
- [19] Seyed Mohamad Javidan, Ahmad Banakar, Keyvan Asefpour Vakilian, and Yiannis Ampatzidis. Diagnosis of grape leaf diseases using automatic k-means clustering and machine learning. *Smart Agricultural Technology*, 3:100081, 2023.
- [20] Feng Jiang, Yang Lu, Yu Chen, Di Cai, and Gongfa Li. Image recognition of four rice leaf diseases based on deep learning and support vector machine. *Computers and Electronics in Agriculture*, 179:105824, 2020.
- [21] Prabhjot Kaur, Shilpi Harnal, Rajeev Tiwari, Shuchi Upadhyay, Surbhi Bhatia, Arwa Mashat, and Aliaa M Alabdali. Recognition of leaf disease using hybrid convolutional neural network by applying feature reduction. *Sensors*, 22(2):575, 2022.
- [22] Aima Khalid, Shahzad Akbar, Syed Ale Hassan, Saba Firdous, and Sahar Gull. Detection of tomato leaf disease using deep convolutional neural networks. In *2023 4th International Conference on Advancements in Computational Sciences (ICACS)*, pages 1–6. IEEE, 2023.
- [23] Jinia Konar, Prerit Khandelwal, and Rishabh Tripathi. Comparison of various learning rate scheduling techniques on convolutional neural network. In *2020 IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS)*, pages 1–5. IEEE, 2020.
- [24] Song LIU, Haoran BAI, Fengmei LI, Dongwei WANG, Yuhui ZHENG, Qiupeng JIANG, and Fengbo SUN. An apple leaf disease identification model for safeguarding apple food safety. *Food Science and Technology*, 43, 2023.
- [25] Yang Lu, Shujuan Yi, Nianyin Zeng, Yurong Liu, and Yong Zhang. Identification of rice diseases using deep convolutional neural networks. *Neurocomputing*, 267:378–384, 2017.

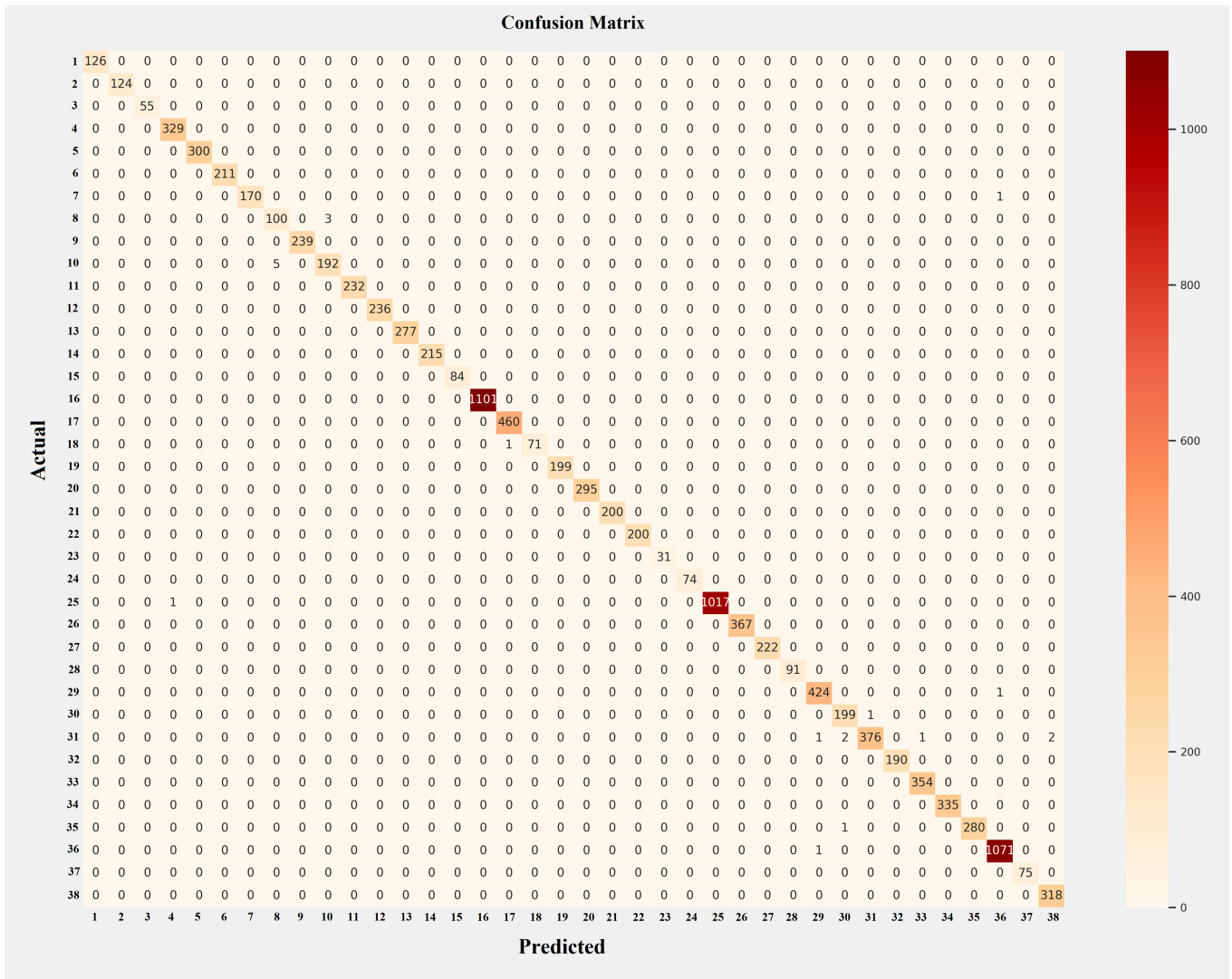


Fig. 5. Confusion matrix of the recommended model.

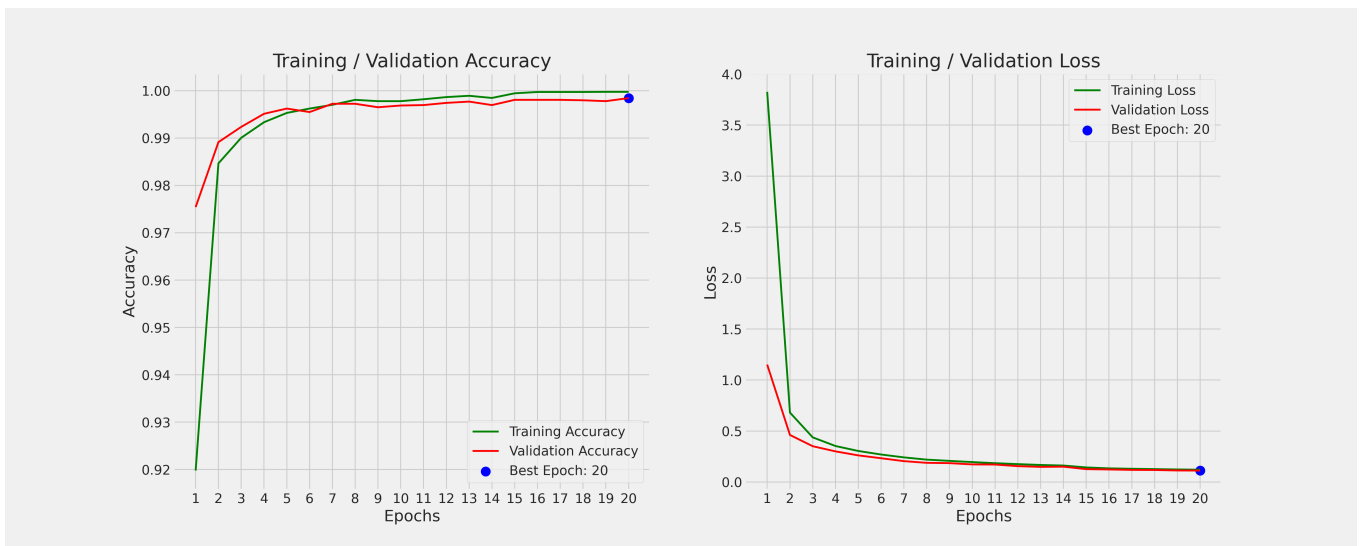


Fig. 6. Loss and accuracy plots of the recommended model.

TABLE II. COMPARE OUR PROPOSED MODEL WITH MODERN METHODS ON SIMILAR PROBLEM

The study	Dataset / Plant Name	The number of classes	The number of images	Method of Use	Accuracy
[12]	Plant Leaf Diseases	39	61,486	CNN model	96.46%
[44]	Soybean Diseases	4	12,673	CNN model	99.32%
[25]	Rice Diseases Dataset	10	500	CNN model	95.48%
[48]	The Tomato Plant	10	4,585	CNN model	99.24%
[27]	PlantVillage's Tomato Crop Dataset	10	18,160	CNN model	99.70%
[43]	PlantVillage's Tomato Crop Dataset	10	3,000	CNN model	98.49%
[49]	Apple Leaf Disease	6	2,462	DenseNet-121	93.71%
[45]	PlantVillage's Apple Crop Dataset	4	2,086	VGG16	90.40%
[35]	PlantVillage' Tomato Leaves Dataset	7	13,262	AlexNet VGG16	97.49% 97.23%
[21]	Grape Leaf Diseases Dataset	4	9,027	EfficientNet B7	98.70%
[13]	The Tomato Plant	9	-	Densenet_Xception	97.10%
[39]	The Tomato Plant	10	17,929	CNN model	98.60%
[42]	The Tomato Plant	10	19,553	VGG19 Inception-V3 Resnet50	99.62% 99.75% 99.50%
[37]	Tomato Plant (PlantVillage and Field)	3	5,225	Inception V3 Inception ResNet V2	99.22% 99.22%
[22]	The Tomato Plant	10	5,524	ResNet-152 EfficientNet-B4 VGG-16	93.75% 97.27% 98.00%
[6]	Tomato Leaf Disease	10	7,301	DenseNet	99.80%
[24]	Apple Leaf Disease	9	11,100	MobileNetV2	96.23%
[4]	Tomato Leaf Diseases	10	11,000	EfficientNetB5 MobileNet Xception VGG16 ResNet50 DenseNet121	99.07% 94.00% 95.32% 93.35% 96.03% 96.30%
[19]	Grape Leaf Diseases	4	3,885	GoogleNet	94.05%
[7]	Tomato Leaves Diseases	9	14,828	GoogleNet AlexNet	99.18% 98.66%
This study	PlantVillage Dataset	38	54,305	EfficientNetB0 + MobileNetV2	99.77%

TABLE III. CLASSIFICATION REPORT

#	Type	Class	Precision	Recall	F1-Score	Accuracy	Support
C1	Apple	Scab	1.00	1.00	1.00	100%	126
C2	Apple	Black Rot	1.00	1.00	1.00	100%	124
C3	Apple	Cedar Apple Rust	1.00	1.00	1.00	100%	55
C4	Apple	Healthy	1.00	1.00	1.00	100%	329
C5	Blueberry	Healthy	1.00	1.00	1.00	100%	300
C6	Cherry (including sour)	Powdery Mildew	1.00	1.00	1.00	100%	211
C7	Cherry (including sour)	Healthy	1.00	0.99	1.00	99.42%	171
C8	Corn (maize)	Cercospora Leaf Spot Gray Leaf Spot	0.95	0.97	0.96	97.09%	103
C9	Corn (maize)	Common Rust	1.00	1.00	1.00	100%	239
C10	Corn (maize)	Northern Leaf Blight	0.98	0.97	0.98	97.46%	197
C11	Corn (maize)	Healthy	1.00	1.00	1.00	100%	232
C12	Grape	Black Rot	1.00	1.00	1.00	100%	236
C13	Grape	Esca (Black Measles)	1.00	1.00	1.00	100%	277
C14	Grape	Leaf Blight (Isariopsis Leaf Spot)	1.00	1.00	1.00	100%	215
C15	Grape	Healthy	1.00	1.00	1.00	100%	84
C16	Orange	Haunglongbing (Citrus Greening)	1.00	1.00	1.00	100%	1101
C17	Peach	Bacterial Spot	1.00	1.00	1.00	100%	460
C18	Peach	Healthy	1.00	0.99	0.99	98.61%	72
C19	Pepper, Bell	Bacterial Spot	1.00	1.00	1.00	100%	199
C20	Pepper, Bell	Healthy	1.00	1.00	1.00	100%	295
C21	Potato	Early Blight	1.00	1.00	1.00	100%	200
C22	Potato	Late Blight	1.00	1.00	1.00	100%	200
C23	Potato	Healthy	1.00	1.00	1.00	100%	31
C24	Raspberry	Healthy	1.00	1.00	1.00	100%	74
C25	Soybean	Healthy	1.00	1.00	1.00	99.9%	1018
C26	Squash	Powdery Mildew	1.00	1.00	1.00	100%	367
C27	Strawberry	Leaf Scorch	1.00	1.00	1.00	100%	222
C28	Strawberry	Healthy	1.00	1.00	1.00	100%	91
C29	Tomato	Bacterial Spot	1.00	1.00	1.00	99.76%	425
C30	Tomato	Early Blight	0.99	0.99	0.99	99.5%	200
C31	Tomato	Late Blight	1.00	0.98	0.99	98.43%	382
C32	Tomato	Leaf Mold	1.00	1.00	1.00	100%	190
C33	Tomato	Septoria Leaf Spot	1.00	1.00	1.00	100%	354
C34	Tomato	Spider Mites Two-spotted Spider Mite	1.00	1.00	1.00	100%	335
C35	Tomato	Target Spot	1.00	1.00	1.00	99.64%	281
C36	Tomato	Tomato Yellow Leaf Curl Virus	1.00	1.00	1.00	99.91%	1072
C37	Tomato	Tomato Mosaic Virus	1.00	1.00	1.00	100%	75
C38	Tomato	Healthy	0.99	1.00	1.00	100%	318

- [26] Chhaya Narvekar and Madhuri Rao. Flower classification using cnn and transfer learning in cnn-agriculture perspective. In *2020 3rd International Conference on Intelligent Sustainable Systems (ICISS)*, pages 660–664. IEEE, 2020.
- [27] Emre Özbilge, Mehtap Köse Ulukök, Önsen Toygar, and Ebru Özbilge. Tomato disease recognition using a compact convolutional neural network. *IEEE Access*, 10:77213–77224, 2022.
- [28] Pranjali B Padol and Anjali A Yadav. Svm classifier based grape leaf disease detection. In *2016 Conference on advances in signal processing (CASP)*, pages 175–179. IEEE, 2016.
- [29] Sinno Jialin Pan and Qiang Yang. A survey on transfer learning. *IEEE Transactions on knowledge and data engineering*, 22(10):1345–1359, 2010.
- [30] Jagadeesh D Pujari, Rajesh Yakkundimath, and Abdulmunaf S Byadgi. Classification of fungal disease symptoms affected on cereals using color texture features. *International Journal of Signal Processing, Image Processing and Pattern Recognition*, 6(6):321–330, 2013.
- [31] Luyl-Da Quach, Nguyen Quoc Khang, Anh Nguyen Quynh, and Tran Ngoc Hoang. Evaluation of the efficiency of the optimization algorithms for transfer learning on the rice leaf disease dataset. *International Journal of Advanced Computer Science and Applications*, 13(10), 2022.
- [32] Luyl-Da Quach, Nghi Pham-Quoc, Duc Chung Tran, and Mohd Fadzil Hassan. Identification of chicken diseases using vggnet and resnet models. In *Industrial Networks and Intelligent Systems: 6th EAI International Conference, INISCOM 2020, Hanoi, Vietnam, August 27–28, 2020, Proceedings 6*, pages 259–269. Springer, 2020.
- [33] Luyl-Da Quach, Nghi Pham Quoc, Nhhien Huynh Thi, Duc Chung Tran, and Mohd Fadzil Hassan. Using surf to improve resnet-50 model for poultry disease recognition algorithm. In *2020 International Conference on Computational Intelligence (ICCI)*, pages 317–321. IEEE, 2020.
- [34] Maithra Raghu, Chiyuan Zhang, Jon Kleinberg, and Samy Bengio. Transfusion: Understanding transfer learning for medical imaging. *Advances in neural information processing systems*, 32, 2019.
- [35] Aravind Krishnaswamy Rangarajan, Raja Purushothaman, and Anirudh Ramesh. Tomato crop disease classification using pre-trained deep learning algorithm. *Procedia computer science*, 133:1040–1047, 2018.
- [36] H Sabrol and K Satish. Tomato plant disease classification in digital images using classification tree. In *2016 international conference on communication and signal processing (ICCSP)*, pages 1242–1246. IEEE, 2016.
- [37] Alaa Saeed, AA Abdel-Aziz, Amr Mossad, Mahmoud A Abdelhamid, Alfadhil Y Alkhaled, and Muhammad Mayhoub. Smart detection of tomato leaf diseases using transfer learning-based convolutional neural networks. *Agriculture*, 13(1):139, 2023.

- [38] Mark Sandler, Andrew Howard, Menglong Zhu, Andrey Zhmoginov, and Liang-Chieh Chen. Mobilenetv2: Inverted residuals and linear bottlenecks. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pages 4510–4520, 2018.
- [39] Parul Sharma, Yash Paul Singh Berwal, and Wiqas Ghai. Performance analysis of deep learning cnn models for disease detection in plants using image segmentation. *Information Processing in Agriculture*, 7(4):566–574, 2020.
- [40] Mingxing Tan and Quoc Le. Efficientnet: Rethinking model scaling for convolutional neural networks. In *International conference on machine learning*, pages 6105–6114. PMLR, 2019.
- [41] Nguyen Viet Thanh and Nguyen Giac Tri. Sustainable agriculture development, acceptable to climate change, digital transformation on mekong delta, vietnam. *resmilitaris*, 12(2):7548–7560, 2022.
- [42] Kai Tian, Jiefeng Zeng, Tianci Song, Zhuliu Li, Asenso Evans, and Jiu hao Li. Tomato leaf diseases recognition based on deep convolutional neural networks. *Journal of Agricultural Engineering*, 54(1), 2023.
- [43] Naresh K Trivedi, Vinay Gautam, Abhineet Anand, Hani Moaiteq Al-jahdali, Santos Gracia Villar, Divya Anand, Nitin Goyal, and Seifedine Kadry. Early detection and classification of tomato leaf disease using high-performance deep neural network. *Sensors*, 21(23):7987, 2021.
- [44] Serawork Walleign, Mihai Polceanu, and Cédric Buche. Soybean plant disease identification using convolutional neural network. In *FLAIRS conference*, pages 146–151, 2018.
- [45] Guan Wang, Yu Sun, and Jianxin Wang. Automatic image-based plant disease severity estimation using deep learning. *Computational intelligence and neuroscience*, 2017, 2017.
- [46] David H Wolpert. Stacked generalization. *Neural networks*, 5(2):241–259, 1992.
- [47] Xiang Yu, Jian Wang, Qing-Qi Hong, Raja Teku, Shui-Hua Wang, and Yu-Dong Zhang. Transfer learning for medical images analyses: A survey. *Neurocomputing*, 489:230–254, 2022.
- [48] Shengyi Zhao, Yun Peng, Jizhan Liu, and Shuo Wu. Tomato leaf disease diagnosis based on improved convolution neural network by attention module. *Agriculture*, 11(7):651, 2021.
- [49] Yong Zhong and Ming Zhao. Research on deep learning in apple leaf disease recognition. *Computers and Electronics in Agriculture*, 168:105146, 2020.

Primal-Optimal-Binding LPNet: Deep Learning Architecture to Predict Optimal Binding Constraints of a Linear Programming Problem

Natdanai Kafakthong, Krung Sinapiromsaran
Department of Mathematics and Computer Science
Chulalongkorn University
Bangkok, Thailand, 10330

Abstract—Identifying an optimal basis for a linear programming problem is a challenging learning task. Traditionally, an optimal basis is obtained via the iterative simplex method which improves from the current basic feasible solution to the adjacent one until it reaches optimal. The obtained result is the value of the optimal solution and the corresponding optimal basis. Even though learning the optimal value is hard but learning the optimal basis is possible via deep learning. This paper presents the primal-optimal-binding LPNet that learns from massive linear programming problems of various sizes casting as all-unit-row-except-first-unit-column matrices. During the training step, these matrices are fed to the special row-column convolutional layer followed by the state-of-the-art deep learning architecture and sent to two fully connected layers. The result is the probability vector of non-negativity constraints and the original linear programming constraints at the optimal basis. The experiment shows that this LPNet achieves 99% accuracy of predicting a single binding optimal constraint on unseen test problems and Netlib problems. It identifies correctly 80% LP problems having all optimal binding constraints and faster than cplex solution time.

Keywords—Deep learning; convolution neural network; linear programming; basic feasible solution; optimization

I. INTRODUCTION

Traditionally solving a linear programming (LP) problem. The authors in [17] requires an iterative simplex method [1] or an iterative interior point method [2]. The simplex method starts from an initial basic feasible solution (BFS) and pivots to the adjacent BFS with the objective improvement. It guarantees to reach the optimal BFS for nondegenerate and bounded LP with a nonempty feasible solution. While the interior point method starts at an interior point inside the feasible region and moves along an improved direction until it reaches the solution close to the optimal one.

The simplex method requires the feasibility of the current basic feasible solution. Since a general linear programming problem may not be feasible, it will need to be reformulated. Two classical artificial-variable techniques have been developed which are the two-phase simplex method [18] and the big-M method [17], [3]. Both techniques increase the dimension of the original problem by adding an artificial variable to each constraint causing more computational solution time.

In 2014, Boonperm, et al. [4] presented a non-acute constraint relaxation technique that eliminates the need for

artificial variables and reduces the start-up time to solve the initial relaxation problem. The algorithm reinserts the non-acute constraints back into the relaxation problem to guarantee the optimal solution or infeasibility or unboundedness of a linear programming problem. Moreover, there is a use case of angle measurement of LP constraints to control a jump direction in a metaheuristic algorithm to solve an LP problem that is introduced by Visuthirattanam [5]. In this paper, angle measurement between constraints is also considered as a part of preprocessing input of a deep learning model.

The deep learning concept mimics the computation from the biology of human brain cells to learn a task directly from numerical source data. It consists of multiple layers of interconnected nodes and arcs with weights and biases. The learning process adjusts weights that work together to recognize accurately and classify objects from data. An alternative method for solving an LP problem has been studied for centuries. Recently, the use of machine learning models such as a deep learning model is investigated. Instead of solving an LP problem every time a new problem is posted. Researchers investigate whether the machine learning model can be used to identify the optimal solution by learning from thousands of solved LP problems. With the appropriate form of the LP problem and the special deep learning architecture, the optimal basis of any linear programming problem can be obtained.

A. Contributions

This paper uses a deep learning model to solve a linear programming problem using only objective coefficients, the right-hand-sided values and the constraint coefficients avoid any iterative procedure that has been used for centuries. The concept is to use million solved linear programming problems as the training data with the appropriate matrix format as the all-unit-row-except-first-unit-column matrix and an additional row-column convolutional layer, which enables the deep learning model to identify the optimal binding constraints from linear programming problems of varying sizes.

The objective of this paper is the LPNet deep learning architecture that can solve a linear programming problem. It has the all-unit-row-except-first-unit column matrix as the input fed to the row-column convolutional layer. Then the output is sent to state-of-the-art deep learning model submitting to two fully connected layers before the last output layer.

In order to achieve the objective, this paper introduces a unit-vector normalization that simplifies the training process compared to the traditional normalization method. This method incorporates two key concepts - reordering constraints and scaling LP problems - to enhance the model's ability to learn effectively.

Finally, the LPNet architecture integrates all these processes together as illustrated in Fig. 1, and the trained model outperforms the benchmark LP datasets when compared to CLPEX [31], the state-of-the-art optimization LP solver.

The remainder of this paper is organized as follows. Section II provides a literature review. Section III covers the methodology of this paper. Section IV provides the analysis and results of the effective deep learning architecture. Section V is the conclusion of this paper, and the last section provides a discussion of this work.

II. LITERATURE REVIEW

Various deep-learning architectures have been proposed to learn different tasks via spatial relationships within the input data. A deep convolution neural network (DCNN) is one of the deep learning architectures which is suitable for computer vision tasks. Many state of the art architectures demonstrate high performance for an image classification task such as Resnet [20], MobileNet [6], EfficientNet [21], XceptionNet [22] and InceptionNet [23].

The study of Khade S. et al. [10], [12], [13] developed multiple DCNNs to identify iris liveness detection based on ResNet50 and EfficientNet for binary classifications. Moreover, the convolutional deep extreme learning machine method [14] can well recognize the pattern of a diabetic retinopathy image using DCNN architectures, that is ResNet, DenseNet [15], and GoogleNet [16]. This paper also developed DCNN with these architectures for multi-label classifications. Multi-label classifications [11] are more complex than binary classifications.

CNN with recurrent neural network (CNN-RNN) technique is utilized to detect and classify sarcasm [28]. In order to boost the detection outcomes of the CNN+RNN technique, a hyperparameter tuning process utilizing a teaching and learning-based optimization (TLBO) algorithm is employed in such a way that the classification performance gets increased.

The integration of a DCNN model to a multiparametric programming problem [24], [7] was demonstrated by Justin et al. [8]. Solving the parametric 0–1 LP problem by a DCNN model was proposed in 2022 [9]. The DCNN model for 0-1 LP learns from a histogram-like image representation.

Effati et al. [27] proposed two recurrent neural network models for solving linear and quadratic programming problems. The first model is derived from an unconstraint minimization reformulation of the program, while the second model is directly obtained from the optimality condition for an optimization problem. The paper compares the convergence of these models using the energy function and the duality gap. The paper also explores the existence and convergence of the trajectory and stability properties for the neural network models.

The use of a neural network as a solution bundle for solving ordinary differential equations (ODEs) for various initial states and system parameters is presented by Flamant et al. [26]. In 2023, Dawen Wu et al. [25] proposed a deep learning approach in the form of feedforward neural networks to solve linear programming (LP) problems. The approach models the LP problem by an ordinary differential equations (ODE) system, the state solution of which globally converges to the optimal solution of the LP problem. A neural network model is constructed as an approximate state solution to the ODE system, such that the neural network model contains the prediction of the LP problem.

III. METHODOLOGY

This paper proposed the deep convolutional neural network model, called LPNet, to learn from linear programming coefficients directly putting in the form of a general all-unit-row-except-first-unit-column matrix. This matrix contains the objective coefficients in the first row, normalized to one, the right-hand-side vector as the first column, and the rest are coefficients from constraints normalized to one. It then passes to the special row-column convolutional layer that is carefully designed with convolution filters for extracting the row-column components of the LP problems. After this layer, the result will pass to the state-of-the-art architectures. Then it will pass to two fully connected layers before connecting to the output layer. Each constraint will be marked as either it is one of the optimal basis or it is not in the output layer, see Fig. 1.

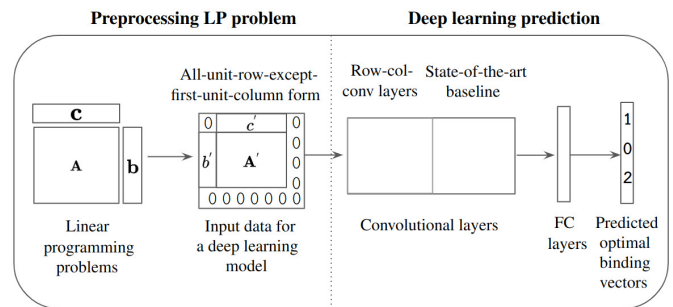


Fig. 1. Overview of an optimal binding prediction.

A. A Linear Programming Model

A linear programming model is an optimization model with a linear real-valued objective function ($c^T \tilde{x}$) and linear constraints ($A\tilde{x} \geq b, \tilde{x} \geq 0$). The optimal solution of this LP model is the feasible point that gives the smallest objective value for the minimization or the largest objective value for the maximization. It can be expressed in the following mathematical form.

$$\begin{aligned} \text{Min} \quad & c^T \tilde{x} \\ \text{s.t.} \quad & A\tilde{x} \geq b \\ & \tilde{x} \geq 0 \end{aligned} \quad (1)$$

where $c \in \mathbb{R}^n$, $A \in \mathbb{R}^{m \times n}$, $b \in \mathbb{R}^m$ and $\tilde{x} \in \mathbb{R}^n$. The optimal solution of the LP model can be solved using various iterative algorithms such as the two-phase simplex algorithm, the big-M algorithm, and the dual-simplex algorithm. Alternatively,

the optimal solution could be obtained if all optimal binding constraints are identified correctly. So learning to solve a linear programming problem can be cast as learning to identify the optimal binding constraint from a million linear programming problems.

For every LP problem, there is a corresponding dual LP problem. The original LP problem is called the primal LP problem. If one of these LP problems obtains an optimal solution then both problems will possess the optimal solution having the same optimal value and satisfying the complementary slackness. The non-zero value of any basic variable will cause the corresponding dual constraint to be binding. From equation (1), the dual LP problem is

$$\begin{aligned} \text{Max} \quad & \mathbf{b}^T \mathbf{y} \\ \text{s.t.} \quad & \mathbf{A}^T \mathbf{y} \leq \mathbf{c} \\ & \mathbf{y} \geq \mathbf{0} \end{aligned} \quad (2)$$

Note that the coefficients of the decision variable from a primal LP problem correspond to the row constraint for the dual LP problem. From the complementary slackness properties, [17] of the optimal conditions, the non-zero value of the dual basic variable will give rise to the corresponding primal constraint to be binding, i.e., if $y_i > 0$, for some $i \in \{1, \dots, m\}$ then the corresponding constraint in the LP primal problem will be binding. Similarly, the non-zero basic variable of the LP primal problem will give rise to the corresponding binding dual constraint. If $x_j > 0$, for some $j \in \{1, \dots, n\}$ then the corresponding constraint in the dual constraints will be binding. These optimal bindings can be predicted by LPNet which will be explained in detail in Section IV. The next section will cover the input design for this deep learning model from the coefficients of the primal LP problem.

B. Basic Feasible Solution

The LP problem from (1) can be converted to a standard form by subtracting non-negative surplus decision variables \mathbf{x}' as

$$\begin{aligned} \text{Min} \quad & \mathbf{c}^T \tilde{\mathbf{x}} + \mathbf{0}^T \mathbf{x}' \\ \text{s.t.} \quad & \mathbf{A} \tilde{\mathbf{x}} - \mathbf{I} \mathbf{x}' = \mathbf{b} \\ & \tilde{\mathbf{x}}, \mathbf{x}' \geq \mathbf{0} \end{aligned} \quad (3)$$

where \mathbf{I} is a $m \times m$ identity matrix, and \mathbf{x}' is $\{x_{n+1}, \dots, x_{m+n}\}$. So a new variable vector of the LP problem (3) is $\mathbf{x} = [x_1, x_2, \dots, x_{m+n}]^T$.

Definition 1: [19] For any nonsingular $m \times m$ submatrix \mathbf{A}_B of \mathbf{A} where $B \subset \{1, 2, \dots, m+n\}$ is the set of basic indices, $\mathbf{x} = [\mathbf{x}_B, \mathbf{0}]^T$ is called a basic solution with respect to the basis (\mathbf{A}_B) , where $\mathbf{0}$ in \mathbf{x} is the zero vector of all leftover components of \mathbf{x} associated with the $n-m$ non-basic variables of \mathbf{A} . From the constraint of the standard LP problem $\mathbf{A}\mathbf{x} = \mathbf{b}$, it can be rewritten as $\mathbf{A}_B \mathbf{x}_B = \mathbf{b}$. \mathbf{x}_B is called a vector of basic variables or basic variables in short.

Definition 2: [19] A vector \mathbf{x} satisfying the system $\mathbf{A}\mathbf{x} = \mathbf{b}, \mathbf{x} \geq \mathbf{0}$ is said to be a feasible solution for the system. A feasible solution with a known basis is called a basic feasible solution.

Theorem 3.1: [19] Given a standard LP problem (3) where \mathbf{A} is an $m \times n$ matrix of rank m ,

1. if the feasible region of the LP problem is nonempty and bounded, then there is a basic feasible solution.
2. if there is an optimal feasible solution, there is an optimal basic feasible solution.

This paper proposes a way to predict the optimal basic feasible solution from binding constraints of the LP problem using the target vector \mathbf{Y} corresponding to each constraint. If the element of \mathbf{Y} , Y_i is zero, then the constraint i will be binding and if the element of \mathbf{Y} , Y_j is one, then the constraint j is not binding and if the element of \mathbf{Y} , Y_k is two, then the constraint k does not exist from the original problem. It is just the padding constraint during the learning step of this deep learning architecture.

The next subsection will cover a theorem of scaling an LP problem which guarantees to have the same optimal basic \mathbf{A}_B . This theorem is designed to support an input form of LPNet in Section III.

C. Scaling LP Problems

Some LP problems may come from the same one with different multipliers to their constraints. Normalization of rows of LP problems helps identify duplicate samples during the training phase of LPNet. The following theorem shows that the scaled LP2 problem still has the same basic feasible solution as the LP1 problem. This implies that only one LP problem from all scaled LP problems is enough to be included in the training phase. This will help LPNet focus on one version of LP problems.

Theorem 3.2: Given LP1 has the optimal solution. For any positive scale α , a set of basic variables of LP1 will be the same as the basic variables of LP2(α). Moreover, the optimal basic indices in LP1 will be the same as the optimal basic indices in LP2(α)

$$\begin{array}{ll} \text{LP1} & \text{Min} \quad \mathbf{c}^T \mathbf{x} \\ & \text{s.t.} \quad \mathbf{A}\mathbf{x} \geq \mathbf{b} \\ & \quad \mathbf{x} \geq \mathbf{0} \end{array} \quad \text{LP2}(\alpha) \quad \begin{array}{ll} \text{Min} & \mathbf{c}^T \mathbf{x} \\ \text{s.t.} & \mathbf{A}\mathbf{x} \geq \frac{\mathbf{b}}{\alpha} \\ & \mathbf{x} \geq \mathbf{0} \end{array}$$

Proof: Assume LP1 has the optimal solution. Assume that the current basis is A_B with the set of basic indices B and let the set of the non-basic indices be N . It is easy to see that the optimal objective value

$$z^* = \mathbf{c}^T \mathbf{x}^* = \mathbf{c}_B^T \mathbf{x}_B^* + \mathbf{c}_N^T \mathbf{x}_N^* \quad \text{and} \quad \mathbf{A}_B \mathbf{x}_B^* + \mathbf{A}_N \mathbf{x}_N^* = \mathbf{b}.$$

Therefore $\mathbf{x}_B^* = \mathbf{A}_B^{-1} \mathbf{b} - \mathbf{A}_B^{-1} \mathbf{A}_N \mathbf{x}_N^*$ and

$$\begin{aligned} z^* &= \mathbf{c}_B^T (\mathbf{A}_B^{-1} \mathbf{b} - \mathbf{A}_B^{-1} \mathbf{A}_N \mathbf{x}_N^*) + \mathbf{c}_N^T \mathbf{x}_N^* \\ &= \mathbf{c}_B^T \mathbf{A}_B^{-1} \mathbf{b} + (\mathbf{c}_N^T - \mathbf{c}_B^T \mathbf{A}_B^{-1} \mathbf{A}_N) \mathbf{x}_N^*. \end{aligned}$$

Since z^* is the optimal objective value then

$$\mathbf{c}_N^T - \mathbf{c}_B^T \mathbf{A}_B^{-1} \mathbf{A}_N \geq \mathbf{0} \quad \text{and} \quad \mathbf{x}_N^* = \mathbf{0}.$$

Let $\alpha \in \mathbb{R}^+$ be such that

$$\begin{aligned} \mathbf{x}'_B &= \frac{\mathbf{x}^*_B}{\alpha} \\ &= \mathbf{A}_B^{-1} \frac{\mathbf{b}}{\alpha} - \mathbf{A}_B^{-1} \mathbf{A}_N \frac{\mathbf{x}^*_N}{\alpha} \\ &= \mathbf{A}_B^{-1} \frac{\mathbf{b}}{\alpha} - \mathbf{A}_B^{-1} \mathbf{A}_N \mathbf{x}'_N \\ &\geq 0 \end{aligned}$$

and

$$\begin{aligned} z' &= \frac{z^*}{\alpha} \\ &= \mathbf{c}_B^T \mathbf{A}_B^{-1} \frac{\mathbf{b}}{\alpha} + (\mathbf{c}_N^T - \mathbf{c}_B^T \mathbf{A}_B^{-1} \mathbf{A}_N) \frac{\mathbf{x}^*_N}{\alpha} \\ &= \mathbf{c}_B^T \mathbf{A}_B^{-1} \frac{\mathbf{b}}{\alpha} + (\mathbf{c}_N^T - \mathbf{c}_B^T \mathbf{A}_B^{-1} \mathbf{A}_N) \mathbf{x}'_N. \end{aligned}$$

That is $\mathbf{x}'_N = \frac{\mathbf{x}^*_N}{\alpha} = 0$, $\mathbf{x}'_B \geq \mathbf{0}$ and $\mathbf{c}_N^T - \mathbf{c}_B^T \mathbf{A}_B^{-1} \mathbf{A}_N \geq \mathbf{0}$. Therefore, the set of indices corresponding to \mathbf{x}' is the current basic feasible solution of LP2 with the same basis B . Similarly, if LP2 has an optimal basic feasible solution then LP1 has the same basic feasible solution.

In addition, the optimal basic indices in LP1 will correspond to the optimal basic indices in LP2(α). ■

D. All-Unit-Row-Except-First-Unit-Column Matrix

In the context of LPNet training, the normalization of inputs plays a crucial role in facilitating deep learning optimization to discover optimal parameters for learning optimal binding constraints. The process of normalization specifically addresses the numerical scaling of the rows within the constraint matrix of LP problems. To address this, the present research introduces a two-step data preprocessing approach for any LP problem prior to its utilization in the learning process.

The first step involves the reordering of all constraints based on the angles formed between the sum vector ($\mathbf{1}$) and the coefficient of each constraint equation. This reordering aims to enhance the structure of the input data for improved learning outcomes.

In the subsequent step, each constraint is individually rescaled to attain a unit norm. This normalization further aids in aligning the constraints on a consistent scale, enabling more effective learning and optimization processes.

By implementing these two preprocessing steps, this research enhances the overall effectiveness of LPNet training by ensuring that the input data is appropriately structured and scaled to facilitate the discovery of optimal binding constraints.

E. LP Constraint Ordering

The research findings demonstrate that the optimal binding constraints remain unchanged even when each row is interchanged with another in LP problems. In order to establish a suitable input format for deep learning, it becomes necessary to rearrange all constraints based on the angle between the gradient vector of primal LP constraints and the sum vector ($\mathbf{1}$), which represents a vector of ones with the appropriate size.

By rearranging the constraints in this manner, the input data is properly structured to align with the requirements of deep learning algorithms. This ensures that the crucial information captured by the gradient vector and the sum vector is effectively utilized, leading to more accurate and meaningful training results. Consequently, this approach enhances the overall effectiveness of the deep learning process in tackling LP problems and discovering optimal binding constraints.

Let \mathbf{a}_i be a gradient vector of the i^{th} constraint from \mathbf{A} . The angle between \mathbf{a}_i and $\mathbf{1}$ of size n is defined as

$$\theta_i^{row} = \arccos\left(\frac{\mathbf{a}_i^T \mathbf{1}}{\|\mathbf{a}_i\| \|\mathbf{1}\|}\right). \quad (4)$$

The primal constraints will be ordered from the smallest angle to the largest angle.

Similarly, the dual constraints corresponding to the column of \mathbf{A} will be rearranged by sorting the angle between the \mathbf{a}_j and $\mathbf{1}$ of size m ,

$$\theta_j^{column} = \arccos\left(\frac{\mathbf{a}_j^T \mathbf{1}}{\|\mathbf{a}_j\| \|\mathbf{1}\|}\right). \quad (5)$$

The next step is to rescale all constraints of the LP problem.

F. LP Scaling

The elimination of duplicate LP problems holds significant importance in the training of LPNet. In Figure 2, three distinct LP problems, namely LP1, LP2, and LP3, are depicted, all of which share the same basic feasible solution while differing only in scaling. In this study, LP1 serves as the normalized version for LP2 and LP3. By identifying the optimal binding constraints of LP1, it becomes possible to determine the optimal binding constraints for LP2 and LP3, as demonstrated in Theorem 2.

This approach of addressing duplicate LP problems streamlines the training process of LPNet. It leverages the knowledge gained from the normalized version (LP1) to efficiently identify the optimal binding constraints for the related LP problems (LP2 and LP3). By avoiding redundant computations, this methodology enhances the overall training efficiency and contributes to the improved performance of LPNet.

From Equation (1), coefficient vector \mathbf{c} , right-hand side vectors \mathbf{b} and matrix \mathbf{A} of the LP problem will be normalized into the unit vector format corresponding to \mathbf{c}' , \mathbf{b}' and \mathbf{A}' respectively. The coefficients of the objective function will be converted to $c'_j = \frac{c_j}{\|\mathbf{c}\|}$ for $j = 1, 2, \dots, n$, the coefficients of the constraint function $a'_{ij} = \frac{a_{ij}}{\|\mathbf{a}_i\|}$ for $i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$ and $b'_i = \frac{b_i}{\|\mathbf{a}_i\|}$ and $b''_i = \frac{b'_i}{\|\mathbf{b}'\|}$ for $i = 1, 2, \dots, m$. These normalized vectors will be stacked together to form the input matrix for the training and testing phases of LPNet. The label vector \mathbf{Y} will contain either 0 for the corresponding binding constraint, 1 for the corresponding non-binding constraint, and 2 for the padding constraint.

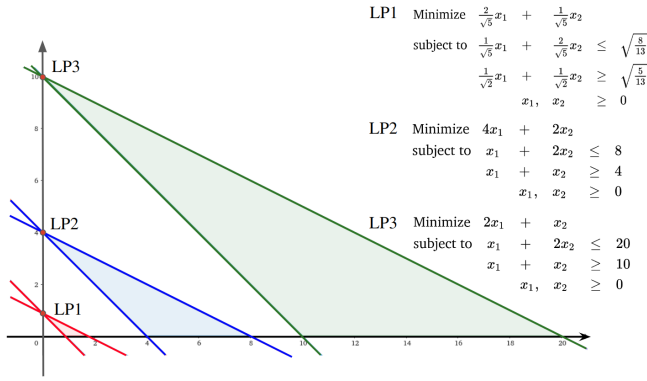


Fig. 2. An example of scaling LP problem of $\mathbf{x} \in \mathbb{R}^2$. Three corresponding LP problems, LP1 is the unit-vector normalization of both LP2 and LP3. These three LP problems are not the same problems but they have the same optimal basic variables. If the optimal binding constraints of LP 1 exist then other LP scales are immediately found. Then any LP sizes $\mathbf{x} \in \mathbb{R}^n$ will be scaled by the unit-vector normalization before entering to LPNet model.

$$\mathbf{X} = \begin{bmatrix} 0 & c'_1 & c'_2 & \dots & c'_n \\ b''_1 & a'_{11} & a'_{12} & \dots & a'_{1n} \\ b_2 & a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ b''_m & a'_{m1} & a'_{m2} & \dots & a'_{mn} \end{bmatrix}$$

$$= \begin{bmatrix} 0 & \frac{c_1}{\|\mathbf{c}\|} & \frac{c_2}{\|\mathbf{c}\|} & \dots & \frac{c_n}{\|\mathbf{c}\|} \\ \frac{b_1}{\|\mathbf{a}_1\| \|\mathbf{b}'\|} & \frac{a_{11}}{\|\mathbf{a}_1\|} & \frac{a_{12}}{\|\mathbf{a}_1\|} & \dots & \frac{a_{1n}}{\|\mathbf{a}_1\|} \\ \frac{b_2}{\|\mathbf{a}_2\| \|\mathbf{b}'\|} & \frac{a_{21}}{\|\mathbf{a}_2\|} & \frac{a_{22}}{\|\mathbf{a}_2\|} & \dots & \frac{a_{2n}}{\|\mathbf{a}_2\|} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \frac{b_m}{\|\mathbf{a}_m\| \|\mathbf{b}'\|} & \frac{a_{m1}}{\|\mathbf{a}_m\|} & \frac{a_{m2}}{\|\mathbf{a}_m\|} & \dots & \frac{a_{mn}}{\|\mathbf{a}_m\|} \end{bmatrix} \quad (6)$$

$$\mathbf{Y} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_m \\ y_{m+1} \\ \vdots \\ y_{m+n} \end{bmatrix} \quad (7)$$

To train LPNet with different LP problem sizes without recreating the specific input size of the deep learning model these inputs need to be embedded into the maximum matrix format. Assume that the maximum LP size is N constraints and N variables so \mathbf{Y} has $2N$ components. To set up a (m, n) input LP sample into the matrix of the maximum LP size (N, N) where $m \leq N$ and $n \leq N$, the small-sized (m, n) LP input matrix are padded with zero rows from the $m + 1$ row to the N row and zero columns from the $n + 1$ column to the N column. The corresponding label vector is assigned to 2, see the matrix below for the padding concept. An example of a $(2, 2)$ LP sample is added into (N, N) matrix \mathbf{X} with padding 2 in the \mathbf{Y} .

$$\mathbf{X} = \begin{bmatrix} 0 & c'_1 & c'_2 & 0 & \dots & 0 \\ b''_1 & a'_{11} & a'_{12} & 0 & \dots & 0 \\ b_2 & a_{21} & a_{22} & 0 & \dots & 0 \\ 0 & 0 & 0 & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \dots & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & \frac{c_1}{\|\mathbf{c}\|} & \frac{c_2}{\|\mathbf{c}\|} & 0 & \dots & 0 \\ \frac{b_1}{\|\mathbf{a}_1\| \|\mathbf{b}'\|} & \frac{a_{11}}{\|\mathbf{a}_1\|} & \frac{a_{12}}{\|\mathbf{a}_1\|} & 0 & \dots & 0 \\ \frac{b_2}{\|\mathbf{a}_2\| \|\mathbf{b}'\|} & \frac{a_{21}}{\|\mathbf{a}_2\|} & \frac{a_{22}}{\|\mathbf{a}_2\|} & 0 & \dots & 0 \\ 0 & 0 & 0 & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \dots & 0 \end{bmatrix}, \quad (8)$$

$$\mathbf{Y} = \begin{bmatrix} y_1 \\ y_2 \\ 2 \\ \vdots \\ 2 \\ y_{m+1} \\ y_{m+2} \\ 2 \\ \vdots \\ 2 \end{bmatrix} \quad (9)$$

The y_1 and y_2 in \mathbf{Y} are represented by the binding constraint status (0 or 1) of the constraints from non-negative variables $x_1, x_2 \geq 0$ respectively. The $N + 1$ and $N + 2$ components of \mathbf{Y} are $y_{N+1} = y_{m+1}$ and $y_{N+2} = y_{m+2}$ denoted by binding constraint status of the first and second constraints. By this concept, the LP model can be trained by many LP problem sizes simultaneously without recreating the CNN model for a specific LP size.

All LP problems will be converted to this all-unit-row-except-first-unit-column matrix as LPNet samples for the training and testing phases.

G. LPNet Architecture

The deep Learning model is an automated learning model that mimics the functioning of human neural networks in machine learning. It uses several layers of neurons arranged in sequential order. The target concept from training data will be learned by the weights and biases of all neurons.

Convolutional neural networks (CNNs) are specialized neural network structures capable of classifying image data much better than conventional neural networks. The main idea of CNN is to use a special type of layer called a convolutional layer that extracts parts of an image such as the borders of objects which is the spatial relation and sends to a pooling layer to extract only the information components from the multi-dimensional array. The proposed LPNet architecture needs a special convolutional layer to extract basic elements from the all-unit-row-except-first unit-column matrix of the LP problem in order to make the state-of-the-art CNN model (baseline model) efficiently be trained. The details of LPNet baseline model are shown in Table I which consists of three stages.

The first stage includes RConv layers that extract row and column features and transform them into spatial relations. To capture the spatial information of an LP problem, the special row-column convolutional layer is introduced, as explained in the following subsection. The second stage of the model is the baseline model, which incorporates a state-of-the-art CNN baseline model. Our results show that the best-performing baseline model for LPNet is MobileNet. The final stage of the model is the estimator, which includes fully connected layers. The last layers consist of 600 nodes, representing the optimal binding constraints status of LP problems with up to 300 constraints and 300 variables. Overall, the LPNet model is designed to effectively extract and utilize features from LP problems to identify optimal binding constraints and provide high-quality solutions.

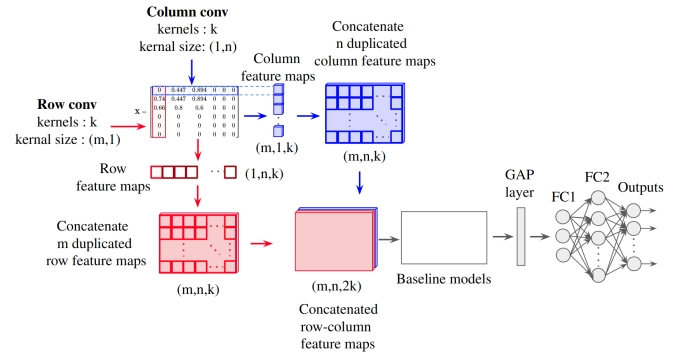


Fig. 3. The LPNet architecture.

TABLE I. LPNET WITH MOBILENET BASELINE

Stage	Type/Stride	Filter Shape	Input Size
RCCConv	Row Conv /s1	$1 \times 301 \times 32$	$301 \times 301 \times 32$
	Concat 301 cols		$301 \times 1 \times 32$
	Concat depth		$301 \times 301 \times 32$
Baseline	Conv /s2	$3 \times 3 \times 3 \times 32$	$301 \times 301 \times 64$
	Conv dw /s1	$3 \times 3 \times 32$ dw	$151 \times 151 \times 32$
	Conv /s1	$1 \times 1 \times 32 \times 64$	$151 \times 151 \times 32$
	Conv dw /s2	$3 \times 3 \times 64$ dw	$151 \times 151 \times 64$
	Conv /s1	$1 \times 1 \times 64 \times 128$	$75 \times 75 \times 64$
	Conv dw /s1	$3 \times 3 \times 3 \times 128$ dw	$75 \times 75 \times 128$
	Conv /s1	$1 \times 1 \times 128 \times 128$	$75 \times 75 \times 128$
	Conv dw /s2	$3 \times 3 \times 128$ dw	$75 \times 75 \times 128$
	Conv /s1	$1 \times 1 \times 128 \times 256$	$37 \times 37 \times 128$
	Conv dw /s1	$3 \times 3 \times 256$ dw	$37 \times 37 \times 256$
	Conv /s1	$1 \times 1 \times 256 \times 256$	$37 \times 37 \times 256$
	Conv dw /s2	$3 \times 3 \times 256$ dw	$37 \times 37 \times 256$
	Conv /s1	$1 \times 1 \times 256 \times 512$	$18 \times 18 \times 256$
	5 × Conv dw / s1	$3 \times 3 \times 3 \times 32$	$3 \times 3 \times 3 \times 32$
	Conv / s1	$3 \times 3 \times 3 \times 32$	$3 \times 3 \times 3 \times 32$
	Conv dw /s2	$3 \times 3 \times 1024$ dw	$18 \times 18 \times 512$
	Conv /s1	$1 \times 1 \times 512 \times 1024$	$9 \times 9 \times 512$
Conv dw /s2	$3 \times 3 \times 1024$ dw	$9 \times 9 \times 1024$	
Conv /s1	$1 \times 1 \times 1024 \times 1024$	$9 \times 9 \times 1024$	
Avg Pool /s1	Pool 7×7	$9 \times 9 \times 1024$	
FC1	1024×512	1024	
Estimator FC2	512×512	512	
Output	512×600	512	

H. Row-Column Convolutional Neural Network

In this research, CNN is used to extract features from the relationship between primal constraints and dual constraints using non-square kernels. A normalized input sample is convoluted over the column and the row to obtain row feature maps and column feature maps, respectively, see Fig. 3. Notice that, these row and column convolutional kernels will transform the row-column (primal-dual) information to spatial feature maps before passing to a state-of-the-art CNN architecture.

Primal constraints (rows of \mathbf{X}) will be convoluted by $(1, n)$ kernel size with k kernels for generating $(m, 1, k)$ column feature maps. Similarly, the dual constraints (columns of \mathbf{X}) will be convoluted by $(m, 1)$ row convolution with k kernels in order to create $(1, n, k)$ row feature maps. These feature maps will be duplicated m times for row feature maps and n times for columns feature maps. The duplicated row and column

feature maps will be concatenated to generate two $m \times n \times k$ spatial feature maps, called RConv. Finally, these features will be concatenated by depth to be an $(m, n, 2k)$ input of a baseline convolution architecture.

I. Baseline Convolution Architectures

CNN combines a convolution layer with other types of layers, such as a pooling layer, and then stacks such layer groups on top of each other. Some hyperparameters, such as the size of the kernel, the number of strides, and the number of padding are combined to become the architecture of CNN. There are many state-of-the-art CNN architectures such as ResNet50, MobileNetv1, EfficientNetB1, Xception, and Inceptionv1 which are famous deep models that are successfully learned to classify images. Resnet50 was the first to introduce a residual block concept that makes the model learn some residual features from the earlier layers. Later, the concept of residual blocks is improved using a depthwise convolution in order to reduce model parameters which are called mobilenet blocks. The depthwise separable convolution in the mobilenet blocks makes MobileNetv1 lighter than other baseline models. The mobilenet block concept is continually improved by searching for the best size of the height, width, and depth of convolutional filters from another deep learning model, and then it becomes EfficientNetB0-B7. This paper focuses on EfficientNetB1 which is suitable for LP samples. The idea of using multiple filters of different sizes on the same level is applied in the inception model. Then the inception model instead of having deep layers also has parallel layers thus making the model wider rather than making it deeper. A baseline model will be an engine for extracting features of LPNet after the LP sample is passed into the row-column convolutional layer. The details of the LPNet architecture with the mobilenet baseline convolution model are shown in the next section.

J. Global Average Pooling Layer and Fully Connected Layers

The feature maps from the baseline convolutional layers will be transformed into the spatial dimensions of feature maps by averaging the spatial features into vector features using a global average pooling layer. These vector features are fed to the first fully connected hidden layer. The first two hidden layers consist of 512 hidden nodes with a relu activation function following the batch normalization layer. Since this

paper aims to predict the maximum optimal binding constraints which are 300 constraints and 300 non-negative constraints of decision variables. Then the total number of constraints is about 600. So the last output layer contains 600 nodes with linear activation function in order to estimate the target vector in $\{0, 1, 2\}$, which is representing the optimal binding constraints. The next section will show the experimental results of LPNet models.

It is straightforward to train LPNet in supervised learning. Training LP samples will be transformed to all-unit-row-except-first-unit-column matrices (\mathbf{X}) from Eq. (8) and the optimal binding vectors (\mathbf{Y}) from Eq.(9). The transformed matrices allow the LPNet model to be trained in many LP problem sizes at the same time without reconstructing the individual input sizes. After the trained LPNet is completed then the next subsection shows the inference algorithm of the LPNet model.

K. LPNet Inference

The inference algorithm of LPNet is summarized as follows:

- 1) Compute angles between the gradient vectors of the primal constraints from Eq. (4).
- 2) Rearrange the order of primal constraints (\mathbf{a}_i and \mathbf{b}_i) by descending angles from 1).
- 3) Compute angles between the gradient vectors of the dual constraints from 2) using Eq. (5).
- 4) Rearrange the order of coefficient variables (\mathbf{a}_j and \mathbf{c}_j) from 2) by descending angles from 3).
- 5) Scale down the LP problem (c_j, b_i, a_{ij}) from 4) into (c'_j, b'_i, a'_{ij}) for $i \in \{1, 2, \dots, m\}$ and $j \in \{1, 2, \dots, n\}$.
- 6) If the LP problem size from 5) is the maximum size (m, n) = (N, N) then the input matrix for the LPNet model will be defined by Eq. (6) and then go to 8). Otherwise, go to 7).
- 7) The LP problem will be padded zeros by using Eq. (8) and then go to 8).
- 8) Take the input matrix from 6) or 7) into the trained LPNet model and the result will be a predicted optimal binding vector $\hat{\mathbf{Y}}$.

The experimental results of the row-column convolution layer plus given a baseline model followed by two fully connected layers and the output layer are presented in this section. About one million LP problems are randomly generated and solved for the training dataset and 500,000 LP problems for the testing dataset. Any small size LP problem is padded to have a matrix size of 300x300. All LP problems guarantee to have the optimal solution. The experiments are performed on Intel(R) Xeon(R) CPU @ 2.20GHz 25GB RAM GPU Tesla P100-PCIE on Ubuntu 18.04.5 LTS. It is implemented by Python programming language based on Tensorflow 2.8.0. [29].

IV. ANALYSIS AND RESULTS

A. Performance Measurement

Most deep learning models use the mean squared logarithmic error (MSLE) as the evaluation measure. It is often used in regression tasks for predicting a continuous value. The MSLE

loss function is defined as the mean of the squared logarithmic errors between the predicted values and the true values:

$$L(\mathbf{Y}, \hat{\mathbf{Y}}) = \frac{1}{m+n} \sum_{i=1}^{m+n} (\log(y_i + 1) - \log(\hat{y}_i + 1))^2,$$

where \hat{y}_i is the predicted value, y_i is the true value, and $n+m$ is the number of samples. The logarithmic transformation helps reduce the impact of large errors, which can be useful when working with skewed data or when there are a few extremely large errors that could dominate the loss. Notice that vector \mathbf{Y} contains a large number of 2's, an imbalance problem occurs during model training, and the error value for 2 is larger than the error from 0 and 1, so the trained model will predict 2 more accurately than 0 or 1. This situation is not reasonable for training the deep learning model for predicting binding and non-binding constraints. Therefore, it is necessary to change the scale of the data to a log scale.

Accuracy is a common metric used to evaluate the performance of a machine-learning model which is defined as the percentage of correct predictions made by the model on a dataset. It is often used to evaluate classification models, where the goal is to predict a class label for a given input. In this case, the model's predictions are compared to the true class labels for the inputs, and the percentage of correct predictions is calculated. This paper proposes two types of accuracy that are 0-1 accuracy and 0-1-2 accuracy. The 0-1-2 accuracy is the accuracy of all optimal binding statuses of \mathbf{Y} . $Y_i = 0$ represents an optimal binding constraint i that is $a_{ij}^T x^* = b_i$. $Y_i = 1$ indicates an optimal nonbinding constraint. $Y_i = 2$ shows an auxiliary constraint for padding zeros rows to an (m,n) LP problem as shown in Eq. (8).

$$Acc_{0-1-2}(\mathbf{Y}, \hat{\mathbf{Y}}) = \frac{\sum_{i=1}^N \beta_i}{N}$$

where

$$\beta_i = \begin{cases} 1 & \text{if } Y_i = \hat{Y}_i, \\ 0 & \text{if } Y_i \neq \hat{Y}_i. \end{cases}$$

The 0-1 accuracy is the accuracy without padding status $Y_i = 2$ of a (m, n) LP problem.

$$Acc_{0-1}(\mathbf{Y}, \hat{\mathbf{Y}}) = \frac{\sum_{i=1}^n \beta_i + \sum_{i=N+1}^{N+m} \beta_i}{m+n}$$

The following subsection will show the result of using the different normalizations with LPNet.

B. Normalization Experiment

All normalizations are applied to the row-column-conv MobileNet baseline model with the row-column arrangement of input samples. From Fig. 4, after 25000 iterations the unit-vector normalization can reduce loss values faster than other normalization methods.

As for the error value of the testing dataset shown in Fig. 5, both the min-max method and the standardization method fluctuated significantly more than the unit-vector method because the normalized input samples did not reduce the variation of the input LP samples. For the unit-vector method which

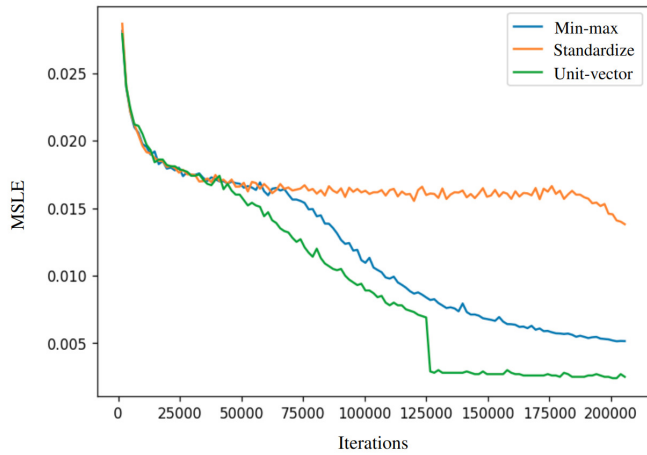


Fig. 4. Error of normalization methods of training dataset.

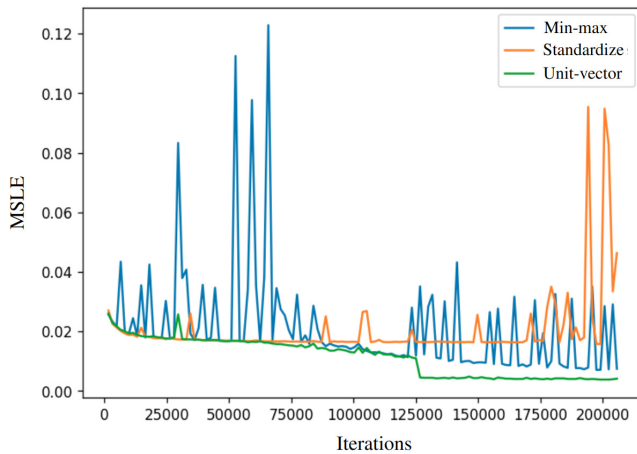


Fig. 5. Error of normalization methods of the testing dataset.

adjusts the problem to have the same scale, the loss value is more stable. Fig. 5 shows the lowest loss value of these normalization methods.

TABLE II. NORMALIZATION METHODS

Normalization	MSLE	0-1-2 acc	0-1 acc
Standardize	0.0078	0.983	0.957
Min-max	0.0068	0.987	0.967
Unit-vector	0.0034	0.996	0.990

C. Row-column Order Experiment

The lowest loss values of the three normalization methods are shown in Table II. The unit-vector normalization achieves the lowest loss value and gains the highest accuracy both the 0-1-2 accuracy and the 0-1 accuracy.

Table III shows MSLE of a different order of the all-unit-row-except-first-unit-column matrix. The original order column represents the order of rows and columns according to the given LP problem. The rearranged row order represents the order of all primal LP constraints according to the angle

TABLE III. THE AVERAGE MSLEs FROM THE ROW-COLUMN CONVOLUTION PLUS THREE STATE-OF-THE-ART CNNs

Models	MSLE		
	Original order	Rearrange row order	Rearrange row-column order
RCCConv ResNet50	0.0168	0.0213	0.0055
RCCConv MobileNetV1	0.0169	0.0061	0.0034
RCCConv EfficientNetB1	0.0164	0.0164	0.0151

between the row-coefficient vector and the sum vector. The rearranged row-column order represents the order of all primal LP constraints and dual LP constraints. Observe that the arrangement of rows and columns of the input samples shows superior performance over the original order and rearrange of row order only.

D. Baseline CNN Architecture Experiment

The validation dataset loss values of LPNet with different baseline models are displayed in Fig. 6. Our results indicate that the MobileNet model exhibits the most stable convergence compared to other baseline models. This suggests that the MobileNet model is a suitable choice for training LPNet and achieving consistent results.

TABLE IV. THE PERFORMANCE OF STATE-OF-THE-ART CNN ARCHITECTURES

Model	Parameters	MSLE	0-1-2 Acc	0-1 Acc
ResNet50	25,205,080	0.0072	0.986	0.966
MobileNetV1	4,327,640	0.0114	0.974	0.935
EfficientNetB0	5,279,415	0.0092	0.978	0.944
EfficientNetB1	7,805,083	0.0138	0.959	0.896
Xception	22,484,544	0.0070	0.990	0.976
InceptionV3	23,425,848	0.0136	0.962	0.902
RCCConv ResNet50	25,422,232	0.0055	0.992	0.981
RCCConv MobileNetV1	4,365,368	0.0034	0.996	0.990
RCCConv EfficientNetB0	5,317,269	0.0049	0.993	0.983
RCCConv EfficientNetB1	7,842,937	0.0151	0.954	0.882
RCCConv Xception	22,522,272	0.0049	0.992	0.982
RCCConv InceptionV3	23,463,576	0.0088	0.979	0.947

All experiments use the row-column arrangement of input samples. MSLEs of all architectures with RCCConv is smaller than the one without. Especially, the MobileNet baseline with RCCConv obtains the lowest loss and the best 0-1-2 accuracy as shown in Table IV.

The results of RCCConv MobileNetV1 in Fig. 7 show the average of all correctly optimal binding predictions (1.0 acc) with respect to many LP problem sizes. LP size ratios (d) are defined as the following conditions:

$$d(m, n) = \begin{cases} \frac{n-m}{n} & \text{if } n > m, \\ 0 & \text{if } n = m. \end{cases} \quad (10)$$

Fig. 7 shows the number of LP models that LPNet can predict all optimal constraints of different ratios of d . When d

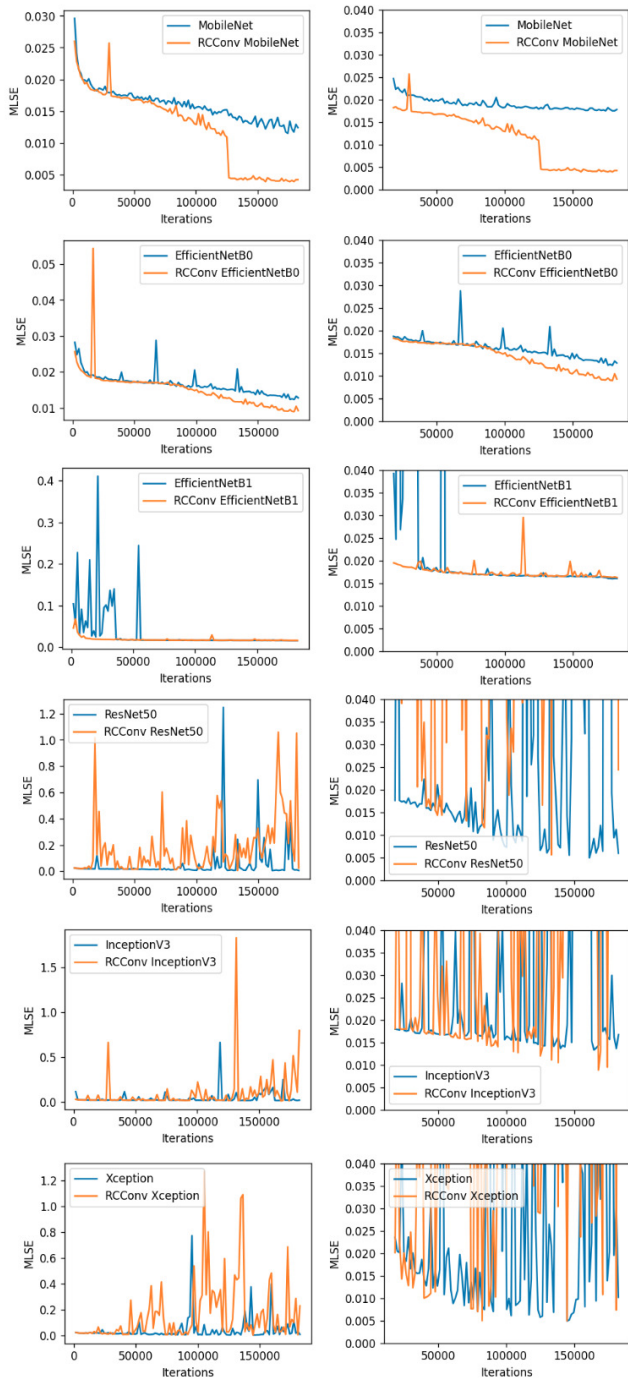


Fig. 6. Mean log square error of CNN baselines and RCConv CNN baselines of the validate dataset.

= 0, it means the number of constraints is equal to the number of decision variables. LPNet can predict all optimal binding constraints of LP problems over 80% when $0.2 \leq d \leq 0.3$. However, this model also suffers from an imbalance problem and many LP problems are infeasible if $m > m$ or $d > 0.8$. The next subsection shows the speed gain using LPNet to obtain the optimal solutions for LP problems.

From the above results, an optimal solution can be directly

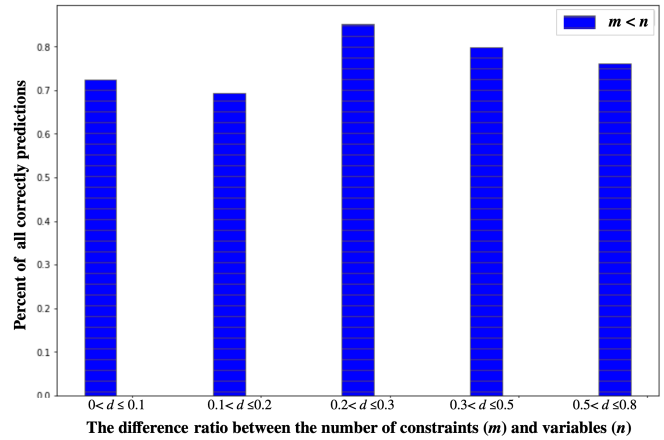


Fig. 7. The bar chart shows the average number of predicted optimal binding constraints that are correctly all components of Y depending on the LP problem ratios d .

obtained by solving the system of linear equations. There are n predicted constraints from $x_j \geq 0$ for $j \in \{1, \dots, n\}$ and $a_{ij}x_j \geq b_i$ for $i \in \{1, \dots, m\}$ that can be selected to solve the exact optimal solution. Fig. 8 shows the average total time for solving the LP problems where the number of constraints and variables are the same. The proposed LPNet algorithm saves a lot of time compared with the commercial solver Cplex [31]. The lowest solution time of the biggest LP size is 0.076 sec on GPU (Tesla-T4) using numpy.linalg solver. However, results are slightly longer on CPU (Xeon(R) 2.20GHz). Fig. 9 shows the average total time where $m < n$ and $n = 300$. LPNet GPU is also faster than LPNet CPU and the Cplex solver. LPNet GPU achieves 7.5 times faster than the cplex solution time.

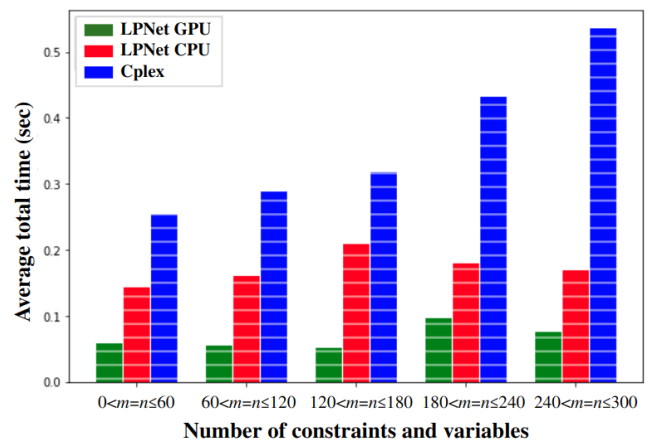


Fig. 8. Total LP solution time for the number of constraints equal to variables.

E. Netlib Dataset

Netlib is a collection of mathematical software, algorithms, and databases that were widely used in the scientific and engineering communities during the 1980s and 1990s. The dataset contains software packages for optimization, linear algebra,

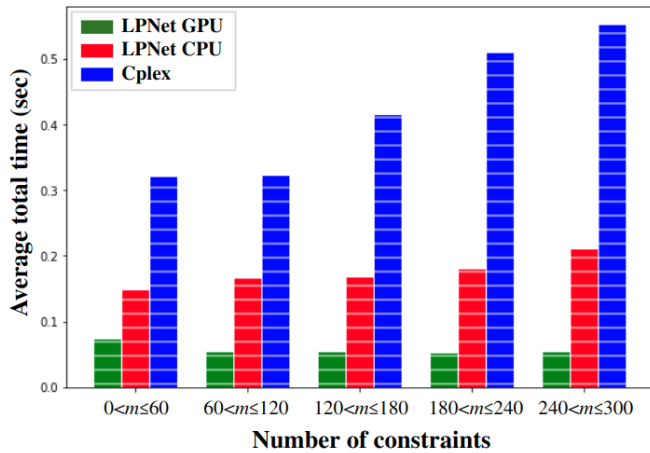


Fig. 9. Total LP solution time for the number of constraints with 300 variables.

differential equations, and other areas of scientific computing. It also includes benchmark datasets, including the Netlib LP dataset, which is a collection of linear programming problems commonly used to evaluate and compare the performance of optimization algorithms. Today, Netlib serves as an archive of legacy software and algorithms and is still widely used in academic research and education as a reference resource.

TABLE V. THE PERFORMANCE OF LPNET MOBILENET BASELINE ON NETLIB DATA

LP problem	Optimal	m	n	0-1-2 Acc	0-1 Acc
ADLITTLE	225494.967	56	97	1.0	1.0
AFIRO	-464.753	28	32	1.0	1.0
BEACONFD	33592.485	173	262	0.998	0.997
BLEND	-30.812	74	83	0.996	0.987
BRANDY	1518.509	220	249	1.0	1.0
E226	-18.751	223	282	1.0	1.0
ISRAEL	-896644.827	174	142	1.0	1.0
SC50A	-64.575	50	48	1.0	1.0
SC50B	-70.0	50	48	1.0	1.0
SC105	-52.202	106	103	1.0	1.0
SC205	-52.202	205	203	1.0	1.0
SCAGR7	-2331389.816	129	140	1.0	1.0
SHARE1B	-76589.318	117	225	1.0	1.0
SHARE2B	-415.732	96	79	1.0	1.0
STOCFOR1	-41131.976	117	111	1.0	1.0

Table V lists selected LP problems from netlib having m and n less than 300. All of them can be directly sent to LPNet to identify the optimal solution.

F. Convolution Analysis

A visual explanation for explaining the relation between a target class and outputs of a CNN layer is introduced by Grad-CAM [30]. The main concept is to choose an interested target class in \mathbf{Y} and take a partial derivative from the output-predicted class with respect to output feature maps of the interested CNN layer for measuring a gradient size corresponding to the sensitive area of the CNN feature maps. The

output feature maps of each CNN layer can be localized maps highlighting important regions related to the target class.

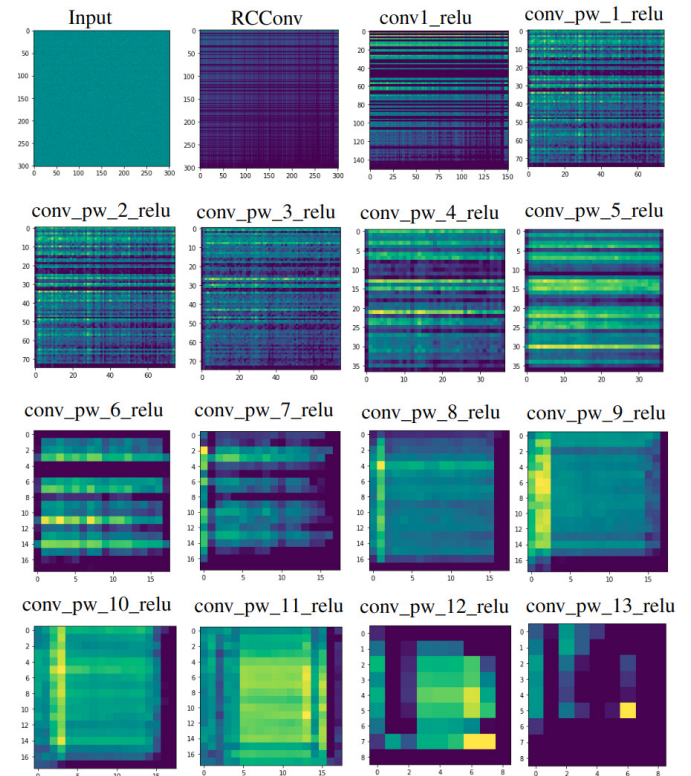


Fig. 10. Output feature maps of convolutional layers of the RCConv MobileNet baseline.

Fig. 10 shows the gradCAM heatmaps of each layer of one of the test problems of size 292×292 from LPNet with the MobileNet baseline. The all-unit-row-except-first-unit-column matrix of the test problem is plotted at the top left of Fig. 10. The second sub-figure to the right comes from the row-column convolutional layers (RCConv) which combine spatial information of rows and columns. By the concept of padding 0, the pixels over the 292×292 rows and columns respectively generate the dark color. The conv1_relu layer will be convoluted and reduced dimensions by half to get a general concept that is related to the prediction $\mathbf{Y}_i = 0$ for $i \in \{0, \dots, 600\}$. MobileNet architecture has a lot of depthwise and pointwise convolutional layers for reducing many parameters compared with regular convolutional layers. Until the last pointwise CNN layer (conv_pw_13_relu), there are some feature maps that respond to the optimal binding prediction. Notice on the highlighted heatmap RCConv to conv_pw_5 layer, LPNet is extracting the sensitive area in terms of highlighted rows which corresponds to the optimal binding constraints. The higher layers will be convoluted and reduced dimensions in order to embed the important features as shown in the conv_pw_13_relu heatmap.

Further, three feature maps of all CNN layers can be localized by gradCAM for nonbinding constraints and padding constraints status in \mathbf{Y} as shown in Fig. 11. For the output layer of LPNet with the MobileNet baseline, the prediction gives three possible prediction statuses which are 0, 1, or 2.

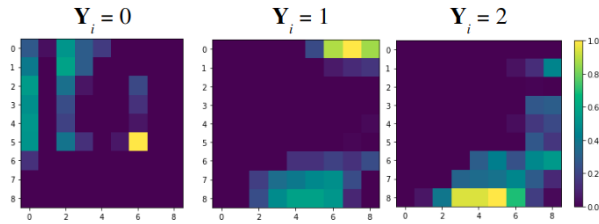


Fig. 11. GradCAM heat maps of the last CNN layer (conv_pw_13_relu) depend on the specific classes in \mathbf{Y} .

The important area of the specific status related to the last convolution (Conv_pw_relu) is shown in Fig. 11. In order to investigate where are the optimal binding constraints, the heatmaps from the gradCAM technique will only consider the prediction at $\mathbf{Y}_i = 0$ for $i \in \{0, \dots, 600\}$ as shown in the left Fig. 11. The middle figure shows the heatmaps of nonbinding constraints that are $\mathbf{Y}_i = 1$ for $i \in \{0, \dots, 600\}$. The heatmaps of the right figure are represented by the padding status $\mathbf{Y}_i = 2$ for $i \in \{0, \dots, 600\}$. Moreover, this heatmap shows the separated area of binding constraints, non-binding constraints, and padding.

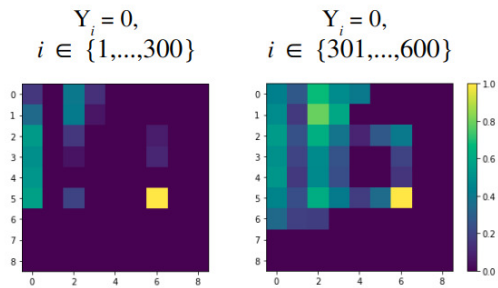


Fig. 12. Both heatmaps show the area highlight of the optimal binding constraints status ($0 \in \mathbf{Y}$) from non-negative variables and regular constraints, respectively.

Fig. 12 shows the localized heatmaps that are related to the non-negative constraints of variables from 1 to 300 and the original constraints from 301 to 600. It indicated that LPNet tried to capture the dual constraints see the left figure with highlight columns that relate to the non-negativity constraints and the right figure shows the highlight of heatmaps that affect the original constraints.

V. DISCUSSION

This LPNet model has a limitation that it works for any linear programming problem having sizes less than 300 rows and 300 columns due to the hardware limitation. To solve a linear programming problem of larger sizes, new training data must be synthesized and solved and weights of the state-of-the-art deep learning model must be retrained on large system resources.

For the perfect prediction of the optimal binding constraints, LPNet determines the optimal solution of a linear

programming problem algebraically, without the need of an iterative step. However, if the prediction is not 100%, some constraints are not the optimal binding constraints. The real optimal constraints must be reidentified. So this work can be extended using the iterative procedure after the optimal binding prediction. A complete linear programming solver utilizing the predicted optimal binding constraints could be created.

In 2023, [25] introduced a novel deep learning approach using feedforward neural networks to solve the LP problem. The approach models the LP problem by an ordinary differential equations (ODE) system, the state solution of which globally converges to the optimal solution of the LP problem. A neural network model is constructed as an approximate state solution to the ODE system, such that the neural network model contains the prediction of the LP problem. The neural network is extended by taking the parameter of LP problems as an input variable so that one neural network can solve multiple LP instances in a one-shot manner. However, it is important to note that the proposed method's performance has only been tested on a specific collection of small LP examples. Its efficacy on more complex or diverse LP problems remains uncertain.

Overall, LPNet provides a promising approach for identifying optimal binding constraints in LP problems, which can greatly reduce the computation time required for traditional iterative solvers. With further development of the algorithm, LPNet has the potential to become a powerful tool for solving complex LP problems in various fields.

VI. CONCLUSIONS

This paper presents the deep learning architecture for identifying the optimal binding constraints called LPNet. A linear programming problem must be cast as the all-unit-row-except-first-unit column matrix with row-column rearrangement before sending it to LPNet. LPNet is composed of the row-column convolutional layer followed by the state-of-the-art convolutional neural network models and two fully connected layers of neural networks and ends with the output layer. With RCCConv + MobileNetV1 + two fully connected layers + output layer, LPNet achieves 99.6% 0-1-2 accuracy from a million synthesized linear programming problems with finite optimal solutions.

The form of the all-unit-row-except-first-unit column has been studied to show the performance obtained for scaling to unit-vector over the max-min normalization and the standardization of rows. Moreover, the arrangement of rows and columns also helps reduce training loss.

LPNet is able to predict 80% of linear programming problems with all optimal binding constraints from generated linear programming problems and it correctly predicts 86% benchmark netlib problems of size smaller than 300 variables and 300 constraints. It can achieve the optimal solution faster than the cplex solver more than 6 times.

In general, any LP problem may not have an optimal solution. It will be very useful to design deep learning to categorize LP problems whether they are infeasible, unbounded optimal, or have a finite optimal solution. Moreover, LPNet weights can be used to accelerate the solution time of any commercial LP solver.

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REFERENCES

- [1] M. R. Hussain, and M. E. Hussain, "Simplex method to Optimize Mathematical manipulation," International Journal of Recent Technology and Engineering (IJRTE), vol. 7, January 2019.
- [2] A. P. Florian, and J. W. Stephen, "Interior-point methods," Journal of Computational and Applied Mathematics, vol. 124, pp. 281–302, 2000.
- [3] M. Soleimani-damaneh, "Modified big-m method to recognize the infeasibility of linear programming models," Knowledge-Based Systems, vol. 21, pp. 377–382, 2008.
- [4] A. Boonperm, and K. Sinapiromsaran, "Artificial-free simplex algorithm based on the non-acute constraint relaxation," Appl. Math. Comput., vol. 234, pp. 385–401, May 2014.
- [5] R. Visuthirattanamane, K. Sinapiromsaran, and Boonperm, "A Self-Regulating Artificial-Free Linear Programming Solver Using a Jump and Simplex Method," Mathematics, vol. 8, 2020.
- [6] G. H. Andrew, Z. Menglong, C. Bo, K. Dmitry, W. Weijun, W. Tobias, A. Marco, and A. Hartwig, "Mobilenets: Efficient convolutional neural networks for mobile vision applications," arXiv, 2017.
- [7] A. Bemporad, M. Morari, V. Dua, and E. N. Pistikopoulos, "The explicit linear quadratic regulator for constrained systems," Automatica, vol. 38, pp. 3–20, January 2002.
- [8] K. Justin, P. Iosif, A. Styliani, and N.P. Efstratios, "Integrating deep learning models and multiparametric programming," Computers & Chemical Engineering, vol. 136, May 2020.
- [9] Z. Ling, R. Liu, Y. Zhang, and X. Chen, "Can Deep Learning Solve Parametric Mathematical Programming? An Application to 0–1 Linear Programming Through Image Representation," IEEE Transactions on Systems, Man, and Cybernetics: Systems, vol. 52, pp. 5656–5667, September 2022.
- [10] S. Khade, S. Gite, B. Pradhan, "Iris Liveness Detection Using Multiple Deep Convolution Networks," Big Data Cogn. Comput., vol. 6, June 2022.
- [11] Y. Yang, Z.-Y. Fu, D.-C. Zhan, Z.-B. Liu, and Y. Jiang, "Semi-Supervised Multi-Modal Multi-Instance Multi-Label Deep Network with Optimal Transport", IEEE Transactions on Knowledge and Data Engineering, PP. 1-1., August 2021.
- [12] T. T. Nguyen, T. T. T. Nguyen, A. V. Luong, Q. V. H. Nguyen, A. W.-C. Liew, and B. Stantic, "Multi-label classification via label correlation and first order feature dependance in a data stream," Pattern recognition, vol. 90, pp. 35–51, June 2019.
- [13] Z.-M. Chen, X.-S. Wei, P. Wang, and Y. Guo, "Multi-label image recognition with graph convolutional networks," in CVPR, 2019.
- [14] D. C. R. Novitasari, F. Fatmawati, R. Hendradi, H. Rohayani, R. Nariswari, A. Arnita, M.I. Hadi, R. A. Saputra, and A. Primadewi, "Image Fundus Classification System for Diabetic Retinopathy Stage Detection Using Hybrid CNN-DELM," Big Data Cogn. Comput., vol. 6, December 2022.
- [15] G. Huang, Z. Liu, L. Van der maaten, and K.Q. Weinberger, "Densely Connected Convolutional Networks," arXiv, 2016.
- [16] S. Christian, L. Wei, J. Yangqing, S. Pierre, E. R. Scott, A. Dragomir, E. Dumitru, V. Vincent, and R. Andrew, "Going Deeper with Convolutions," 2015 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Boston, MA, USA, pp. 1–9, October 2015.
- [17] M. S. Bazaraa, J. J. Jarvis, and H. D. Sherali, Linear Programming and Network Flows, 3rd ed., John, W, New York, 2005.
- [18] G. B. Dantzig, Linear Programming and Extensions, Princeton Univ. Press: Princeton, NJ, 1963.
- [19] D. G. Luengberger, Linear and Nonlinear Programming, 2nd ed., Springer, New York, 2005.
- [20] K. He, X. Zhang, S. Ren, and J. Sun, "Deep Residual Learning for Image Recognition," IEEE Conference on Computer Vision and Pattern Recognition (CVPR), pp. 770–778, 2016.
- [21] M. Tan, and Q. Le, "Efficientnet: Rethinking model scaling for convolutional neural networks," International Conference on Machine Learning, PMLR, pp. 6105–6114, 2019.
- [22] F. Chollet, "Xception: Deep learning with depthwise separable convolutions," Proceedings of the IEEE CVPR, pp. 1251–1258, 2017.
- [23] C. Szegedy, W. Liu, Y. Jia, P. Sermanet, S. Reed, D. Anguelov, D. Erhan, V. Vanhoucke, and A. Rabinovich, "Going deeper with convolutions," IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Boston, MA, pp. 1–9, 2015.
- [24] C. N. Jones, and M. Morrari, "Multiparametric linear complementarity problems," Proceedings of the 45th IEEE Conference on Decision and Control, pp. 5687–5692, 2006.
- [25] D. Wu, and A. Lisser, "A deep learning approach for solving linear programming problems," Neurocomputing, vol. 520, pp. 15–24, 2023.
- [26] C. Flamant, P. Protopapas, and D. Sondak, "Solving differential equations using neural network solution bundles," arXiv, 2020.
- [27] S. Effati and A. R. Nazemi, "Neural network models and its application for solving linear and quadratic programming problems," Applied Mathematics and Computation, vol. 172, pp. 305–33, 2006.
- [28] K. Kavitha and Suneetha Chittineni, "An Intelligent Metaheuristic Optimization with Deep Convolutional Recurrent Neural Network Enabled Sarcasm Detection and Classification Model," International Journal of Advanced Computer Science and Applications(IJACSA), vol. 13, 2022.
- [29] Large-Scale Machine Learning on Heterogeneous Distributed Systems. Available online: <https://www.tensorflow.org>
- [30] R. S. Ramprasaath, C. Michael, D. Abhishek, V. Ramakrishna, P. Devi, and B. Dhruv, "Grad-CAM: Visual Explanations from Deep Networks via Gradient-Based Localization," International Journal of Computer Vision, vol. 128, pp. 336–359, 2019.
- [31] Cplex, I. I. (2009). V12. 1: User's Manual for CPLEX. International Business Machines Corporation, 46(53), 157.

Detection of Epileptic Seizures Based-on Channel Fusion and Transformer Network in EEG Recordings

José Yauri*¹, Manuel Lagos², Hugo Vega-Huerta³, Percy De-La-Cruz-VdV³
Gisella Luisa Elena Maquen-Niño⁴, Enrique Condor-Tinoco⁵

Computer Vision Center, Universitat Autònoma de Barcelona, Barcelona, Spain¹

Dpt. Mathematics and Physics, Universidad Nacional de San Cristóbal de Huamanga, Ayacucho, Peru²

Dpt. Computer Science, Universidad Nacional Mayor de San Marcos, Lima, Peru³

Dpt. of Computing and Electronics, Universidad Nacional Pedro Ruíz Gallo, Lambayeque, Peru⁴

Dpt. Engineering and Information Technology, Universidad Nacional José María Arguedas, Apurímac, Peru⁵

Abstract—According to the World Health Organization, epilepsy affects more than 50 million people in the world, and specifically, 80% of them live in developing countries. Therefore, epilepsy has become among the major public issue for many governments and deserves to be engaged. Epilepsy is characterized by uncontrollable seizures in the subject due to a sudden abnormal functionality of the brain. Recurrence of epilepsy attacks change people's lives and interferes with their daily activities. Although epilepsy has no cure, it could be mitigated with an appropriated diagnosis and medication. Usually, epilepsy diagnosis is based on the analysis of an electroencephalogram (EEG) of the patient. However, the process of searching for seizure patterns in a multichannel EEG recording is a visual demanding and time consuming task, even for experienced neurologists. Despite the recent progress in automatic recognition of epilepsy, the multichannel nature of EEG recordings still challenges current methods. In this work, a new method to detect epilepsy in multichannel EEG recordings is proposed. First, the method uses convolutions to perform channel fusion, and next, a self-attention network extracts temporal features to classify between interictal and ictal epilepsy states. The method was validated in the public CHB-MIT dataset using the k-fold cross-validation and achieved 99.74% of specificity and 99.15% of sensitivity, surpassing current approaches.

Keywords—Epilepsy; epilepsy detection; EEG; EEG channel fusion; convolutional neural network; self-attention

I. INTRODUCTION

Epilepsy is a neurological disease that disturbs the normal functionality of the brain [1]. Epilepsy provokes sudden seizures in the subject, which go from subtle loss of gaze to violent convulsions of the body and extremities, often jointly with fainting, salivation up to the subject's unconscious [2]. Epileptic seizures are produced by a sudden abnormal activity of neurons. The cause that fires such abnormality is still unknown [3]. Recurrence of seizures disrupt the patient's daily activity and damages his personal life, even acquiring additionally psychological illness, such as depression, anxiety, and schizophrenia [4]. Furthermore, patients with epilepsy are often excluded and stigmatized by society [5].

Epilepsy can affect any people without condition of age, gender, or race [6]. According to the World Health Organization (WHO) [7], there are more than 50 million of people suffering of epilepsy around the world, and 80% of patients

live in low income countries, facing difficulties in accessing medical services and treatments in order to alleviate the undesired symptoms of epilepsy [8]. As a results, epilepsy has become in a public health problem for many governments and it deserves to make efforts to improve the quality of life of millions of patients with epilepsy [9].

Since the invention of the electroencephalogram (EEG) in 1929, EEG has widely used to study the brain functionality and its associated diseases [10]. Thereby, EEG has become in the standard medical device to detect and diagnose epilepsy due to its easy to use, non-invasive nature, non-age restriction, and real-time sensing features [1]. An EEG records the electric potential generated by neurons while interacting with each others. To do that an EEG employs an array of electrodes which are tied to the head scalp. As a result, an EEG recording provides multiple time-varying signals, one signal for each electrode [1], [2], [11]. As illustration, Fig. 1 shows an EEG recording of three signals from three electrodes.

In order to diagnose epilepsy using EEG, the EEG recording of a patient is analyzed by the neurologist, who performs a visual exploration of signals and searching for spikes, sharp, and slow wave patters that characterize an epileptic seizure [12]. However, epileptic disease can vary widely and shows a wide range of symptoms in patients. As a result, the traditional visual analysis of EEG recordings to diagnose epilepsy is a time-consuming process and quite prone to misdiagnose [13], [14]. Misdiagnosis may lead to maltreatment with undesirable consequences for the patient [15]. Thus, a proper diagnosis of epilepsy is very important in order to provide proper treatment.

Over the past decade, many studies have been carried out with the aim of developing automatic systems for the detection of epilepsy [16], [17], [18] and towards the prediction of seizure episodes [19], [20], [21], [22]. Most studies exploit machine learning (ML) and deep learning (DL) algorithms to build classification models capable of detecting seizure patterns in EEG records. While ML employs hand-crafted features, DL has the capability to learn automatically a rich set of features from training data, offering a more flexible feature space for modeling [23].

Despite the recent advances, detecting epileptic seizures still defies current methods and there are still many unresolved problems. This work addressees two major questions that are

*Corresponding authors

stated below:

- 1) An EEG device has several electrodes for more accurate medical diagnosis. Although there are methods for merging multiple EEG signals, the method that best suits for an optimal combination of EEG information coming from multiple electrodes is still undefined.
- 2) The epileptic seizure detection is an unbalanced classification problem in essence, with long hours of normal states (or non-seizure episodes) and a few seconds of abnormal states (seizure episodes). Most existing approaches use certain sampling criteria to balance the number of samples in the training and testing set; however, the effect of using the full dataset on classification performance remains unknown.

So, the main contribution of this study is twofold:

- 1) An improved EEG channel fusion method for an optimal combination of information from multiple EEG signals, while increasing the classification performance. The proposed classification model firstly uses convolutions to merge EEG channels and increase the representativeness of input signals. Next, a self-attention transformer extracts temporal features of the fused signal to improve the classification performance.
- 2) The use of a data augmentation method and a weighted loss function that enables the use of large and unbalanced EEG datasets, while improving classification performance.

The remainder of this paper is organized as follows. Section II exposes the background about epilepsy, as well as, the related work. Section III summarizes the methods employed to detect epileptic seizures. Section IV presents the results achieved and provides an analysis of the results compared to previous work. Finally, Section V enlists the findings of this work and the forthcoming investigations.

II. BACKGROUND

The EEG is the standard device to detect and diagnose epilepsy and other brain diseases [1]. An EEG records the electrical activity of the brain for a certain interval of time (minutes, hours, days) and results in a recording file for further visual analysis by the neurologist [24]. To overcome the time-consuming and visual demand process of the traditional analysis of EEG recordings, many automatic methods have been proposed; being the majority of current methods based on DL algorithms [16], [17], [18]. In this way, the detection of epileptic seizures is commonly stated as supervised classification problem of two classes or binary classification [25], [23].

In order to build a classification model, an enough EEG data should be available. However, typically, researchers do not use all EEG data to avoid unbalance between classes and to reduce the computational burden. Instead, they use specific segment of signals from an EEG recording as training. In such manner, it is common that selected segments correlate the phases of epilepsy experienced by the patient. According to the process of epileptogenesis [19], [26], [1], a patient faces

four phases of epilepsy: interictal, preictal, ictal, and postictal. The ictal phase is the seizure episode or attack episode, and the other phases are located in temporal reference to this state. Thereby, the interictal phase is the state a few hours away of a seizure and is considered as the normal state of the patient; the preictal phase is the state of the minutes preceding a seizure; and the postictal phase is the state of the minutes after a seizure. It is worth mentioning that there is still non-consensus in the duration of such stages due to the variability of the epilepsy disease, with the exception of the seizure state [27], [28], [29]. Fig. 1 shows the four phases of epilepsy in an EEG recording of three channels. Note that the seizure (ictal) phase duration is too short in the recording and this makes the EEG data very unbalanced. In addition, because of the diversity of epilepsy among patients, seizure patterns are too diverse and are the main challenge for learning algorithms. Fig. 2 illustrates the seizure segment which is red shaded, showing variability of the signals between EEG channels.

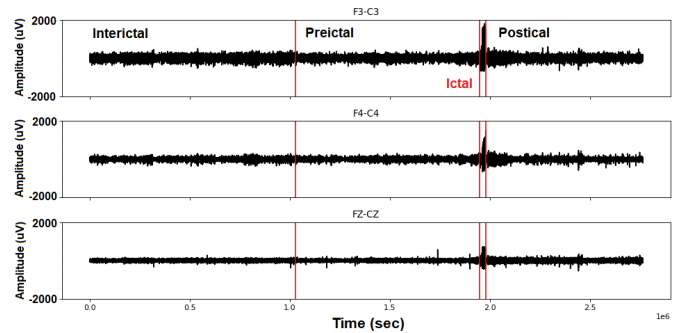


Fig. 1. Epilepsy phases in a long time EEG recording. For convenience, only three channels are plotted.

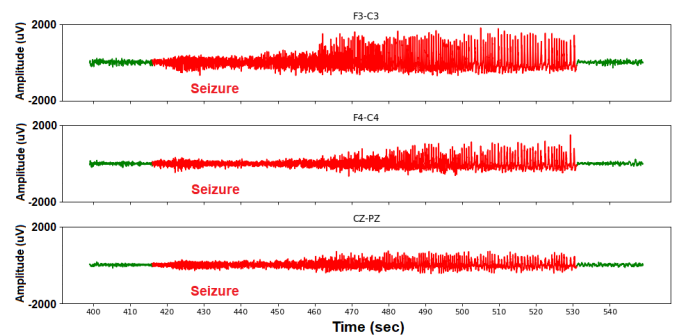


Fig. 2. The epilepsy seizure stage into an EEG recording. The seizure is red shaded, whereas the non-seizure parts are green shaded. For convenience, only three channels are plotted.

Aiming to build a classifier for seizure detection, most researchers use interictal and ictal signals as input data [26], [30], [31], [32], [33], and other investigators use preictal and ictal stages as input data [34], [35], which is also used for researchers that intend to predict a seizure attack [28], [22]. Either using interictal and ictal or preictal and ictal to develop a seizure detector, the classifier is trained to learn how to discriminate between normal and abnormal signals, or non-seizure and seizure segments. On the other hand, tanking into account the classification performance, although the authors

have reported high accuracies in their model performance, the majority of the results are not reproducible due to the lack of consensus on the selection of the portion of the signals used for model training and testing.

Dealing with the problem of epilepsy detection, another issue arises during data selection for training a model: the selected signals are too unbalanced because the patients stay many hours normally (interictal phase), but stay just a few seconds of a seizure (ictal phase) [36]. The high unbalance of classes often cripples any learning algorithm [25]. To overcome class imbalance, researchers have proposed undersampling the majority class, oversampling the minority class, and some data augmentation. It is common to find methods which combine majority class undersampling with increasing minority class data [18]. For data augmentation, the method of sliding a window with overlap has provided great results [37], [34], [31] when compared to the generation of new samples by a specialized model [36].

Another problem that hinders epilepsy detection is that EEG recordings are inherently multichannel data. This is because EEG employs an array of electrodes to record the brain activity in many different locations of the head at a given time. So, an EEG recording consists of spatio-temporal sample points recorded by each electrode. For medical diagnostics of epilepsy, EEG headsets with as many electrodes as possible are preferred in order to reach a higher performance in detection, e.g., an EEG with 19 electrodes arranged according to the international 10/20 system [38]. On the other hand, for non-medical applications, an EEG with fewer electrodes is enough [39], e.g. mental fatigue detection in drivers.

In medical diagnosis using EEG, simultaneous EEG signals increase the visual effort of the neurologist and make it prone to misdiagnosis. With the goal to develop robust automatic system for epilepsy detection, the multichannel issue, also named spatial filtering [40], should be addressed. While some researchers have searched for the most discriminative channel that allows the best classification, a few researchers have proposed a specific method to combine multichannel EEG signals. The former strategy consists of evaluating EEG channels, one by one, and selecting the channel that provides the best performance [20]. This procedure might be slow and the trained model relies heavily on the domain of application, e.g., epilepsy detection [41], [42], mental fatigue detection [43], and active brain computer interfaces (BCI) [40]. The latter strategy consists of designing a specific method that carries out the combination of multiple EEG signals. The main advantage of these methods is that they are more scalable and independent of the application domain [35].

More specifically, although the combination of EEG channels might be performed using learnable DL-based models, there are some mathematical transformations to merge multiple EEG channels into single channel, such as the common spatial pattern (CSP) [44] and the Choquet fuzzy integral [45]. Actually, the CSP is still widely used and actively studied to overcome the limitation of the original CSP [46], [47], [33].

On the other hand, some researchers have leveraged the latest developments in DL and have proposed methods to discriminate between non-seizure and seizure segments while combining multiple EEG channels. Usually, these methods are

based on convolutional neural networks (CNN) and long short-term memory (LSTM) neural networks, which are able to learn both spatial and temporal features from training data [48], [34], [35]. As a results, different DL-based models have been proposed for epilepsy detection, such as based only in CNN models [26], [31], only in LSTM models [35], or CNN-LSTM hybrid models [42], including the plethora of LSTM variations like the bidirectional-LSTM and nested-LSTM [49], [50], [51]. Recently, the self-attention transformer [52] has also been introduced to classify EEG signals due to its ability to capture long-term temporal dependencies analogously to the LSTM network [53]. In spite of recent advances, the question of how to combine several EEG signals whilst increasing classification performance remains unanswered.

Because our approach proposes to take advantage of recent advances in DL, this work has looked at the latest approaches focused on detecting epilepsy using DL and the largest EEG database CHB-MIT [54]. As follows, we sum up the most important related works which have established the current state of the art (SoA). Furthermore, this study takes into account the works that employ interictal and ictal signals as input data due to two reasons. First, interictal and ictal signals are used by the majority of studies as input data source. Second, interictal and ictal segments seem the correct way to discriminate between normal and abnormal states of an epileptic patient due to higher performance that it provides rather than other sources of data.

One of the first works that applied DL towards seizure detection is the work of Zhou et al. [26]. The authors use CNN to detect seizure at a level of patient. The model consists of a 2D convolution layer, an activation function, a 2D max-pooling, and followed by a fully connected (FC) layer for classification. The input data is extracted from the interictal and ictal signals of epilepsy, and next, they were split into time windows of 1 sec. Two experiments were carried out using two different data sources: using time-domain signals and using 2D-spectrogram. Spectrogram is computed using the fast Fourier transform (FFT) for each time window and its channels, and next, they are concatenated along the depth. Assessing the model performance in the CHB-MIT dataset, the use of spectrogram outperforms the time-domain input data, 97.5% against 62.3% of accuracy, respectively. However, because the model is too simple, the high gain may result from data preparation rather than from the data source used (e.g., spectrogram images are normalized between 0 and 1, while time-domain signals not). Also, no information is provided about the data selection process, neither about the treatment of unbalancing between interictal and ictal samples. In contrast, recent approaches mainly use time domain signals, but increasing the model complexity.

Then, Hossain et al. [34] proposed a specialized EEG channel fusion layer before temporal feature extraction for seizure detection. In a cross-patient scheme, input data belongs to preictal and ictal stages, which are split into time windows of 2 sec, 80% overlap. The model contains four CNN blocks. Each block consists of a convolution, an activation function, and a max-pooling. However, the first block is slightly different: first, a convolution operates along time, and next, a convolution operates along channels, both performing feature extraction, then an activation function is applied. Assessing

in the CHB-MIT dataset, the model achieved a sensitivity of 90%, a specificity of 91.65%, and an accuracy of accuracy of 98.05%. Despite the reported high performance, the data selection is unclear and number of seizures recognized is unknown.

Later, Gao et al. [55] proposed to classify image spectrogram of EEG signals by using transfer learning. The authors stated a classification problem of four classes: interictal (selected from two hours away from the ictal), preictal I (selected from 30 min before the ictal), preictal II (chosen 10 min before the seizure), and ictal. First, only 11 patients were selected from the CHB-MIT dataset. Then, signals are cleaned using the discrete wavelet transform (DWT) and split into time windows of 4 sec. Next, time-domain signals are converted to spectrogram images. A data augmentation of ictal signals is employed using a sliding window with 50% overlap. The authors use three pretrained models from image classification task, Inception-ResNet-v2, Inception-v3, and ResNet152, whose outputs are fed to two FC layers of 1,024 and 512 neurons that are used for classification. Validation is performed in a hold-out cross-validation, 70:30, achieving a sensitivity of 95.8% and a specificity of 99.3% detecting the ictal state.

Then, Li et al. [30] proposed a hybrid architecture of CNN and nested LSTM networks. The model consists of three 1D-CNN layers and 100 nested cells of LSTM. Data was carefully selected from interictal and 135 seizures, which are split into time window of 4 sec. Each time window is reshaped in such a way that EEG channels are as features to be processed by the 1D-CNN, and then, after feature extraction, output features are fed to a FC layer of 50 neurons before classification. The model achieved 95.42% of sensitivity, 95.29% of specificity, and 95.29% of accuracy in a 10-fold cross validation. Although the achieved metrics are higher, this is because seizures to be detected have been carefully selected and reduced to 135.

Next, Wang et al. [31] proposed to classify interictal and ictal signals using only a 1D-CNN model. Selected signals is split into time windows of 2 sec and a data augmentation is applied just to ictal segments with 50% overlap. The model architecture consists of two CNN heads, like an ensemble, whose outputs are fed into two FC layers of 256 and 128 neurons before classification. The model validation is performed in a k-fold cross validation scheme, but at level of seizures in the dataset. Working with 145 seizures, the model achieved in average 88.14% of sensitivity, 99.62% of specificity, and 99.54% of accuracy. It is noticeable that 1D CNN alone does not provide a reliable sensitivity to detect epileptic seizures.

Later, Abdelhameed et al. [32] proposed a 2D autoencoder (AE), together with a LSTM network to classify interictal and ictal signals. Data from 16 patients are selected according to the age criterion within the CHB-MIT dataset. Next, the whole dataset is standardized at once, and later, data is split into time window of 4 sec. Then, each window is normalized to 0-1 to ensure reconstruction by the AE. The AE module consists of four layers of conventional 2D-CNN for encoding and decoding. The classification module employs the latent encoded vector as input data and consists of a LSTM network, followed by a FC layer of 256 neurons. The method was assessed in a 10-fold cross validation, achieving $98.72 \pm 0.77\%$ of sensitivity, $98.86 \pm 0.53\%$ of specificity, and $98.79 \pm 0.53\%$

of accuracy. Despite reported the performance is too high, the standardization of the whose dataset before data splitting is not according to ML practices [25].

As exposed above, CSP still is used for EEG channel fusion and the proposal of Li et al. [33] have reported recently high performances in 5-fold cross validation. The authors used the empirical mode decomposition (EMD) to increase the signal-to-noise ratio before to apply CSP. Next, a support vector machine (SVM) is trained using the variance of signals as input features. The method achieved in average, 97.34% of sensitivity, 97.50% of specificity, and 97.49% of accuracy. Despite the sensitivity is higher, the number of detected seizures is just 131, which have no explanation of their selection criteria.

More recently, the self-attention transformer has been introduced in many areas and is widely used for natural language processing (BERT, GPT-3), image classification (vision transformer-ViT), and others applications [56]. In this way, Pan et al. [53] proposed a transformer model to detect epilepsy. Dataset is prepared as non-epilepsy and epilepsy segments, and next, data is split into time windows of 4 sec, with 50% overlap. Also, to ensure balanced samples, an undersampling of the majority class is carried out. Finally, only three EEG channels are fed to the transformer encoder, whose outputs are send to a FC layer for classification. Evaluation in a 5-fold cross validation, the model achieved 94.96% of sensitivity, 93.97% of specificity, and 94.46% of accuracy. Despite the high performance, the authors do not provide sufficient information about what EEG channels are use as input data, and which phase of epilepsy is considered as non-epilepsy and how is trained the model with a fair five thousand samples of each class.

It should be mentioned that previous studies have used certain sampling criteria to balance the number of samples in each class, regardless of whether or not they have used any method of data augmentation. However, the joint use of data augmentation and weighted loss function methods has not been fully explored and remains also as an open question.

This work addresses two main issues outlined above: combining EEG channels as well as the joint use of data augmentation and weighted loss functions in order to increase the classification performance towards epileptic seizure detection.

III. OUR APPROACH

Fig. 3 presents the general pipeline to detect epileptic seizures in EEG recordings. First, a brief description of the dataset is furnished. Then, the preprocessing methods used are described. Next, the neural network model that performs EEG channels fusion and involves a transformer network is presented. Finally, the classification step is performed and the model performance is validated.

As follows, a deep description of each step of the pipeline is provided.

A. EEG Dataset

The EEG data used in this study comes from the CHB-MIT public dataset [54] and contains almost 980 hours of EEG recordings and 198 seizures. The dataset was collected from 23 pediatric patients with incurable epilepsy, 3–22 age. The

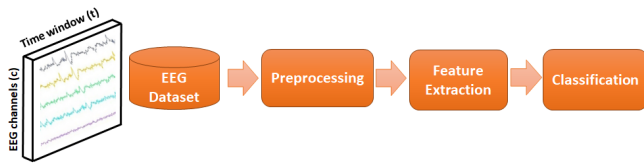


Fig. 3. The epileptic seizure detection pipeline.

recording chb21 was obtained 1.5 years later from the same patient chb01, and because seizure patterns are different, this is treated as a new patient’s recording.

Recordings are stored at the sampling frequency of 256 Hz and different EEG devices with different number of electrodes/channels were employed during recording of data, however, EEG recordings of 23 channels are the most common in the dataset. To release the dataset, longtime recordings were usually split into one hour long recording, and sometimes into two or four hours long recording. EEG recordings that contain seizures are referred to as seizure records; otherwise, non-seizure records. As ground truth (GT), the dataset provides the start and end for each seizure in the seizure record.

B. Preprocessing

In this stage, two main processes are performed: data selection and data windowing.

The former process, data selection, aims to select the EEG recordings and their signals to be used to train a model. In previous studies [16], [17], [18], researchers have found that interictal and ictal signals are the best ones to discriminate between NON-SEIZURE and SEIZURE sample data (see Fig. 1 to illustrate about these epilepsy phases). In addition, researchers have used recordings of 23 channels to overcome the diversity of EEG montages in the CHB-MIT dataset. In this work, we also use interictal and ictal signals among the EEG recordings of 23 channels which involve 181 seizures. Interictal data consist of signals two hours away of a seizure (we name non-seizure signals). On Further, ictal data consists of each seizure signals from all patients (we name seizure signals). Moreover, to reduce computations, signals were downsampled to 128 Hz because it does not affect the classification performance [57]. Moreover, no filtering technique is used as in previous studies [26], [32], [20].

The latter process, data windowing, aims to split the selected EEG segments into small processable time windows. A time window is the sampling unit and is used as input data of the model. This work uses a time window of 1 sec. Besides, in order to mitigate the unbalancing between non-seizure and seizure samples, data augmentation is applied to seizure signals. The data augmentation strategy consists in sliding a window with 80% overlap. Fig. 4 delineates the approach of data splitting and data augmentation employed in this work.

C. Neural Network Architecture

Fig. 5 depicts the proposed neural architecture for epilepsy detection. The neural model receives the time windows as input data. Input data is in time-domain window. Then, it performs

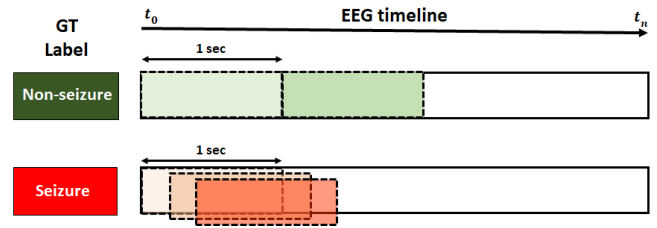


Fig. 4. Data windowing of non-seizure and seizure signals. The image in the top row illustrates the splitting of non-seizure data. The image in the bottom row shows the simultaneous splitting and augmentation of the seizure data.

EEG channel fusion and extracts features for classification. Finally, the model predicts outputs in the form of two categorical data: either non-seizure (interictal) or seizure (ictal) class.

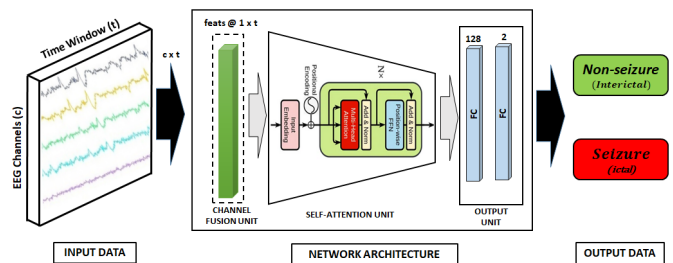


Fig. 5. The neural network architecture.

In brief, the neural network consists of three basic units. First, the Channel Fusion Unit fuses the information coming from different EEG channels into a single channel signal. Second, the Self-attention Unit extracts temporal features based on the previous single channel signal. Third, the Output Unit combines the learned representations for a successful classification.

In this work, the Channel Fusion Unit is inspired by the study of Hossain et al. [34], however, with a slight variation. In our case, once EEG channels are combined, two additional convolutions still refine the spatial features using a small kernel size to diminish the computation burden. The Self-attention Unit is based on the classical transformer architecture proposed by Vaswani et al. [52] and processes the enhanced single channel signal to learn long temporal dependencies of the signal. Ultimately, the Output Unit consists of two layers of fully connected neurons and performs classification.

Table I details the neural network architecture and its parameters. The input data consists of a 2D matrix $X^{c \times t}$, where c is the number of EEG channels (23) and t is the number of time points in the time window (128).

D. Classification

After model training, it is capable to classify non-seizure versus seizure sample units. To predict the label class, the latest layer of the model employs the Softmax activation function to estimate the probability distribution of the input data [25].

TABLE I. DETAILS OF THE PROPOSED NEURAL NETWORK.

Unit	Layer	Output size	Parameters
-	Input	23x128	-
Channel Fusion Unit	Conv 11	23x128x16	kernel 1x3, map 16, None
	Conv 12	1x128x16	kernel 23x1, map 16, BN, Relu
	Conv 2	1x64x256	kernel 1x3, map 256, BN, Relu
	Conv 3	1x60x256	kernel 1x3, map 256, BN, Relu
Self-attention Unit	Transformer	60x256	n_heads=8, n_layers=4
	AvgPool	1x256	d_model=256
Output Unit	FC 1	128	ReLU, Dropout=0.5
	FC 2	2	Softmax

E. Experimental Design

In order to evaluate the feasibility of the proposed neural architecture and to compare its performance with related work, the model is validated using the k-fold cross validation (k=5). The k-fold cross validation was widely employed in previous studies to validate their model performance [16], [17], [18]. However, to ensure a fair assessment and comparison of model performance, in addition to the accuracy, the sensitivity, specificity, precision, and F1-score should be used as validation metrics, because detecting epilepsy is an extremely unbalanced classification problem [25].

IV. RESULTS AND DISCUSSION OF RESULTS

The proposed model is implemented in the Python 3.9 environment and the Pytorch 1.13 deep learning framework and runs in a computer desktop with a GPU NVIDIA GeForce RTX 2070 Super. The hyper-parameters used to train the model are: the Adam optimizer, the cross-entropy loss function which should use normalized weights depending on the proportion of samples from each class in the training set (the larger the number of samples of the class, the smaller the weight, and conversely), the batch size of 128, the learning rate of 1e-4, and 150 number of epochs for model training.

The model performance is assessed using the 5-fold cross validation, and the achieved results are shown in Table II. The results follow the format of the average plus/minus the standard deviation. The proposed model achieved 99.74 ± 0.08 of sensitivity and 99.15 ± 0.1 of specificity detecting epilepsy patterns, with high precision and great F1-score.

TABLE II. CLASSIFICATION PERFORMANCE OF THE PROPOSED MODEL USING 5-FOLD CROSS VALIDATION IN THE CHB-MIT DATASET.

Classifier	Sensitivity	Specificity	Precision	F1-score	Accuracy
This work	99.74 ± 0.08	99.15 ± 0.1	97.66 ± 0.71	98.4 ± 0.32	99.68 ± 0.06

To ensure an equitable and fair comparison of our achieved results against related work, we selected the most recent SoA methods that use interictal and ictal signals as input data and validate their results using the k-fold cross-validation scheme. Table III summarizes the performance reported by several SoA studies.

On the other hand, there are studies that have presented some specific EEG channel fusion approaches, like Hossain

et al. [34] and Chakrabarti et al. [35] for epilepsy detection using preictal and ictal signals, and the work of Gao et al. [58] for fatigue detection in drivers. Because the source of data to train and test their models differs from ours, we implemented such models and trained them using their own suggested hyperparameters for a fair comparison of performance. These studies are highlighted with an * in Table III.

After reviewing Table III, it can be seen that our model is significantly better than models that do not perform channel fusion, being the work of Abdelhameed et al. [32] the only one that comes close to our results, however, the authors just worked with 86 seizures from 16 subjects.

On the other hand, comparing our results against approaches that specifically perform EEG channel fusion, first, it is interesting to observe that the study of Li et al. [33] achieves a higher sensitivity and specificity of almost 97% working with 131 seizures. As this work uses CSP/EMD to fuse EEG channels, we can deduce from this that working with all EEG channels or searching for the best single channel is not good enough for the model, even using the most advanced transformer architecture like in the study of Pan et al. [53]. As a result, fusion of EEG channels before feature extraction can be quite advantageous.

Next, we compare our results against approaches that perform specialized EEG channel fusion based on neural networks. In this way, the study of Hossain et al. [34] implements the channel fusion before the feature extraction, whereas the study of Gao et al. [58] and Chakrabarti et al. [35] implement the channel fusion after feature extraction. Again, it is noted that channel fusion approaches work better than non-channel fusion approaches. Taking into account the achieved performances in descending order, they go from Chakrabarti et al. [35], Gao et al. [58], to Hossain et al. [34]. It seems that EEG channel fusion also is feasible before and after temporal feature extraction. However, our approach, that simultaneously fuses EEG channels and enhance spatial features at input data level before feature extraction, and next, leverages a simple self-attention transformer, outperforms all these approaches and provides the highest sensitivity and specificity to classify between non-seizure and seizure EEG signals.

V. CONCLUSION

In this work, a new approach to detect epileptic seizures has been described. The method is based on a specific channel fusion layer that optimally combines multiple EEG channels into a single channel and enhances spatial features. Then, a simple self-attention transformer is employed to extract temporal features in order to improve the classification performance.

The feasibility of the method was validated in the public CHB-MIT EEG dataset using 5-fold cross validation. In a highly unbalanced dataset and assessing 181 seizures from 24 patients, the proposed model achieved 99.74 ± 0.08 of specificity, 99.15 ± 0.1 of sensitivity, 97.66 ± 0.71 of precision, 98.4 ± 0.32 of F1-score, and 99.68 ± 0.06 of accuracy. Comparing with current SoA methods, the proposed method surpasses them considerably.

In the course of future work, further studies are still needed on new methods of merging EEG channels, especially those

TABLE III. BENCHMARKING THE PERFORMANCE OF THE PROPOSED MODEL AND RELATED WORK IN THE CHB-MIT DATABASE.

Author	Method	Total seizures	Sensitivity	Specificity	Precision	F1-score	Accuracy
Zhou et al. [26]	2D-CNN	-	-	-	-	-	97.5
Gao et al. [55]	Transfer Learning	-	95.8	99.3	-	-	96.9
Li et al. [30]	CNN-nested LSTM	135	95.42	95.29	-	-	95.29
Wang et al. [31]	1D-CNN	145	88.14	99.62	-	-	99.54
Abdelhameed et al. [32]	AE-2D-CNN - LSTM	86	98.72±0.77	98.86 ± 0.53	98.86±0.53	98.79 ± 0.53	98.79±0.53
Li et al.[33]	CSP/EMD-SVM	131	97.34	97.50	-	-	97.49
Pan et al.[53]	Transformer	-	94.96	93.97	-	-	94.46
Hossain et al. [34] *	CNN	181	91.44±1.32	96.86±0.67	76.17±3.51	83.05±1.62	96.33±0.48
Chakrabarti et al. [35] *	LSTM	181	98.29±0.38	99.52±0.07	95.75±0.6	97±0.24	99.4±0.05
Gao et al. [58] *	CNN-FC	181	97.7±0.18	99.49±0.04	95.43±0.32	96.55±0.12	99.32±0.02
This work	Channel Fusion-Transformer	181	99.15±0.1	99.74±0.08	97.66±0.71	98.4±0.32	99.68±0.06

* After training the model architecture from scratch because the original studies use different data sources.

of a linear nature, as they are easier to understand by humans. Furthermore, new data augmentation techniques are needed and generative neural networks may provide an improvement over existing ones.

REFERENCES

- [1] G. Cascino, J. I. Sirven, and W. O. Tatum, *Epilepsy*, 2nd ed. Wiley, 2021.
- [2] M. Z. Koubeissi and N. J. Azar, *Epilepsy Board Review : A Comprehensive Guide*, 2017.
- [3] S. Shorvon, R. Guerrini, and M. Cook, *Oxford Textbook of Epilepsy and Epileptic Seizures*. OUP Oxford, 2012.
- [4] M. Gandy, A. C. Modi, J. L. Wagner, W. C. LaFrance, M. Reuber, V. Tang, K. D. Valente, L. H. Goldstein, K. A. Donald, G. Rayner, and R. Michaelis, "Managing Depression and Anxiety in People with Epilepsy: A Survey of Epilepsy Health Professionals by the ILAE Psychology Task Force," *Epilepsia Open*, vol. 6, no. 1, pp. 127–139, 2021.
- [5] N. F. Bandstra, C. S. Camfield, and P. R. Camfield, "Stigma of Epilepsy," *Canadian Journal of Neurological Sciences*, vol. 35, no. 4, pp. 436–440, 2008.
- [6] J. G. Burneo, L. Black, R. Martin, O. Devinsky, S. Pacia, E. Faught, B. Vasquez, R. C. Knowlton, D. Luciano, W. Doyle, S. Najjar, and R. I. Kuzniecky, "Race/Ethnicity, Sex, and Socioeconomic Status as Predictors of Outcome After Surgery for Temporal Lobe Epilepsy," *Archives of Neurology*, vol. 63, no. 8, pp. 1106–1110, 2006.
- [7] World Health Organization, "Epilepsy," Available on line at: <https://www.who.int/health-topics/epilepsy>, 2022. [Online]. Available: <https://www.who.int/news-room/fact-sheets/detail/epilepsy>
- [8] C. Espinosa-Jovel, R. Toledano, A. Aledo-Serrano, I. García-Morales, and A. Gil-Nagel, "Epidemiological Profile of Epilepsy in Low Income Populations," *Seizure*, vol. 56, pp. 67–72, 2018.
- [9] Center for Disease Control and Prevention, "Epilepsy Is a Public Health Problem," Available on line at: <https://www.cdc.gov/epilepsy/communications/infographics/cdc-epilepsy-text.htm>, 9 2022. [Online]. Available: <https://www.cdc.gov/epilepsy/communications/infographics/cdc-epilepsy-text.htm>
- [10] R. Ince, S. S. Adanir, and F. Sevmez, "The Inventor of Electroencephalography (EEG): Hans Berger (1873–1941)," *Child's Nervous System*, vol. 37, no. 9, pp. 2723–2724, 2021.
- [11] V. S. Wasade and M. V. Spanaki, *Understanding Epilepsy: A Study Guide for the Boards*. Cambridge University Press, 2019.
- [12] N. M. Jadeja, *How to Read an EEG*. Cambridge University Press, 2021.
- [13] W. O. Tatum, "Mistaking EEG Changes for Epilepsy," in *Common Pitfalls in Epilepsy: Case-Based Learning*, D. Schmidt, W. O. Tatum, and S. Schachter, Eds. Cambridge: Cambridge University Press, 2018, ch. 2, p. 25–42.
- [14] U. Amin and S. R. Benbadis, "The Role of EEG in the Erroneous Diagnosis of Epilepsy," *Journal of Clinical Neurophysiology*, vol. 36, no. 4, pp. 294–297, 2019.
- [15] E. R. Somerville, "Some Treatments Cause Seizure Aggravation in Idiopathic Epilepsies (especially absence epilepsy)," *Epilepsia*, vol. 50, no. SUPPL. 8, pp. 31–36, 2009.
- [16] M. K. Siddiqui, R. Morales-Menendez, X. Huang, and N. Hussain, "A Review of Epileptic Seizure Detection using Machine Learning Classifiers," *Brain Informatics*, vol. 7, no. 1, pp. 1–18, 2020.
- [17] J. Prasanna, M. S. P. Subathra, M. A. Mohammed, R. Damaševičius, N. J. Sairamy, and S. T. George, "Automated Epileptic Seizure Detection in Pediatric Subjects of CHB-MIT EEG Database - A Survey," *Journal of Personalized Medicine*, vol. 11, no. 10, p. 1028, 2021.
- [18] A. Shoeibi, M. Khodatars, N. Ghassemi, M. Jafari, P. Moridian, R. Alizadehsani, M. Panahiazar, F. Khozeimeh, A. Zare, H. Hosseini-Nejad, A. Khosravi, A. F. Atiya, D. Aminshahidi, S. Hussain, M. Rouhani, S. Nahavandi, and U. R. Acharya, "Epileptic Seizures Detection Using Deep Learning Techniques: A Review," *International Journal of Environmental Research and Public Health* 2021, Vol. 18, Page 5780, vol. 18, no. 11, p. 5780, 2021.
- [19] S. M. Usman, M. Usman, and S. Fong, "Epileptic Seizures Prediction Using Machine Learning Methods," *Computational and Mathematical Methods in Medicine*, vol. 2017, p. 9074759, 2017.
- [20] S. Toraman, "Automatic Recognition of Preictal and Interictal EEG Signals using 1D-Capsule Networks," *Computers & Electrical Engineering*, vol. 91, p. 107033, 2021.
- [21] R. Hussein, S. Lee, and R. Ward, "Multi-Channel Vision Transformer for Epileptic Seizure Prediction," *Biomedicines*, vol. 10, no. 7, p. 1551, 2022.
- [22] Z. Altaf, M. A. Unar, S. Narejo, M. A. Zaki, and Naseer-u-Din, "Generalized Epileptic Seizure Prediction using Machine Learning Method," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 1, 2023.
- [23] I. Goodfellow, Y. Bengio, and A. Courville, *Deep Learning*. MIT Press, 2016.
- [24] L. Hu and Z. Zhang, *EEG Signal Processing and Feature Extraction*. Springer Singapore, 1 2019.
- [25] K. Murphy, *Machine Learning : A Probabilistic Perspective*. Cambridge: MIT Press, 2012.
- [26] M. Zhou, C. Tian, R. Cao, B. Wang, Y. Niu, T. Hu, H. Guo, and J. Xiang, "Epileptic Seizure Detection Based on EEG Signals and CNN," *Frontiers in Neuroinformatics*, vol. 12, p. 95, 2018.
- [27] A. Shoeb and J. Guttag, "Application of Machine Learning to Epileptic Seizure Detection," in *ICML'10: Proceedings of the 27th International Conference on Machine Learning*, 2010, pp. 975–982.
- [28] S. M. Usman, S. Khalid, R. Akhtar, Z. Bortolotto, Z. Bashir, and H. Qiu, "Using Scalp EEG and Intracranial EEG Signals for Predicting Epileptic Seizures: Review of Available Methodologies," *Seizure*, vol. 71, pp. 258–269, 2019.
- [29] J. Zhou, L. Liu, Y. Leng, Y. Yang, B. Gao, Z. Jiang, W. Nie, and Q. Yuan, "Both Cross-Patient and Patient-Specific Seizure Detection Based on Self-Organizing Fuzzy Logic," *International Journal of Neural Systems*, vol. 32, no. 6, 2022.

- [30] Y. Li, Z. Yu, Y. Chen, C. Yang, Y. Li, X. Allen Li, and B. Li, "Automatic Seizure Detection using Fully Convolutional Nested LSTM," *International Journal of Neural Systems*, vol. 30, no. 4, 2020.
- [31] X. Wang, X. Wang, W. Liu, Z. Chang, T. Kärkkäinen, and F. Cong, "One Dimensional Convolutional Neural Networks for Seizure Onset Detection using Long-term Scalp and Intracranial EEG," *Neurocomputing*, vol. 459, pp. 212–222, 2021.
- [32] A. Abdelhameed and M. Bayoumi, "A Deep Learning Approach for Automatic Seizure Detection in Children With Epilepsy," *Frontiers in Computational Neuroscience*, vol. 15, p. 29, 2021.
- [33] C. Li, W. Zhou, G. Liu, Y. Zhang, M. Geng, Z. Liu, S. Wang, and W. Shang, "Seizure Onset Detection Using Empirical Mode Decomposition and Common Spatial Pattern," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 29, pp. 458–467, 2021.
- [34] M. Shamim Hossain, S. U. Amin, M. Alsulaiman, and G. Muhammad, "Applying Deep Learning for Epilepsy Seizure Detection and Brain Mapping Visualization," *ACM Transactions on Multimedia Computing, Communications and Applications*, vol. 15, no. 1s, 2019.
- [35] S. Chakrabarti, A. Swetapadma, and P. K. Patnaik, "A Channel Independent Generalized Seizure Detection Method for Pediatric Epileptic Seizures," *Computer Methods and Programs in Biomedicine*, vol. 209, p. 106335, 2021.
- [36] B. Gao, J. Zhou, Y. Yang, J. Chi, and Q. Yuan, "Generative Adversarial Network and Convolutional Neural Network-based EEG Imbalanced Classification Model for Seizure Detection," *Biocybernetics and Biomedical Engineering*, vol. 42, no. 1, pp. 1–15, 2022.
- [37] Z. Wei, J. Zou, J. Zhang, and J. Xu, "Automatic Epileptic EEG Detection using Convolutional Neural Network with Improvements in Time-domain," *Biomedical Signal Processing and Control*, vol. 53, p. 101551, 2019.
- [38] M. Tacke, K. Janson, K. Vill, F. Heinen, L. Gerstl, K. Reiter, and I. Borggräfe, "Effects of a Reduction of the Number of Electrodes in the EEG Montage on the Number of Identified Seizure Patterns," *Scientific Reports*, vol. 12, no. 1, p. 4621, 2022.
- [39] J. LaRocco, M. D. Le, and D. G. Paeng, "A Systemic Review of Available Low-Cost EEG Headsets Used for Drowsiness Detection," *Frontiers in Neuroinformatics*, vol. 14, p. 553352, 2020.
- [40] N. Tiwari, D. R. Edla, S. Dodiya, and A. Bablani, "Brain Computer Interface: A Comprehensive Survey," *Biologically Inspired Cognitive Architectures*, vol. 26, pp. 118–129, 2018.
- [41] S. Ammar and M. Senouci, "Seizure Detection with Single-channel EEG using Extreme Learning Machine," in *17th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering, STA 2016 - Proceedings*. Institute of Electrical and Electronics Engineers Inc., 2017, pp. 776–779.
- [42] G. Xu, T. Ren, Y. Chen, and W. Che, "A One-Dimensional CNN-LSTM Model for Epileptic Seizure Recognition Using EEG Signal Analysis," *Frontiers in Neuroscience*, vol. 14, p. 1253, 2020.
- [43] P. Li, W. Jiang, and F. Su, "Single-channel EEG-based Mental Fatigue Detection Based on Deep Belief Network," in *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS*. Institute of Electrical and Electronics Engineers Inc., 2016, pp. 367–370.
- [44] Y. Wang, S. Gao, and X. Gao, "Common Spatial Pattern Method for Channel Selection in Motor Imagery Based Brain-computer Interface," in *Conference proceedings : ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual Conference*, vol. 2005. Conf Proc IEEE Eng Med Biol Soc, 2005, pp. 5392–5395.
- [45] S. A. Ludwig, "Performance Analysis of Data Fusion Methods Applied to Epileptic Seizure Recognition," *Journal of Artificial Intelligence and Soft Computing Research*, vol. 12, no. 1, pp. 5–17, 2022.
- [46] L. Zhang, C. Zhang, H. Higashi, J. Cao, and T. Tanaka, "Common Spatial Pattern Using Multivariate EMD for EEG Classification," in *APSIPA ASC 2011 - Asia-Pacific Signal and Information Processing Association Annual Summit and Conference 2011*. APSIPA, 2011, pp. 244–248.
- [47] R. Fu, Y. Tian, P. Shi, and T. Bao, "Automatic Detection of Epileptic Seizures in EEG Using Sparse CSP and Fisher Linear Discrimination Analysis Algorithm," *Journal of Medical Systems 2020 44:2*, vol. 44, no. 2, pp. 1–13, 2020.
- [48] R. T. Schirrmester, J. T. Springenberg, L. D. J. Fiederer, M. Glasstetter, K. Eggensperger, M. Tangermann, F. Hutter, W. Burgard, and T. Ball, "Deep Learning with Convolutional Neural Networks for EEG Decoding and Visualization," *Human Brain Mapping*, vol. 38, no. 11, pp. 5391–5420, 2017.
- [49] D. D. Chakladar, S. Dey, P. P. Roy, and D. P. Dogra, "EEG-based Mental Workload Estimation Using Deep BLSTM-LSTM Network and Evolutionary Algorithm," *Biomedical Signal Processing and Control*, vol. 60, p. 101989, 2020.
- [50] X. Hu, S. Yuan, F. Xu, Y. Leng, K. Yuan, and Q. Yuan, "Scalp EEG Classification using Deep Bi-LSTM Network for Seizure Detection," *Computers in Biology and Medicine*, vol. 124, 2020.
- [51] G. Liu, L. Tian, and W. Zhou, "Patient-Independent Seizure Detection Based on Channel-Perturbation Convolutional Neural Network and Bidirectional Long Short-Term Memory," *International Journal of Neural Systems*, vol. 32, no. 6, 2021.
- [52] A. Vaswani, N. Shazeer, N. Parmar, J. Uszkoreit, L. Jones, A. N. Gomez, L. Kaiser, and I. Polosukhin, "Attention is All You Need," in *Advances in Neural Information Processing Systems*, I. Guyon, U. V. Luxburg, S. Bengio, H. Wallach, R. Fergus, S. Vishwanathan, and R. Garnett, Eds., vol. 30. Curran Associates, Inc., 2017.
- [53] H. Pan, S. Gong, F. Dong, and L. Jiang, "Epilepsy Seizure Detection using Transformer," *Highlights in Science, Engineering and Technology*, vol. 1, pp. 325–329, 2022.
- [54] A. Shoeb and J. Gutttag, "CHB-MIT Scalp EEG Database," 2010. [Online]. Available: <https://physionet.org/content/chbmit/1.0.0/>
- [55] Y. Gao, B. Gao, Q. Chen, J. Liu, and Y. Zhang, "Deep Convolutional Neural Network-based Epileptic Electroencephalogram (EEG) Signal Classification," *Frontiers in Neurology*, vol. 11, p. 375, 2020.
- [56] Y. Tay, M. Dehghani, D. Bahri, and D. Metzler, "Efficient Transformers: A Survey," *ACM Comput. Surv.*, vol. 55, no. 6, pp. 1–28, 2022.
- [57] L. A. Moctezuma and M. Molinas, "EEG Channel-Selection Method for Epileptic-Seizure Classification Based on Multi-Objective Optimization," *Frontiers in Neuroscience*, vol. 14, p. 593, 2020.
- [58] Z. Gao, X. Wang, Y. Yang, C. Mu, Q. Cai, W. Dang, and S. Zuo, "EEG-Based Spatio-Temporal Convolutional Neural Network for Driver Fatigue Evaluation," *IEEE Transactions on Neural Networks and Learning Systems*, vol. 30, no. 9, pp. 2755–2763, 2019.

Light Field Spatial Super-resolution via Multi-level Perception and View Reorganization

Yifan Mao

School of Computer and Information,
Anqing Normal University
Anqing, 246000, China

Zaidong Tong

School of Computer and Information,
Anqing Normal University
Anqing, 246000, China

Xin Zheng

School of Computer and Information,
Anqing Normal University
Anqing, 246000, China

Xiaofei Zhou

School of Automation,
Hangzhou Dianzi University,
Hangzhou 310018, China

Youzhi Zhang

School of Computer and Information,
Anqing Normal University
Anqing, 246000, China

Deyang Liu*

School of Computer and Information,
Anqing Normal University
Anqing, 246000, China

Abstract—Light field (LF) imaging can obtain spatial and angular information of three-dimensional (3D) scene through a single shot, which enables a wide range of applications in the fields of 3D reconstruction, refocusing, virtual reality, *etc.* However, due to the inherent trade-off problem, the spatial resolution of acquired LF images is low, which hinders the widespread application of LF imaging technique. In order to relieve this issue, an end-to-end LF spatial super-resolution network is proposed by considering the multi-level perception and view reorganization. This method can fully explore the highly interwoven LF spatial and angular structure information. Specifically, a multi-feature fusion enhancement block is introduced that can fully perceive LF spatial, angular, and EPI information for LF spatial super-resolution. Furthermore, the angular coherence between LF views is exploited by reorganizing the LF sub-aperture images and constructing a multi-angular stack structure. Compared with other state-of-the-art methods, the proposed method achieves superior performance in both visual and quantitative terms.

Keywords—Light field image; spatial super-resolution; multi-level perception; view reorganization

I. INTRODUCTION

Light Field (LF) image with four-dimensional structure not only contains the intensities of light ray, but also records the directions of light ray. Compared with traditional 2D imaging which can only capture the spatial information of light ray, LF imaging technique has great potential in many fields, such as image refocusing [1], 3D reconstruction [2], and virtual reality [3], *etc.* However, due to the inherent trade-off problem between spatial and angular resolution in the imaging plane, low spatial resolution hinders the application of LF imaging. High-efficiency spatial super-resolution methods for LF imaging play a crucial role in advancing technological development and have wide-ranging applications in medical treatment, security monitoring, and related fields. The significance of these methods lies in their ability to enhance the resolution of LF data, enabling the reconstruction of high-quality images with greater detail and precision. Therefore, it is imperative to investigate and develop efficient LF super-resolution techniques to address the challenges posed by low spatial resolution of LF data and improve their usability in various applications.

LF image has several representations, such as lenslet image, Sub-Aperture Image (SAI) array and Pseudo Video Sequence (PVS), *et al.* For SAI (also called view) array representation, the adjacent SAIs records the same 3D scene information with a small disparity. This means that the SAI array is highly correlated, which benefits in enhancing the LF spatial super-resolution performance. SAI array representation is always adopted for LF spatial super-resolution task. Especially with the development of deep learning, the convolutional neural Network (CNN) has been widely used in LF image processing tasks with SAI array representation. However, due to the complex LF structure, and the interweaving of spatial and angular information in LF images, there are great challenges to further improve the super-resolution performance by using CNNs under SAI array representation. To solve this problem, most existing methods usually consider exploring the structure information of LF image or reducing the dimensionality of the LF image. Although these methods can reconstruct high spatial resolution LF images, their performance is limited. The reason lies in two aspects. One is that the LF structure information is under-explored. The other is that the rich angular information contained in LF image is under-used. Fully exploring LF structure and angular information is more conducive to improving LF super-resolution performance.

In order to mitigate these issues, in this paper, we propose a LF spatial super-resolution network via multi-level perception and view reorganization. By introducing the multi-feature fusion enhancement block, our network can adequately explore and fuse LF structure information, including spatial, angular, and Epipolar Plane Image (EPI) information, so as to recover more details, especially for some occlusion regions. In addition, in order to better mine the abundant angular information, we reorganize the LF SAIs in different angular directions. Specifically, we arrange the horizontal and vertical SAIs in the LF image array with the same angular coordinate element into a stack, and construct a Multi-Angular Stack (MAS) structure. The MAS structure can provide rich angular and spatial information for LF image spatial super-resolution. The main contributions of this paper are as follows:

- We propose a multi-feature fusion enhancement block

to fully perceive LF spatial, angular, and EPI information for LF spatial super-resolution.

- We construct a multi-angular stack structure to adequately explore LF angular information to enhance LF spatial super-resolution performance.
- Comprehensive experiments demonstrate the superiority of the proposed method than the other state-of-the-art approaches.

The rest of this paper will be organized in the following way. A brief review of related work will be provided in Section II. In Sections III, we present our approach. Section IV discusses the simulation results. Finally, the paper is concluded in Section V.

II. RELATED WORKS

LF spatial super-resolution aims to generate high spatial resolution LF images from densely sampled low spatial resolution one. To achieve this goal, two approaches can be used. One is to apply a single image super-resolution method [4] to super-resolve each SAI separately. The other is to build a mathematical model based on prior information to directly reconstruct high spatial resolution LF image. With the development of deep learning, researchers are more inclined to use CNN to realize the spatial resolution reconstruction of LF images, which can take full use of LF abundant structure information and improve the LF reconstruction performance. A brief reviews of single image super-resolution and LF image super-resolution are given in this section.

A. Single Image Super-resolution

Single image super-resolution does not involve multi-view tasks, for which the goal is only to generate a high-resolution 2D image from a low-resolution 2D image. Shi *et al.* [5] constructed a structure-aware single image super-resolution network to further generate structure and details of images. Song *et al.* [6] developed a criss-cross network to reduce the computation complexity for single image super-resolution task. In their method, few feature points were used to compute long-range dependencies. Hsu *et al.* [7] proposed a detail-enhanced wavelet residual network for single image super-resolution to resolve the details over smooth problem. Wang *et al.* [8] developed an end-to-end joint framework to super-resolve single image by considering the issue of no ground truth high resolution images and degradation models are available. Lan *et al.* [9] put forward a lightweight network for single image super-resolution, which can decrease computational burden by expressing multiscale feature and learning feature correlation.

Single image super-resolution method can reconstruct high spatial resolution LF image by super-resolve each SAI. However, the inherent structure information is under-explored in this kind of method, which limits the LF super-resolution performance.

B. Light Filed Super-resolution

Different from 2D image super-resolution, the pixel information required for LF super-resolution actually exists in each SAI. The four-dimensional information of the LF image

can be decomposed into many SAIs recording the scene, and there is a certain disparity between different SAIs, which has a strong correlation. Therefore, the SAIs of LF images are highly correlated, and the utilization of single view spatial information and angular correlation between different views is the key factor to improve the performance of LF image super-resolution.

Early studies followed the traditional paradigm by developing different models to achieve super-resolution in LF image space. Among them, LFBM5D [10] extends the BM3D [11] filtering to 5D to provide more prior information and thus improve the super-resolution performance. Mitra *et al.* [12] proposed a Gaussian mixture model for encoding the spatial structure of the LF to cope with noise and super-resolution issues. Farrugia *et al.* [13] used multivariate ridge regression to approximate the subspace linear projection method of the adjacent SAIs to the middle SAI. Rossi *et al.* [14] utilized the complementary information between different views to achieve spatial super-resolution through graph optimization based on regularized coupling of graphs. Although these models can encode the structure of the LF by establishing a mathematical model, they rely too much on the prior information of the image, resulting in limited super-resolution performance.

With the development of deep learning, researchers are more inclined to build different super-resolution networks to learn the mapping relationship between low-resolution and high-resolution LF images. For example, Yoon *et al.* [15] proposed a model for LF image super-resolution based on deep convolutional networks. Zhang *et al.* [16] divided the views into four groups, and used the residual information between adjacent views to cope with super-resolution tasks. They explored the correspondences between different viewpoints and divided the SAIs into multiple image stacks with a consistent sub-pixel offset. However, the complementary information between all views was not fully utilized, and the disparity consistency was not well maintained. In order to make full use of the high-dimensional features of LF data, Yeung *et al.* [17] alternately used convolutions to characterize the relationship between pixels in the 4D structural information of spatial domain and angular domain. However, the inherent disparity structure of LF images is ignored. Jin *et al.* [18] proposed an all-to-one light-field super-resolution strategy to strengthen the disparity structure. They explored the complementary information between the views to perform individual super-resolution for each SAI of LF image. Wang *et al.* [19] proposed a spatial-angular interaction strategy and designed different networks to extract spatial and angular features respectively. Wang *et al.* [20] further used separable convolutional networks to explore the spatial-angular information of LF. Although they explore the spatial-angular information to a certain extent, they do not effectively mine the high-dimensional information of the LF image. As a result, the LF super-resolution performance is affected to a certain extent. Liu *et al.* [21] extracted global view information and simultaneously modeled the correlation within each view to achieve better super-resolution performance. Although these methods have shown remarkable performance, there are still some problems that are not well addressed. One is that the high-dimensional information of LF images is not fully utilized, especially the complementary information between spatial angulars and the geometric consistency information of LF EPIs. The other is that the angular structure

between the LF views is not broken, and the angular correlation between the LF images is not explored enough.

Focusing on the above problems, we propose a novel network for LF spatial SR based on the content characteristics of LFs. We introduce two strategies to mitigate the above problems. Since the high-dimensional features of the LF image contain rich information, we fully explore the LF spatial information, LF angular information, and the geometric information of the LF EPIs, respectively. The information is interacted and the channel attention is increased to obtain the enhanced information after interaction. In order to further explore the angular correlation between the LF views, we break the angular structure of the LF array and rearrange it into multiple stacks, and super-resolve each horizontal view stack separately. The network makes full use of the content characteristics of LF images and further improves the performance of LF spatial resolution reconstruction by fully exploring the information of different dimensions of the LF and designing the cross-arrangement of views to mine the angular correlation between views. Experimental results on both real and synthetic datasets demonstrate the superiority of the proposed method.

III. PROPOSED METHOD

In the proposed method, the spatial information of the LF image, the angular information and the geometric information of the LF EPIs were used to interact with the multi-dimensional features of the LF and reorganize the array structure based on the content characteristics of the LF. The method makes full use of multi-dimensional information and angular correlation of LF images, and is composed of two main modules: multi-stream feature fusion enhancement module and structure reorganization module. The overall network structure is shown in Fig. 1. We formulate LF in terms of a four-dimensional tensor $L(u, v, x, y) \in \mathbb{R}^{U \times V \times X \times Y}$, where U and V denote the angular dimensions, and H and W denote the spatial dimensions. Specifically, the SAI of a $U \times V$ array represents the LF, and the resolution of each SAI is $H \times W$. The high-resolution LF image $L \in \mathbb{R}^{U \times V \times \alpha X \times \alpha Y}$ is reconstructed from the low-resolution LF image $L \in \mathbb{R}^{U \times V \times X \times Y}$, where α is the magnification factor. Following [16-19], we perform SR only on the Y channel to reduce the computational complexity. The Cb and Cr channels are upsampled using bicubic interpolation algorithms. Then the super-resolved Y, Cb and Cr channels are converted into an RGB image. The proposed reconstruction network can be written as

$$L_{HR}(u, v, \alpha x, \alpha y) = f(L_{LR}(u, v, x, y), \Theta),$$

$$\Theta^* = \arg \min_{\Theta} \|L_{GT}(u, v, \alpha x, \alpha y) - L_{HR}(u, v, \alpha x, \alpha y)\| \quad (1)$$

where $L_{HR}(u, v, \alpha x, \alpha y)$ is the reconstructed dense LF, $L_{GT}(u, v, \alpha x, \alpha y)$ is the ground truth, $f(\cdot)$ represents the mapping from low resolution LF image to high resolution LF image, Θ is the network parameter.

To achieve a high-quality dense LF reconstruction and obtain optimal network parameter Θ , we propose a multi-stream reconstruction network. To effectively extract distinctive information from various view images, we propose a novel approach that combines multiple features to enhance the representation of LF spatial, angular, and EPI information. Specifically, we present a multi-feature fusion enhancement

block that can accurately capture spatial and angular details contained in the LF data (See Sec. III-A). Moreover, we design a Structure-based Super-Resolution Module that utilizes the angular information present in the subaperture view array to perform super-resolution reconstruction, thus optimizing the quality of the reconstructed views (see Sec. III-B). To further enhance the geometric consistency between the reconstructed views and maintain the valuable disparity structure of the LF data, we propose a mixed loss function that incorporates both reconstruction loss and EPI gradient loss (see Sec. III-C). The network architecture is elaborated in the following subsections.

A. Multi-stream Feature Fusion Enhancement Module

To enhance the characteristics of decoupling, this paper proposes the addition of a channel information, $L \in \mathbb{R}^{U \times V \times X \times Y \times C}$, to the 5D data. Multiple representation methods of the LF image in various dimensions were utilized to explore its content characteristics and extract feature information. The fusion process of multi-stream feature, denoted as L_{MFFE} , is expressed as follows:

$$L_{MFFE} = f_{MFFE}(\text{CA}(\text{SFE} + \text{AFE}) + \text{CA}(\text{EPI}^H + \text{EPI}^V)) \quad (2)$$

Here, **SFE** stands for the spatial feature extraction module of subaperture view, **AFE** indicates the angular feature extraction module of subaperture view, **EPI^H** and **EPI^V** denote the feature extraction modules of the EPI in the vertical and horizontal directions (EPI-H and EPI-V), respectively, and **CA** represents the attention module. In what follows, we expound on each module of the Multi-stream Feature Fusion Enhancement Module.

Spatial Feature Extraction(SFE): We focus on the information of SAI in the dimension and reshape the 5D LF data with increased channel information $S^{lr} \in \mathbb{R}^{UV \times C \times X \times Y}$. The SFE module is used to extract the spatial features of the SAI. Specifically, SFE is a module composed of three convolutions with a kernel size of 3×3 , a step size of 1, a dilation rate of 2, and a Relu activation layer after each convolution layer. Since we focus on $H \times W$, the dimension information, SFE only includes the pixel information of the context in each SAI, which has a good refinement of the global features of each SAI and has rich texture information.

Angular Feature Extraction(AFE): In view of the multi-angular characteristics of LF, we centers on the $U \times V$ angular information. Similarly, we reshape the original 5D light field data $A^{lr} \in \mathbb{R}^{HW \times C \times U \times V}$. The AFE module is used to extract the angular feature from the pixel information of the same angular position of the SAI. Specifically, AFE is a module composed of three convolutions with a kernel size of 3×3 and a step size of 1. Each convolution layer is followed by a Relu activation layer. Different from SFE, AFE pays more attention to the correlation in angular, and different SAIs have strong correlation in the same pixel position, which can provide more pixel information for the occlusion area.

EPI Feature Extraction(EPI-H, EPI-V): EPI is the horizontal $E_H^{lr} \in \mathbb{R}^{VW \times C \times U \times H}$ or $E_W^{lr} \in \mathbb{R}^{UH \times C \times V \times W}$ vertical two-dimensional slice information of SAI by sampling angular coordinates and corresponding spatial coordinates in multi-dimensional data of LF. Acknowledging the effectiveness

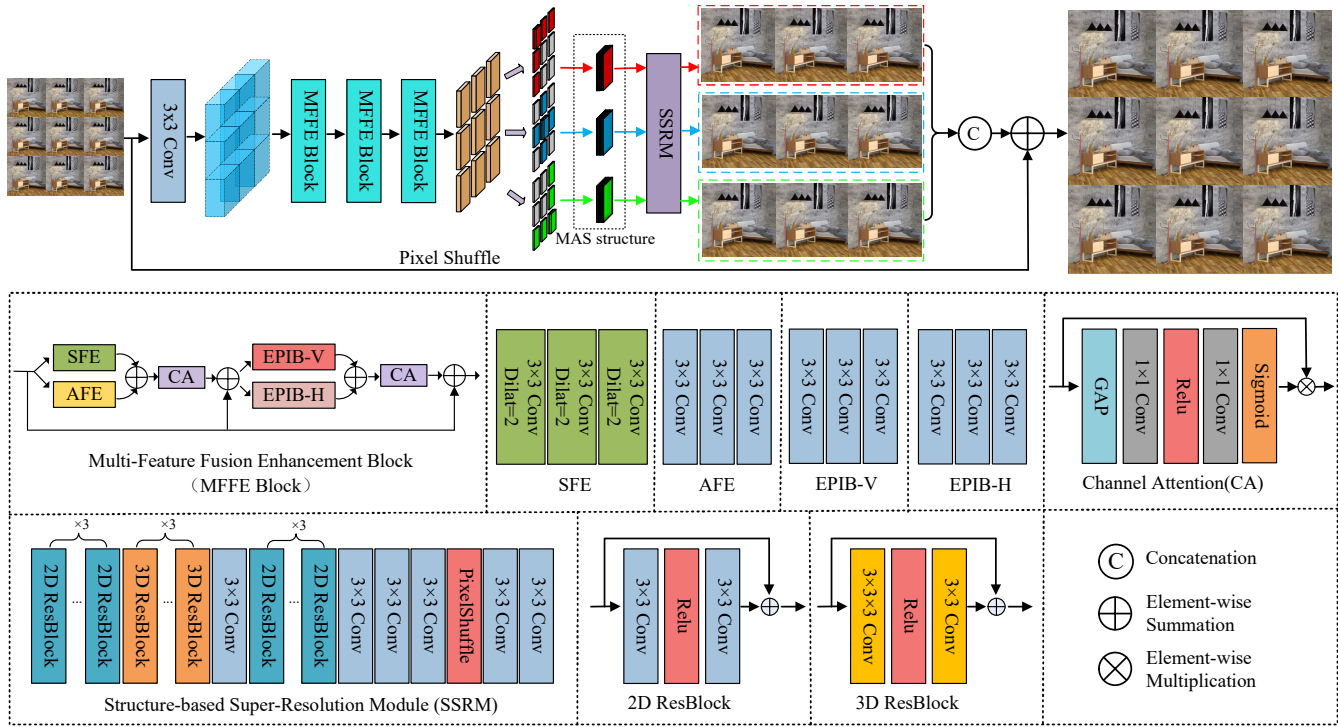


Fig. 1. The architecture of our light field spital reconstruction network.

of EPI in reflecting the geometrical consistency of LF, we delves into the analysis of LF geometric information, both horizontally and vertically. Specifically, EPI-H and EPI-V are modules composed of three convolutions with a kernel size of 3×3 and a step size of 1. Each convolution layer is followed by a relu activation layer. The EPI slices have a simple linear structure, which is basically a slanted straight line composed of homogeneous regions, and perform well for the analysis of features in the scene slices even for the rather complex shape and intensity variations in SAI.

Channel Attention(CA): Due to the local nature of convolutional operations, obtaining sufficient information to extract inter-channel relationships in LF imager can be challenging. To address this limitation, we integrate CA into our proposed architecture after the SFE and AFE fusion, as well as after the EPI-H and EPI-V fusion. The CA module compresses the feature map into a feature vector via global average pooling (GAP) to obtain a global description feature. Non-linear relationships between channels are then learned by compressing the channel count through 1×1 convolutions, using the rule activation layer, and subsequently amplifying the channel count via another 1×1 convolution layer. Finally, the weighting coefficients assigned to each channel by the sigmoid function enable effective cross-channel interaction and enhancement of fusion interaction amongst the information.

B. Structure-base Super-resolution Module

This paper proposes a novel approach to leverage the angular information contained in the subaperture view array for super-resolution reconstruction. Specifically, a cross-arrangement structure of the angular view and a reorganized

parallax structure of the view are proposed to enhance the utilization of angular information. Then, a multi-stream feature fusion module is introduced to extract rich and high-dimensional features, which are subsequently fed into the structure-based super-resolution module. The network structure can be expressed as:

$$L_{HR} = \text{Concat}(f_{SSRM}^1(MFFE^1), \dots, f_{SSRM}^i(MFFE^i)) \quad (3)$$

where $f_{SSRM}^i(\cdot)$ represents the Structure-base Super-resolution module, $MFFE^i$ represents the input information of the first row in the cross-arrangement structure of angulars and views, and i represents the number of rows, where the main scenario in this paper is $i = 5$. The designed super-resolution network comprises three 2D ResBlock convolutions, three 3D ResBlock convolutions, one 3×3 convolution, three 2D ResBlock convolutions, three 3×3 convolutions, one pixel shuffle layer, and two 3×3 convolutions. Different ResBlock convolutions are utilized to fuse rich information in both the spatial and angular domains, while the pixel shuffle layer achieves spatial super-resolution via upsampling.

C. Training Details

In this method, we adopt the $L1$ loss function to measure the reconstructed target LF $L_{HR}(u, v, \alpha x, \alpha y)$, and supervise our network by its ground truth value $L_{GT}(u, v, \alpha x, \alpha y)$, which is defined as:

$$loss_1 = \sum_{u,v,x,y} (|L_{GT}(u, v, \alpha x, \alpha y) - L_{HR}(u, v, \alpha x, \alpha y)|) \quad (4)$$

To further preserve the valuable disparity structure of the

TABLE I. QUANTITATIVE COMPARISON RESULTS OF DIFFERENT METHODS FOR TASK $2 \times$ SR AND $4 \times$ SR (PSNR/SSIM)

Task	$2 \times$					$4 \times$				
	EPFL	HCI new	HCI old	INRIA	STFgantry	EPFL	HCI new	HCI old	INRIA	STFgantry
Bicubic	29.50/0.935	31.69/0.934	37.46/0.978	31.10/0.956	30.82/0.947	25.14/0.831	27.61/0.851	32.42/0.984	26.82/0.886	25.93/0.843
VDSR	32.50/0.960	34.37/0.956	40.61/0.987	34.43/0.974	35.54/0.979	27.25/0.878	29.31/0.883	34.81/0.952	29.19/0.921	28.51/0.901
EDSR	33.09/0.963	34.83/0.960	41.01/0.988	34.97/0.977	36.29/0.982	27.84/0.886	29.60/0.887	35.18/0.954	29.66/0.926	28.70/0.908
RCAN	33.16/0.964	34.98/0.960	41.05/0.988	35.01/0.977	36.33/0.983	27.88/0.886	29.63/0.888	35.20/0.954	29.76/0.927	28.90/0.921
resLF	32.75/0.967	36.07/0.972	42.61/0.992	34.57/0.978	36.89/0.987	27.46/0.890	29.92/0.901	36.12/0.965	29.64/0.934	28.99/0.921
LFSSR	33.69/0.975	36.86/0.975	43.75/0.994	35.27/0.983	38.07/0.990	28.27/0.908	30.72/0.912	36.70/0.969	30.31/0.945	30.15/0.939
LF-ATO	34.27/0.976	37.24/0.977	44.20/0.994	36.15/0.984	39.64/0.993	28.52/0.912	30.88/0.914	37.00/0.970	30.71/0.949	30.61/0.943
LF-InterNet	34.14/0.976	37.28/0.977	44.45/0.995	35.80/0.985	38.72/0.992	28.67/0.914	30.98/0.917	37.11/0.972	30.64/0.949	30.53/0.943
LF-DFnet	34.44/0.977	37.44/0.979	44.23/0.994	36.36/0.984	39.61/0.994	28.77/0.917	31.23/0.920	37.32/0.972	30.83/0.950	31.15/0.949
MEG-Net	34.31/0.977	37.42/0.978	44.10/0.994	36.10/0.985	38.77/0.992	28.75/0.916	31.10/0.918	37.29/0.972	30.67/0.949	30.77/0.945
DPT	34.49/0.976	37.36/0.977	44.30/0.994	36.41/0.984	39.42/0.993	28.94/0.917	31.20/0.919	37.41/0.972	30.96/0.950	31.15/0.949
Proposed	34.56/0.977	37.64/0.979	44.55/0.995	36.36/0.985	39.64/0.993	28.88/0.915	31.23/0.919	37.32/0.972	30.87/0.950	31.08/0.948

LF and promote the geometric consistency between the reconstructed views, this paper refers to the EPI gradient loss function proposed by [22], which is defined as follows

$$\begin{aligned}
 loss_2 = & \sum_{y,v} (|E_{GT}^x(x,u) - E_{HR}^x(x,u)| \\
 & + |E_{GT}^u(x,u) - E_{HR}^u(x,u)|) \\
 & + \sum_{x,u} (|E_{GT}^y(y,v) - E_{HR}^y(y,v)| \\
 & + |E_{GT}^v(y,v) - E_{HR}^v(y,v)|)
 \end{aligned} \quad (5)$$

The training objective of our method is to minimize these two losses: $\min loss_1 + loss_2$.

IV. EXPERIMENTS

To confirm the efficacy of the proposed approach, a range of detailed experimental results have been presented, comprising ablation experiments and comparisons with the existing methods. Specifically, we follow [20] which utilize five publicly available LF datasets (namely EPFL, HCInew, HCIold, INRIA, STFgantry) during both the training and testing phases. The training and test sets follow the same partitioning as provided in [20]. The LFs within these datasets possess an angular resolution of 9×9 . During the training procedure, we downsample the SAI into LF patches of size 32×32 via bicubic downscaling. The optimization of our network utilizes both $L1$ and EPI loss functions and the Adam method. Our network is implemented in PyTorch, leveraging an RTX 5000 GPU. The learning rate is initially configured to 2×10^{-4} and subsequently reduced by a factor of 0.5 every 15 epochs. The performance of our proposed method is evaluated using objective measures, including Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity (SSIM), while simultaneously conducting a subjective comparison of detail texture regions after SR.

A. Comparison With State-of-the-Art Methods

The proposed method is compared with several state-of-the-art methods, comprising three single-image SR techniques [7-9] and seven LF image SR methods [16,17,18,19,20,23,24].

To ensure a uniform training process, we retrained all these methods using the same dataset. **Quantitative Results:** Table I presents quantitative results for $2 \times$ SR and $4 \times$ SR. The proposed method significantly outperforms three single image super-resolution methods, VDSR[7], EDSR[8], and RCAN[9]. This improvement is mainly attributed to the complex texture details present in the comprehensive scene, which renders the reconstruction method of single image unsuitable for LF image reconstruction. Moreover, our approach attains the best overall performance compared to resLF[16], LFSSR[17], LF-ATO[18], LF-Internet[19], LF-DFnet[20], MEG-Net[23], and DPT[24]. Our proposed method outperforms the comparative methods in all five datasets for two primary reasons. Firstly, the comparative methods are less effective in fully exploiting the LF's rich angular information and handling complex scenes. resLF[16] constructs view stacks to explore LF information in five directions: horizontal, vertical, left, right, and tilt, fails to fully use complementary information among all views while maintaining disparity consistency. Similarly, though the LF-ATO[18] method proposes an all-to-one architecture that explores complementary information between views, the feature information between spatial and angular domains is not entirely fused. This deficiency affects the spatial super-resolution performance. Second, the comparative methods fail to exploit the LF's geometric structure information to its full potential. LF-Internet[19] utilized the spatial and angular interaction strategy and different networks to extract spatial and angular features while making use of the spatial and angular correlations. However, they neglected the EPI structure information and angular geometric information, which deteriorated the quality of LF spatial reconstruction. Similarly, although LFSSR[17] utilized convolution to characterize the relationship between pixels in a 4D information space in the spatial and angular domains, it ignored the inherent geometric structure of the LF and failed to fully utilize the angular geometric structure. Observing the evaluation metrics presented in Table I, we note that the proposed method outperforms the comparative methods significantly.

Qualitative Results: The qualitative results of the Bedroom in the HCInew scene and ISO_Chart_1_Decoded in EPFL scene reconstructed by different methods under task $2 \times$ SR and $4 \times$ SR is presented in Fig.2 and Fig.3, respectively.

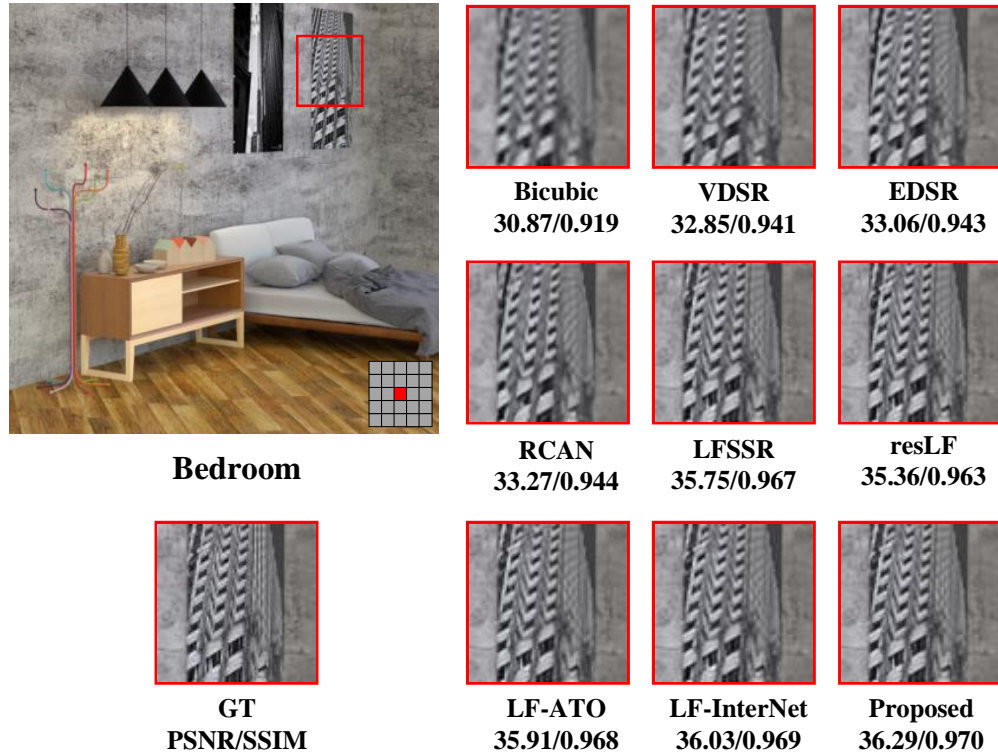


Fig. 2. Visual comparisons for $2\times$ SR. The super-resolved center view images are shown. The PSNR and SSIM scores achieved by different methods on the presented scenes are reported below the zoom-in regions.

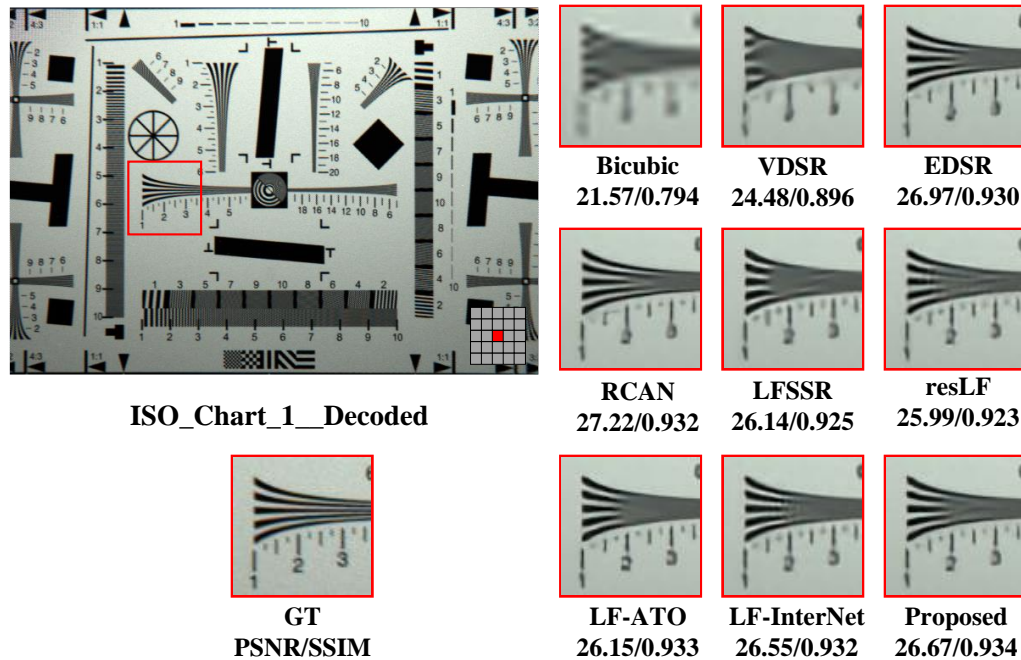


Fig. 3. Visual comparisons for $4\times$ SR. The super-resolved center view images are shown. The PSNR and SSIM scores achieved by different methods on the presented scenes are reported below the zoom-in regions.

TABLE II. TASK 2× QUANTITATIVE COMPARISON RESULTS OF DIFFERENT VARIANTS OF THE PROPOSED METHOD (PSNR/SSIM)

Method	EPFL	HCI new	HCI old	INRIA	STFgantry
w/o CA	34.43/0.977	37.58/0.979	44.56/0.995	36.22/0.985	39.55/0.993
w/o EPI-H	34.34/0.976	37.46/0.978	44.36/0.994	36.13/0.984	39.13/0.992
w/o EPI-V	34.33/0.976	37.39/0.978	44.25/0.994	36.09/0.984	39.09/0.992
w/o AFE	34.28/0.976	37.33/0.977	44.40/0.994	36.18/0.984	39.15/0.992
w/o SFE	34.38/0.977	37.65/0.979	44.54/0.995	36.22/0.985	39.67/0.993
w/o SSRM	34.21/0.975	37.11/0.976	44.11/0.994	36.09/0.984	38.77/0.992
Proposed	34.56/0.977	37.64/0.979	44.55/0.995	36.36/0.985	39.64/0.993

TABLE III. TASK 2× SR QUANTITATIVE COMPARISON RESULTS OF DIFFERENT ANGULAR RESOLUTIONS OF THE PROPOSED METHOD (PSNR/SSIM)

Method	EPFL	HCI new	HCI old	INRIA	STFgantry
3 × 3	33.94/0.972	37.10/0.976	43.74/0.994	35.85/0.982	38.94/0.992
5 × 5	34.56/0.977	37.64/0.979	44.55/0.995	36.36/0.985	39.64/0.993
7 × 7	34.69/0.978	37.80/0.980	44.73/0.995	36.39/0.985	39.65/0.993

The magnification of the local view of the reconstructed sub-aperture is shown in the red box. In Fig.2, although the Bedroom scene contains complex textures, which makes reconstruction challenging. Our method leverages high-dimensional features of the LF and combines spatial and angular domain with EPI information to recover more detailed information of the scene. It can be seen from the Fig.3, the scene is composed of numerous lines and gaps that are difficult to reconstruct. While the LF reconstruction method can capture more information, it still has limitations in such complex line scenes with small gaps. Instead, EDSR[8] and RCAN[9], two single image super-resolution methods, show better reconstruction performance on these scenes. This is because the real pixel information is insufficient at a higher super-resolution size, and the LF reconstruction method synthesizes more new pixel information, which is intertwined with each other and blocks the gaps between lines. Compared with current state-of-the-art SISR and LF image SR methods, our method produces images with more accurate details and fewer artifacts.

B. Ablation Experiments

To gain a deeper understanding of the proposed network’s properties, an ablation study was performed to demonstrate the efficacy of the feature fusion and angular view intersection arrangement structure for high-dimensional data in the LF context. The study involved removing various components from the network, including the channel attention module, EPI feature extraction module (EPI-H, EPI-V), angular feature extraction module, spatial feature extraction module, and structure-based super-resolution module. These were identified as the variants of the proposed network for the purposes of the study and are respectively denoted as “w/o CA”, “w/o EPI-H”, “w/o EPI-V”, “w/o AFE”, “w/o SFE” and “w/o the SSRM”. The comparison results (PSNR/SSIM) of the different variants of the proposed method for task 2×SR on five public datasets are presented in Table II. The results indicate that the proposed method significantly outperforms the other variants with the removal of any module leading to an adverse effect on the reconstruction performance.

Specifically, compared with “w/o CA”, the proposed

method has obvious advantages in PSNR. This can be attributed to the channel attention module, which analyzes the weight of each channel by fusing spatial and angular with horizontal and vertical information of the polar plane. It strengthens the channel weight coefficient that has a greater impact on reconstruction. In comparison to “w/o EPI-H” and “w/o EPI-V”, the proposed method attains higher PSNR and SSIM scores due to the EPI module’s ability to analyze the section information of the LF geometrically, resulting in better recovery of the structural information. The proposed method outperforms “w/o AFE” by achieving a 0.28 dB PSNR gain by using the angular information to improve the LF reconstruction performance significantly. The multi-stream feature fusion module extracts diverse structural information by analyzing multiple dimensions of the high-dimensional data of the LF, thereby enhancing spatial angular correlations. Thus, all modules in multi-stream feature fusion contribute positively to the reconstruction performance. Significantly, the proposed method achieves the best gain compared to “w/o SSRM”, with the PSNR value increasing from 34.21 dB to 34.56 dB for 2×SR. This is because the cross-arrangement of angular viewpoints offers geometric structure analysis of the angular correlation of the LF, leading to an improvement in reconstruction quality.

C. Extended Experiments

In this paper, we investigate the impact of angular resolution on the performance of our proposed method. We evaluate the super-resolution performance under different angular resolutions by extracting $A \times A$ sub-aperture views of the center from the input LF image, where A represents the number of views ($A = 3, 5, 7$). We train separate models for the 2× super-resolution task with each angular resolution setting. Our results, as shown in Table III, reveal that increasing the angular resolution from 3×3 to 7×7 improves the PSNR values. This improvement can be attributed to the richer angular information provided by additional views, which enhances the spatial super-resolution. However, we observe that the performance saturates for angular resolutions greater than 5×5 . This is because the information obtained from the 7×7 sub-

aperture views is already sufficient, and further increasing the angular resolution yields only marginal improvements in performance.

D. Discussions

This paper proposes a new method for learning LF spatial SR by interweaving LF spatial and angular structure information. Here, some discussions are presented. (1) Similar to previous literature, we adopt publicly available LF data to conduct detailed experiments. The qualitative and quantitative comparisons with the state-of-the-art SR methods demonstrate the superior performance of the proposed method. (2) Our ablation study highlights the effectiveness of multi-stream feature fusion by means of the integration and interlacing of high-dimensional data from diverse sources during the multi-stream feature fusion phase. This approach facilitates the extraction of comprehensive information, thereby enhancing reconstruction performance. Furthermore, the ablation experimental outcomes validate the effectiveness of both the proposed MFFE and SSRM. (4) Considering the quantitative results presented in Subsection IV, the performance of the proposed method for the narrow-baseline LF images is significantly better than that for the widebaseline LF images, mainly because the latter has a larger parallax range, posing greater challenges to feature extraction.

V. CONCLUSION

In this paper, we present a multi-stream feature fusion spatial reconstruction network with cross-arranged viewpoints. The network consists of two stages: multi-stream feature fusion and reconstruction based on cross-permutation of angular viewpoints. In the multi-stream feature fusion stage, we combine and interweave high-dimensional data from different sources to extract rich information that can be used to improve the reconstruction performance. Additionally, this stage allows us to fully explore the high-dimensional data of the LF and fuse different dimensional data. Then the rich information obtained in the multi-stream feature fusion stage is used to mine the LF information from the geometric structure level to improve the reconstruction performance. Through experiments on five public datasets, we demonstrate that our proposed method produces high-quality spatial reconstructions of LF images under both $2\times$ SR and $4\times$ SR reconstruction tasks. Furthermore, we analyze the influence of the input angular resolution on reconstruction performance. Our results show that our method significantly outperforms state-of-the-art approaches.

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REFERENCES

- [1] Y. Wang, J. Yang, Y. Guo, C. Xiao, and W. An, "Selective light field refocusing for camera arrays using bokeh rendering and super resolution," *IEEE Signal Processing Letters*, vol. 26, no. 1, pp. 204-208, 2018.
- [2] Z. Wang, L. Zhu, H. Zhang, *et al.*, "Real-time volumetric reconstruction of biological dynamics with light-field microscopy and deep learning," *Nature Methods*, vol. 18, pp. 551-556, 2021.
- [3] J. Yu, "A light-field journey to virtual reality," *IEEE Multi Media*, vol. 24, no. 2, pp. 104-112, 2017.
- [4] W. Yang, X. Zhang, Y. Tian, W. Wang, J. -H. Xue and Q. Liao, "Deep Learning for Single Image Super-Resolution: A Brief Review," *IEEE Transactions on Multimedia*, vol. 21, no. 12, pp. 3106-3121, 2019.
- [5] W. Shi, F. Tao and Y. Wen, "Structure-Aware Deep Networks and Pixel-Level Generative Adversarial Training for Single Image Super-Resolution," *IEEE Transactions on Instrumentation and Measurement*, vol. 72, pp. 1-14, 2023.
- [6] Z. Song, B. Zhong, J. Ji and K. -K. Ma, "A Direction-Decoupled Non-Local Attention Network for Single Image Super-Resolution," *IEEE Signal Processing Letters*, vol. 29, pp. 2218-2222, 2022.
- [7] W. -Y. Hsu and P. -W. Jian, "Detail-Enhanced Wavelet Residual Network for Single Image Super-Resolution," *IEEE Transactions on Instrumentation and Measurement*, vol. 71, pp. 1-13, 2022.
- [8] L. Wang, T. -K. Kim and K. -J. Yoon, "Joint Framework for Single Image Reconstruction and Super-Resolution With an Event Camera," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 44, no. 11, pp. 7657-7673, 2022.
- [9] R. Lan, L. Sun, Z. Liu, H. Lu, C. Pang and X. Luo, "MADNet: A Fast and Lightweight Network for Single-Image Super Resolution," in *IEEE Transactions on Cybernetics*, vol. 51, no. 3, pp. 1443-1453, 2021.
- [10] M. Alain and A. Smolic, "Light field super-resolution via lfbm5d sparse coding," *IEEE International Conference on Image Processing (ICIP)*, 2018, pp. 2501-2505.
- [11] K. Egiastian and V. Katkovnik, "Single image super-resolution via bm3d sparse coding," *European Signal Processing Conference (EU-SIPCO)*, 2015, pp. 2849-2853.
- [12] K. Mitra and A. Veeraraghavan, "Light field denoising, light field super resolution and stereo camera based refocussing using a gmm light field patch prior," *IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, 2012, pp. 22-28.
- [13] R. A. Farrugia, C. Galea, and C. Guillemot, "Super resolution of light field images using linear subspace projection of patch-volumes," *IEEE Journal of Selected Topics in Signal Processing*, vol. 11, no. 7, pp.1058-1071, 2017.
- [14] M. Rossi and P. Frossard, "Geometry-consistent light field super-resolution via graph-based regularization," *IEEE Transactions on Image Processing*, vol. 27, no. 9, pp. 4207-4218, 2018.
- [15] Y. Yoon, H.-G. Jeon, D. Yoo, *et al.*, "Learning a deep convolutional network for light-field image super-resolution," *IEEE International Conference on Computer Vision Workshop (ICCVW)*, 2015, pp. 24-32.
- [16] S. Zhang, Y. Lin, H. Sheng, "Residual networks for light field image super-resolution," In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, 2019, pp. 11046-11055.
- [17] H. W. F. Yeung, *et al.*, "Light field spatial super-resolution using deep efficient spatial-angular separable convolution," *IEEE Transactions Image Processing*, vol. 28, no. 5, pp. 2319-2330, 2018.
- [18] J. Jin, *et al.*, "Light field spatial super-resolution via deep combinatorial geometry embedding and structural consistency regularization," In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, 2020, pp. 2260-2269.
- [19] Y. Wang, *et al.*, "Spatial-angular interaction for light field image super-resolution," In *Proceedings of the European Conference on Computer Vision*, 2020, pp. 290-308.
- [20] Y. Wang, J. Yang, L. Wang, X. Ying, T. Wu, W. An, and Y. Guo, "Light field image super-resolution using deformable convolution," *IEEE Transactions on Image Processing*, vol. 30, pp. 1057-1071, 2020.
- [21] G. Liu, H. Yue, J. Wu, *et al.*, "Intra-Inter View Interaction Network for Light Field Image Super-Resolution," *IEEE Transactions on Multimedia*, vol. 25, pp. 256-266, 2023.

- [22] J. Jin, J. Hou, H. Yuan, and S. Kwong, "Learning light field angular super-resolution via a geometry-aware network," In Proceedings of AAAI Conference on Artificial Intelligence (AAAI), 2020, pp. 11141-11148.
- [23] S. Zhang, S. Chang, and Y. Lin, "End-to-end light field spatial super-resolution network using multiple epipolar geometry," *IEEE Trans. Image Process.*, vol. 30, pp. 5956-5968, 2021.
- [24] S. Wang, T. Zhou, Y. Lu, H. Di, "Detail-preserving transformer for light field image super-resolution," In Proceedings of the AAAI Conference on Artificial Intelligence. vol. 36, No. 3, pp. 2522-2530, 2022.

Enhancing Intrusion Detection Systems with XGBoost Feature Selection and Deep Learning Approaches

Khalid A.Binsaeed, Prof.Alaaeldin M. Hafez

College of Computer and Information Sciences, King Saud University, Riyadh, KSA

Abstract—As cyber-attacks evolve in complexity and frequency; the development of effective network intrusion detection systems (NIDS) has become increasingly important. This paper investigates the efficacy of the XGBoost algorithm for feature selection combined with deep learning (DL) techniques, such as ANN, 1DCNN, and BiLSTM, to create accurate intrusion detection systems (IDSs) and evaluating it against NSL-KDD, CIC-IDS2017, and UNSW-NB15 datasets. The high accuracy and low error rate of the classification models demonstrate the potential of the proposed approach in IDS design. The study applied the XGBoost feature extraction technique to obtain a reduced feature vector and addressed data imbalance using the synthetic minority oversampling technique (SMOTE), significantly improving the models' performance in terms of precision and recall for individual attack classes. The ANN + BiLSTM model combined with SMOTE consistently outperformed other models within this paper, emphasizing the importance of data balancing techniques and the effectiveness of integrating XGBoost and DL approaches for accurate IDSs. Future research can focus on implementing novel sampling techniques explicitly designed for IDSs to enhance minority class representation in public datasets during training.

Keywords—Intrusion detection system; deep learning (DL); XG-Boost; feature extraction; Bidirectional Long Short-Term Memory (BiLSTM); Artificial Neural Networks (ANN); 1D Convolutional Neural Network (1DCNN); Synthetic Minority Oversampling Technique (SMOTE); NSL-KDD dataset; CIC-IDS2017; UNSW-NB15

I. INTRODUCTION

As computer networks continue to play an increasingly important role in modern life, ensuring cybersecurity has become a crucial area of research. One method to protect against potential threats is using an Intrusion Detection System (IDS). By continuously monitoring the state of both software and hardware on a network, IDS plays a critical role in maintaining cybersecurity [1]. Many Intrusion Detection Systems (IDSs) generate alerts, even in low-threat situations, straining cybersecurity experts and increasing the risk of actual intrusions going undetected. The literature includes extensive research on the subject, and different approaches to IDSs have been developed. However, current IDSs still face difficulty detecting unknown or novel attacks due to the constantly evolving network configurations. Therefore, it is critical to continue the research on IDSs to identify and detect such attacks [2].

Attackers can initiate attacks by distributing malicious files to devices connected to a network, resulting in potential

damage to the device or theft of sensitive information [3]. Various technologies, such as firewalls, anti-virus software, email filters, and virtual private networks (VPN), protect networks from such threats. Intrusion Detection System (IDS) is another commonly used approach, where network traffic is monitored to detect any unusual activities. Network intrusion detection can be categorized into anomaly-based and signature-based [4]. Signature-based methods rely on predetermined criteria to identify attacks and categorize threats, while anomaly-based methods classify threats by studying regular traffic to develop profiles based on available data. Based on the given definitions, we can infer that Signature-based IDS are vulnerable to new undefined attacks as they solely depend on the current rules to generate their alerts. However, anomaly-based IDS are more effective when dealing with new threats as they do not base their alerts on existing rules [5] [6]. That does not mean that Signature-based IDS are less critical; it offers improved detection accuracy and reduced triggers of false alarms while identifying known threats. Although there is a high probability of false positives associated with anomaly detection IDS, the research community has widely accepted it due to its theoretical potential for identifying new threats [7].

A. Feature Engineering Challenges within NIDS

Creating a dependable and flexible NIDS that detects unknown future attacks presents two significant challenges. Selecting appropriate features from internet traffic collection for anomaly detection can present a noticeable challenge [7]. The features selected for one type of threat may not be practical for other attacks due to the ever-changing and evolving nature of attack scenarios. The literature has already proposed potential ways to address the challenge, the most common of which is the use of deep learning, a subset of machine learning techniques that uses hierarchical layers of data processing stages to learn features or representations and classify patterns [8]. Deep learning plays a crucial role in image categorization. It is also frequently utilized in natural language processing, speech recognition, audio, picture, video processing, graphical modeling, pattern identification, and language-related tasks. Improvements in learning algorithms can enhance IDS's ability to achieve a higher detection rate and lower false alarm rate. The use of deep learning-based techniques is anticipated to assist in overcoming the challenges of developing an effective NIDS [8].

Unlabeled network traffic data can be collected from various sources, and deep learning algorithms can be applied to generate a good feature representation of these datasets. These

characteristics can then be utilized for supervised classification on a small, labeled traffic dataset consisting of regular and anomalous traffic records. A spoofed, private, and isolated network environment can be used to collect the traffic data for the labeled dataset [9].

B. Aim and Objective

The study aims to provide a reliable and efficient approach for identifying different cyber-attack types using sequence modeling and deep learning by proposing the following:

Developing an effective intrusion detection model for detecting malicious traffic, leveraging SMOTE, BiLSTM, XGBoost, and 1DCNN/DNN for improved intrusion detection.

To achieve the aim of this study, the following objectives have been created:

- Identify all the model variations that need to be evaluated using SMOTE, BiLSTM, XGBoost, and 1DCNN/DNN.
- Evaluate the identified models against well-known IDS datasets from the literature (NSL-KDD [10], CIC-IDS2017 [11], and UNSW-NB15 [12]).

C. Problem Statement

The increasing use of interconnected computing systems has brought numerous benefits to daily activities and exposed us to vulnerabilities beyond human control. As a result, cybersecurity measures must be included in communication exchanges to ensure secure communication. However, with evolving security risks and threats, there is a constant need to improve security measures, including Intrusion Detection Systems (IDS). Despite the efforts of researchers to develop novel IDS systems, achieving high detection accuracy while reducing false alarm rates remains a challenge.

II. RESEARCH STRUCTURE

This paper is organized into seven sections, providing a comprehensive examination of the research topic:

- **Section 1: Introduction** - This initial section provides an overview of the paper's structure and objectives, setting the stage for the subsequent discussion and analysis.
- **Section 2: Background and Related Work** - This section explores key concepts and offers some background information to facilitate the understanding of the rest of the paper.
- **Section 3: Proposed Model (Methodology)** - This section explains the methodology of the proposed model and how it works.
- **Section 4: Results** - This section presents the results obtained by applying the newly proposed model to the experimental datasets.

- **Section 5: Evaluation** - This section compares different results using evaluation metrics such as precision and recall.
- **Section 6: Discussion** - This section provides a discussion of the results, offering insights and interpretations.
- **Section 7: Conclusion** - The final section concludes the paper, addressing the limitations encountered during the research and proposing potential directions for future work, aiming to expand upon and build on the current study.

III. BACKGROUND AND RELATED WORK

The field of intrusion detection systems (IDS) has been rapidly evolving in recent years, with a focus on improving the accuracy and efficiency of detection methods. Various techniques have been proposed in this paper, including, IDS data preprocessing (data cleansing - removal of null and duplicate values, data balancing using SMOTE, and data standardization using standard scalar techniques), feature engineering (using XGBoost), and data classification (One-dimensional CNN, DNN Models, and Bidirectional Long-Short-Term Memory (BiDLSTM)). These methods have demonstrated promising results in detecting various network intrusions, including Denial of Service (DoS) attacks, intrusion attempts, and unauthorized access attempts. Furthermore, DNN Models and BiDLSTM have emerged as powerful tools for identifying complex patterns in network traffic data, making them valuable additions to the IDS toolbox. This background section provides an overview of these topics, discussing their underlying principles.

A. Feature Engineering

In machine learning, feature engineering plays a vital role as it converts raw data into a more suitable format, which allows for a better representation of the underlying issue and enhances model performance. XGBoost, a gradient-boosted decision tree algorithm, is renowned for its effectiveness and efficiency in feature engineering. Introduced by Mounika and Rao [13] and embraced by numerous researchers [14] [15], XGBoost is part of the Community for Distributed Machine Learning and excels in optimizing memory and hardware utilization in tree-boosting algorithms. Kasongo and Sun [16] employed XGBoost in their intrusion detection research, using the UNSW-NB15 dataset for model training and evaluation. They implemented a filter-based feature reduction technique alongside the XGBoost algorithm and used specific machine-learning approaches for binary and multi-class classification scenarios. The study showed that the XGBoost-driven feature selection method increased test accuracy for binary classification from 88.13% to 90.85%, demonstrating its effectiveness in boosting the precision of ML-based models. Dhaliwal et al. [17] conducted another study, developing a model to assess various network data attributes such as precision, accuracy, and confusion matrix. They employed the NSL-KDD dataset and XGBoost to achieve their objectives. The primary goal was to better understand data integrity and enhance data detection accuracy. The researchers recommended further investigations to facilitate the deployment of intrusion detection models.

XGBoost supports gradient, regularized, and stochastic gradient boosting techniques and permits the incorporation and adjustment of regularization parameters [18]. The algorithm optimizes memory usage, significantly reduces computation time, and manages missing values. Its sparse-awareness allows for a unified framework in tree structures, improving the trained model with new data [19]. XGBoost constructs a sequential decision tree, assigning a weight to each data value, which influences the likelihood of a decision tree selecting it for analysis [20]. Although challenges exist in network data preprocessing, data classification, and labeling, XGBoost tackles issues such as high-level preprocessing, DDoS attack mitigation, false alarm rates, and semi-supervised techniques necessary for a dependable IDS model [21]. Due to its capability to address most problems encountered in feature selection, XGBoost serves as a potent instrument for developing efficient intrusion detection systems [22].

B. Deep Learning Classification

In this section, we will review the relevant literature on various deep learning classification techniques that have been employed in the proposed model. The methods discussed include XGBoost, BiLSTM, DNN, One-dimensional CNN and Long Short-Term Memory (LSTM). These techniques have been applied in a wide range of intrusion detection systems and have demonstrated their effectiveness in handling complex and large-scale data. We will explore the key aspects of each method, as well as their applications in the field of intrusion detection. By examining the current state looking into the background of these techniques, we aim to provide a functional understanding, ultimately informing the development of a robust and efficient intrusion detection model.

1) One-dimensional CNN and Long Short-Term Memory (LSTM): Recurrent Neural Networks (RNNs) are a class of neural networks that can generate cycles through links between nodes, allowing the output of certain nodes to influence their future input and enabling temporal dynamic behavior. RNNs, derived from feed-forward neural networks, use their internal state (memory) to handle input sequences of varying length, making them ideal for AI tasks such as speech and handwriting recognition [23]. Long Short-Term Memory (LSTM) networks, a specialized form of RNNs, were developed to address the vanishing gradient problem commonly encountered during the training of conventional RNNs [24]. LSTMs, equipped with memory cells and gating structures, can effectively store information across extended sequences. In one study, the authors of [25] used an RNN with LSTM to recognize threats and normal patterns within IoT traffic. They trained their model using the UMSW-NB15 dataset and found that the LSTM RNN-based IDS was efficient and could detect threats with high accuracy. However, they suggested that further verification with a larger dataset was necessary. Agrawal and Duvey [26] aimed to develop an intrusion detection system using deep learning technology to identify infiltration and malicious activities that could disrupt the network environment. They proposed a hybrid DL-driven method that employs one-dimensional CNN and LSTM to detect attacks on the KDD99 dataset. The proposed model's performance was evaluated on binary and multiclass classifications using the KDD99 datasets. In another study, Qazi et al. [27] proposed a deep learning architecture for network intrusion detection based on a one-dimensional

convolutional neural network. The study aimed to identify three types of network attacks, namely PortScan, DoS, and DDoS, using the CICIDS2017 dataset. The results showed an accuracy of 98.96%, but the authors suggested further analysis, such as using Principal Component Analysis (PCA), to investigate the reduction in input characteristics.

2) Bidirectional Long-Short-Term Memory (Bi-LSTM): Bidirectional Long Short-Term Memory (Bi-LSTM) is a variant of Recurrent Neural Network (RNN) that processes input sequences in both forward and backward directions using two hidden layers [28]. It predicts the order of elements based on prior and future context through two LSTMs operating simultaneously in opposite directions, generating a combined output that approximates the target signal. Imrana et al. [1] proposed a BiDLSTM-based intrusion detection system to address challenges faced by IDS. They used the NSL-KDD dataset for training and evaluating the model, a widely recognized dataset in IDS research. Experimental results demonstrated the effectiveness of the BiDLSTM approach, showing superior performance in accuracy, precision, recall, and F-score compared to conventional LSTM and other state-of-the-art models. The false positive rate was also significantly lower. The researchers studied integrated systems by combining cutting-edge feature selection approaches with conventional LSTM and BiDLSTM models. Traditional machine learning methods struggle to effectively identify complex and multidimensional intrusion data in real-world network application environments [29]. In contrast, deep learning-based Network Intrusion Detection Systems (NIDS) have gained interest due to their ability to handle large-scale data and extract essential traffic features. Research by Alghazzawi et al. [30] proposed a hybrid Deep Neural Network (DNN) model that outperformed traditional machine learning classifiers in network and host-level event monitoring. Sun et al. [31] developed the LuNet deep neural network architecture, using RNNs for temporal feature learning and CNNs for spatial characteristic extraction from traffic data. This approach reduced false positives and enhanced validation accuracy. Al-Omari et al. [32] developed an intrusion detection model by combining RNN and LSTM approaches, while Alwan et al. [33] created a Bi-LSTM network using the UNSW-NB15 dataset as a benchmark, achieving an accuracy above 95%. Yu et al. [34] proposed a session detection method using Bi-LSTM, leveraging advancements in Natural Language Processing (NLP) made by LSTMs to represent sessions in a specific language. They based their experiments on the ISCX IDS dataset, grouping packets by IP addresses to create sessions and encoding them using word embedding. They trained an LSTM model to predict anomalous sessions, utilizing a Bi-LSTM model to learn sequence properties in both directions.

In conclusion, deep learning techniques like Bi-LSTM, hybrid models incorporating CNNs and LSTMs, and LSTM-based approaches have shown considerable promise in intrusion detection systems. These methods outperform conventional machine learning approaches in terms of accuracy, recall, and F-score [35]. They provide effective solutions for intrusion detection in real-world network application environments due to their ability to process complex, large-scale data and extract fundamental features from traffic data. Their development and implementation have improved network intrusion detection systems' overall performance and

strengthened network security infrastructure.

3) *Deep Neural Network (DNN)*: Deep Neural Networks (DNNs) are a type of artificial neural network (ANN) that consist of multiple layers between their input and output layers. They are composed of biases, synapses, neurons, weights, and functions, which work together to mimic the human brain's processing capabilities. DNNs can be trained like any other machine learning algorithm, making them suitable for various artificial intelligence tasks, such as image and speech recognition [36]. In one study, Devan and Khare [37] proposed an XGBoost-DNN model for network intrusion detection. The XGBoost algorithm was employed for feature selection, while DNNs were used to classify network intrusions. During DNN training, the Adam optimizer was utilized to optimize the learning rate, and the Softmax classifier was employed to categorize network intrusions. To validate their proposed model, cross-validation was performed, and it was compared to other shallow machine learning techniques such as SVM, logistic regression, and naive Bayes. Classification assessment metrics, including accuracy, precision, recall, and F1-score, were computed and contrasted with the existing shallow approaches. In another study, Kumar et al. [38] investigated DNNs to develop a flexible and efficient intrusion detection system (IDS) for identifying and categorizing unanticipated cyber-attacks. The study thoroughly analyzes DNN and other traditional machine learning classifier studies on several freely accessible benchmark malware datasets. However, the study's limitation is that the complex DNN structures have a high computational cost, so they were not trained using benchmark IDS datasets. Other research includes Tang et al. [39], who devised a deep learning-based approach for intrusion detection in software-defined networking (SDN) architecture. Potluri et al. [40] adopted a deep neural technique to manage large volumes of network data for deep-category identification. Kang et al. [41] developed a potential intrusion detection system for vehicular networks using deep neural networks. These studies, among others, demonstrate the potential of DNNs in intrusion detection systems and their ability to effectively classify various types of network intrusions.

IV. PROPOSED MODEL (METHODOLOGY)

In this paper, we proposed BiLSTM and neural network models for classification and XGBoost for feature engineering. Moreover, in order to make the evaluation scientifically accurate, we will be using the datasets from the literature (NSL-KDD [10], CIC-IDS2017 [11], and UNSW-NB15 [12]). Unfortunately, these datasets suffer from significant class imbalance problems between the different categories. Prior researchers have not always addressed this issue, which presents a high risk of failing to detect the minority class target value. While the accuracy of these studies may be high due to the low number of candidates for some target classes, it is essential to note that accuracy alone can be misleading. To overcome this problem, we will incorporate oversampling techniques into the proposed algorithms to improve the detection of target classes in the imbalanced data. In addition to accuracy, we will also focus on precision and recall as performance metrics in this research. A. Modeling Process The proposed study will employ two main modeling processes to train the chosen dataset for intrusion detection. These two processes are combined:

- Xgboost + 1DCNN, BiLSTM
- Xgboost + DNN, BiLSTM.

Furthermore, the hyperparameter tuning process will be applied to both models to ensure the most accurate testing. B. Training and Testing This section will provide an overview of the four models utilized in this study. These models were created to evaluate and compare the performance of the proposed framework under varying circumstances. The defined models are as follows:

- Model 1: Using a standard dataset and applying [1D CNN + BiLSTM]
- Model 2: Using a standard dataset and applying [ANN + BiLSTM]
- Model 3: Using a balanced dataset (created with SMOTE) and applying [1D CNN + BiLSTM].
- Model 4: Using a balanced dataset (created with SMOTE) and applying [ANN + BiLSTM].

The split model framework is illustrated in Fig. 1.

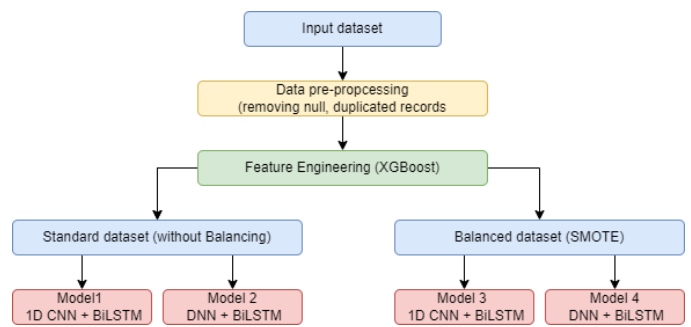


Fig. 1. Proposed model framework.

For this study, three datasets have been utilized, namely NSL-KDD, CIC-IDS2017, and UNSW-NB15. The dataset underwent several preprocessing steps, including removing null elements and duplicate rows, changing data types to use lower memory, and performing label encoding. The presence of any missing values in the selected dataset was analyzed, and the results are presented in Fig. 2.

```
print('total number of null elements present in the dataset : ', combined_data.isnull().sum().sum())
total number of null elements present in the dataset : 0
```

Fig. 2. Null elements.

A. Converting Data to Numerical Values

To utilize the categorical features in deep learning algorithms, the data needs to be converted into numerical values. One way to achieve this is through one hot encoding, a technique that represents categorical variables as numerical values in a machine learning model. One hot encoding offers several advantages, such as enabling categorical variables in models requiring numerical input and improving model performance by providing more information about the categorical variable. For this study, the categorical variables identified

in the features selection stage have been used, and one hot encoding is performed on these variables. An example of the resulting output is shown below using the NSL-KDD dataset after performing the one hot encoding function. The pre-processed data can now be used for training the deep learning models.

In their study, Mohammed [42] designed a fully connected network structure consisting of input, hidden, and output layers. To define these layers, the author utilized the Dense class, which allows them to specify the number of nodes or neurons in the layer as the first argument and the activation function to use the activation argument. In their architecture, the ReLU activation function was applied to the first two layers to introduce non-linearity. In contrast, the Sigmoid activation function was used in the output layer to ensure the network output is confined between 0 and 1. Moreover, the author implemented a dropout regularization technique to mitigate overfitting during training.

In the proposed model, one-hot encoding is crucial since both BiLSTM and XGBoost have been shown to work better with numerical values rather than categorical values [43], [44]. By applying one-hot encoding to categorical variables such as Protocol type, service, and Flag, a more appropriate input format is achieved for our machine learning algorithms. This approach ensures enhanced performance and more accurate results. One-hot encoding is applied to variables such as Protocol type, service, and Flag [44], as shown in Fig. 3 (before encoding) and Fig. 4 (after encoding).

protocol_type	service	flag
tcp	private	REJ
tcp	private	REJ
tcp	ftp_data	SF
icmp	eco_i	SF
tcp	telnet	RSTO

Fig. 3. Data before One Hot Encoding.

flag_REJ	flag_RSTO	flag_RSTO50	flag_RSTR	flag_50	flag_51	flag_52	flag_53	flag_SF	flag_SH
0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	1	0
0	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	1	0

Fig. 4. Data after One Hot Encoding.

B. Data Standardization

To bring the numeric columns in the dataset to a standard scale without distorting their differences in ranges of values, the data needs to be standardized. Standardization is a process that rescales the distribution of values so that the mean of the observed values becomes 0 and the standard deviation becomes 1. To achieve this, the standard scalar method was used for standardization. A value is standardized as follows:

$$y = \frac{x - \text{mean}}{\text{standard_deviation}} \quad (1)$$

Where the mean is calculated as:

$$\text{mean} = \frac{\sum x}{\text{count}(x)} \quad (2)$$

And the standard deviation is calculated as:

$$\text{standard_deviation} = \sqrt{\frac{\sum (x - \text{mean})^2}{\text{count}(x)}} \quad (3)$$

C. Oversampling Technique

The data preprocessing and standardization steps are applied uniformly to all three datasets. However, since the datasets are highly imbalanced, it is necessary to use data-balancing techniques to improve performance. Imbalanced data refers to datasets in which the target class has an uneven distribution of observations, with one class label having a significantly higher number of observations than the other. To address this issue, we will use an oversampling technique called SMOTE (Synthetic Minority Oversampling Technique) to balance the data. The SMOTE technique uses a hybrid method called SMOTE+TOMEK [45] to remove overlapping data points for each class dispersed in the sample space. Once SMOTE has finished its oversampling, the class clusters may encroach on each other's space, causing the classifier model to overfit. The pairs of samples from opposing classes closely related are called Tomek linkages. Most of the class observations from these linkages are eliminated to improve class separation near decision boundaries. The links are applied to oversampled minority class samples from SMOTE to obtain better class clusters. Therefore, both class observations from the Tomek linkages are typically deleted, rather than just the observations from the majority class. In their study, Mohammed [42] designed a fully connected network structure consisting of input, hidden, and output layers. To define these layers, the author utilized the Dense class, which allows them to specify the number of nodes or neurons in the layer as the first argument and the activation function to use the activation argument. In their architecture, the ReLU activation function was applied to the first two layers to introduce non-linearity. In contrast, the Sigmoid activation function was used in the output layer to ensure the network output is confined between 0 and 1. Moreover, the author implemented a dropout regularization technique to mitigate overfitting during training. The hyper parameters for the four models were tuned based on their performance on selected performance metrics, which include accuracy, precision, recall, and F1 score. Tables 1 and 2 list the hyper parameters chosen for each model.

D. Feature Engineering and DL Classifications

The next step involves performing feature engineering to develop a deep learning model. In this study, XGBoost, an optimized gradient boosting algorithm, will be used for feature engineering as it performs better on numerical datasets for both Model 3 and Model 4. The top 20 essential features from the used dataset were identified using the XGBoost classifier algorithm to perform feature extraction. This was achieved by tuning hyperparameters such as the number of estimators, leaves, and the maximum depth of trees in the algorithm.

The literature describes that sequence modeling algorithms have shown promising results in handling numerical data in recent years. Various algorithms such as RNN, LSTM, MLP, DNN, and BiLSTM have been used as classification models for Intrusion detection problems. For instance, an unsupervised deep learning technique called Autoencoder takes a vector as input and produces the same dimension vector as output. The primary process involves taking input data, reducing its dimensionality, reconstructing it into a lower dimension, and then attempting to reconstruct it back to its original dimension. During this process, the noise in the data is removed, and only the essential features are retained as input data shape.

The hyper-parameters tuned for these four models are outlined in Tables I and II. These were selected based on the performance metrics chosen for evaluation. The considered performance metrics include Accuracy, Precision, Recall, and F1 Score.

TABLE I. HYPER PARAMETER USED FOR MODELS 1 AND 3

Hyper parameters	ID CNN (Model 1 and 3)
Epochs	150
Optimizer	Adam
Batch Size	128
# of Layers (1D)	2
Maxpooling Layers	3
Batch Normalization	3
BiLSTM Layers	2

TABLE II. HYPER-PARAMETER USED FOR MODELS 2 AND 4

Hyper parameters	DNN (Model 2 and 4)
Epochs	150
Optimizer	Adam
Batch Size	256
# of Layers (NN)	2
Maxpooling Layers	1
Batch Normalization	1
BiLSTM Layers	2

The dataset has been divided into training, and testing data using the Train Test Split function from Sci-Kit Learn to prepare for training the model. For the model an optimal ratio of 80% has been selected for training data and 20% for testing data.

V. RESULTS

this section present the results of the proposed module aimed at enhancing the performance of an Intrusion Detection System (IDS). After running the module, we have reached some critical conclusions regarding the efficacy of the proposed approach. Specifically, we have utilized four different models to assess the system's performance and determine which model performs better based on various metrics. In this section, we will discuss the results of the evaluations and highlight the strengths and weaknesses of each model.

Various performance metrics determine which of the four models performs better. The metrics used to evaluate the models include precision and recall. Precision measures the percentage of correctly predicted positive outcomes out of all the predicted positive outcomes. It can be expressed as the ratio of true positives (TP) to the sum of true and false

positives (TP + FP). Mathematically, precision can be defined as $TP / (TP + FP)$. Precision primarily focuses on the positive class rather than the negative class. Recall, also known as sensitivity, measures the percentage of correctly predicted positive outcomes out of all the actual positive outcomes. It can be expressed as the ratio of true positives (TP) to the sum of true positives and false negatives (TP + FN). Mathematically, recall can be defined as $TP / (TP + FN)$. The definitions of precision and recall are:

$$Precision = \frac{TP}{(TP + FP)}$$

Another metric is The F1-score, which is a weighted harmonic mean of precision and recall and measures the overall performance of a classifier model. The highest possible F1 score is 1.0, while the lowest is 0.0. As the F1-score is based on precision and recall, it is always lower than accuracy measures, which incorporate only one of these factors. The weighted average of F1-scores should be used to compare classifier models rather than a global accuracy measure.

$$F1 = \frac{2 \times (Precision \times Recall)}{(Precision + Recall)}$$

In this paper, we will explain how we implemented the four modules on the NSL-KDD datasets. The performance metrics described earlier were used to evaluate the three datasets using the four models previously defined. All four models were implemented for each dataset, and the results were compared to determine which model performed best. Subsequently, we will present a summarized table of the results obtained from the other two datasets without delving into the implementation details since we followed the same approach as the first dataset.

1) Model 1: imbalanced dataset: 1D CNN + BiLSTM:

In the case of the ND-L-KDD dataset, model 1 achieved better accuracy, which is noteworthy given the imbalance in the data. Specifically, the training accuracy was 98.3%, and the testing accuracy was 97.9%. The accuracy plot in Fig. 5 provides additional insight into the model's behavior and can be used to identify any inconsistencies that may have occurred during training.

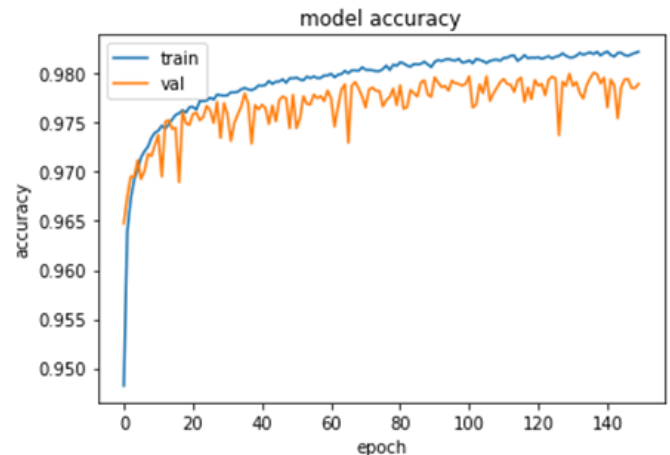


Fig. 5. Model 1 accuracy-epoch.

Fig. 5 demonstrates a typical trend, with a gradual decrease in loss observed during the training phase and some fluctuations across all epochs for the testing dataset. These fluctuations are also visible in the accuracy plot, indicating that the model tries to learn from the loss experienced in the previous epoch.

TABLE III. MODEL 1: CONFUSION MATRIX

Attacks	Normal	Dos	Probe	R2L	U2R
Normal	10609	49	1	3	0
Dos	52	15208	97	167	6
Probe	4	64	2683	10	0
R2L	0	158	1	569	1
U2R	0	9	0	3	10

The confusion matrix in Table III indicates that the model performed exceptionally well for more class variables. In contrast, the last two classes, R2L and U2R, had very few correctly classified target variables. This could be due to the imbalance in the dataset, which contains only a few classes for these categories. Table 4 shows each class's false positive rate, recall, and F1 score to understand better which class had the lowest correct classification rate.

TABLE IV. MODEL 1: CLASSIFICATION REPORT

Attacks \ metrics	Precision	Recall	F1-Score	Support
Normal	0.99	1.00	0.99	10662
Dos	0.99	0.98	0.98	15530
Probe	0.96	0.97	0.97	2671
R2L	0.76	0.78	0.77	729
U2R	0.59	0.45	0.51	22

The output from the classification report in Table IV indicates that the U2R class has the lowest precision and recall values, with a precision value of 59%, recall of 45%, and F1 score of 51%. This is likely due to the imbalance in the dataset. However, the precision and recall values for the overall model are high, at 97.9% and 97.8%, respectively.

```
precision_score(y_eval,pred, average='weighted')
0.9790783062879445
```

Fig. 6. Model 1 precision score.

Although the total recall and precision values in Fig. 6 and 7 provide an overview of the model's performance, they do not fully capture the degree of imbalance in the data when classifying the testing dataset. To gain a more nuanced understanding of the model's performance, it is necessary to examine each class's precision and recall values separately.

```
recall_score(y_eval,pred, average='weighted')
0.9789590627524912
```

Fig. 7. Model 1 recall score.

2) Model 2: Imbalanced dataset: ANN + BILSTM: accuracy of nearly 99%. Fig. 8 show that accuracy has consistently increased with each epoch. However, some epochs have lower validation accuracy, possibly because the model encountered new images that it had not seen in previous epochs. The same trend is observed in the loss plot.

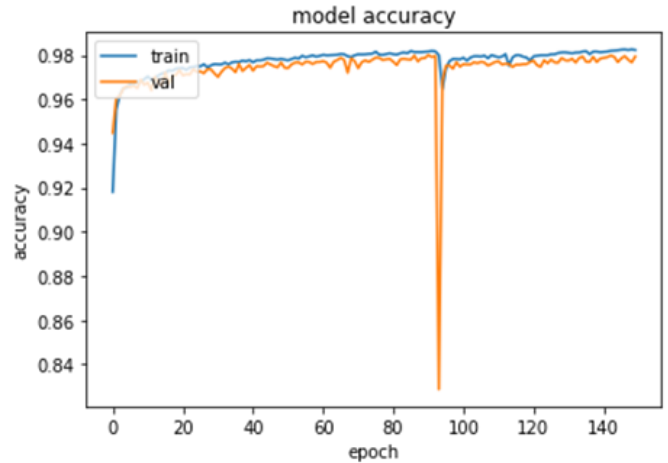


Fig. 8. Model 1 accuracy-epoch.

TABLE V. MODEL 2: CONFUSION MATRIX

Attacks	Normal	Dos	Probe	R2L	U2R
Normal	10583	36	8	0	0
Dos	64	15136	88	135	3
Probe	12	52	2805	10	0
R2L	2	182	2	557	1
U2R	1	12	0	4	11

The confusion matrix in Table V reveals that the normal class outperforms all other target classes. The U2R and R2L classes demonstrate the weakest performance in accurately classifying the test dataset, which may also be attributed to class imbalance in the dataset.

TABLE VI. MODEL 2: CLASSIFICATION REPORT

Attacks \ metrics	Precision	Recall	F1-Score	Support
Normal	0.99	1.00	0.99	10627
Dos	0.98	0.98	0.98	15426
Probe	0.97	0.97	0.97	2879
R2L	0.79	0.75	0.77	744
U2R	0.73	0.39	0.51	28

Examining the classification report in Table VI, it can be concluded that precision is improved for all classes when compared to Model 1. However, the recall for the U2R class in Model 2 is the lowest among all classes. This indicates that the ratio of correctly predicted positive elements to the total positive elements is low. As a result, the model struggles to predict the U2R class accurately and often misclassifies it as another class.


```
precision_score(y_eval,pred, average='weighted')
0.9790410957911807
```

Fig. 9. Model 2 precision score.

```
recall_score(y_eval,pred, average='weighted')
0.9793967142472394
```

Fig. 10. Model 2 recall score.

The precision and recall values for Model 2 shown in Fig. 9 and 10 are 97.9% and 97.9%, respectively. Although the overall performance of the model is quite remarkable, it is crucial to evaluate the model’s performance for individual classes, particularly those with fewer samples in the dataset. The U2R and R2L classes, for example, exhibit lower performance metrics, which could be ascribed to the class imbalance in the dataset. The total recall and precision do not fully reveal the extent of data imbalance when classifying the testing dataset. It is only by examining each class individually that one can fully understand the model’s performance.

3) *Model 3: Balanced dataset with SMOTE: 1D CNN + BILSTM*: For models 3 and 4, the dataset will be preprocessed using SMOTE to oversample the least represented target classes and increase their count to match the highest represented target classes. This oversampling process balances each category in the dataset and eliminates any class imbalance. The resulting model achieved an accuracy of 95%, indicating that it did not perform better than the first two models that used the imbalanced dataset. The accuracy plot for this model are shown in Fig. 11.

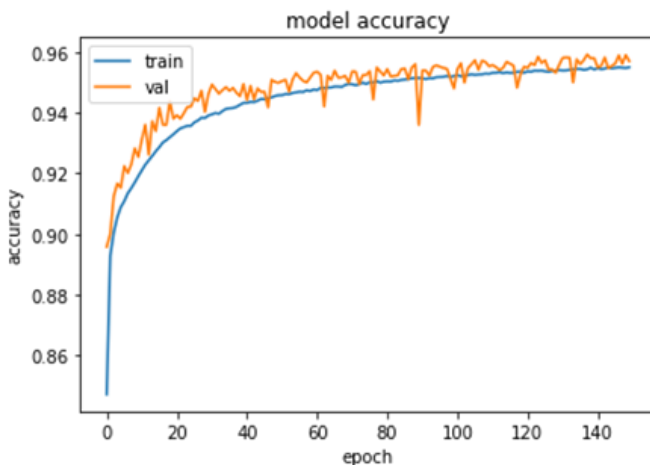


Fig. 11. Model 3 accuracy-epoch.

The confusion matrix presented in Table VII reveals that almost all the target classes have performed better than in the previous two models. The reason for the lower accuracy is that the number of incorrectly classified instances is higher,

as the dataset size increased due to the oversampling of the data. This increase in dataset size led to more opportunities for misclassification, resulting in a lower overall accuracy.

TABLE VII. MODEL 3: CONFUSION MATRIX

Attacks	Normal	Dos	Probe	R2L	U2R
Normal	15377	18	37	6	0
Dos	28	14255	115	814	180
Probe	1	32	15308	83	7
R2L	0	278	10	14972	144
U2R	0	206	0	1361	13870

TABLE VIII. MODEL 3: CLASSIFICATION REPORT

Attacks\metrics	Precision	Recall	F1-Score	Support
Normal	1.00	1.00	1.00	15438
Dos	0.96	0.93	0.94	15392
Probe	0.99	0.99	0.99	15431
R2L	0.87	0.97	0.92	15404
U2R	0.98	0.90	0.94	15437

The classification report in given in Table VIII. The precision and recall of Model 3 for all the target classes were better than those of the previous two models. When comparing these metrics for Models 1 and 2, the precision of the U2R class for Model 3 was 98%, while for the others, it was 73% and 59%. For the U2R class in recall, Model 3 had 90%, whereas Model 1 had 45% and Model 2 had 39%. This demonstrated that Model 3 performed significantly better than the other models and had a higher prediction rate for less frequent target classes. This performance improvement was solely due to the balancing of the data, which allowed the model to learn more about the less frequent target variable classes. The classification report was provided as well. The average weighted precision and recall values for Model 3 were 95.9% and 95.6%, respectively.

4) *Model 4: Balanced dataset with SMOTE: ANN + BILSTM*: The accuracy plot shown in Fig. 12 displays a significant amount of fluctuation in the validation dataset, which can be attributed to the fact that the model may have encountered a different set of data during testing on that epoch.

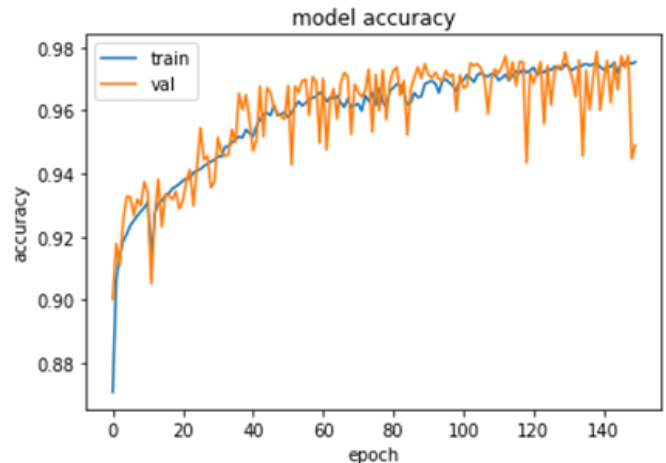


Fig. 12. Model 4 Accuracy-Epoch.

As seen in the confusion matrix in Table IX, the values appear similar to those of Model 3, with the ratio of correctly predicted classes remaining consistent between the two models. To gain a deeper understanding of the model's performance, it is necessary to examine the precision, recall, and F1 score mentioned in Table X. When compared to Model 3, Model 4 exhibits weaker performance, as the precision for the U2R class is lower, and the recall for the R2L class is significantly lower than the previous model. The precision and recall values obtained for this model are 95.3% and 94.8%, respectively.

TABLE IX. MODEL 4: CONFUSION MATRIX

Attacks	Normal	Dos	Probe	R2L	U2R
Normal	15336	17	81	2	2
Dos	24	14374	128	555	311
Probe	3	37	15320	28	43
R2L	0	164	13	12766	246
U2R	0	20	0	44	15373

TABLE X. MODEL 4: CLASSIFICATION REPORT

Attacks/metrics	Precision	Recall	F1-Score	Support
Normal	1.00	0.99	1.00	15438
Dos	0.98	0.93	0.96	15392
Probe	0.99	0.99	0.99	15431
R2L	0.95	0.83	0.89	15404
U2R	0.85	1.00	0.91	15437

VI. EVALUATION

A. Evaluation of the Models Against the NSL KDD Dataset

In the NSL-KDD dataset, when considering accuracy, Model 1 and Model 2 perform better than Model 3 and Model 4, achieving a high accuracy of approximately 99%. When taking average precision and recall into account, Models 1 and 2 still outperform Models 3 and 4. However, Models 1 and 2 predict poorly for two attack classes, namely R2L and U2R, which can be clearly observed in both the confusion matrix and classification report. The number of incorrect predictions is higher in Models 1 and 2 compared to Models 3 and 4.

In Models 3 and 4, the precision and recall for U2R and R2L are above 85%, and for other attack classes, they are above 93%. Model 3 demonstrates better precision and recall rate performance compared to Model 4, as Model 3 combines Bi-LSTM and 1D-CNN with balanced data, whereas Models 1 and 2 were trained on imbalanced data.

Additionally, Model 3 excels at correctly detecting most of the classes in the dataset. This model incorporates SMOTE for balancing data, XGBoost for feature engineering, and a combination of 1D-CNN and Bi-LSTM as the classification algorithm. Although the training and testing accuracy of Model 3 is lower than that of Models 1 and 2, this is due to the significantly smaller number of elements in the target classes with the least representation in Models 1 and 2 (U2R - 52, R2L - 995). Consequently, even if these classes were entirely misclassified, only 1,047 out of 125,973 would be incorrectly classified. However, if these classes were misclassified in real-time, they would be detected as normal or other attacks, undermining the goal of detecting intrusions.

To address this issue, precision and recall were calculated for each target class in the dataset. This approach allows to evaluate how well the model has predicted each target class individually, rather than. Models 1, 2, and 4 exhibit lower precision and recall for the U2R and R2L classes. In contrast, Model 3 demonstrates a precision of 98% for U2R and 87% for R2L, along with a recall of 90% for U2R and 97% for R2L. Table XI provide a summery of NSL-KDD dataset performance. While Table XII and XIII provides a comparison of the performance of the best model against similar research in the literature.

TABLE XI. SUMMARY OF THE NSL - KDD DATASET PERFORMANCE

Models	Precision	Recall
1	97.9	97.8
2	97.9	97.9
3	95.9	96.9
4	95.3	94.8

TABLE XII. PRECISION PERFORMANCE METRIC - COMPARISON OF OTHER PAPERS

Target class	Best model	Chongzhen	Mohammed	Yakubu Imrana
Normal	100%	71%	61%	75%
DoS	96%	96%	94%	97%
Probe	99%	86%	97%	84%
R2L	87%	81%	99%	98%
U2R	98%	73%	100%	77%

TABLE XIII. RECALL PERFORMANCE METRIC - COMPARISON OF OTHER PAPERS

Target class	Best model	Chongzhen	Mohammed	Yakubu Imrana
Normal	100%	71%	61%	75%
DoS	96%	96%	94%	97%
Probe	99%	86%	97%	84%
R2L	87%	81%	99%	98%
U2R	98%	73%	100%	77%

B. Evaluation of the models against the CIC-IDS2017 dataset

For the CIC-IDS2017 dataset, Model 1 exhibits better accuracy, considering the data imbalance, with a training accuracy of 97.4% and a testing accuracy of 97.3%. The confusion matrix and classification report can be found in Tables XIV and XV.

TABLE XIV. MODEL 1: CIC-IDS2017'S - CONFUSION MATRIX

Attacks	Benign	Port Scan	DDos	WEBattack	Bot
Benign	82423	35	1599	1	3
PortScan	64	12308	0	0	0
DDos	818	0	11340	0	0
Web Attack	120	0	0	64	0
Bot	194	0	0	0	13

TABLE XV. MODEL 1: CIC-IDS2017'S - CLASSIFICATION REPORT

Attacks/metrics	Precision	Recall	F1-Score	Support
Benign	0.99	0.98	0.98	84061
PortScan	1.00	0.99	1.00	12376
DDos	0.88	0.93	0.90	12158
Web Attack	0.81	0.06	0.12	207
Bot	0.98	0.35	0.52	185

Based on the confusion matrix in Table XIV, it is evident that the model performs exceptionally well for the classes with a higher number of instances. The last two classes, DDOS and Web Attack, have very few correctly classified target instances. This can be attributed to the imbalance in the dataset, as there are very few instances for those categories. To understand which class has performed the poorest in terms of correct classification, the false positive rate, recall, and F1 score of the model can be examined in Table XV.

TABLE XVI. MODEL 2: CIC-IDS2017's - CONFUSION MATRIX

Attacks	Benign	Web Attack	PortScan	DDos	Bot
Benign	83824	1	36	157	43
Web attack	127	58	0	0	0
PortScan	18	0	12358	0	0
DDos	114	0	9	12033	2
Bot	145	0	0	0	62

TABLE XVII. MODEL 2: CIC-IDS2017's - CLASSIFICATION REPORT

Attacks \ metrics	Precision	Recall	F1-Score	Support
Benign	1.00	1.00	1.00	84061
Web attack	0.98	0.31	0.48	185
PortScan	1.00	1.00	1.00	12376
DDos	0.99	0.99	0.99	12158
Bot	0.58	0.30	0.39	207

From the confusion matrix XVI, it can be observed that model 2 performs exceptionally well for the classes with a higher number of instances. Similar to Model 1, the last two classes, DDOS and Web Attack, have very few correctly classified target instances. This can be attributed to the imbalance in the dataset, as there are very few instances for those categories. The false positive rate, recall, and F1 score of the model can be seen in Table XVII to understand which class has performed the poorest in terms of correct classification.

For Models 3 and 4, a new dataset will be created using SMOTE, which over samples the least represented target classes and matches their count to that of the most represented target classes.

TABLE XVIII. MODEL 3: CIC-IDS2017's - CONFUSION MATRIX

Attacks	Benign	Web Attack	PortScan	DDos	Bot
Benign	23314	553	16	997	312
Web attack	24	25234	0	0	0
PortScan	395	0	24861	0	0
DDos	1	0	0	25176	21
Bot	2	0	0	6	25251

TABLE XIX. MODEL 3: CIC-IDS2017's - CLASSIFICATION REPORT

Attacks \ metrics	Precision	Recall	F1-Score	Support
Benign	0.98	0.93	0.95	25192
Web attack	0.98	1.00	0.99	25258
Port Scan	1.00	0.98	0.99	25256
DDoS	0.96	1.00	0.98	25198
Bot	0.99	1.00	0.99	25259

The confusion matrix in Table XVIII demonstrates that almost all the target classes in model 3 have performed better than in the previous two models. The lower accuracy can be

attributed to the increased number of mis-classifications due to the over-sampled data, which increased the dataset size.

The precision and recall of this model for all the target classes are better than the previous two models. For instance, the precision of the Web Attack class for Model 3 is 99%, while the other models have 81% and 58%. In terms of recall for the Web Attack class, Model 3 has 100%, whereas Model 1 has 6% and Model 2 has 30%. This indicates that Model 3 has performed significantly better than the other models and has a higher prediction rate for less frequent target classes. This performance improvement is primarily due to the balancing of the data, allowing the model to learn more about the underrepresented target classes. The classification report is provided in Table XIX. The weighted precision and recall values for this model are 98.1% and 98.1%.

TABLE XX. MODEL 4: CIC-IDS2017's - CONFUSION MATRIX

Attacks	Benign	Web Attack	PortScan	DDos	Bot
Benign	24550	470	2	70	100
Web attack	0	25258	0	0	0
PortScan	23	0	25233	0	0
DDos	21	0	0	25173	4
Bot	16	0	0	6	25237

TABLE XXI. MODEL 4: CIC-IDS2017's - CLASSIFICATION REPORT

Attacks \ metrics	Precision	Recall	F1-Score	Support
Benign	1.00	0.97	0.99	25192
Web attack	0.98	1.00	0.99	25258
PortScan	1.00	1.00	1.00	25256
DDos	1.00	1.00	1.00	25198
Bot	1.00	1.00	1.00	25259

In the CIC-IDS2017 dataset, and based on Tables XX and XXI. When evaluating average precision and recall for all models, each one performs well. However, when examining individual precision and recall, Models 1 and 2 under-perform in two classes, namely Web Attack and Bot, which might be due to the imbalance in the dataset. The number of incorrect predictions is higher in Models 1 and 2 compared to Models 3 and 4 for the attack classes. After balancing the data, Model 4 outperforms all other models we have built, with an accuracy of 99% and individual precision and recall for the two classes that performed poorly in Models 1 and 2. For these classes, Model 4 achieves a recall of 100% and precision of 99%.

TABLE XXII. SUMMARY OF THE CIC-IDS2017 DATASET PERFORMANCE

Models	Precision	Recall
1	97.4	97.3
2	99.3	99.3
3	98.2	98.2
4	99.4	99.4

Table XXII presents the precision and recall results of four different models for the CIC-IDS2017 dataset. Model 1 achieves a precision of 97.4% and a recall of 97.3%, indicating good performance, but not the best among the tested models. Model 2 performs exceptionally well, achieving a precision and recall of 99.3% each, which suggests a high degree of accuracy in identifying true positives and avoiding

false negatives. Model 3 shows slightly lower results, with a precision and recall

C. Evaluation of the Models Against the UNSW-NB15 Dataset

For the UNSW-NB15 dataset, Model 1 exhibits better accuracy considering the data imbalance, with a training accuracy of 94.6% and a testing accuracy of 94.5%. The confusion matrix and classification report can be found in Fig. 13 and 14

Attacks	Analysis	Backdoor	Dos	Exploits	Recon	generic	Normal	Fuzzers	Worm
Analysis	86	0	2	29	1	0	0	0	0
Backdoor	0	1	0	12	1	0	0	0	0
Dos	5	2	57	287	4	7	0	7	1
Exploits	23	2	22	3154	28	11	0	5	3
Recon	6	0	0	47	29	0	0	0	1
Generic	0	1	11	47	1	780	0	0	1
Normal	0	0	0	0	0	1	3948	0	0
Fuzzers	1	0	1	287	3	4	0	12	0
Worm	0	0	0	16	1	0	0	0	2

Fig. 13. Model 1 -UNSW-NB15 - confusion matrix.

Attacks\ metrics	Precision	Recall	F1-Score	Support
Analysis	0.71	0.73	0.72	118
Backdoor	0.17	0.07	0.10	14
Dos	0.61	0.15	0.25	370
Exploits	0.81	0.97	0.89	3248
Reconnaissance	0.88	0.84	0.86	348
Generic	1.00	0.99	0.99	7861
Normal	1.00	1.00	1.00	3949
Fuzzers	0.50	0.04	0.07	308
Worm	0.25	0.11	0.15	19

Fig. 14. Model 1 -UNSW-NB15 - classification report.

Fig. 15 and 16 presents the confusion matrix and the classification report for Model 2 on the UNSW-NB15 dataset, showing precision, recall, F1-score, and support for each attack category. The best precision and recall scores of 1.00 are seen in the Generic and Normal classes, indicating perfect classification for these categories. Exploits and Reconnaissance classes also perform well, with precision scores of 0.88 and 0.88, and recall scores of 0.92 and 0.94, respectively. These scores suggest accurate and comprehensive classification in these categories. However, the Backdoor and Worm classes exhibit lower performance, with Backdoor having a precision of 0.38 and a recall of 0.21, and Worm having a precision of 0.50 and a recall of 0.26. The F1-scores for these classes

are also relatively low at 0.27 for Backdoor and 0.34 for Worm, indicating weaker classification performance for these categories.

Attacks	Analysis	Backdoor	Dos	Exploits	Recon	generic	Normal	Fuzzers	Worm
Analysis	88	0	2	28	00	0	0	0	0
Backdoor	0	3	1	7	1	1	0	1	0
Dos	1	3	12	215	13	3	0	15	0
Exploits	15	0	38	298	29	26	0	14	5
Recon	7	0	0	12	32	1	0	2	0
Generic	0	2	7	26	1	782	0	0	0
Normal	0	0	0	1	0	0	394	0	0
Fuzzers	2	0	3	90	1	3	0	20	0
Worm	0	0	0	13	1	0	0	0	5

Fig. 15. Model 2 -UNSW-NB15 - confusion matrix.

Attacks\ metrics	Precision	Recall	F1-Score	Support
Analysis	0.78	0.75	0.76	118
Backdoor	0.38	0.21	0.27	14
Dos	0.70	0.32	0.44	370
Exploits	0.88	0.92	0.90	3248
Reconnaissance	0.88	0.94	0.91	348
Generic	1.00	1.00	1.00	7861
Normal	1.0	1.00	1.0	3949
Fuzzers	0.56	0.68	0.61	308
Worm	0.50	0.26	0.34	19

Fig. 16. Model 2 -UNSW-NB15 - classification report.

The classification report for Model 3 in Fig. 17 includes metrics such as precision, recall, and F1-score for each class in the UNSW-NB15 dataset. These metrics allow us to assess how well the model is able to identify each individual class. The model shows remarkable performance for “Generic” and “Normal” classes, achieving nearly perfect precision, recall, and F1-scores. Additionally, “Analysis” and “Reconnaissance” classes exhibit strong performance with high precision and recall values resulting in impressive F1-scores. However, there are some classes that have weaker performance. For example, the “Backdoor” and “Exploits” classes have a notable discrepancy between their precision and recall values, leading to lower F1-scores. Additionally, the “Dos” class has balanced precision and recall values, but they are still lower than those of other

classes. The “Fuzzers” class has a low precision of 0.44 but a high recall of 0.94, resulting in a moderate F1-score. Lastly, the “Worm” class has a high precision of 0.89 but a low recall of 0.37, leading to a relatively low F1-score of 0.52.

The evaluation of Model 3’s classification report and confusion matrix shown in Fig. 19 and 18 weights revealed that the model can accurately identify positive instances for each class with a precision score of 84.15%. However, it is only able to capture 78.6% of the actual positive instances in the dataset, indicating room for improvement in recall performance. Despite the model’s varied performance across different classes, the higher precision score suggests that the model is relatively reliable when it makes predictions for a specific class. In summary, these results suggest that the model can benefit from further optimization to improve its overall performance, especially in the under performing classes.

Attacks/ metrics	Precision	Recall	F1-Score	Support
Analysis	0.93	0.98	0.95	7896
Backdoor	0.80	0.62	0.70	7865
Dos	0.74	0.74	0.74	7803
Exploits	0.84	0.62	0.71	7682
Reconnaissance	0.93	0.83	0.88	7885
Generic	1.00	0.99	0.99	7894
Normal	1.00	1.00	1.00	7899
Fuzzers	0.44	0.94	0.60	7717
Worm	0.89	0.37	0.52	7884

Fig. 19. Model 3 -UNSW-NB15 - classification report.

Model 4’s performance is similar to that of Model 3, with accuracy improving gradually with each epoch. However, there are some fluctuations in the validation accuracy that could be due to the model being exposed to new, unseen data during specific epochs. The same is true for the loss plot.

Attacks	Analysis	Backdoor	Dos	Exploits
Analysis	7702	0	182	9
Backdoor	2	4862	243	13
Dos	289	165	5767	786
Exploits	164	81	1335	4745
Reconnaissance	116	828	96	29
Generic	2	2	39	27
Normal	0	0	0	0
Fuzzers	39	61	124	10
Worm	0	47	29	2

Fig. 17. Model 3 -UNSW-NB15 - confusion report (Part1).

Attacks	Analysis	Backdoor	Dos	Exploits
Analysis	7839	0	33	13
Backdoor	0	7433	11	12
Dos	48	47	6894	438
Exploits	58	142	916	5902
Reconnaissance	31	23	33	36
Generic	1	1	21	32
Normal	0	0	0	0
Fuzzers	5	244	65	94
Worm	0	17	19	17

Fig. 20. Model 4 -UNSW-NB15 - confusion matrix (Part1).

Attacks	Reconnaissance	generic	Normal	Fuzzers	Worm
Analysis	3	0	0	0	0
Backdoor	126	0	0	2583	39
Dos	56	0	0	610	130
Exploits	86	4	0	1164	103
Reconnaissance	6553	0	0	240	43
Generic	0	7820	0	3	1
Normal	0	1	7898	0	0
Fuzzers	152	2	0	7284	45
Worm	90	0	0	4832	2884

Fig. 18. Model 3 -UNSW-NB15 - confusion report (Part 2).

The classification report and confusion matrix for Model 4, presented in the Fig. 20 and 21 and 22, indicates that the model performs exceptionally well in most categories. Precision and recall scores are notably high for Analysis, Reconnaissance, Generic, Normal, and Worm attack types, with values near or at 1.00, indicating excellent performance. The performance for Backdoor, Dos, Exploits, and Fuzzers is also quite good, with precision and recall scores ranging between 0.85 and 0.99. Overall, the high scores across the board suggest that Model 4 is highly effective at identifying various attack types in the UNSW-NB15 dataset.

In the UNSW dataset, a total of nine attack classes have been used, with a higher number of attacks features present in Generic, Normal, and Exploits. Other attack classes have fewer rows, resulting in data imbalance. Models 1, 2, and 4 achieve an accuracy of around 95%, while Model 3 has an accuracy of 78%. This clearly demonstrates that Model 3

Attacks	Reconnaissance	generic	Normal	Fuzzers	Worm
Analysis	8	0	0	3	0
Backdoor	7	0	0	325	80
Dos	32	1	0	329	14
Exploits	51	6	0	544	63
Reconnaissance	7723	0	0	35	4
Generic	2	7832	0	4	1
Normal	0	0	7899	0	0
Fuzzers	8	4	0	7264	33
Worm	0	0	0	9	7822

Fig. 21. Model 4 -UNSW-NB15 - confusion matrix (Part2).

Attacks\ metrics	Precision	Recall	F1-Score	Support
Analysis	0.98	0.99	0.99	7896
Backdoor	0.94	0.94	0.94	7868
Dos	0.86	0.88	0.87	7803
Exploits	0.90	0.77	0.83	7682
Reconnaissance	0.99	0.98	0.98	7885
Generic	1.00	0.99	1.00	7894
Normal	1.00	1.00	1.00	7899
Fuzzers	0.85	0.94	0.90	7717
Worm	0.98	0.99	0.98	7884

Fig. 22. Model 4 -UNSW-NB15 - classification report

significantly under performs compared to the other models. When examining the individual precision and recall of the attack classes in Models 1 and 2, only the classes with a higher number of data points perform well, while others, aside from Generic, Normal, and Exploits attack classes, perform poorly. The least performing class is Backdoor, where the recall in Model 2 is around 7%. After oversampling the dataset using SMOTE, Model 4 performs better than the other models, with an accuracy of 95% and improved individual precision and recall for each of the classes. Classes with fewer data points, such as Analysis, Backdoor, DoS, and Exploits, perform better in Model 4, which incorporates ANN + Bi-LSTM models after data balancing.

D. Evaluation Summary for the Three Datasets

In summary, for the NSL-KDD, CIC-IDS2017, and UNSW-NB15 datasets, Models 1 and 2 generally perform well in terms of accuracy, while Model 3 under performs. Model 4, which employs ANN + Bi-LSTM models after data balancing using SMOTE, consistently outperforms the other models, especially when considering individual precision and recall for each attack class. Model 4 improves performance for underrepresented attack classes, indicating that balancing

the dataset and using ANN + Bi-LSTM models contribute to better overall performance in intrusion detection. Table XXIII demonstrate the results of the best performing model.

TABLE XXIII. BEST MODEL (MODEL 4) - RESULTS

Dataset	Accuracy	Precision	Recall
NSL-KDD	95.8	95.3	94.8
CIC-IDS2017	99.0	99.3	99.3
UNSW-NB15	95.3	94.4	94.2

VII. DISCUSSION

The results presented in this study provide valuable insights into the performance of four different intrusion detection models across three distinct cybersecurity datasets. Through a rigorous evaluation process, we have demonstrated the effectiveness of the proposed model, which combines BiLSTM, XGBoost, and 1DCNN/DNN, in detecting intrusions across diverse cybersecurity environments.

The findings show that Model 4, which utilizes ANN + Bi-LSTM architecture with data balancing using SMOTE, consistently outperforms the other models in terms of precision and recall. This indicates the model's capability to effectively detect intrusion attempts, even in underrepresented attack classes. These results suggest that data balancing techniques combined with deep learning architectures offer a promising approach to improving the performance of intrusion detection models.

Additionally, the study shows that the proposed model is adaptable to different cybersecurity contexts, as demonstrated by its strong performance across the NSL-KDD, CIC-IDS2017, and UNSW-NB15 datasets. The diversity of these datasets highlights the need for intrusion detection models that can effectively handle varying cybersecurity landscapes. The results suggest that the proposed model has the potential to offer an effective solution to the ongoing challenge of intrusion detection in such environments.

It is worth noting that the study is not without limitations. While we have evaluated the proposed model across three distinct datasets, there exist many other cybersecurity datasets that could provide a more comprehensive evaluation of the model's performance. Additionally, the study has focused solely on the effectiveness of intrusion detection models and has not explored other potential applications of deep learning in cybersecurity, such as anomaly detection or threat intelligence.

Overall, our study provides evidence that combining deep learning architectures with data balancing techniques can lead to improved performance in intrusion detection. The proposed model's adaptability to diverse cybersecurity contexts offers promise for the development of effective and robust intrusion detection systems. Future research could explore the use of the proposed model on other cybersecurity datasets and investigate the potential applications of deep learning in other areas of cybersecurity.

VIII. CONCLUSION

This study investigated the effectiveness of using the XG-Boost algorithm for feature selection in combination with dif-

ferent deep learning (DL) approaches, such as ANN, 1DCNN, and BiLSTM, to build accurate intrusion detection systems (IDSs) in both binary and multiclass classification settings. Three datasets were used to evaluate the proposed methods: NSL-KDD, CIC-IDS2017, and UNSW-NB15. The results demonstrate the classification models' high accuracy and low error rate, indicating that the proposed methods are a viable and promising approach for designing IDS.

Initially, the suggested DL techniques were used to test the datasets across the entire feature space, followed by the implementation of the XGBoost feature extraction technique presented in this study to obtain a reduced feature vector. The study also analyzed the performance results of researchers who utilized various classifiers. The experimental results showed that using a reduced feature vector can help reduce the model's complexity while improving detection accuracy on test data.

The datasets used in this study all contained data imbalance, which can lead to biased models over the larger categorical class. This issue was observed in models 1 and 2 on all three datasets. The SMOTE data balancing technique was introduced to address this issue, resulting in better performance in models 3 and 4, as indicated by the individual class's precision and recall. Specifically, for the NSL-KDD dataset, models 1 and 2 had low U2R class performance, with precision and recall values of 59

Overall, the performance of Models 1 and 2 is generally good in terms of accuracy for the NSL-KDD, CIC-IDS2017, and UNSW-NB15 datasets, while Model 3 does not perform as well. However, Model 4, which involves the use of ANN + Bi-LSTM models after applying SMOTE for data balancing, consistently outperforms the other models, particularly when looking at the precision and recall of each individual attack class. By improving the performance of underrepresented attack classes, Model 4 suggests that balancing the dataset and utilizing ANN + Bi-LSTM models contribute to overall improvement in intrusion detection performance.

Therefore, future work could involve implementing a novel sampling technique designed explicitly for IDSs to boost the prevalence of the minority classes in other public datasets during the training phase. Overall, this study's findings highlight the importance of data balancing techniques in addressing data imbalance issues and the effectiveness of using XGBoost and DL approaches in building accurate IDSs.

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REFERENCES

- [1] Y. Imrana, Y. Xiang, L. Ali, and Z. Abdul-Rauf, "A bidirectional lstm deep learning approach for intrusion detection," *Expert Systems with Applications*, vol. 185, p. 115524, 2021. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S09574174211009337>
- [2] M. D. Hossain, H. Inoue, H. Ochiai, D. Fall, and Y. Kadobayashi, "Lstm-based intrusion detection system for in-vehicle can bus communications," *IEEE Access*, vol. 8, pp. 185 489–185 502, 2020.
- [3] P. Wei, Y. Li, Z. Zhang, T. Hu, Z. Li, and D. Liu, "An optimization method for intrusion detection classification model based on deep belief network," *IEEE Access*, vol. 7, pp. 87 593–87 605, 2019.

- [4] Y. Xiao, C. Xing, T. Zhang, and Z. Zhao, "An intrusion detection model based on feature reduction and convolutional neural networks," *IEEE Access*, vol. 7, pp. 42 210–42 219, 2019.
- [5] J. L. Leevy and T. M. Khoshgoftaar, "A survey and analysis of intrusion detection models based on cse-cic-ids2018 big data," *Journal of Big Data*, vol. 7, no. 1, pp. 1–19, 2020.
- [6] Y. Zhong, W. Chen, Z. Wang, Y. Chen, K. Wang, Y. Li, X. Yin, X. Shi, J. Yang, and K. Li, "Helad: A novel network anomaly detection model based on heterogeneous ensemble learning," *Computer Networks*, vol. 169, p. 107049, 2020.
- [7] Z. A. A. Alyasseri, M. A. Al-Betar, I. A. Doush, M. A. Awadallah, A. K. Abasi, S. N. Makhadmeh, O. A. Alomari, K. H. Abdulkareem, A. Adam, R. Damasevicius *et al.*, "Review on covid-19 diagnosis models based on machine learning and deep learning approaches," *Expert systems*, vol. 39, no. 3, p. e12759, 2022.
- [8] R. Magán-Carrión, D. Urda, I. Díaz-Cano, and B. Dorronsoro, "Towards a reliable comparison and evaluation of network intrusion detection systems based on machine learning approaches," *Applied Sciences*, vol. 10, no. 5, 2020. [Online]. Available: <https://www.mdpi.com/2076-3417/10/5/1775>
- [9] H. M. Song, J. Woo, and H. K. Kim, "In-vehicle network intrusion detection using deep convolutional neural network," *Vehicular Communications*, vol. 21, p. 100198, 2020.
- [10] MIT Lincoln Laboratory, "1998 DARPA Intrusion Detection Evaluation Dataset," <https://www.ll.mit.edu/r-d/datasets/1998-darpa-intrusion-detection-evaluation-dataset>, 1998, accessed: April 2023.
- [11] I. Sharafaldin, A. H. Lashkari, and A. A. Ghorbani, "Toward generating a new intrusion detection dataset and intrusion traffic characterization," *IEEE Communications Surveys & Tutorials*, vol. 20, no. 3, pp. 1976–1999, 2018.
- [12] N. Moustafa, J. Slay, and G. Creech, "Unsw-nb15: a comprehensive data set for network intrusion detection systems (unsw-nb15 network data set)," *Military Communications and Information Systems Conference (MilCIS)*, pp. 1–6, 2015.
- [13] K. Mounika and P. V. Rao, "Idcsnet: Intrusion detection and classification system using unified gradient-boosted decision tree classifier," in *2022 International Conference on Automation, Computing and Renewable Systems (ICACRS)*, Dec 2022, pp. 1159–1164.
- [14] J. Hancock and T. M. Khoshgoftaar, "Performance of catboost and xgboost in medicare fraud detection," in *2020 19th IEEE International Conference on Machine Learning and Applications (ICMLA)*, 2020, pp. 572–579.
- [15] Y. Zhou, G. Cheng, S. Jiang, and M. Dai, "Building an efficient intrusion detection system based on feature selection and ensemble classifier," *Computer Networks*, vol. 174, p. 107247, 2020. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S1389128619314203>
- [16] S. M. Kasongo and Y. Sun, "Performance analysis of intrusion detection systems using a feature selection method on the unsw-nb15 dataset," *Journal of Big Data*, vol. 7, pp. 1–20, 2020.
- [17] S. S. Dhaliwal, A.-A. Nahid, and R. Abbas, "Effective intrusion detection system using xgboost," *Information*, vol. 9, no. 7, 2018. [Online]. Available: <https://www.mdpi.com/2078-2489/9/7/149>
- [18] N. Qu, Z. Li, X. Li, S. Zhang, and T. Zheng, "Multi-parameter fire detection method based on feature depth extraction and stacking ensemble learning model," *Fire Safety Journal*, vol. 128, p. 103541, 2022. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0379711222000194>
- [19] A. Asselman, M. Khaldi, and S. Aammou, "Enhancing the prediction of student performance based on the machine learning xgboost algorithm," *Interactive Learning Environments*, vol. 0, no. 0, pp. 1–20, 2021. [Online]. Available: <https://doi.org/10.1080/10494820.2021.1928235>
- [20] I. F. Kilincer, F. Ertam, and A. Sengur, "A comprehensive intrusion detection framework using boosting algorithms," *Computers and Electrical Engineering*, vol. 100, p. 107869, 2022. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0045790622001598>
- [21] Z. Liu, N. Thapa, A. Shaver, K. Roy, X. Yuan, and S. Khorsandroo, "Anomaly detection on iot network intrusion using machine learning," in *2020 International Conference on Artificial Intelligence, Big Data, Computing and Data Communication Systems (icABCD)*, 2020, pp. 1–5.

- [22] D. Andrešič, P. Šaloun, and B. Pečiková, *Large Astronomical Time Series Pre-processing for Classification Using Artificial Neural Networks*. Cham: Springer International Publishing, 2021, pp. 265–293. [Online]. Available: https://doi.org/10.1007/978-3-030-65867-0_12
- [23] S. Mao and E. Sejdić, “A review of recurrent neural network-based methods in computational physiology,” *IEEE Transactions on Neural Networks and Learning Systems*, pp. 1–21, 2022.
- [24] G. Van Houdt, C. Mosquera, and G. Nápoles, “A review on the long short-term memory model,” *Artificial Intelligence Review*, vol. 53, no. 8, pp. 5929–5955, 2020.
- [25] B. Roy and H. Cheung, “A deep learning approach for intrusion detection in internet of things using bi-directional long short-term memory recurrent neural network,” in *2018 28th International Telecommunication Networks and Applications Conference (ITNAC)*, 2018, pp. 1–6.
- [26] P. Agrawal and A. Duvey, “Detecting infiltration and intrusive behaviours in wireless networks using deep learning and long short-term memory.”
- [27] M. Waqas, K. Kumar, A. A. Laghari, U. Saeed, M. M. Rind, A. A. Shaikh, F. Hussain, A. Rai, and A. Q. Qazi, “Botnet attack detection in internet of things devices over cloud environment via machine learning,” *Concurrency and Computation: Practice and Experience*, vol. 34, no. 4, p. e6662, 2022.
- [28] D. C. Asogwa, S. O. Anigbogu, I. E. Onyenwe, and F. A. Sani, “Text classification using hybrid machine learning algorithms on big data,” *CoRR*, vol. abs/2103.16624, 2021. [Online]. Available: <https://arxiv.org/abs/2103.16624>
- [29] M. A. Khan, “Hcrnnids: Hybrid convolutional recurrent neural network-based network intrusion detection system,” *Processes*, vol. 9, no. 5, 2021. [Online]. Available: <https://www.mdpi.com/2227-9717/9/5/834>
- [30] D. Alghazzawi, O. Bamasag, H. Ullah, and M. Z. Aşghar, “Efficient detection of ddos attacks using a hybrid deep learning model with improved feature selection,” *Applied Sciences*, vol. 11, no. 24, 2021. [Online]. Available: <https://www.mdpi.com/2076-3417/11/24/11634>
- [31] P. Sun, P. Liu, Q. Li, C. Liu, X. Lu, R. Hao, and J. Chen, “Dlids: Extracting features using cnn-lstm hybrid network for intrusion detection system,” *Security and Communication Networks*, vol. 2020, p. 8890306, 2020.
- [32] M. Al-Omari, M. Rawashdeh, F. Qutaishat, and K. Al-Faour, “An intelligent tree-based intrusion detection model for cyber security,” *Journal of Network and Systems Management*, vol. 29, no. 1, pp. 20–38, 2021.
- [33] M. H. Alwan, Y. I. Hammadi, O. A. Mahmood, A. Muthanna, and A. Koucheryavy, “High density sensor networks intrusion detection system for anomaly intruders using the slime mould algorithm,” *Electronics*, vol. 11, no. 20, 2022. [Online]. Available: <https://www.mdpi.com/2079-9292/11/20/3332>
- [34] D. Yu, X. Hou, C. Li, Q. Lv, Y. Wang, and N. Li, “Anomaly detection in unstructured logs using attention-based bi-lstm network,” in *2021 7th IEEE International Conference on Network Intelligence and Digital Content (IC-NIDC)*, 2021, pp. 403–407.
- [35] M. Abdallah, N. A. Le Khac, H. Jahromi, and A. D. Jurcut, “A hybrid cnn-lstm based approach for anomaly detection systems in sdns,” in *The 16th International Conference on Availability, Reliability and Security (ARES 2021)*. New York, NY, USA: ACM, August 2021, p. 7. [Online]. Available: <https://doi.org/10.1145/3465481.3469190>
- [36] M. A. Abdou, “Literature review: efficient deep neural networks techniques for medical image analysis,” *Neural Computing and Applications*, vol. 34, no. 8, pp. 5791–5812, 2022.
- [37] P. Devan and N. Khare, “An efficient xgboost–dnn-based classification model for network intrusion detection system,” *Neural Computing and Applications*, vol. 32, pp. 12 499–12 514, 2020.
- [38] R. Vinayakumar, M. Alazab, K. P. Soman, P. Poornachandran, A. Al-Nemrat, and S. Venkatraman, “Deep learning approach for intelligent intrusion detection system,” *IEEE Access*, vol. 7, pp. 41 525–41 550, 2019.
- [39] T. A. Tang, L. Mhamdi, D. McLernon, S. A. R. Zaidi, and M. Ghogho, “Deep learning approach for network intrusion detection in software defined networking,” in *2016 International Conference on Wireless Networks and Mobile Communications (WINCOM)*, 2016, pp. 258–263.
- [40] S. Potluri and C. Diedrich, “Accelerated deep neural networks for enhanced intrusion detection system,” 09 2016.
- [41] M.-J. Kang and J.-W. Kang, “Intrusion detection system using deep neural network for in-vehicle network security,” *PLOS ONE*, vol. 11, no. 6, pp. 1–17, 06 2016. [Online]. Available: <https://doi.org/10.1371/journal.pone.0155781>
- [42] B. Mohammed and E. K. Gbashi, “Intrusion detection system for nsl-kdd dataset based on deep learning and recursive feature elimination,” *Engineering and Technology Journal*, pp. 1069–1079, 2021.
- [43] S. Wunderlich, M. Ring, D. Landes, and A. Hotho, “Comparison of system call representations for intrusion detection,” in *Advances in Intelligent Systems and Computing*. Springer International Publishing, apr 2019, pp. 14–24. [Online]. Available: https://doi.org/10.1007/978-3-030-20005-3_2
- [44] W.-F. Zheng, “Intrusion detection based on convolutional neural network,” in *2020 International Conference on Computer Engineering and Application (ICCEA)*, 2020, pp. 273–277.
- [45] M. H. Kotb and R. Ming, “Comparing smote family techniques in predicting insurance premium defaulting using machine learning models,” *International Journal of Advanced Computer Science and Applications*, vol. 12, no. 9, 2021. [Online]. Available: <http://dx.doi.org/10.14569/IJACSA.2021.0120970>

QMX-BdSL49: An Efficient Recognition Approach for Bengali Sign Language with Quantize Modified Xception

Nasima Begum*, Saqib Sizan Khan, Rashik Rahman, Ashraful Haque, Nipa Khatun, Nusrat Jahan, Tanjina Helaly
Department of Computer Science and Engineering, University of Asia Pacific,
Dhaka, Bangladesh

Abstract—Sign language is developed to bridge the communication gap between individuals with and without hearing impairment or speech difficulties. Individuals with hearing and speech impairment typically rely on hand signs as a means of expressing themselves. However, people, in general, may not have sufficient knowledge of sign language, thus a sign language recognition system on an embedded device is most needed. Literature related to such systems on embedded devices is scarce as these recognition tasks are very complex and computationally expensive. The limited resources of embedded devices cannot execute complex algorithms like Convolutional Neural Network (CNN) properly. Therefore, in this paper, we propose a novel deep learning architecture based on default Xception architecture, named Quantized Modified Xception (QMX) to reduce the model's size and enhance the computational speed without compromising model accuracy. Moreover, the proposed QMX model is highly optimized due to the weight compression of model quantization. As a result, the footprint of the proposed QMX model is 11 times smaller than the Modified Xception (MX) model. To train the model, BDSL 49 dataset is utilized which includes approximately 14,700 images divided into 49 classes. The proposed QMX model achieves an overall F1 accuracy of 98%. In addition, a comprehensive analysis among QMX, Modified Xception Tiny (MXT), MX, and the default Xception model is provided in this research. Finally, the model has been implemented on Raspberry Pi 4 and a detailed evaluation of its performance has been conducted, including a comparison with existing state-of-the-art approaches in this domain. The results demonstrate that the proposed QMX model outperforms the prior work in terms of performance.

Keywords—Bengali sign language; CNN; computer vision; model quantization; Raspberry Pi 4; transfer learning; Tiny ML

I. INTRODUCTION

Disability is a crucial issue in terms of human rights because a person with an impairment is usually deprived of ordinary public welfare. Almost a billion of the world's population has some form of physical disability¹. Individuals with disabilities experience more negative socioeconomic consequences, resulting in a poorer standard of life. While over 430 million people worldwide suffer from hearing impairment², there are more than 1.7 million hearing and speaking impaired people in Bangladesh alone³. These impaired people belong to

the Bangladesh Deaf and Mute Community (BDMC). Due to their communication impediment, the BDMC, faces numerous obstacles while attempting to participate in education, work, social activities, and other aspects of everyday life.

Sign language employs the visual-manual paradigm to communicate meaning. Sign language is conveyed via hand and finger movements to create gestures. The only way to communicate with people with hearing or speaking disabilities is through sign language. Similar to every other language, the Bengali language has its own sign language, which is known as Bengali Sign Language (BdSL). The BDMC uses only BdSL to communicate with everyone, which restricts their ability to converse with society, as the majority of the society does not know sign language due to a lack of social awareness.

In the aforementioned scenario, communication between the BDMC and society requires a sign language interpreter. However, a skilled interpreter may not always be readily available, and in such circumstances, paying fair fees may be a serious worry. An automated recognition system for sign language can play a vital role in reducing the basic and social differences between society and BDMC. Therefore, sign language recognition is a popular area of study. Current research in this area focuses mostly on either sensor-based [1] or vision-based [2] systems.

Numerous studies have been conducted on BdSL recognition, and there are numerous benchmarking datasets [3], [4], [5], [6], [7] for BdSL recognition. However, these datasets are insufficient for training and evaluating deep learning models, and the majority are not open-source. CNN [8], [9] is a popular choice along with the transfer learning [10], [11], [12] model to recognize BdSL.

Several research implements the CNN model for recognizing BdSL. Hossain et al. [13] proposed a CNN-based sign language recognition model and achieved 98.75% accuracy. Islam et al. [14] also proposed a CNN-based model, and they evaluated their model using 10-fold cross-validation. They achieved 99.80% accuracy. Some research utilized CNN-based transfer learning models for recognition. Rafi et al. [4] utilized the VGG19 transfer learning model with 89.6% accuracy. To our knowledge, no prior work exists on constructing an efficient deep learning model that can be implemented in embedded or IoT devices via model quantization. The majority of recent work employed mainstream or pre-trained models. Therefore, these models cannot be implemented on devices with a low configuration.

¹<https://www.who.int/news-room/fact-sheets/detail/disability-and-health>

²<https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss>

³https://en.wikipedia.org/wiki/Deafness_in_Bangladesh

Therefore, this research proposes a BdSL recognition deep learning system in which the available default Xception [15] model has been extensively altered to obtain a new model with greater accuracy. In addition, the novel Modified Xception (MX) model has been quantized in order to be applied in embedded systems. Thus in this research, a novel Quantized Modified Xception (QMX) model is proposed. This paper also offers a comprehensive investigation of QMX, Modified Xception Tiny (MXT), Modified Xception (MX), and the default Xception model. Furthermore, the developed QMX model has been successfully implemented on an embedded device, namely the Raspberry Pi 4. The QMX recognition model is only 3.3MB in size and contains just 3,317,201 trainable parameters, making it an extremely lightweight model for embedded system implementation. To train and evaluate the model, an open-source benchmark dataset named BDSL 49 [16] that contains 14,700 images divided into 49 classes is utilized. The QMX model achieved an overall F1 accuracy of 98%.

The main contributions of this research are as follows:

- A quantization algorithm for the Modified Xception (MX) model.
- A Quantized Modified Xception (QMX) model has been proposed to recognize hand signs and predict the characters. The QMX model is 72 and 11 times lighter than the default Xception and Modified Xception (MX) models respectively. Moreover, it achieved an average F1-score of 98%.
- For IoT implementation, the proposed QMX model is deployed on an embedded system, which is Raspberry Pi 4 for evaluating the model efficiency and inference time.

The rest of the paper is structured as follows: Section II represents the literature review. The dataset description is provided in Section III. The proposed methodology is described in Section IV. Section V analyzes the results of the conducted experiments. Lastly, Section VI concludes the paper with some future works.

II. LITERATURE REVIEW

Recognition of sign language is a very intriguing area of study. Although research on BdSL recognition is abundant, few have managed to make it implementable and attainable in a practical situation; therefore, it remains unexplored. This section outlines the evolution of research regarding BdSL recognition.

Islam et al. [17] provided a Bengali sign language digit recognition system using deep learning, which delivers the output in text form. Using the Ishara-Lipi dataset, they developed the proposed model, which gained about 95% accuracy. However, they did not use RGB images during model training. Khan et al. [18] proposed a CNN and Region of Interest (ROI) segmentation-based BdSL translator device that can translate only five sign gestures. It has a 94% accuracy rate for recognizing signs in real-time. Due to the lack of available signs for different words, they built the device using five words only. The authors of [19], reviewed the research approaches of BdSL from 2002 to 2021 and discussed each work's contributions

and weaknesses. The Scale Invariant Feature Transform (SIFT) technique and CNN were used in the proposed system of [3] to detect one-handed gestures of 38 Bengali signs. However, they used grayscale images for training their proposed model. Using CNN, the authors of [13] achieved 98.75% accuracy in recognizing Bengali signs. However, they only used one-handed sign gestures. Shurid et al. [9], proposed a Bengali sign language recognition and sentence building CNN-based model and achieved 90% accuracy using their augmented dataset. However, their proposed model could not work properly to recognize critical sign gestures.

Ishara-Lipi [6] is a commonly used dataset for BdSL recognition, though it consists of only 36 characters out of 49. "BenSignNet" a CNN and concatenated segmentation-based model, was proposed in [8] that only detects Bengali Sign Language alphabets using three different datasets. However, the model is computationally expensive as it used several image processing techniques. Ilias et al. [20] proposed a Sign Language Recognition Generative Adversarial Network (SLRGAN) using a Context-Aware Generative Adversarial Network architecture. The proposed model achieved 23.4%, 2.1%, and 2.26% word error rates for three primarily used datasets such as RWTH-Phoenix-Weather-2014, Chinese Sign Language (CSL), and Greek Sign Language (GSL). However, they considered only the contextual information of the sign language. A CNN-LSTM model was proposed to recognize both hands' lexical signs in Bangla [7]. However, the BdSL dataset has only 36 classes with 13,400 images and produced 90% training accuracy and 88.5% testing accuracy. Rafi et al. [4], proposed a VGG-19-based model to recognize 38 different classes of Bengali sign gestures and obtained 89.6% test accuracy. However, their dataset contains a low amount of sample images. In order to enhance inter-dataset performance, the research work [10] uses a variety of deep learning models and angular loss functions to highlight the significance of generalization in finger-spelled BdSL recognition. Due to a lack of diversity in the dataset, they achieved 55.93% and 47.81% test accuracy using the SphereFace loss function in the VGG-19 architecture. A pre-trained model called "MobileNet" was proposed in [11]. The authors proposed an approach for converting signs made in BdSL into their appropriate Bengali letters. They evaluated the model using the Ishara-Lipi dataset and achieved 95.71% accuracy. However, this model could not detect the hand signs in different backgrounds.

The authors of [21] presented a quantization method to estimate the floating-point calculations in a neural network using just integer arithmetic. The network quantization techniques are discussed by Garifulla et al. [22] which are used for disease diagnosis on portable medical devices to reduce the CNN models' size and inference time. The authors of [23] examined the mathematical properties of quantization parameters and assessed the choices made for a large variety of neural network models for various domains of application, such as voice, language, and vision. Koutayni [24] introduced a low-energy solution for depth camera-based hand posture estimation methods and compressed the deep neural network model using dynamic quantization approaches at various levels to gain maximum compression without sacrificing accuracy.

Most of the existing BdSL recognition models are trained with datasets, which are insufficient due to the lack of data

TABLE I. CLASSES LABEL AND NAME

label	0	1	2	3	4	5	6
Class Name	অ	আ	ই	উ	এ	ও	ক
label	7	8	9	10	11	12	13
Class Name	খ	গ	ঘ	চ	ছ	জ	ঝ
label	14	15	16	17	18	19	20
Class Name	ট	ঠ	ড	ঢ	ত	থ	দ
label	21	22	23	24	25	26	27
Class Name	ধ	প	ফ	ব	ভ	ম	য়
label	28	29	30	31	32	33	34
Class Name	র	ল	ন	স	হ	ড়	ং
label	35	36	37	38	39	40	41
Class Name	ঃ	০	১	২	৩	৪	৫
label	42	43	44	45	46	47	48
Class Name	৬	৭	৮	৯	—	space	ঐ

TABLE II. CLASSWISE DATA DISTRIBUTION

Label	Train Sample	Test Sample	Pixel	Format
0	240	60	128 x 128	RGB
1	240	60	128 x 128	RGB
2	240	60	128 x 128	RGB
...
48	240	60	128 x 128	RGB

samples in them. Furthermore, hardly any research focuses on the real-life implementation of BdSL recognition systems on low-end devices.

III. DATASET DESCRIPTION

The use of sign language is essential to communicate with persons with hearing disabilities or persons with speaking disabilities. A dataset is highly useful for an automated system to recognize the hand signs of Bengali Sign Language. For this research purpose, a dataset named BdSL 49 [16] is utilized with 49 classes. Each class represents a Bengali alphabet, numeric character, or special character (space, Hasantha). The dataset consists of 14,700 images organized into 49 categories. In Table I, 49 labels of the dataset referring to the naming of Bengali letters are listed. Fig. 1 illustrates sample images of each class.

Each sample image is labeled with the appropriate Bengali characters. Each class has approximately 300 images and is divided into two sections: one for training and the other for testing the model. 80% of the images for each class is considered for training, while the remaining 20% is considered for testing. Table II illustrates the data distribution between the train and the test set of the BdSL 49 dataset. As shown in Table II, there are 240 samples in the train set and 60 samples in the test set of each class. All images are in RGB format with a 128X128 pixel size.

IV. METHODOLOGY

This section discusses the proposed methodology. As the embedded low-end devices are unable to run computationally expensive models, thus a novel Modified Xception (MX)

model is proposed and described in subsection IV-A. However, when the MX model is implemented in an embedded device to perform in real-time, its footprint needs to be compressed further. Hence, in subsection IV-B, a quantization method is proposed that quantizes the MX model, and thus, the QMX model is achieved by converting the float 32-bit MX model into an int 8-bit QMX model. The QMX model is proposed to run the model specifically in a relatively low-configuration devices in real time environment.

Initially, some benchmark transfer learning models, namely Xception, InceptionV3, InceptionResNetV2, MobileNet, MobileNetV2, ResNet50V2, ResNet101V2, and ResNet152V2 are trained using the BdSL 49 dataset. Among these eight models, the Xception model performed comparatively well. However, it provides only 93% accuracy. Based on the performance analysis, Xception has the best level of accuracy. The Xception model architecture is chosen as a framework for developing the proposed QMX architecture. However, the Xception model size is around 240MB, which is very large. Therefore, to improve the model's performance and decrease the model's size, the Xception model's architecture is altered, and a novel MX model is proposed. Afterward, the MX model is quantized to implement it in embedded devices. Thus, the Quantized Modified Xception (QMX) model is attained. Finally, the QMX model is implemented on an embedded device, namely the Raspberry Pi 4, for inference.

A. Proposed Modified Xception Architecture

The proposed MX model is a highly comprehensive architectural model featuring 31 layers instead of the 71 layers of the original Xception model. The architecture of Xception is divided into three components. Initially, the data passed via the entry flow, then eight times repeated in the middle flow, and finally, passed through the exit flow. However, the precision of hand sign recognition is inadequate. Additionally, since Xception is a generalized architecture, it contains an extensive number of trainable parameters that are not optimal for all types of recognition. Hence, the purpose of our research is to design an effective architecture with the essence of the Xception model and achieve adequate precision for BdSL recognition.

The proposed MX model utilizes the Depthwise Separable Convolutional (DSC) layer which is a variant of the Separable Convolutional layer. The DSC layer partitions the process into two or more sub-processes. Upon the conclusion of each sub-process, the outcomes are integrated with the overarching result. Therefore, it reduces the multiplication costs resulting for a similar type of process. The utilization of Separable Convolution reduces the computational cost as well as the number of trainable parameters. The standard convolution operation incurs a substantial computational expense due to the simultaneous processing of all color channels, as indicated by the multiplication cost outlined in Eq. (1). In contrast, separable convolution is a technique that separates the color channels. Consequently, the multiplication of the number of kernels presented in Eq. (2) is performed on a single channel.

$$Conv2D = K^2 * d^2 * C * N \quad (1)$$



Fig. 1. Sample images from the dataset.

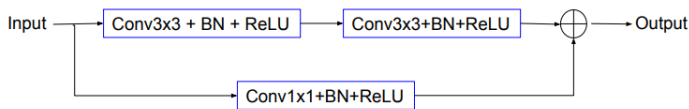


Fig. 2. Sample of the residual network.

$$SepConv2D = d^2 * 1 + 1^2 * N \quad (2)$$

Eq. (1) and Eq. (2) represents the complete multiplication costs for ordinary and separable convolution, respectively. The dimension K , as derived from the convolution process in Eq. (2), undergoes a transformation where it is multiplied by N after switching to a value of 1. Similarly, the variable d , which represents the size of the filter, is multiplied by 1 after undergoing a transformation and the variable C , representing the color channels in Eq. (2), is reduced to a value of 1. Finally, the variable N denotes the number of kernels. On the other hand, the neural network's architecture which comprises an excessive number of layers, may suffer from data loss resulting from a vanishing gradient. The MX model employs residual connections (a type of skip connection) which is illustrated in Fig. 2. The implementation of a residual layer mitigates this phenomenon and effectively incorporates various forms of data.

Fig. 3 illustrates the changes made to the default Xception architecture. Many layers are removed and a few layers are added in the Xception architecture in order to achieve an efficient architecture with sufficient precision. Changes in the architecture are classified in colors where “Green” signifies

the addition of a new layer or connections to the Xception architecture. “Blue” signifies a modification of the parameter values of any existing layer in the Xception which is known as fine-tuning. “Red” signifies the elimination of the layers from the default Xception model.

The starting layer of the MX architecture is a standard convolutional layer with the kernel size modified to 5×5 to avoid overfitting. It was only performed in the top two convolution layers. After the first Separable Convolution layer, several layers are further added to the structure. The new architectural layers include Depthwise Convolution, Batch normalization, and LeakyReLU activation function. The RGB images that are provided to the Depthwise Convolution undergoes a process of channel separation, convolution, and subsequent re-stacking, as demonstrated in Eq. 3. The Separable Convolution process corresponds to the Depthwise Convolution, with the exception of an additional step. The process of pointwise convolution involves an additional step. Following the stacking process, the features depicted in Eq. 2 are extracted through the utilization of a 1×1 filter.

$$DepthwiseConv2D = d^2 * 1(C1) + d^2 * 1(C2) + d^2 * 1(C3) \quad (3)$$

In the given context, the variable d denotes the dimensions of the filter, while the C variables correspond to the color channels. Each color channel is assigned a value of 1 and subsequently multiplied by d . Hence, the aforementioned methodology exhibits swifter and more effective outcomes in comparison to traditional convolution. Batch Normalization is employed subsequent to the Depthwise Convolution layer to expedite the training process and streamline the learning

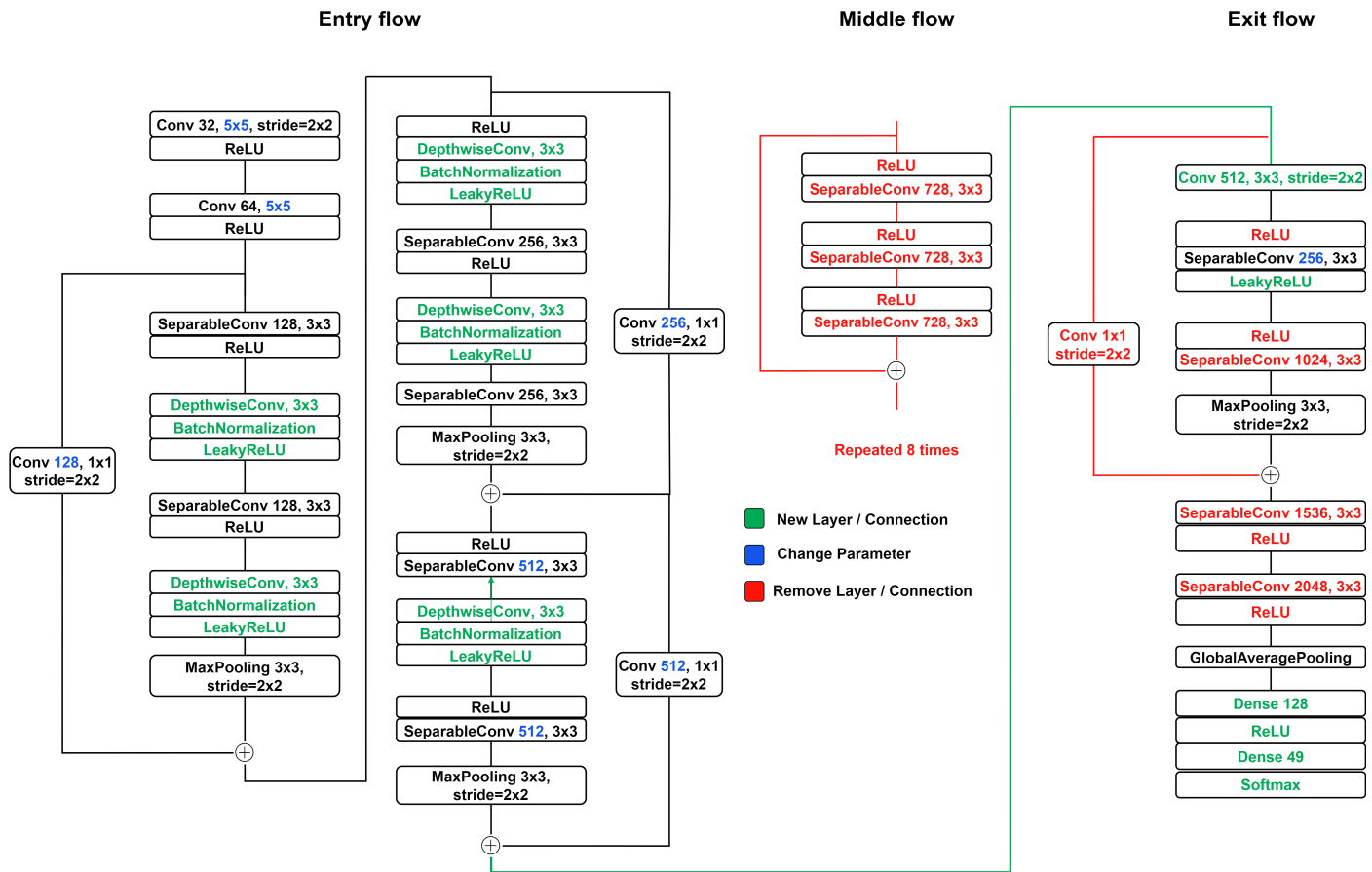


Fig. 3. Architectural modification of the Xception model.

procedure. Subsequently, the Leaky Rectified Linear Unit (LeakyReLU) activation function is employed. The Rectified Linear Unit (ReLU) activation function is triggered when the neurons within a neural network produce a positive value. In the absence of a positive value, the output of the function is zero. The LeakyReLU activation function is designed to mitigate the issue of “dead ReLU” that arises when the output of a ReLU is consistently negative. The system is capable of accepting certain numerical values that fall within the negative range and are in close proximity to zero. The LeakyReLU is mathematically represented by Eq. (4), where α is a constant parameter which is assigned a value of -0.01.

$$f(x) = \max(\alpha x, x) \quad (4)$$

The objective of utilizing Depthwise Convolution and LeakyReLU is to derive supplementary features from images. It improves the precision of the model. The “Entry Flow” architecture employs the Depthwise Convolution and Batch Normalization techniques, along with the LeakyReLU activation function, at multiple locations, as illustrated in Fig. 3. Additionally, the filter value of the final two separable convolution layers in the “Entry Flow” segment is reduced, and the parameters of the residual connection layers are modified. This makes the model more lightweight. To make the model lighter and more streamlined, the entirety of the “Middle Flow”

design is eliminated. This modification extensively reduces the computational cost of the model. An immediate connection between “Entry Flow” and “Exit Flow” is established. “Exit Flow” is also customized. A new convolution layer and LeakyReLU activation are added to this segment, and most of the separable convolution layers are omitted. The residual layer is also removed from this portion. After the GlobalAverage-Pooling layer, two fully connected layers are added with ReLU and Softmax activation functions respectively. An overview of the proposed MX model architecture is illustrated in Fig. 4.

B. Quantized Modified Xception (QMX)

Model Quantization is a well-known model compression approach that reduces the computational load and memory usage of the neural network models. The proposed quantization technique for the MX model is presented in this section. In this method, r represents the real number, q denotes the bit representation of the values, or quantized values. Most of the time, quantized networks are trained using floating point numbers, and then the weights are quantized. The before and after quantization of each of the convolutional layers are illustrated in Fig. 5, where (a) introduces 8-bit integers and 32-bit integer accumulator and (b) illustrates that the convolution layers are trained using simulated quantization. All variables and calculations utilize 32-bit floating-point arithmetic. To imitate the effects of variable quantization, the computation graph

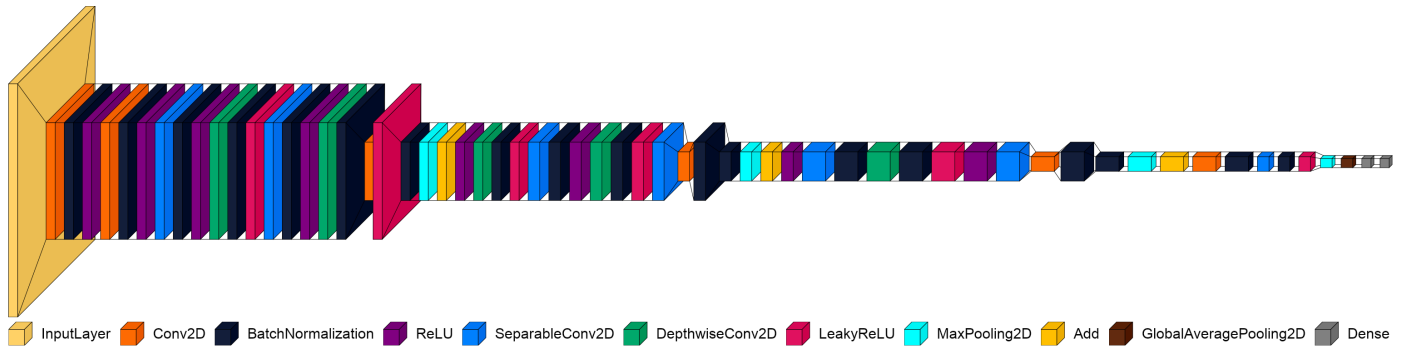


Fig. 4. Proposed MX architecture.

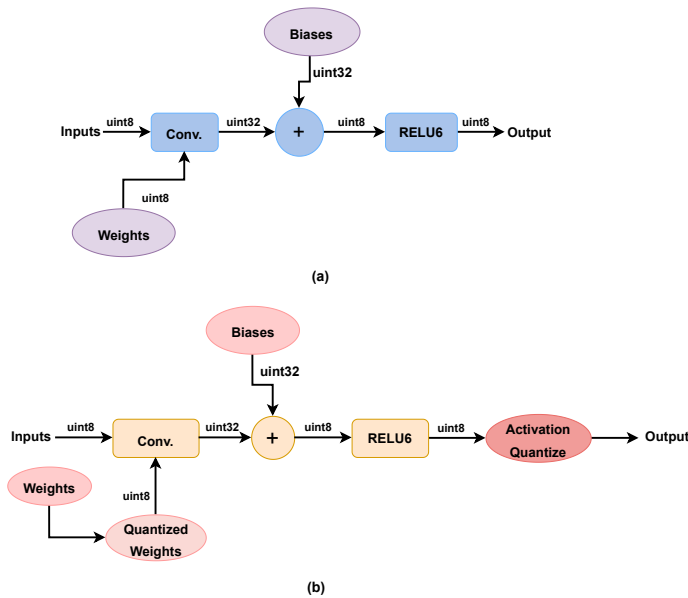


Fig. 5. Integer quantization in the convolution layer.

is infused with weight quantization and activation quantization endpoints. The resulting graph estimates the integer-only computation graph during training with standard optimization techniques for floating-point models.

A technique is provided during the forward pass of training for simulating quantization effects. The Backpropagation proceeds as usual, and floating point values are utilized for all weights and biases, allowing straightforward correction of minor values. Conversely, the forward propagation pass simulates quantized inference as implemented by the inference engine. The quantization technique's rounding behavior is integrated into floating-point arithmetic, such as: 1) The weights are quantized before convolving. The layer is normalized with batch normalization prior to quantization. The weights, \hat{w} are incorporated with the batch normalization parameters using Eq. (5), where γ is the batch normalization scale parameter. The symbol φ is a very small constant, and η is a moving average estimation of the variance of convolution results throughout the batch. 2) Activation functions are quantified where they arise during inference.

$$\hat{w} = \frac{\gamma \times w}{(\eta + \varphi)^{\frac{1}{2}}} \quad (5)$$

The point-wise quantization function q in Eq. (6) is used to perform quantization, which is controlled for each layer by the quantization level numbers and the clipping range.

$$clip(R; p, q) = \min(\max(x, p), q)$$

$$s(p, q, \kappa) = \frac{q - p}{\kappa - 1}$$

$$q(R; p, q, \kappa) = \lfloor \frac{clip(R, p, q) - p}{s(p, q, \kappa)} \rfloor * s(p, q, \kappa) + p \quad (6)$$

Here, R represents the real value that must be quantized and the notation for the quantization spectrum is p, q, κ indicates the number of quantization levels, while “ $\lfloor \cdot \rfloor$ ” indicates rounding to the nearest integer. The value of κ is set to 8 because, for 8-bit quantization, $\kappa = 2^8 = 256$ is utilized.

The quantized model's workflow is described by Algorithm 1. At first, the model receives the sign image and its corresponding labels as initial input. Following this, the MX floating point deep learning architecture shown in Fig. 4 is constructed (step 1). Following the development of the model, it is quantized to enable quantize-aware training (step 2). The quantized model is finally trained until it reaches convergence (step 3). The model is thus ready for inference, at which point, it can predict the desired output based on an input image (steps 4 and 5). Here, Quantization Aware Training (QAT) is used for compressing the proposed model. QAT is a model quantization technique where quantization operations are inserted before training the model. It enables the quantized weights and activation functions of the model to be adjusted.

C. Raspberry Pi Integration

The QMX model is implemented into Raspberry Pi 4 embedded system in order to evaluate the performance of the model in a real-world configuration. Python is utilized as the programming language for model implementation and TensorFlow 2.6 for inference. Initially, the input images or video frames are streamed by the device's camera module. Then, it predicts the corresponding signs. Finally, the output is displayed on a display screen connected to the device through

Algorithm 1 Training Steps of Quantization

Input: Sign images and corresponding labels.

Output: Recognize class name of sign images.

- 1: Create a training graph for a floating point model.
- 2: During training and inference, tensors will be reduced into fewer bits while inserting the quantization operations.
- 3: Train the quantized model using training data until convergence.
- 4: Perform the necessary improvements and build the inference graph for usage in a low-bit inference engine.
- 5: Use the quantized inference graph to draw conclusions from the data.

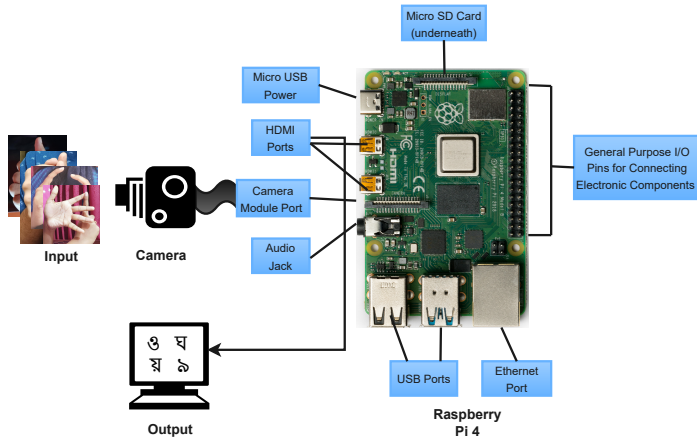


Fig. 6. Overview of raspberry pi 4 implementation.

its HDMI connector. Fig. 6 represents an overview of the Raspberry Pi 4 implementation.

D. Experimental Setup

The Google Colab Pro edition is utilized to execute the training procedure. A variety of Python packages are utilized for implementation. Pickle is used for data loading. Tensorflow serves as the backend to the Keras framework for model development. “Categorical Cross-Entropy” is chosen as a loss function for model compilation. Adaptive Moment Optimization (Adam) is utilized as an optimizer with a learning rate of 0.01. The Adam optimizer offers a quicker computation time and requires fewer training parameters. The gradient descent algorithm uses this approach by taking the gradients’ exponentially weighted average into account. Using averages accelerates the algorithm’s convergence towards minima. The batch size is set to 58 for 60 epochs and evaluates the model using the test dataset. The batch size of 58 is determined since the entire train sample is a factor of 58.

After the QMX model has been established, it is implemented on a Raspberry Pi 4 for inference. The original Xception, MX, and MXT models are also incorporated into the embedded device, enabling the examination of real-world performance. As a result of implementing all four models on Raspberry Pi 4, a quantitative analysis of the performance of these models in terms of model flash occupancy, inference time, and energy consumption is obtained. Energy consumption and inference time are important considerations

for evaluating real-world performance. The embedded device is a stand-alone device connected to a power bank, thus if the model is very efficient, then it consumes less power. Additionally, shorter estimation time indicates greater real-time accuracy.

V. RESULT ANALYSIS

In this section, experimental results and model assessments are quantitatively analyzed. The QMX model has been subjected to comparative analysis with several existing models. Besides, an estimation is conducted on the memory consumption, average operational duration, and average energy consumption of the MX, MXT, and QMX variants. The precision, recall, and F1 accuracy of the quantized model are also measured.

A. Evaluation Matrices

To evaluate the QMX model, five evaluation metrics are selected, namely precision, recall, F1-score, ROC-AUC curve, and confusion matrix. For an ideal classification model, both precision and recall tend to be one (1). The F1 score is determined by the weighted average of precision and recall. Therefore, this score takes into account both false positives and false negatives.

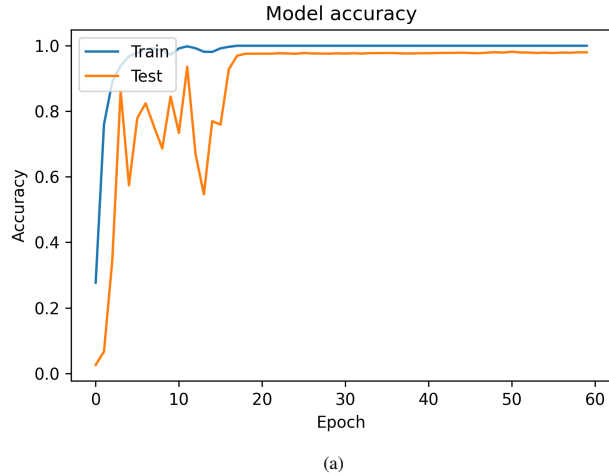
The confusion matrix is a prominent metric used in classification problems. It is applicable to both binary classification and multiclass classification problems. The comparison between the predicted outcome and the actual result can be derived using the confusion matrix. The AUC (Area under the ROC Curve) - ROC curve (Receiver Operating Characteristic curve) is a performance metric for classification problems with different threshold values.

B. Evaluation of the QMX Model

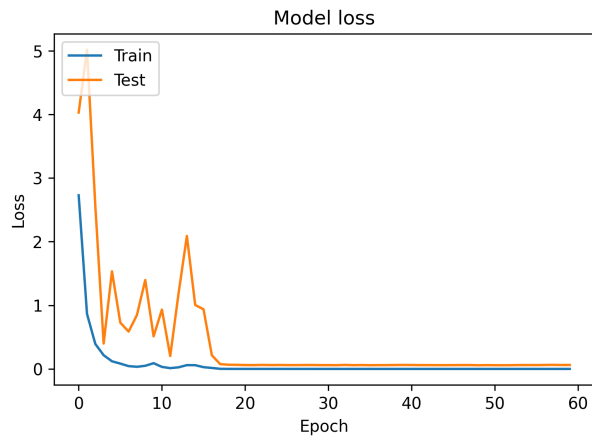
Fig. 7 illustrates the accuracy and loss graph of the QMX model while training. Here, the training score is represented by the blue line and the test score is represented by the yellow line during the training phase. From this figure, it is observed that the training score converges rapidly just within 10 epochs and remains constant for the rest of the epochs. On the contrary, the test score converges within 20 epochs after significant fluctuation. In addition, after convergence, the train and test scores become almost the same, the test score is slightly lower than the training score. Therefore, it can be concluded that the model exhibits a high degree of generalization.

Fig. 8 depicts the confusion matrix of the QMX model, revealing that the model is quite accurate at recognizing 49 distinct hand signs. Sixty images per class are used to evaluate the trained model. Approximately 59 to 60 images, and in some instances 57 or 58, are accurately predicted for each class.

Table III presents the classification report which contains evaluation metrics, namely precision, recall, and F1-score for each class of the MX, MXT, and QMX models. Although the average, macro average and mean average are the same for all three models, the QMX model is lighter, faster, and more efficient among these three. Moreover, embedded devices can utilize the QMX model better. Thus, the QMX model is



(a)



(b)

Fig. 7. QMX model accuracy and loss graph.

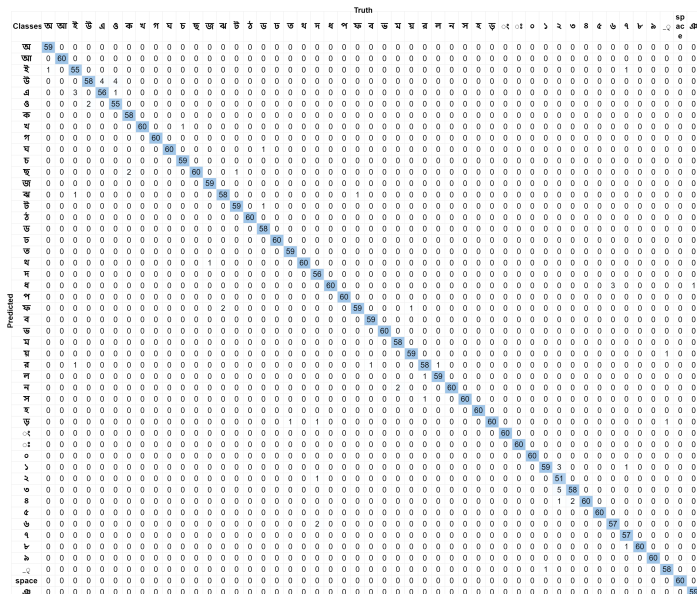


Fig. 8. Confusion matrix of QMX model.

TABLE III. PERFORMANCE EVALUATION OF DIFFERENT MODELS

label	MX			QMX		
	precision	recall	f1-score	precision	recall	f1-score
0	0.97	0.98	0.98	1.00	0.98	0.99
1	0.98	1.00	0.99	1.00	1.00	1.00
2	0.98	0.97	0.97	0.96	0.88	0.92
3	0.89	0.93	0.91	0.87	0.97	0.91
4	0.96	0.92	0.94	0.93	0.93	0.93
5	0.95	0.97	0.96	0.97	0.93	0.95
6	0.97	1.00	0.98	1.00	0.97	0.98
7	0.97	1.00	0.98	0.98	1.00	0.99
8	1.00	1.00	1.00	1.00	1.00	1.00
9	0.97	1.00	0.98	0.97	1.00	0.98
10	1.00	0.97	0.98	1.00	0.98	0.99
11	0.98	0.97	0.97	0.95	1.00	0.98
12	1.00	0.98	0.99	1.00	0.98	0.99
13	0.98	0.92	0.95	0.97	0.97	0.97
14	1.00	0.98	0.99	1.00	0.98	0.99
15	1.00	1.00	1.00	1.00	0.98	0.99
16	1.00	1.00	1.00	1.00	0.97	0.98
17	0.98	1.00	0.99	0.98	1.00	0.99
18	1.00	0.98	0.99	1.00	1.00	1.00
19	0.98	1.00	0.99	0.98	1.00	0.99
20	1.00	0.95	0.97	0.98	0.93	0.96
21	0.95	1.00	0.98	0.92	1.00	0.96
22	0.97	0.97	0.97	1.00	1.00	1.00
23	0.92	0.98	0.95	0.95	0.98	0.97
24	1.00	1.00	1.00	0.98	1.00	0.99
25	1.00	1.00	1.00	1.00	1.00	1.00
26	0.98	0.97	0.97	0.98	0.97	0.97
27	1.00	1.00	1.00	0.98	0.98	0.98
28	0.98	0.95	0.97	0.98	0.98	0.98
29	0.98	0.98	0.98	0.97	0.98	0.98
30	0.95	1.00	0.98	0.97	0.98	0.98
31	1.00	0.98	0.99	1.00	1.00	1.00
32	1.00	1.00	1.00	1.00	1.00	1.00
33	0.94	1.00	0.97	0.97	1.00	0.98
34	1.00	0.98	0.99	0.98	1.00	0.99
35	1.00	1.00	1.00	1.00	1.00	1.00
36	1.00	1.00	1.00	1.00	1.00	1.00
37	1.00	1.00	1.00	0.92	0.98	0.95
38	1.00	0.97	0.98	0.98	0.85	0.91
39	0.95	0.98	0.97	0.92	0.95	0.93
40	1.00	0.98	0.99	0.97	1.00	0.98
41	1.00	1.00	1.00	1.00	1.00	1.00
42	0.98	0.95	0.97	0.97	0.93	0.95
43	1.00	0.95	0.97	1.00	0.92	0.96
44	0.97	1.00	0.98	0.97	1.00	0.98
45	1.00	0.98	0.99	1.00	1.00	1.00
46	1.00	1.00	1.00	1.00	0.97	0.98
47	1.00	1.00	1.00	1.00	1.00	1.00
48	1.00	0.98	0.99	1.00	0.98	0.99
accuracy	0.98	0.98	0.98	0.98	0.98	0.98
macro avg	0.98	0.98	0.98	0.98	0.98	0.98
weighted avg	0.98	0.98	0.98	0.98	0.98	0.98

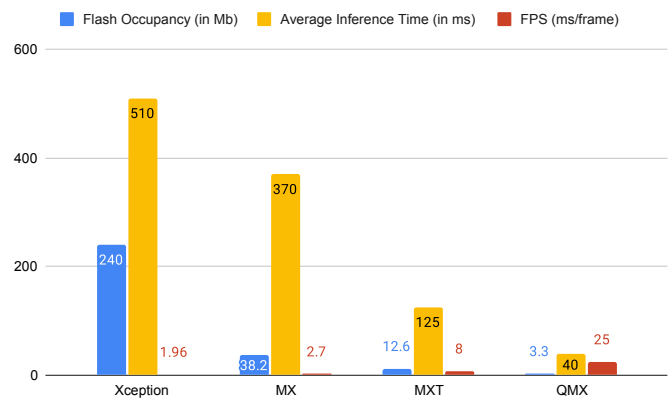


Fig. 9. Comparison of Xception, MX, MXT, and QMX model regarding flash Occupancy, inference time and Frames Per Second (FPS).

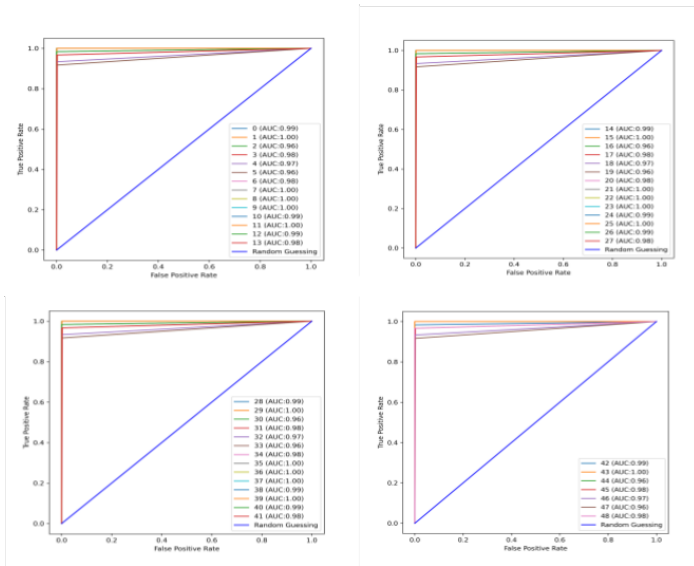


Fig. 10. ROC and AUC curve of QMX model.



(a) Input image (b) Feature matrix (c) Saliency visualization

Fig. 11. Saliency map visualization.

better in terms of space and time complexity while maintaining accuracy.

Fig. 9 establishes that, compared to the original Xception, MX, and MXT models, the int8 QMX model consumes less flash memory and average inference time. The average inference time of these four models is calculated after 100 iterations using the Raspberry Pi 4. The QMX model's flash occupancy is 72, 11, and 3 times less than the original Xception, MX, and MXT models, respectively. Besides, the recognition performance of the QMX model is 12, 9, and 3 times faster than the original Xception, MX, and MXT models, respectively. In a nutshell, Fig. 9 displays the lightweight features of the QMX model, and these percentages imply a significant increase in the model's lightweight characteristics. In addition, the QMX model can process 25 frames per second, as demonstrated in Fig. 9; hence, the model can predict hand gestures in real-time.

The average F1-score is 0.98, which means the model's F1 accuracy is 98%. Fig. 10 represents the ROC and AUC graph. Here, the ROC threshold value is plotted for each class and then the AUC curve for each class is determined. For all classes, AUC lies between 0.96 and 1.00, making it a very generalized model that can perform well in real-life configurations.

C. Saliency Visualization

A saliency map is a visual representation of the area where viewers' attention tends to first focus [25]. It can be used to focus on the most prominent areas of a picture that are most likely to influence the model's prediction. By using Eq. (7) and (8), a saliency map can be visualized.

$$S_x(i) = w_x^T * i + b_x \quad (7)$$

$$w = \frac{\partial S_x}{\partial i} \quad (8)$$

Here, $S_x(i)$ represents the score of the predicted class x , the one-dimensional image vector is referred to by i , w indicates the weight and b represents the bias for the predicted class x . The gradient specifies how strongly each pixel of the image (i) can influence the outcome of the prediction (S). Knowing the weights (w ; using Eq. (8)) for each pixel allows us to display the information as a saliency map, where each pixel represents the strength with which it influences the outcome of the prediction. Fig. 11 reveals which pixels are crucial for predicting the signs. And it can be seen from this figure that the saliency map highlights the pixels of the hand signs, indicating that the QMX model takes into account the hand elements from the image to produce precise predictions.

To generate a saliency map, the first input images shown in Fig. 11(a) are fed to the model. Afterward, the corresponding class x is predicted by the model. A 2D matrix is constructed utilizing a Gaussian pyramid from an image vector, which is responsible for activating class x , by employing the established weights (w). This 2D matrix is shown in Fig. 11(b) and it depicts the important pixel areas of the images responsible for the prediction of class x . Furthermore, upon projecting the aforementioned 2D matrix onto the input image, it becomes apparent that the salient features of the image are distinctly emphasized, as illustrated in Fig. 11(c). Depending on the prediction score S_x , the important areas are strongly or weakly highlighted. Fig. 11(c) reveals that the areas of the hand signs are prominently highlighted and concentrated, indicating that the model considers the hand signs to be the most essential attribute for predicting the related signs.

D. Comparison with State of the Arts

The present investigation employs BDSL 49 for the purpose of training pre-existing architectures. Table IV presents a visual representation of the results obtained by various architectures on the BDSL 49 dataset. By recreating, training and testing the model of [14],[4],[3],[6] and [8] on the BDSL

TABLE IV. PERFORMANCE COMPARISON BETWEEN PROPOSED QMX MODEL WITH THE STATE-OF-THE-ART ARCHITECTURES WHEN TRAINED ON BDSL 49 DATASET

Research	Dataset	Classes	F1 Accuracy
Islalm et al. [14]	BDSL 49	49	92%
Rafi et al. [4]	BDSL 49	49	93%
Shanta et al. [3]	BDSL 49	49	93%
Islam et al. [6]	BDSL 49	49	94%
Miah et al. [8]	BDSL 49	49	77%
Proposed QMX Architecture	BDSL 49	49	98%

TABLE V. PERFORMANCE ANALYSIS OF PROPOSED QMX MODEL WHEN TRAINED ON OTHER AVAILABLE DATASETS

Dataset	Train Data	Test Data	Classes	F1 Accuracy
38 BdSL [14]	11061	1520	38	89%
KU-BdSL [26]	1200	300	30	99%
Ishara-Lipi [6]	3333	792	36	93%
BdSL 49 [16]	11774	2940	49	98%

49 dataset, the QMX model achieved an F1 accuracy of 92%, 93%, 93%, 94%, and 77%, respectively. The QMX model got the highest accuracy of 98% for the proposed QMX architecture. On the other hand, Table V shows the performance of the proposed QMX architecture using some benchmark datasets. For the proposed QMX architecture, it achieved 89%, 99%, and 93% respectively, using the datasets [14], [26] and [6]. Besides, utilizing BDSL 49 dataset the QMX model achieved an F1 accuracy of 98%. This comprehensive comparison indicates that the proposed QMX architecture is quite standard for BdSL recognition.

VI. CONCLUSION

Persons with hearing impairment may face challenges in interacting with those who primarily use verbal language for communication. On the other hand, the majority of people in society can not understand sign language, which creates a communication gap between them. Therefore, in order to address this concern, this research has devised a QMX framework for the identification of BdSL that can be implemented on an embedded system. The model under consideration has been trained on a large dataset, referred to as BdSL 49, which has been designed to closely resemble real-world scenarios. This has resulted in the development of a model that exhibits a high degree of accuracy. The dataset maintains the standard sign representation of Bengali Sign Language, containing 49 different classes. Furthermore, the proposed QMX model is efficient as it requires low resources and can run in real time on a low-end device or embedded system. Besides, it is 11 times smaller than the proposed MX model and achieves an overall accuracy of 98%. In order to alleviate the challenges faced by persons with hearing disabilities or persons with speaking disabilities, our proposed future research endeavors involve the development and implementation of a language model capable of generating text from video streaming.

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REFERENCES

- [1] K. Kudrinko, E. Flavin, X. Zhu, and Q. Li, "Wearable sensor-based sign language recognition: A comprehensive review," *IEEE Reviews in Biomedical Engineering*, vol. 14, pp. 82–97, 2020.
- [2] S. Sharma and S. Singh, "Vision-based sign language recognition system: A comprehensive review," in *2020 International Conference on Inventive Computation Technologies (ICICT)*. IEEE, 2020, pp. 140–144.
- [3] S. S. Shanta, S. T. Anwar, and M. R. Kabir, "Bangla sign language detection using sift and cnn," in *2018 9th international conference on computing, communication and networking technologies (ICCCNT)*. IEEE, 2018, pp. 1–6.
- [4] A. M. Rafi, N. Nawal, N. S. N. Bayev, L. Nima, C. Shahnaz, and S. A. Fattah, "Image-based bengali sign language alphabet recognition for deaf and dumb community," in *2019 IEEE global humanitarian technology conference (GHTC)*. IEEE, 2019, pp. 1–7.
- [5] P. P. Urme, M. A. Al Mashud, J. Akter, A. S. M. M. Jameel, and S. Islam, "Real-time bangla sign language detection using xception model with augmented dataset," in *2019 IEEE International WIE Conference on Electrical and Computer Engineering (WIECON-ECE)*. IEEE, 2019, pp. 1–5.
- [6] M. S. Islam, S. S. S. Mousumi, N. A. Jessan, A. S. A. Rabby, and S. A. Hossain, "Ishara-lipi: The first complete multipurposeopen access dataset of isolated characters for bangla sign language," in *2018 International Conference on Bangla Speech and Language Processing (ICBSLP)*. IEEE, 2018, pp. 1–4.
- [7] N. Basnin, L. Nahar, and M. S. Hossain, "An integrated cnn-lstm model for bangla lexical sign language recognition," in *Proceedings of International Conference on Trends in Computational and Cognitive Engineering*. Springer, 2021, pp. 695–707.
- [8] A. S. M. Miah, J. Shin, M. A. M. Hasan, and M. A. Rahim, "Bensignnet: Bengali sign language alphabet recognition using concatenated segmentation and convolutional neural network," *Applied Sciences*, vol. 12, no. 8, p. 3933, 2022.
- [9] S. A. Shurid, K. H. Amin, M. S. Mirbahar, D. Karmaker, M. T. Mahtab, F. T. Khan, M. G. R. Alam, and M. A. Alam, "Bangla sign language recognition and sentence building using deep learning," in *2020 IEEE Asia-Pacific Conference on Computer Science and Data Engineering (CSDE)*. IEEE, 2020, pp. 1–9.
- [10] S. K. Youme, T. A. Chowdhury, H. Ahamed, M. S. Abid, L. Chowdhury, and N. Mohammed, "Generalization of bangla sign language recognition using angular loss functions," *IEEE Access*, vol. 9, pp. 165 351–165 365, 2021.
- [11] T. M. Angona, A. S. Shaon, K. T. R. Niloy, T. Karim, Z. Tasnim, S. S. Reza, and T. N. Mahub, "Automated bangla sign language translation system for alphabets by means of mobilenet," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 18, no. 3, pp. 1292–1301, 2020.
- [12] K. K. Podder, M. E. Chowdhury, A. M. Tahir, Z. B. Mahub, A. Khandakar, M. S. Hossain, and M. A. Kadir, "Bangla sign language (bdsl) alphabets and numerals classification using a deep learning model," *Sensors*, vol. 22, no. 2, p. 574, 2022.
- [13] S. Hossain, D. Sarma, T. Mitra, M. N. Alam, I. Saha, and F. T. Johora, "Bengali hand sign gestures recognition using convolutional neural network," in *2020 Second International Conference on Inventive Research in Computing Applications (ICIRCA)*. IEEE, 2020, pp. 636–641.
- [14] M. S. Islalm, M. M. Rahman, M. H. Rahman, M. Arifuzzaman, R. Sassi, and M. Aktaruzzaman, "Recognition bangla sign language using convolutional neural network," in *2019 international conference on innovation and intelligence for informatics, computing, and technologies (3ICT)*. IEEE, 2019, pp. 1–6.
- [15] F. Chollet, "Xception: Deep learning with depthwise separable convolutions," in *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2017, pp. 1251–1258.
- [16] A. Hasib, S. S. Khan, J. F. Eva, M. Khatun, A. Haque, N. Shahrin, R. Rahman, H. Murad, M. Islam, M. R. Hussein *et al.*, "Bdsl 49: A comprehensive dataset of bangla sign language," *arXiv preprint arXiv:2208.06827*, 2022.

- [17] S. Islam, S. S. S. Mousumi, A. S. A. Rabby, S. A. Hossain, and S. Abujar, "A potent model to recognize bangla sign language digits using convolutional neural network," *Procedia computer science*, vol. 143, pp. 611–618, 2018.
- [18] S. A. Khan, A. D. Joy, S. Asaduzzaman, and M. Hossain, "An efficient sign language translator device using convolutional neural network and customized roi segmentation," in *2019 2nd International Conference on Communication Engineering and Technology (ICCET)*. IEEE, 2019, pp. 152–156.
- [19] A. Khatun, M. S. Shahriar, M. H. Hasan, K. Das, S. Ahmed, and M. S. Islam, "A systematic review on the chronological development of bangla sign language recognition systems," in *2021 Joint 10th International Conference on Informatics, Electronics & Vision (ICIEV) and 2021 5th International Conference on Imaging, Vision & Pattern Recognition (icIVPR)*. IEEE, 2021, pp. 1–9.
- [20] I. Papastratis, K. Dimitropoulos, and P. Daras, "Continuous sign language recognition through a context-aware generative adversarial network," *Sensors*, vol. 21, no. 7, p. 2437, 2021.
- [21] B. Jacob, S. Kligys, B. Chen, M. Zhu, M. Tang, A. Howard, H. Adam, and D. Kalenichenko, "Quantization and training of neural networks for efficient integer-arithmetic-only inference," in *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2018, pp. 2704–2713.
- [22] M. Garifulla, J. Shin, C. Kim, W. H. Kim, H. J. Kim, J. Kim, and S. Hong, "A case study of quantizing convolutional neural networks for fast disease diagnosis on portable medical devices," *Sensors*, vol. 22, no. 1, p. 219, 2021.
- [23] H. Wu, P. Judd, X. Zhang, M. Isaev, and P. Micikevicius, "Integer quantization for deep learning inference: Principles and empirical evaluation," *arXiv preprint arXiv:2004.09602*, 2020.
- [24] M. R. Al Koutayni, V. Rybalkin, J. Malik, A. Elhayek, C. Weis, G. Reis, N. Wehn, and D. Stricker, "Real-time energy efficient hand pose estimation: A case study," *Sensors*, vol. 20, no. 10, p. 2828, 2020.
- [25] K. Simonyan, A. Vedaldi, and A. Zisserman, "Deep inside convolutional networks: Visualising image classification models and saliency maps," *arXiv preprint arXiv:1312.6034*, 2013.
- [26] I. R. Abdullah Al Jaid Jim, M. Z. Akon, and A.-A. Nahid, "Ku-bdsl: Khulna university bengali sign language dataset," 2021. [Online]. Available: <https://data.mendeley.com/datasets/scpvm2nbkm/1>

Exploring Forest Transformation by Analyzing Spatial-temporal Attributes of Vegetation using Vegetation Indices

Anubhava Srivastava¹, Sandhya Umrao², Susham Biswas^{3*}

Dept. of Computer Science and Engineering,

Rajiv Gandhi Institute Of Petroleum Technology, Jais, Amethi, Uttar Pradesh, India^{1,3}

Dept. of Computer Science and Engineering, Noida Institute of Engineering and Technology, Uttar Pradesh, India²

Abstract—The world's ecosystem and environment are rapidly deteriorating with an increase in the depletion of forest conditions due to forest fires. In recent past years, wildfire incidents in Sikkim have increased due to severe climatic changes such as turbulent rainfall, untimely summers, extreme droughts in winters, and a reduction in the percentage of yearly rainfall. Forest fires are one of the numerous kinds of disasters that impose disastrous changes on the entire environment and disrupt the complex correspondence of the flora and fauna. The research's goal is to examine the vegetation indices based on different climates to know why forest vegetation is decreasing day by day from 2000 to 2023. The frequent changes in forest vegetation are extensively studied by using satellite images. This data has been collected by three satellites Landsat-5, Landsat-8, and Landsat-9 on different vegetation indices NDVI, EVI, and NDWI. East Sikkim area is chosen to compute forest vegetation indices based on the heap's landmass this region is unexplored yet and also studied about the forest changes by using different spatial temporal indices in the range of the entire district in the future. The authors of this paper have used Landsat multi-spectral data to assess changes in the area of vegetation in a sub-tropical region like a dense forest region in east Sikkim. The analysis depicts space images, computes vegetation indices (NDVI, EVI, NDWI), and accomplishes mathematical computation of findings. The proposed method will be helpful to discuss the variance of vegetation in the entire East Sikkim region at the time span of 2000–2023. In the analysis, we find that mean and standard deviation values change over the years in all indices. Later, we also calculated changes by using a classification model and find a total 10% change in forest areas in approximately 22 years.

Keywords—Classification; change detection; vegetation indices; landsat; machine learning

I. INTRODUCTION

It is found that climate is very much affected by global warming throughout the world. Spectral Indices detected different factors like rainfall and temperature within 1 to 15 years [1]. Based on the increasing extremes caused by human-induced climate change, as well as the limited progress made towards finding climate change solutions, the National Academies of Science and Engineering recently recommended that the USA develop a trans-disciplinary research program into proposed climate intervention techniques [1]. Earth quacks also deteriorate the vegetation area because of their frequent occurrence as earlier we used to hear about earth quacks

occurring in 4 to 5 years but now every month it probably happens. Due to earthquakes lots of forest decaying problem arises like plant community shift, Species loss, and productivity reduction of alpine grasslands [2]. Flood is also one crucial factor to decrease the vegetation area but it is also found that initially, floods affected crops but later crop productivity and fertile land improved and resulted in dense vegetation area [3]. By mapping vegetation cover before and after floods, spacecraft images, rainfall data, a tool used for analyzing the geographical area, and a rain gauge were used to evaluate post-flood loss or benefit[3]. The deforestation and degradation of forests alone contribute between 20 and 25% of global greenhouse gas emissions [4]. District-wise Sikkim climate data is analyzed over the period 1901 to 2007 to predict rainfall, precipitation, and temperature followed by mean 17.82 mm per day, Standard Deviation 3.55 mm per day, Coefficient of Variation (C.V.) 20%, precipitation Trend is - 2.627mm per day/100 years, minimum temperature trend 2.86 0C/100 years and maximum temperature 0.730C/100 years. The environmental influence on vegetation increases as more regions of the world become forested. Inside the city limits, there are forests, which causes changes in the vegetation of the forests. Computing the quality of forest areas and the surrounding environment and making decisions to ensure the population's sanitary and environmental safety depends on understanding where these changes occur, in what quantities, and in response to what variables [5]. The dynamics of forest vegetation may be studied in great detail using satellite photos over Google Earth Engine [6]. Satellite photos enable us to get factual data about the temporal and spatial variations in vegetation. The commonly uses type of satellite data is Landsat, Sentinel, and MODIS from various very famous data archive providers like USGS, Copernicus Programme, NASA, etc. [7]. Landsat itself has various development, from Landsat 1 to Landsat 9. Sentinel also has various versions from Sentinel 1 to Sentinel 5.

A number of methods have been employed to determine the area occupied by vegetation [8]. These methods involve classifying the outcome based on supervised and unsupervised learning, automatic image processing, the generation of index pictures, as well as visual interpretation [9]. The dynamics of plant cover can be analyzed using spectral and temporal indices obtained from time-lapse images.

*Corresponding authors.

Two categories can be used to categorize these applications. The first category consists of universal systems, which help us analyze data obtained through remote sensing of the Earth and address a variety of issues [10]. The second category consists of software (tools) designed to handle extremely specific jobs. Such programs have the undeniable advantage of being made specifically to address a given practical issue. In these programs, the majority of the steps are automated. Upon examining the current approaches to evaluating vegetation changes within a forest agglomeration based on multi-temporal photographs, we decided that it would be beneficial to develop a tool for the evaluation of vegetation changes based on multi-temporal images [11].

To analyze satellite images, an algorithm was created. This application performed a number of functions, including the study of satellite images, the calculation of spectral indices, the evaluation of the cloud cover mask, and the statistic-based analysis of interpretation results. This algorithm categorizes multi-temporal images to detect the dynamics of land occupied by vegetation.

The research's goal is to use remote sensing data from the year 2000 to the year 2023 to examine the forest vegetation in the east Sikkim forest area. Principal research goals: (1) Building a database of Landsat satellite photos for the years 2000 to 2023; (2) Creating an algorithm along with software development acquired from several vegetation indices. (3) The identification of the primary mechanisms that brought about the observed alterations in the east Sikkim forest areas. A unique algorithm was developed for the detailed examination of Landsat remote sensing data in East Sikkim through which the originality of the proposed scientific research is explained. This is a feasibility study organized in the East Sikkim region. So far, no such studies have been conducted on forest cover changes in the East Sikkim region related to changes in social, economic, and political conditions. A more rigorous explanation of the novelty's position is required. Our own algorithm's development opens up various possibilities for its widespread practical application.

II. RELATED WORK

The most common origin for the remote sensing data of Earth for a variety of examinations is Landsat pictures. The benefit of Landsat data is related to the policy of free picture access and the continuity of observations over a 50-year period. As per the analysis of spatiotemporal characteristics, the moderate forest conquered approximately 46% in 1985 and 57% in 2005, and 58% of the total land is occupied by open forests which were a replacement for these [12]. In addition to this, we have analyzed spatial and temporal indices in the East Sikkim area. The majority of India's forests are degrading due to forest fires. In East Sikkim, forest fire is a frequent process as the water stress level is very high in the summers. It is a tedious task to figure out the statistical data on the occurrence of forest fires in a year, but statistics cleared that estimated that 33% of a few states and more than 90% of other states are exposed to forest fires annually [13]. The burnt areas could be easily seen in the SWIR band when using band(3 2 1), and band(4 3 1) [14]. The Sikkim Mountains, a crucial phytogeographical reserve for the nation, contain more than 26% of all blooming plants. Landsat data are

useful for tracking forest regions. Many different techniques are used for analyzing and monitoring the Landsat input data. Several image processing techniques created in remote sensing are used in extracting area-covering details with the help of satellite images. Using Landsat to map forests, presents a variety of challenges. Landsat images of forested areas typically include a combination of data about anthropogenic items and vegetation in their pixels. When recognizing forest areas, more vegetation cover from the image must be retrieved. To distinguish between forest and non-forest regions, one method uses spectral vegetation indices such as the Normalized Difference Vegetation Index and vegetation index sensitive to the water content of plants normalize difference water index. Another spectral technique makes the assumption that forest pixels are linear mixtures of the three common land cover, vegetation, impervious surface, and soil components (the so-called V-I-S model). In the paper, it is suggested that mapping of the forest area be done using a mix of spectral and spatial data. The technique comprises these two distinct categories of elementary coverage classes based on pixels and segments (segment-based).

III. STUDY AREA

Sikkim is one of the largest forest heaps in the northeast of India. Sikkim state covers a total area of 7096 sq Km. The geographical area we have targeted as the study area is the East Sikkim region, which is approximately 964 sq. km in size and located at 27.3084° N, 88.6724° E in Fig. 1. As per the Forest Management Department, 14.44% area of Sikkim is covered under scrub-(RF) and alpine pasture, and 29.5% area is occupied by perpetual snow cover. Remote Sensing Data for the year 1988 depicts that the vegetation area for crops which may be Terraced/Semi Terraced is 604.85 sq. km and this cropland is mixed with dense forest of capacity 603.34 sq. km. The district area is 173.19 sq km which is 2.44% of the total area. As stated by the Forest Survey of India (FSI), the reported Forest State covers an area of 5841.39 sq km which is equal to 82.32% and 0.8% of the whole nation's forest region. According to the State of Forest Report of the Forest Survey of India, Ministry of Environment & Forest, Government of India, the status of Forest cover evaluation is gradually increasing which was 2756 sq km in 1987 and 3262 sq km in 2003. In 2021, the number of trees and forests in India covered 80.9 million hectares, which is equal to 24.62% of the country's total land area. Areas that are part of a biosphere reserve's buffer zone are excluded from the Protected Area Network.

The amount of area covered by the protected Area Network of State is 2177.10 sq km. (i.e.30.68% of the entire geographical area) whereas the amount of land covered by the protected Area Network and biosphere reserve in the State is 3013.10 sq km (i.e.42.46% of the entire geographical area). There is mainly five types of forest present in East Sikkim: wet temperate forests find generally in hilly areas, subtropical or moist broad-leaf forests, which are areas of forests where half of the world species are living in different zones, moist mixed forests are types where greenery increases or decreases with the season these are also known as dry deciduous forest, other types of forest are conifer forest and sub-alpine forest, conifer forests are also deciduous forest but the property of these forests are these are always green but sub-alpine forests are primary factors of nature and environmental disturbance

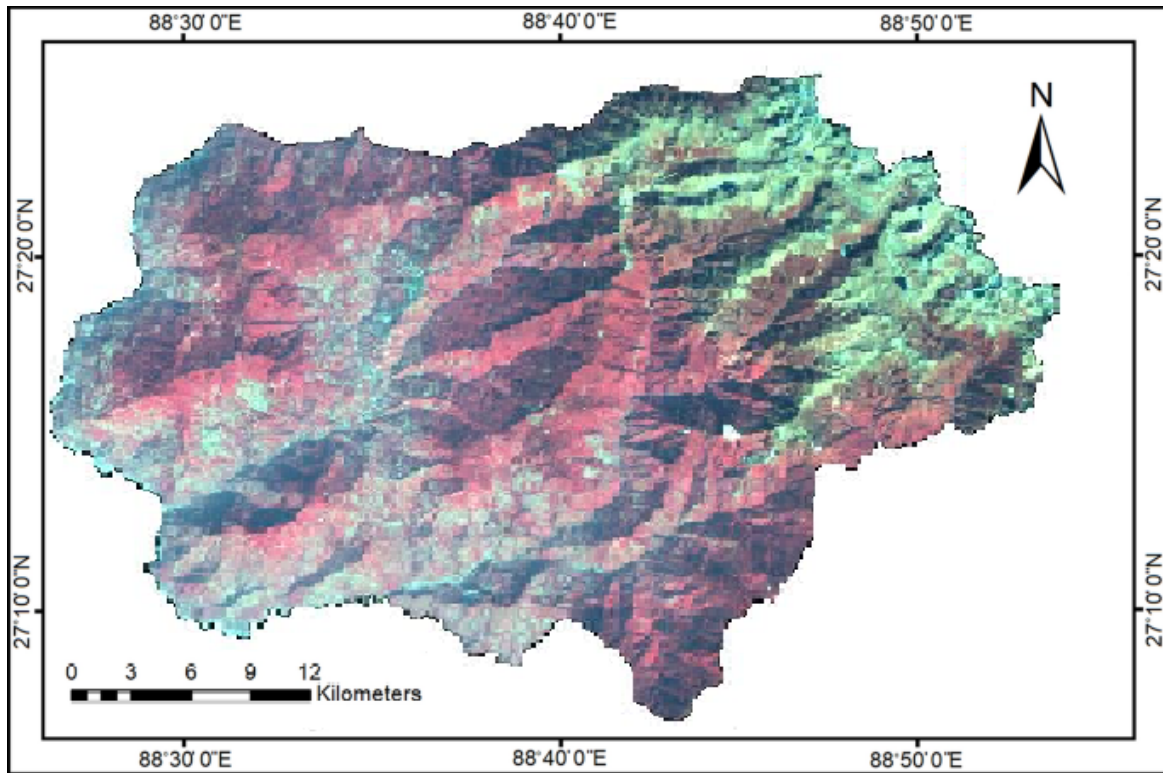


Fig. 1. Location of study area.

these are basically prone to fire and 80% forest fire incident are happened due to these indices in India these are basically found at eastern middle Himalayas. Sikkim is India's greenest state but with time and change in climate and environmental conditions, we find that there are high changes are occur from one type of forest to another type of forest which also leads to deforestation.

IV. METHOD AND DATA

For analysis of change in East Sikkim, Fig. 2 we are google earth engine (GEE) satellite-based planetary tool [14], It has a collection of many satellites based real-time data sets like Landsat, Sentinel, and MODIS as well as provides users, a tool (code editor) for analyzing these data. Here we are using Landsat data for finding changes in the forest area as well as East Sikkim from the year 2000 to 2023. Landsat has a collection of data from 1972 to 2023. Landsat has different versions based on time of availability, spatial resolution, and wavelength. Till now USGS has launched nine versions of Landsat data sets from Landsat 1 to Landsat 9. We are using, data from the Landsat-5 (Thematic Mapper), Landsat-7 (Enhanced Thematic Mapper Plus), and Landsat-9 (Operational Land Imager-II) satellites to examine the dynamics of the study area's forest vegetation. Many scenes are present in the chosen location. The work uses five bands (Short Wave Infrared, Green, Red, Near Infrared and Blue), which have a spatial resolution of 30m. Landsat uses a worldwide reference system (WRS) that catalog Landsat data by path and row. Table I represent used datasets and band for analysis of change in the study area. Fig. 2 shows the technique used in research for the analysis of change using different data sets and vegetation indices. Later

for verification of the result, it also calculates changes in land cover areas of the study area, East Sikkim using the supervised classification model Random forest.

A. Vegetation Indices

Low vegetation and high vegetation land cover class contain all the land cover areas which having some greenery or dense forest, for proper differentiating between these two land cover classes we are using Normalize Difference Vegetation Index (NDVI) [15], [16], Normalized Difference Water Index (NDWI) [17] and Enhance Vegetation Index (EVI) [18]. After calculating the ground reference point we observed the study area and calculated its daily average temperature and rain and peak months as August to October rain goes above 90mm. From the observation, we find the average temperature is high in the month between May to July and the average rain is maximum in the month of August and September.

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad (1)$$

The NIR and SWIR bands are used by NDBI to highlight man-made built-up regions. It is ratio-based to lessen the impact of variations in terrain illumination and atmospheric effects.

$$NDWI = \frac{Green - NIR}{Green + NIR} \quad (2)$$

In Landsat 8 and Landsat 9, Enhanced Vegetation Index is calculated as

$$EVI = \frac{2.5 * ((Band5 - Band4))}{(Band5 + 6 * Band4 - 7.5 * Band2 + 1)} \quad (3)$$

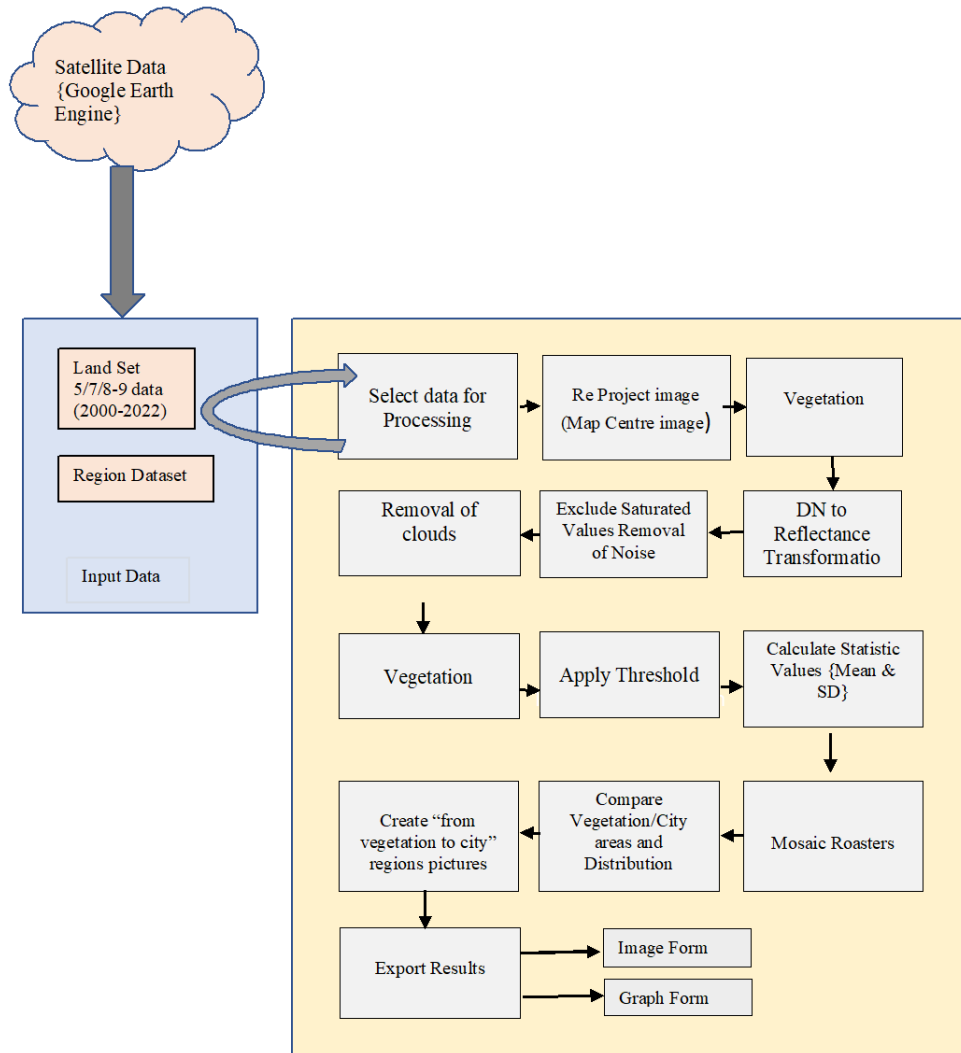


Fig. 2. Methodology used in research.

TABLE I. BAND USES FOR CALCULATING CHANGES IN FOREST COVER

Landsat Datasets	Blue	Green	Red	Near Infrared	SWIR 2
Landsat 5 TM (Band number: Wavelength)	B1: 0.45–0.52	B2: 0.52–0.60	B3: 0.63–0.69	B4: 0.76–0.90	B7: 2.08–2.35
LANDSAT 7 ETM+ (Band number: Wavelength)	B1: 0.45–0.52	B2: 0.52–0.60	B3: 0.63–0.69	B4: 0.77–0.90	B7: 2.08–2.35
Landsat 9 OLI (Band number: Wavelength)	B2: 0.45–0.51	B3: 0.53–0.59	B4: 0.64–0.67	B5: 0.85–0.88	B7: 2.11–2.29

V. RESULT

Vegetation Indices (VIs) combine surface reflectance at two or more wavelengths to emphasize a specific characteristic of vegetation. They are created using vegetation's reflective qualities. Each VI is intended to calculate a specific characteristic of the vegetation. Every VI needs accurate reflectance readings from multispectral or hyperspectral sensors. The spectral bands sampled in the input dataset dictate which VIs can be generated on that dataset. A VI is accessible for the dataset if it has all the spectral bands necessary for that index. Some place is used to calculate density by using the normalized difference vegetation index.

NDVI is frequently used in agriculture, forestry, and the environment to track the development and well-being of vegetation as well as to spot stressed or damaged areas. In addition to mapping and categorizing different vegetation types, NDVI values can be used to track changes in vegetation cover over time. Fig. 6 shows the change occurring in NDVI value on the study area over the period of time. Every time it is changed with time but in the year 2022- 2023, this data is changed more number times. Enhanced Vegetation Index (EVI) [19] is also a mechanism for measuring vegetation greenness that is similar to the Normalised Difference Vegetation Index (NDVI). EVI, on the other hand, compensates for some atmospheric

Land Cover Areas in East Sikkim in Year 2000

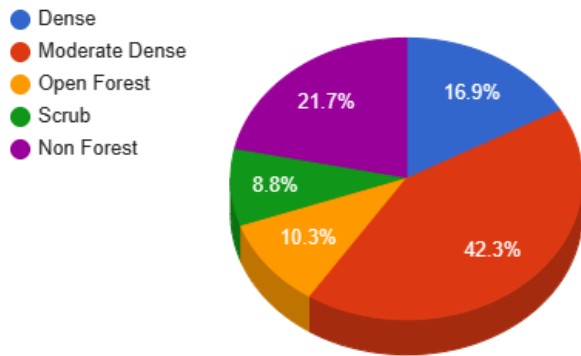


Fig. 3. Forest cover area of East Sikkim in the year 2000.

Land Cover Areas in East Sikkim in Year 2010

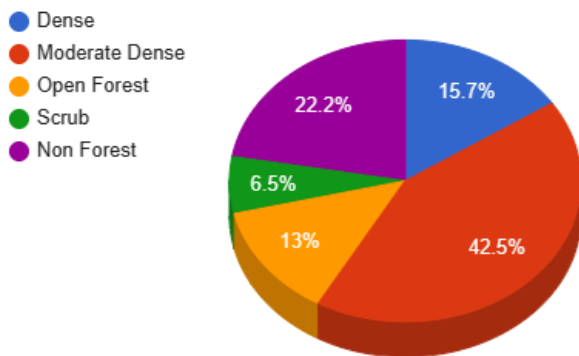


Fig. 4. Forest cover area of East Sikkim in the year 2010.

Land Cover Areas in East Sikkim in Year 2023

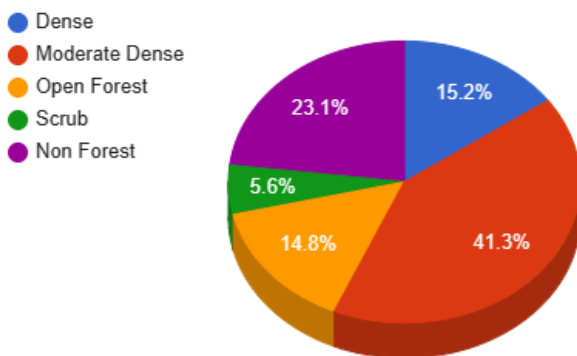


Fig. 5. Forest cover area of East Sikkim in the year 2023.

factors and background noise from the canopy and is more sensitive in regions with dense vegetation. EVI also provides producers the ability to precisely compare data and monitor changes. These comparisons are quick and simple thanks to the use of our vigor items scaled to an absolute standard. Fig. 7 provides a change in the study between the years 2000 to 2023. EVI values are changed rapidly between these years. Later for verification purposes, we calculate the change in the study area using the ensemble-based [20] classification algorithm random forest [21] and find nearly 10% of land cover classes are changing. Later we calculate the change in water content over vegetation in the study area using the normalized difference water index (NDWI) [22], [23]. The Near-Infrared (NIR) and Short Wave Infrared (SWIR) channels are used to create the Normalised Difference Water measure, which is a satellite-derived measure. While the NIR reflectance is influenced by changes in leaf internal structure and dry matter content but not water content, the SWIR reflectance reflects changes in both vegetation water content and the spongy mesophyll structure in vegetation canopies. The accuracy of determining the water content of vegetation is increased when the NIR and SWIR are combined because they eliminate changes brought on by the internal structure and dry matter content of leaves. The spectral reflectance in the SWIR region of the electromagnetic spectrum is substantially governed by the quantity of water present in the interior leaf structure. Therefore, leaf water content has a negative relationship with SWIR reflectance. Fig. 6, Fig. 7, and Fig. 8 show the change that arises over the study area Fig. 1 mainly in the forest region. From Fig. 3, 4 and 5, it is quite clear that deforestation happened over the study area. Still, due to good climate and environmental conditions, this deforestation is not converted into non-forest areas. From the calculation, we find about 10% of forest loss present over the study area. Fig. 9 shows the yearly forest in square meters from the year 2000 to the year 2022. Here if we focus on the output generated by vegetation indices, Fig. 6, 7 and 8, overall mean and standard deviation values are not changed but the pattern of these changes are frequent in the current year. By the above findings, it is figured out that moderate dense forest is higher in comparison to the non-forest area, dense forest area, open forest area, and scrub which is 42.3 %, 21.7 %, 16.09%, 10.3 %, and 8.8% in the year 2000, respectively and it is also analyzed that moderate dense forest area is decreasing year by year due to forest fire which is 42.5 % in the year 2010 which gradually decreasing after decades too. It became 41.3 % in 2023 and for other land areas transformation can also be seen. Dense forests were 16.9 % in the year 2000 which decreased by 15.70% in 2010 and 15.20 % in 2023. The non-forest area is decreasing by these fire incidents and it is clearly shown by the graph that it was 21.7 % in 2000 which increased to 22.20 % in 2010 and 23.10 in the year 2023. Open forest area is also increasing by the incident of forest fire while scrubs are continuously decreasing. By the Fig. 10, it is concluded that open forest area is gradually increasing i.e. 10.3% (2000), 13 % (2010), and 14.3 % (2023). In this proposed study area it is observed that we can generate land cover area loss or affected parameters by forest fire by using this developed tool or framework on any land with approximately similar spectral indices.

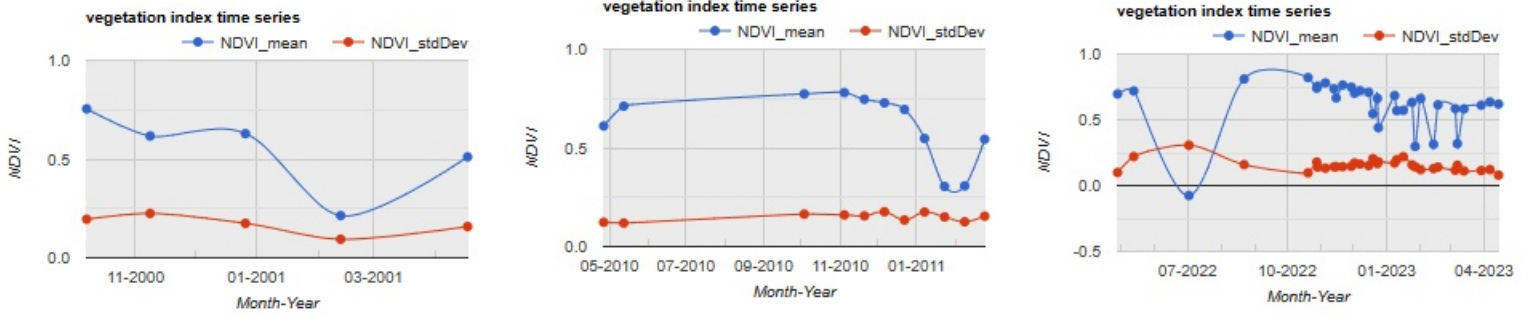


Fig. 6. Change in normalize difference vegetation index between the year 2000-2023.

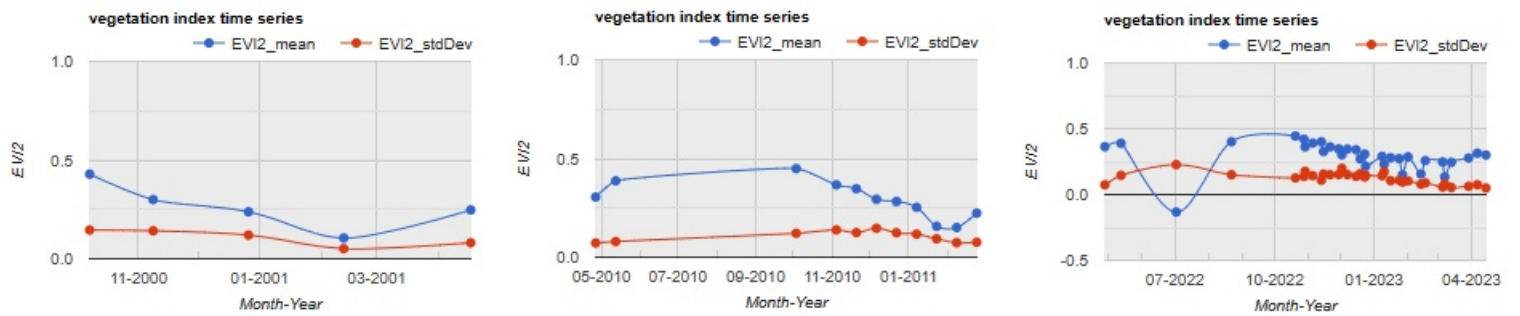


Fig. 7. Change in enhanced vegetation index between the year 2000-2023.

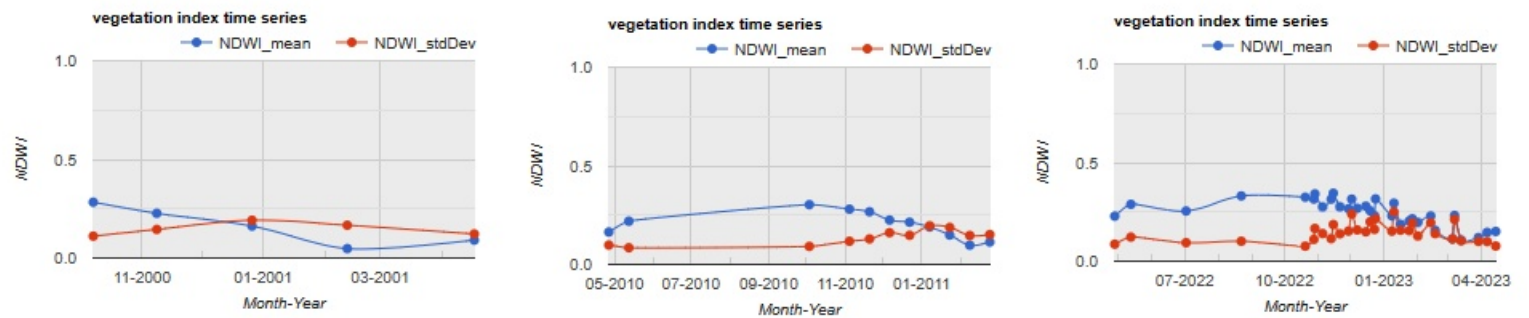


Fig. 8. Change in NDWI between the year 2000-2023.

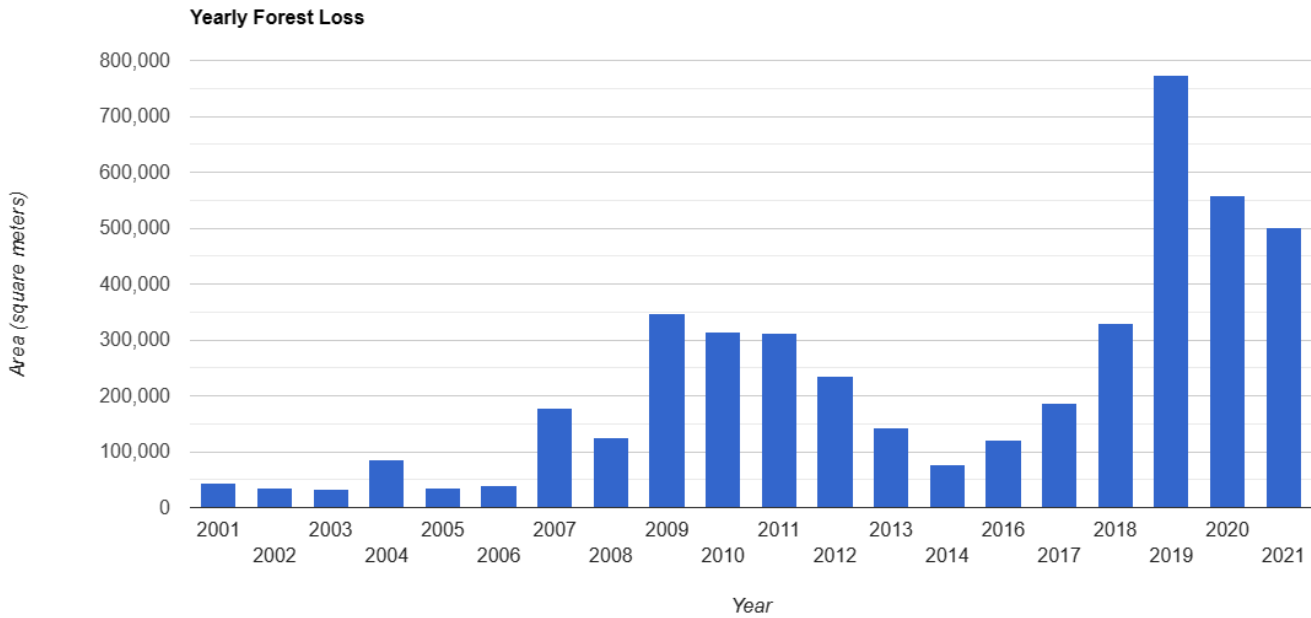


Fig. 9. Yearly forest loss between the years 2000- 2023.

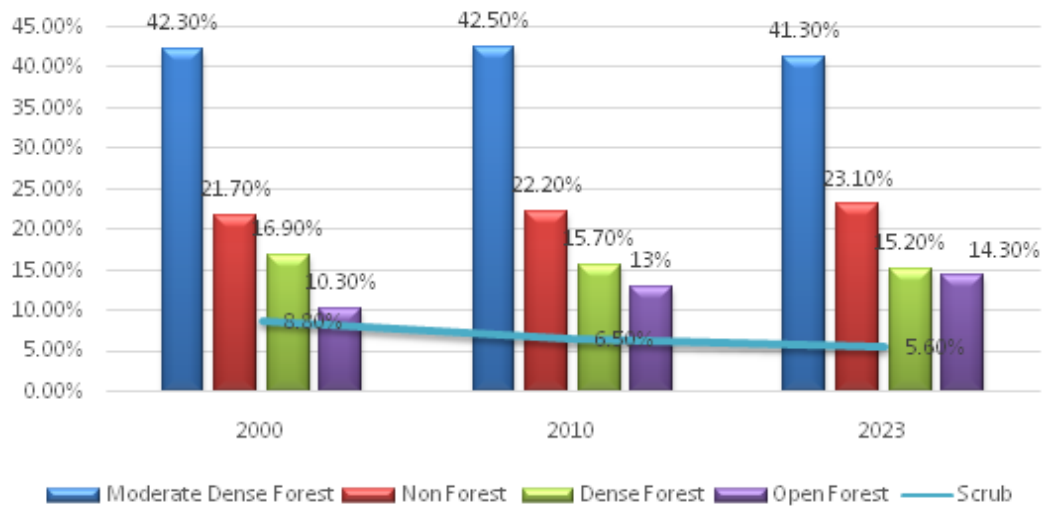


Fig. 10. Change in LULC areas between the years 2000-2023.

VI. CONCLUSION

The ability to perform high-frequency time series analyses using new-generation multi-spectral sensors aboard the Landsat 5, Landsat 8, and Landsat 9 satellite platforms opens up previously unheard-of possibilities for multi-temporal change detection studies on phenomena with significant dynamic behavior (for example, high-frequency mapping for disaster management) or on regions with recurring cloud cover issues. These new sensors' radiometric properties, while similar, are not equivalent, and this might result in noticeable variations in the radiometric amounts that are received. Forest changes are easily computed using these vegetation indices, and verified by using supervised classification results and global forest loss computation technique. Later our objective is to develop a GUI that calculates the change in vegetation indices. There are nearly more than 97 vegetation indices available that may be used for computing change in vegetation. These indices will be very help full for finding changes in climate conditions, environmental deterioration, Soil erosion, and many places.

REFERENCES

- [1] Barnes, Elizabeth & Hurrell, James & Sun, Lantao. (2022). Detecting Changes in Global Extremes Under the GLENS-SAI Climate Intervention Strategy. *Geophysical Research Letters*. 49. 10.1029/2022GL100198.
- [2] Zuo H, Shen H, Dong S, Wu S, He F, Zhang R, Wang Z, Shi H, Hao X, Tan Y, Ma C, Li S, Liu Y, Zhang F. Effects of Strong Earthquake on Plant Species Composition, Diversity, and Productivity of Alpine Grassland on Qinghai-Tibetan Plateau. *Front Plant Sci*. 2022 Apr 12;13:870613. doi: 10.3389/fpls.2022.870613. PMID: 35498647; PMCID: PMC9039666.
- [3] Talpur, Z.; Naseer, T.; Memon, A.R.; Zaidi, A. Impact of Floods on Vegetation Cover in the Sanghar District of Sindh, Pakistan. *Environ. Sci. Proc.* 2021, 7, 5. <https://doi.org/10.3390/ECWS-5-08009>
- [4] Hengaju, Krishna & Manandhar, Ugan. (2015). Analysis on causes of deforestation and forest degradation of Dang district: using DP-SIR framework. *Nepal Journal of Environmental Science*. 3. 27-34. 10.3126/njes.v3i0.22732.
- [5] Sedjo, R. A., & Sohngen, B. (2007). Carbon Credits for Avoided Deforestation. Resources for the Future, Discussion paper 07 - 47. Washington, DC.
- [6] Gorelick, Noel & Hancher, Matt & Dixon, Mike & Ilyushchenko, Simon & Thau, David & Moore, Rebecca. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*. 202. 10.1016/j.rse.2017.06.031.
- [7] Loveland, T. R., and A. S. Belward. 1997. "The IGBP-DIS Global 1km Land Cover Data Set, DISCover: First Results." *International Journal of Remote Sensing* 18 (15): 3289–3295. doi:10.1080/014311697217099.
- [8] Srivastava, A.; Bharadwaj, S.; Dubey, R.; Sharma, V.B.; Biswas, S. Mapping Vegetation and Measuring the Performance of Machine Learning Algorithm in Lulc Classification in the Large Area Using Sentinel-2 and Landsat-8 Datasets of Dehradun as a Test Case. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* 2022, 43, 529–535. [Google Scholar] [CrossRef]
- [9] A. Srivastava and S. Biswas, "Analyzing Land Cover Changes over Landsat-7 Data using Google Earth Engine," 2023 Third International Conference on Artificial Intelligence and Smart Energy (ICAIS), Coimbatore, India, 2023, pp. 1228-1233, doi: 10.1109/ICAIS56108.2023.10073795.
- [10] Korhonen, L., P. Packalen, and M. Rautiainen. 2017. "Comparison of Sentinel-2 and Landsat 8 in the Estimation of Boreal Forest Canopy Cover and Leaf Area Index." *Remote Sensing of Environment* 195: 259–274. doi:10.1016/j.rse.2017.03.021
- [11] Moreno, J., J. A. Johannessen, P. F. Levelt, and R. F. Hanssen. 2012. "ESA's Sentinel Missions in Support of Earth System Science." *Remote Sensing of Environment* 120: 84–90. doi:10.1016/j.rse.2011.07.023.
- [12] Suleiman, M.S., Wasonga, O.V., Mbau, J.S. et al. Spatial and temporal analysis of forest cover change in Falgore Game Reserve in Kano, Nigeria. *Ecol Process* 6, 11 (2017).
- [13] Roy, P.S. 2004. Forest Fire and Degradation Assessment using Satellite Remote Sensing and Geographic Information System. *Satellite Remote Sensing and GIS Applications in Agricultural Meteorology*, pp. 362-363.
- [14] Gorelick, Noel & Hancher, Matt & Dixon, Mike & Ilyushchenko, Simon & Thau, David & Moore, Rebecca. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*. 202. 10.1016/j.rse.2017.06.031.
- [15] Xu, Y.; Yang, Y.; Chen, X.; Liu, Y. Bibliometric Analysis of Global NDVI Research Trends from 1985 to 2021. *Remote Sens.* 2022, 14, 3967. <https://doi.org/10.3390/rs14163967>
- [16] Matsushita, B.; Yang, W.; Chen, J.; Onda, Y.; Qiu, G. Sensitivity of the Enhanced Vegetation Index (EVI) and Normalized Difference Vegetation Index (NDVI) to Topographic Effects: A Case Study in High-density Cypress Forest. *Sensors* 2007, 7, 2636-2651. <https://doi.org/10.3390/s7112636>
- [17] Bajocco, S.; Ginaldi, F.; Savian, F.; Morelli, D.; Scaglione, M.; Fanchini, D.; Raparelli, E.; Bregaglio, S.U.M. On the Use of NDVI to Estimate LAI in Field Crops: Implementing a Conversion Equation Library. *Remote Sens.* 2022, 14, 3554. <https://doi.org/10.3390/rs14153554>
- [18] Zhangyan Jiang, Alfredo R. Huete, Kamel Didan, Tomoaki Miura, Development of a two-band enhanced vegetation index without a blue band, *Remote Sensing of Environment*, Volume 112, Issue 10, 2008, Pages 3833-3845, ISSN 0034-4257, <https://doi.org/10.1016/j.rse.2008.06.006>.
- [19] Garrouette, E.L.; Hansen, A.J.; Lawrence, R.L. Using NDVI and EVI to Map Spatiotemporal Variation in the Biomass and Quality of Forage for Migratory Elk in the Greater Yellowstone Ecosystem. *Remote Sens.* 2016, 8, 404. <https://doi.org/10.3390/rs8050404>
- [20] Pintelas, P.; Livieris, I.E. Special Issue on Ensemble Learning and Applications. *Algorithms* 2020, 13, 140. <https://doi.org/10.3390/a13060140>
- [21] Ho, T. K. (1995). Random decision forests. In Proceedings of 3rd international conference on document analysis and recognition (Vol. 1, pp. 278–282).
- [22] McFeeters, S.K. Using the Normalized Difference Water Index (NDWI) within a Geographic Information System to Detect Swimming Pools for Mosquito Abatement: A Practical Approach. *Remote Sens.* 2013, 5, 3544-3561. <https://doi.org/10.3390/rs5073544>
- [23] Shashikant, V.; Mohamed Shariff, A.R.; Wayayok, A.; Kamal, M.R.; Lee, Y.P.; Takeuchi, W. Utilizing TVDI and NDWI to Classify Severity of Agricultural Drought in Chuping, Malaysia. *Agronomy* 2021, 11, 1243. <https://doi.org/10.3390/agronomy11061243>

A Novel Mango Grading System Based on Image Processing and Machine Learning Methods

Thanh-Nghi Doan

Faculty of Information Technology,
An Giang University, An Giang, Vietnam

Vietnam National University, Ho Chi Minh City, Vietnam

Duc-Ngoc Le-Thi

Student of Faculty of Information Technology,
An Giang University, An Giang, Vietnam

Vietnam National University, Ho Chi Minh City, Vietnam

Abstract—Mangoes are a great commercial fruit and are widely cultivated in tropical areas. In smart agriculture, the automatic quality inspection and grading application is essential to post-harvest processing, due to the laborious nature and inconsistencies of traditional manual visual grading. This paper presents a low-cost, efficient, and effective mango grading system based on image processing and machine learning methods to generate higher quality fruit sorting, quality maintenance, production, and cut back labor concentration. A novel database of classified mangoes was collected and built in An Giang province. Methodologies and algorithms that utilize digital image processing, content-predicated analysis, and statistical analysis are implemented to determine the grade of local mango production. On our collected dataset, the proposed system achieved overall with an overall accuracy of 88% for all mango grades. The system shows compromised results for higher-quality fruit sorting, quality maintenance, and production while reducing labor concentration.

Keywords—Smart agriculture; mango grading; image processing; machine learning methods

I. INTRODUCTION

Mango production is a major industry worldwide, contributing significantly to the economy of many countries. Asia is the dominant continent in terms of mango production, making up approximately 76% of the global industry [18]. In many mango planting areas, the level of automation and efficiency of post-harvest processing is far from satisfactory in terms of accuracy and throughput: Although mango is a quick-rotten and short-lived fruit, its post-harvest processing is still carried out manually via visual inspection [14]. Mango farmers may face significant expenses if mangoes are not sorted promptly after harvest. When it comes to marketing mangoes, external quality features play a vital role in their grading. Size, shape, ripeness, and the presence of surface defects are commonly used standards for assessing mangoes [15]. To facilitate this grading process, computer vision techniques have emerged as the most widely employed approach in modern systems, particularly in quality inspection and grading. These techniques enable the creation of a machine vision system that not only mimics the human grading process but also significantly accelerates it. As a result, there is a growing demand for efficient and effective solutions that allow enterprises and farmers to leverage these new technologies. Over the past two decades, the field of agriculture has witnessed a shift from traditional human grading to automated grading for fruits. Many companies have adopted automated grading for various crops, including peaches and oranges [?]. Notably, a researcher has developed an image analysis-based system for grading

apples. Their study involved training the system with numerous examples to enable it to become proficient in distinguishing fruit differences and creating a reliable reference dataset for the grading system [3]. To properly classify mangoes, it is important to be familiar with the mango grading standards. While color and size are significant criteria for fruit sorting, there is another crucial factor for sorting mangoes: the texture of their skin. Incorporating skin texture into the classification system can enhance the accuracy of sorting. Therefore, this study focuses on the processing and analysis of images to automate the grading and sorting process, which represents a crucial phase within the productive mango supply chain system.

II. RELATED WORKS

Grading and sorting fruits is a crucial stage in the agro-processing industry. Manual sorting of fruits is time-consuming, laborious, and prone to human error. Therefore, grading and sorting of fruits using image processing or computer vision techniques have gained significant attention in recent years. Various research studies have been conducted to develop automated systems for the grading and sorting of fruits. Regarding fruit grading and quality evaluation, the authors in [5] reviewed the basic process flow of fruit classification and grading. Feature extraction methods for color, size, shape, and texture are discussed with feature extraction algorithms used in computer vision and image processing such as Speeded Up Robust Features (SURF), Histogram of Oriented Gradient (HOG), and Local Binary Pattern (LBP). Additionally, this research briefly touches upon some popular machine learning algorithms like k-Nearest Neighbors (k-NN), Support vector machines (SVM), Artificial neural networks (ANN), and Convolutional neural networks (CNN). By presenting a theoretical foundation for the identification, classification, and grading of horticultural products, this study aims to facilitate the practical application of these methods in a real-world setting. The authors in [16] proposed an image processing algorithm combined with machine learning to detect and identify defects on the surface of mango skin. The algorithm consists of the main steps: extracting the area containing the mango fruit from the background and extracting the defective skin from the left region after improving the contrast of the left region from the input image. The researchers of [27] proposed a mobile visual-based system for food grading that involves three levels of image processing: low level for image acquisition and pre-processing, intermediate level for segmentation, representation, and description, and high level for recognition and interpretation. The study compared different classifiers,

including SVM, k-NN, Random Forest, and Naive Bayes, and found that SVM performed the best with an accuracy of 98.5% using the extracted feature vector. The system successfully graded bananas based on ripeness and overcame the challenge of identifying and outputting small defects on the fruit. To evaluate the quality of apples and gauge their level of maturity, the authors in [1] employed algorithms that utilized digital fuzzy image processing, statistical analysis, and content analysis. Along with a variety of filtering techniques for processing images, MATLAB's color-based segmentation method has been adopted to improve precision in finding the RGB component of a good apple and a ripened apple. By converting the image to grayscale, the system generated a histogram graph to analyze the results. The data confirmed that this automatic grading system was beneficial in reducing processing time and decreasing errors in assessment. In another work, this research [13] reported an automatic adjustable algorithm for sorting and grading apples using linear SVM and Otsu's thresholding method [17] for color image segmentation. It automatically adjusts the classification hyperplane with minimal training and time required. Additionally, it is not affected by changes in lighting or fruit color, making it an efficient and reliable option. This approach can effectively segment and sort apples in a multi-channel color space and can be adapted for other imaging-based agricultural applications. In terms of processing time efficiency, the authors in [21] introduced a split and merge approach that exhibits advantages over both Otsu's method and graph-based segmentation. This approach utilizes both local and global characteristics of color intensities in an image to improve blemish detection. The method first subdivides the image into a set of disjoint and arbitrary regions using the k-means clustering algorithm, which groups together pixels with similar feature vectors. The regions are then merged iteratively, and a graph called Region Adjacent Graph (RAG) is built to represent neighborhood relations among the segmented regions. The merging process continues until the regions satisfy the homogeneous condition or until no further merging is possible. To achieve citrus diameter detection, the researchers of [2] employed Canny edge for edge detection and DP algorithm for contour extraction to find the two points with the largest distance in the contour to achieve citrus diameter detection, which achieves a good balance between false detection and missed detection, and has a good edge detection performance. Furthermore, the RGB color space is converted into HSV color space, and the parameters of the H component are extracted to obtain the citrus coloring rate, thus realizing the citrus appearance quality grading system. By comparing manual and systematic tests, the study's authors achieved a measurement accuracy of 99%. This level of accuracy is practical for real-world applications. The article [7] proposes a method for estimating the size, volume, and mass of a Laba banana using just a single camera mounted on top of the fruit. This addresses the need to avoid setting up multiple 3D or camera projections to calculate the volume of the object for weight grading. The proposed method involves capturing top-view images of the banana, converting them to grayscale, and applying a traditional Otsu thresholding scheme for the GREEN channel of the images. The height and width of the banana are estimated from the resulting segmented image, which is then used to calculate the banana's weight using the product of the estimated volume and the average density of bananas.

In addition to the aforementioned studies, a number of studies have been undertaken to investigate the grading of mangoes through the utilization of image processing or computer vision approaches. For example, in a comprehensive review [24], an overview of the computer vision-based mango grading system was presented, which has been widely adopted in research works. The study identified image acquisition, image pre-processing, segmentation, background removal, feature extraction, and classification as fundamental steps in the mango classification process. A detailed analysis of appearance-based mango grading was conducted, and a parameter-wise survey was recommended. The authors concluded that the accuracy of ripeness analysis is better when using HSV, HSI, and CIELab color models rather than RGB color models. Furthermore, geometrical features such as area, major axis, and minor axis provide better size-based classification, while thresholding techniques are successful in segmenting defects, and Fourier descriptors can be best used for shape classification. Many machine learning models were examined for classification; however, Support Vector Machine (SVM) and Fuzzy classifiers were found to perform better. By using the image-extracted parameters for grading, accurate, reliable, and consistent mango grading can be achieved. The authors in [19] defined seven Hue moments for shape analysis and improved efficiency by using Green's formula for calculating the Hue contour. This reduces computation time and resources needed for Hue moment calculation. For this reason that applying Green's formula to the Hue vector field of an image allowed calculation of the Hue moment using only the boundary, or contour, of the image. Binarized images were used to detect defective skin, where pure skin was black and damaged areas were white. The developed system achieved 83.33% accuracy, correctly sorting 10 out of 12 mangoes into their respective categories. Methodologies and algorithms that utilize digital fuzzy image processing, content-predicated analysis, and statistical analysis to determine the grade of local mango production have been implemented in [22] for the purpose of contributing for a design and development of an efficient algorithm for detecting and sorting the mango at more than 80% accuracy in grading compared to human expert sorting. By making use of the Fuzzy Inference Rule, which is capable of dealing with the inherent ambiguity and vagueness in images, it becomes possible to conduct more flexible and intuitive image analysis. Besides, this approach can enhance the accuracy of image segmentation and reduce noise. It has proven to be effective in several applications such as image enhancement, edge detection, and object recognition. Specifically, in this context, putting in the Fuzzy Inference Rule to compute the grade of mango based on three parameters - size, color, and skin - led to the improvement of the scheme based on digital image processing techniques by selecting the best threshold scheme that produced an accurate result of classification. The authors in [10] offered a novel evaluation of the internal quality of mango based on its external features and weight, using four machine learning models - Random Forest (RF), Linear discriminant analysis (LDA), Support vector machines (SVM), and K-nearest neighbors (k-NN). The models take inputs such as length, width, defect, and weight, and output the mango classifications into different grades. The captured images and load-cell signals are converted to structured data using data normalization methods and elimination of outliers (DNEO) and normalization and outliers are eliminated to improve the dataset. Morphological

processing and different image processing algorithms including filtered noise, edge detection, and boundary trace are used to detect objects in binary images. The results show that this method is more effective than using external features or weight alone, and does not require expensive non-destructive measurements (NDT).

A growing body of research on image processing techniques for the quality grading of fruits highlights their potential, including for mangoes, as a non-destructive and automated alternative to traditional grading methods. Such techniques have the potential to improve the efficiency and accuracy of fruit grading. However, numerous techniques for sorting or evaluating mangoes have been studied both domestically and internationally, there is no universally effective approach due to the inconsistent standardization of mango grading. Because criteria used for grading mangoes may differ not only between regions and countries but also from the seller to seller. Consequently, it is worth noting that none of the discussed research on mango grading has explicitly focused on the local mangoes of An Giang province. And this shortage underscores the need for an intuitive grading system that meets the requirements of mango grading in this region. The aim of the image processing-based system for mango grading is to professionalize the grading process by utilizing computer vision techniques to enhance accuracy and efficiency. The main contributions of this paper include:

- Build a new comprehensive dataset of high-quality images of local mangoes in An Giang Province for training and evaluation of the system's machine-learning algorithms.
- Employ state-of-the-art image processing techniques to accurately and efficiently classify mangoes based on their size and blemishes, reducing human error and increasing the speed of the grading process.
- Create the groundwork for easy-to-use software that connects with the grading system, allowing users to upload images of mangoes and receive reliable and impartial grading results.
- Reduce the cost of manual grading by automating the grading process, thus reducing labor requirements, increasing throughput, and enhancing scalability.

III. MATERIALS AND METHODS

A. Overview of the Proposed System

The proposed mango grading methodology consists of five essential steps. These steps involve image acquisition, followed by image augmentation to improve the dataset's diversity. Next, the state-of-the-art Otsu method [17] is utilized to isolate the mangoes and segment them from the background. Then, the contour analysis is performed to measure the mangoes' circumference accurately. In the final step, the effectiveness of our proposed method is evaluated on our mango dataset. By following these steps, our system utilizes several image-processing methods to effectively isolate and segment the mangoes, accurately compute their size, and detect blemishes using Canny edge detection and contour detection techniques. We leverage these techniques to identify an extensive range of blemishes, such as brown or black spots and insect scars.

To evaluate the performance of our methodology, the Random Forest model is used to predict the mangoes' grades on the test set. We then calculate the F_1 score, along with accuracy, precision, and recall for each class, to evaluate the model's performance.

B. Data Collection and Preprocessing

Taiwanese mango is a popular mango variety due to its large, fleshy fruit, sweet flavor when the fruit is still green, origin in eastern India, and high-profit rates when exported to the Chinese market. Therefore, in this study, the Taiwan mango is used to acquire images and evaluate our proposed system. Our imaging system consisted of a Canon 1300D camera with a Canon 50mm f1.8 STM lens and a T660EX tripod to ensure stability. The camera was positioned 42 cm from the mango, with a TR120N1/40W.H bulb placed 63 cm above the mango to maintain consistent illumination. Multiple angles were captured for a comprehensive view of the mango. The mango is placed on a white background. Each fruit is captured at 5-6 different angles and the mango is rotated vertically along the stem. The complete experimental setup is illustrated in Fig. 1.



Fig. 1. Experimental setup for image collection.

Post-capture, each image is uniformly resized and their pixel values are normalized to adjust brightness and color. Additionally, the images are cropped to focus on the region of interest and remove any visible noise. However, having only 110 samples may not be sufficient for machine learning methodologies, as it can lead to overfitting. In order to improve the dataset, a multitude of data augmentation techniques was employed, including horizontal flipping, and rotation by 90 degrees both clockwise and counterclockwise, thereby augmenting the original dataset from 110 to 440 images. This augmentation process is visually depicted in Fig. 2. These augmentation techniques also help improve the generalizability of the model and avoid training overfitting, as well as the system will have more diverse instances to learn from the datasets [12], [23] (see Table I).

The images were categorized into three distinct groups based on the grading standards provided by local expert

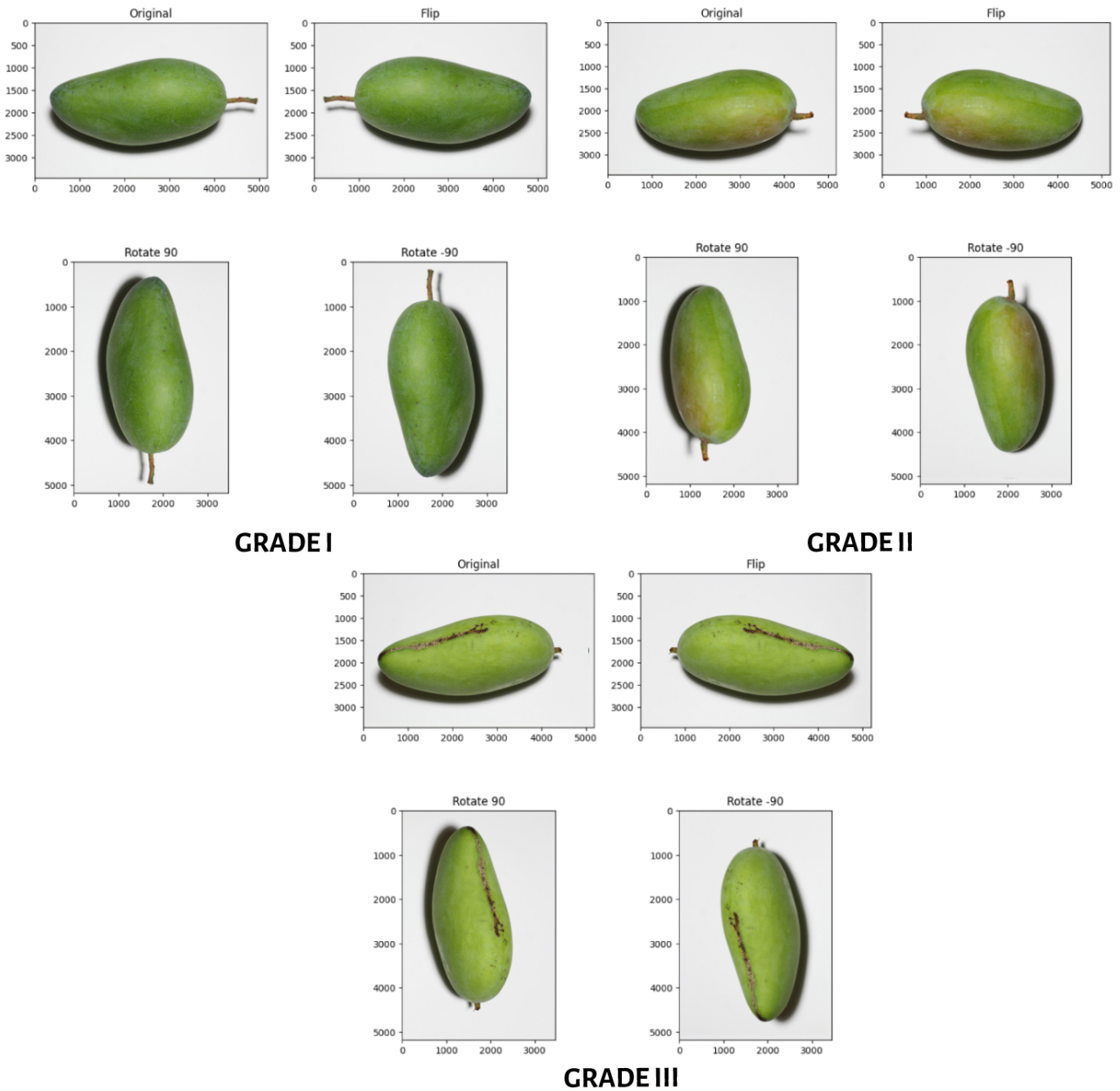


Fig. 2. Visual Representation of Data Augmentation Results.

TABLE I. THE TOTAL DATA SET AFTER DATA AUGMENTATION

Origin	Flipping	90° Rotation	-90° Rotation	Total
110	110	110	110	440

graders. These groups were Grade I, II, and III, and the details of these standards are shown in Table II. The dataset was then divided into a training set that contained 90% of the images. To evaluate the performance of image processing techniques on new and unseen data, 10% of the images were reserved for

future evaluation. The training set was further randomly split into training and validation sets in an 80:20 proportion. This separation is crucial for ensuring that the techniques are robust and can generalize well to new data, beyond merely performing well on the training data. Some representative samples from our mango dataset are shown in Fig. 3. The first line exhibits images of a grade I mango, which is the best quality. Images in the second row are of Grade II mango, while the images in the third row are of Grade III mango, which is the lowest quality. An overview of the dataset structure is illustrated in Fig. 4.

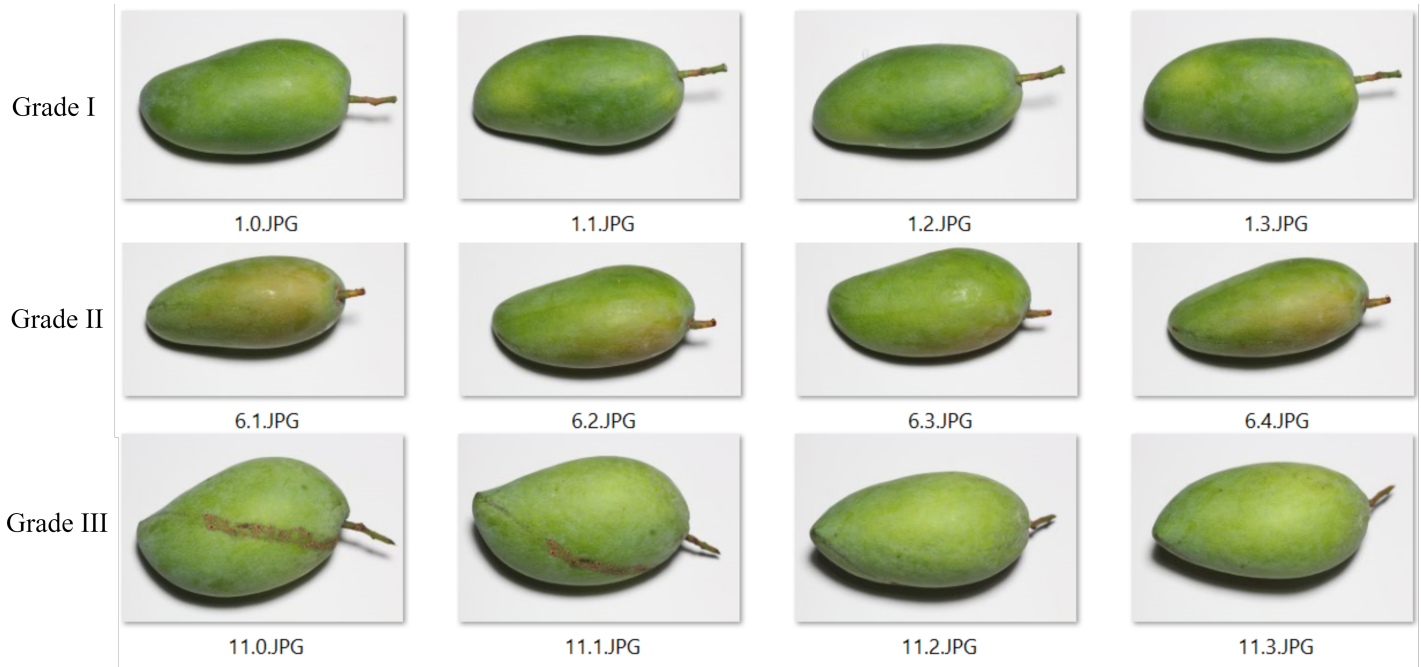


Fig. 3. Some representative samples from our mango dataset.

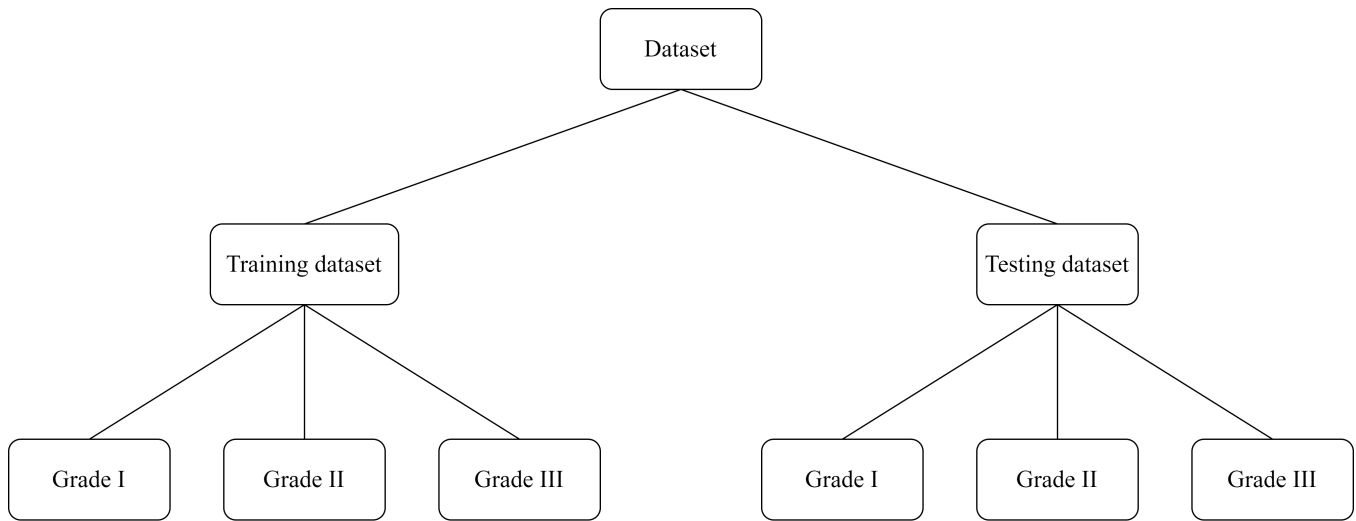


Fig. 4. Structure of mango dataset for image processing.

TABLE II. AN GIANG PROVINCE MANGO GRADING STANDARDS

Grade	Weight (g)	Blemishes	Description
I	> 620	Absent	Grade I mango has no dark spots, smooth, beautiful skin, is older, and weighs 620g or more.
II	500 - 620	Moderate	Grade II mango has few dark spots, flawless skin, and weighs 500-620gr.
III	< 500	Severe	Grade III mango is ripe, has dark spots, scars, and heavily soiled skin, and weighs 500g or less.

[17]. It can determine the optimal threshold value used to segment an image into foreground and background regions. In the case of our study, this approach would be particularly useful when the background of the mango image has varying intensities and the lighting is uneven.

Given the input image be denoted as I with size $M \times N$. The gray levels of the image range from 0 to $L - 1$, where L is the number of gray levels in the image. The histogram of the image is defined as (1):

$$H(k) = \frac{n_k}{N} \quad (1)$$

Where n_k is the number of pixels with gray level k and N is the total number of pixels in the image.

C. Image Segmentation using Otsu Method

The Otsu method is a popular technique characterized by its non-parametric and unsupervised nature of threshold selection

Let T be the threshold value, where $0 \leq T \leq L-1$, and let ω_0 and ω_1 be the weights of the background and foreground classes, respectively. The background class consists of pixels with a gray level less than or equal to T , while the foreground class consists of pixels with a gray level greater than T .

The mean intensity of the background class and foreground class is denoted as μ_0 and μ_1 , respectively. The between-class variance σ_B^2 is calculated as (2):

$$\sigma_B^2 = \omega_0 \times \omega_1 \times (\mu_0 - \mu_1)^2 \quad (2)$$

The within-class variance σ_W^2 is also calculated for each possible threshold value T :

$$\sigma_W^2 = \omega_0 \times \sigma_0^2 + \omega_1 \times \sigma_1^2 \quad (3)$$

Here, σ_0^2 and σ_1^2 are the variances of the background and foreground classes, respectively. The total within-class variance is:

$$\sigma_T^2 = \sigma_W^2 + \sigma_B^2 \quad (4)$$

The optimal threshold value T^* is selected by maximizing the between-class variance σ_B^2 :

$$T^* = \operatorname{argmax}_{0 \leq T \leq L-1} \sigma_B^2(T) \quad (5)$$

By applying the Otsu method to our mango images, we obtain binary images where the mango is represented with white pixels, and the background is represented with black pixels, as demonstrated in Fig. 5.

D. Contour Analysis for Finding Mango Circumference

The contour area is a critical feature for size grading agricultural produce. Its measurement allows for the identification of size distribution, sorting, and grading of fruits and vegetables for the market. In fact, contour area calculation is a powerful tool in image processing applications for accurate size grading. In light of this, this study focuses on the use of the *findContours* function in the OpenCV library, a cross-platform, lightweight, and open-source computer vision library, which supports various machine languages [8], to detect mango contours in images, which is a fundamental step in contour area calculation. To ensure high-accuracy results, we have skillfully employed Otsu-based techniques in image preprocessing, helping us to effectively separate the mango fruits from their backgrounds. The result obtained from contour detection is shown in Fig. 6

However, selecting appropriate parameters using the *findContours* function is central to obtaining precise image segmentation, unsuitable parameter configuration could lead to potential errors, inevitably reducing the overall accuracy of the system. Thus, we conducted experiments to evaluate the effectiveness of different retrieval modes and approximation techniques. In terms of retrieval modes, four hierarchical retrieval modes were investigated, including RETR_EXTERNAL, RETR_LIST, RETR_CCOMP, and RETR_TREE. While RETR_EXTERNAL retrieves only the exterior or outermost contours of the objects in the images and ignores any nested contours inside them, RETR_LIST returns all of the contours as a flat list. RETR_CCOMP organizes all of the contours into a two-level hierarchy, where external contours

come first, and boundaries of the holes reside on the second level. Finally, RETR_TREE reconstructs a complete hierarchy of nested contours. Each contour represents a node in a tree structure, and there exists a parent-child relationship between contours based on their nesting level. The RETR_EXTERNAL mode was found to be the optimal retrieval mode as it detected only the outer contours of the fruits.

In addition, our research has evaluated various approximation methods, including CHAIN_APPROX_NONE, CHAIN_APPROX_SIMPLE, and CHAIN_APPROX_TC89_L1. CHAIN_APPROX_NONE returns all the contours without removing any redundant points, making it the most precise representation of the contour. However, it is computationally expensive and less efficient due to the generation of a large number of points. CHAIN_APPROX_SIMPLE offers a balance between efficiency and accuracy; it only returns the endpoints of the contours, making it an ideal method for applications that require faster processing times. However, this method may lead to shape approximation errors and may not accurately represent curved contours. Conversely, CHAIN_APPROX_TC89_L1 provides a more precise representation of the original shape and is more accurate than CHAIN_APPROX_SIMPLE. However, it generates a large number of points and takes more time to process the contours. The outcomes of the experiments showed that CHAIN_APPROX_TC89_L1, a modified version of the Douglas-Peucker algorithm, produced the most desirable contour approximations.

In order to evaluate the efficacy of the contour detection technique, the circumferences of the fruits identified through this method were recorded and subsequently compared. The findings of this analysis have been reported in Table III.

TABLE III. CIRCUMFERENCE OF DETECTED MANGO FRUITS USING DIFFERENT COMBINATION OF RETRIEVAL MODE AND APPROXIMATION METHOD

Retrieval Mode	Approximation Method	Circumference (pixels)
RETR_EXTERNAL	CHAIN_APPROX_NONE	452
RETR_EXTERNAL	CHAIN_APPROX_TC89_L1	448
RETR_LIST	CHAIN_APPROX_NONE	1247
RETR_LIST	CHAIN_APPROX_SIMPLE	1298
RETR_LIST	CHAIN_APPROX_TC89_L1	1271
RETR_CCOMP	CHAIN_APPROX_NONE	1264
RETR_CCOMP	CHAIN_APPROX_SIMPLE	1279
RETR_CCOMP	CHAIN_APPROX_TC89_L1	1270
RETR_TREE	CHAIN_APPROX_NONE	1189
RETR_TREE	CHAIN_APPROX_SIMPLE	1227
RETR_TREE	CHAIN_APPROX_TC89_L1	1219

The results indicate that using the RETR_EXTERNAL retrieval mode combined with the CHAIN_APPROX_TC89_L1 approximation method resulted in the most accurate detection of mango fruits, with a circumference of 448 pixels. Although the CHAIN_APPROX_NONE method produced the most precise representation of the contour, it required considerable computational resources and generated a high number of points, which could eventually affect the overall processing and detection speed.

Upon completion of the contour-detection step, the results

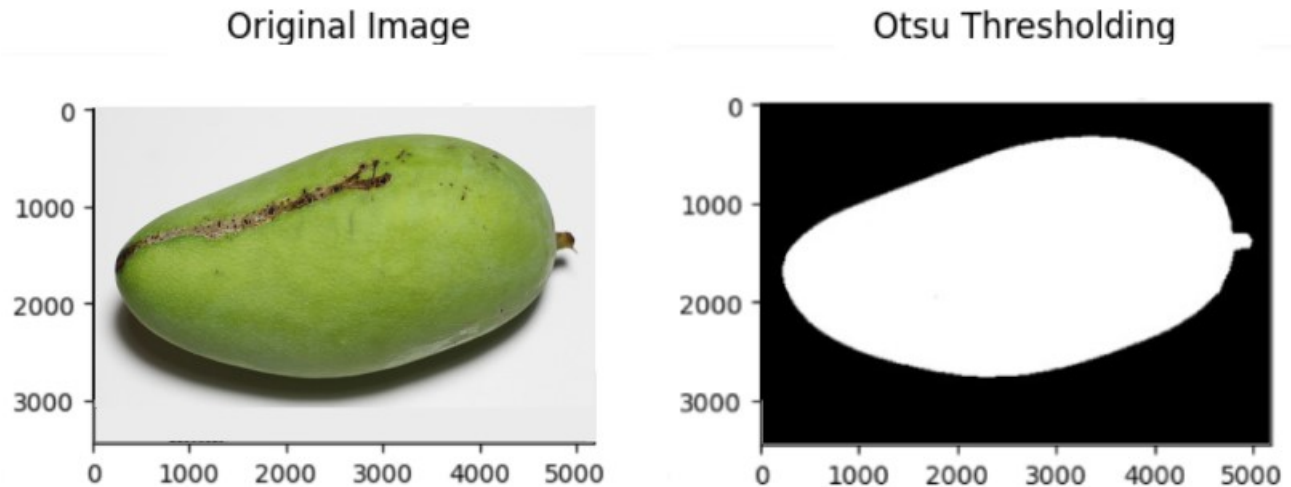


Fig. 5. Original and binary image of mango after Otsu thresholding for segmentation.

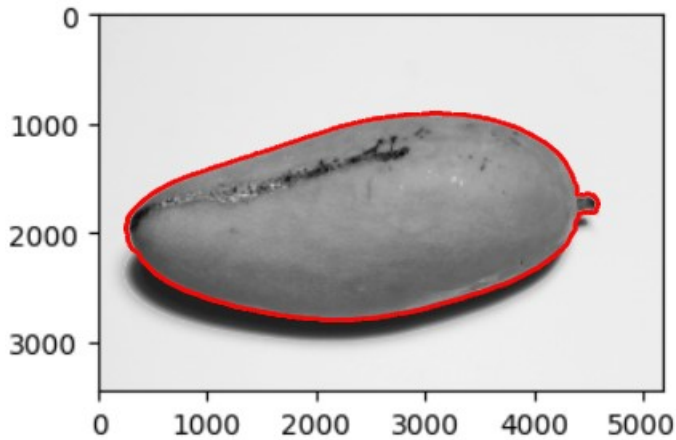


Fig. 6. Contour detected mango image.

were used for calculating the surface area by the *contourArea* function. The effectiveness of the contour area feature in mango size grading is evaluated by conducting several experiments. The results reveal that contour area is a highly effective feature in the mango size grading process, outperforming other commonly used features.

These exceptional results can be correlated with the capability of the contour area feature to capture the size and shape of the mango fruit accurately. Therefore, the implementation of contour area as a size grading feature is a robust and reliable approach that could be adopted in the industry to significantly enhance the grading process's accuracy and efficiency.

E. Blemish Detection

Blemish detection [9] is a crucial area of study in the context of mango grading, as it directly affects the overall quality and commercial value of the fruit. In recent years, there has been a considerable shift towards the use of image processing techniques for non-destructive and efficient evaluation of fruit quality [11]. One such technique that has

shown promising results in blemish detection is the use of edge detection algorithms coupled with contour detection.

Canny edge detection [4] is a popular edge detection algorithm known for its noise immunity and high accuracy. Specifically, it detects the intensity changes that occur at the edges of the object and produces a thin line that outlines the object boundary. Canny edge detection is particularly useful in highlighting blemishes present on the mango's surface. Contour detection, on the other hand, identifies smooth curves that outline objects, making it ideal for identifying fruit blemishes.

By leveraging advanced techniques such as Canny edge detection and contour detection, we are able to achieve a multitude of advantages when evaluating fruit quality. These methods exhibit a remarkable level of accuracy, which means that even minor flaws and imperfections can be accurately identified. Furthermore, they are efficient and non-destructive, allowing for quick and smooth evaluations. Through their use, we can eliminate subjective judgments and human errors that are common with conventional inspection methods. That ultimately leads to more objective results, making the assessments of the fruit quality more dependable and reliable. Fig. 7 displays the outcome of utilizing the Canny edge detection technique.

Once the edge detection process is completed, the resulting output is used as input for the contour detection algorithm to accurately identify and extract the contours of the mango blemishes. The contour detection algorithm traces the edges detected by the Canny algorithm and links them to form closed contours, thus enabling the identification of the blemish areas.

Analyzing these contours, the algorithm is able to output the boundary coordinates of the blemish contours on the surface of the mango. In terms of visualization, the contour of the mango's blemishes is displayed in Fig. 8.

Additionally, Table IV illustrates the efficacy of the blemish detection algorithm through a set of representative samples. In order to accurately represent the entire dataset, the table includes various examples with both large and small blemishes, different values for each column, and a few instances of

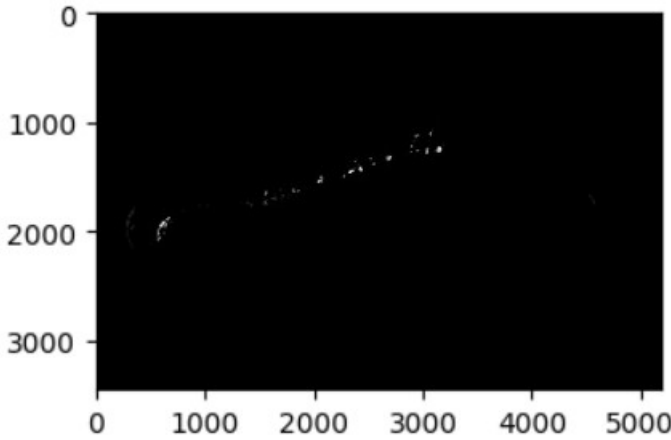


Fig. 7. Mango image obtained after canny edge detection.

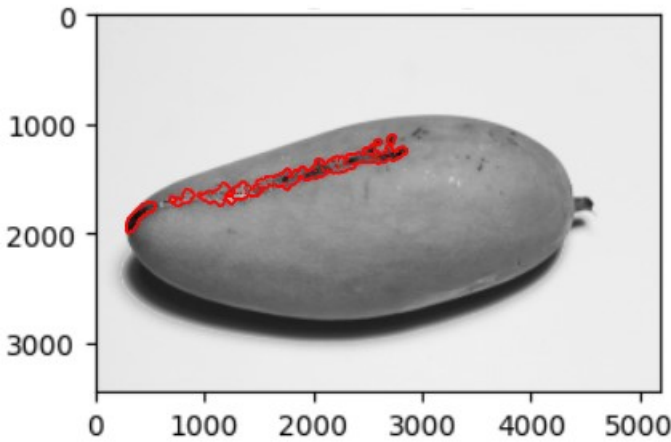


Fig. 8. Contour detection following the canny edge detection algorithm.

duplicate values. The selection of rows has been made with utmost care to ensure that the table is an accurate reflection of the data in its entirety.

TABLE IV. BLEMISH DETECTION ALGORITHM RESULTS

Area	Perimeter	X	Y	Width	Height
16.5	17.071067690849304	1323	1656	5	7
12.5	21.899494767189026	1042	1689	4	9
19.0	24.14213538169861	1431	1666	9	7
47.0	38.14213538169861	1230	1677	12	10
13.0	14.828427076339722	1261	1659	5	5
16.0	18.485281229019165	1080	1685	6	7
22.0	25.313708305358887	2376	2651	8	7
21.5	25.727921843528748	2796	2204	11	7
21.0	24.485281229019165	2268	2585	6	7
13.0	23.313708305358887	2998	1984	6	8
29.0	32.14213538169861	1262	2991	8	12
99.5	84.1837653058624	1324	1654	21	19
21.5	28.727921843528748	1278	1665	11	6
15.0	20.485281229019165	1241	2789	5	9
12.0	23.313708305358887	1233	1663	10	6

To summarize, the use of Canny edge detection and contour detection for identifying mango blemishes proves to be a promising non-destructive technique that enhances grading accuracy through reliable and effective edge detection. This

approach also reduces inspection time and human errors, ultimately increasing grading efficiency.

F. Data Training with Random Forest Algorithm

The selection of an appropriate machine learning algorithm is critical for successful image processing. Decision Tree (DT) and Random Forest (RF) are commonly used due to their effectiveness in handling complex datasets and feature engineering. However, DT tends to overfit and require a large number of decision nodes, leading to slow and inaccurate predictions, while RF overcomes these limitations by using an ensemble of decision trees that randomly select feature and data subsets for training, resulting in higher accuracy [25].

The RF algorithm constructs a forest of decision trees by randomly selecting subsets of features and data samples from the training set [6]. The algorithm builds a decision tree on each selected subset, reduces variance, and improves accuracy by aggregating predictions of all decision trees. The RF comprises the following steps:

- Randomly select a subset of features and data samples from the training set.
- Build a decision tree on the selected subset.
- Repeat the above two steps multiple times to build a forest of decision trees.
- Predict the output by aggregating the predictions of all decision trees.

The RF algorithm uses a training dataset with N observations and M features to build T decision trees. For each tree t , a random subset of m features is selected, and a bootstrap sample of n observations is drawn. The algorithm builds a decision tree on this subset, and to obtain the final prediction for the i -th observation, the algorithm considers y_i as the true label of the i -th observation and $\hat{y}_{i,t}$ as the predicted label by the t -th decision tree. The final prediction is obtained by aggregating the predictions of all T decision trees in the forest using the formula:

$$\hat{y}_i = \text{aggregate}(\hat{y}_{i,1}, \hat{y}_{i,2}, \dots, \hat{y}_{i,T}) \quad (6)$$

To optimize the performance of the RF algorithm for a specific task, fine-tuning its parameters is necessary. The following RF parameters were fine-tuned:

- *n_estimators*: the number of decision trees in the forest. Increasing the number of trees can improve accuracy but also increases computation time. A value of 100 was chosen as it provided good results without significantly increasing computation time.
- *max_depth*: the maximum depth of each decision tree. A higher depth can increase model complexity and lead to overfitting, where the model memorizes the training data instead of learning general patterns. To prevent overfitting while still providing good results, a *max_depth* of 10 was chosen.
- *min_samples_split*: the minimum number of samples required to split a node. This parameter helps to

balance bias and variance in the model, and a value of 5 was selected.

- *min_samples_leaf*: the minimum number of samples required to be at a leaf node. This parameter reduces the complexity of decision trees and prevents overfitting. A value of 2 was chosen.
- *max_features*: the maximum number of features considered when splitting a node. This parameter can help prevent overfitting by reducing the number of irrelevant features used in the model. The value of *sqrt* was chosen, meaning that the maximum number of features considered at each split is the square root of the total number of features.

By fine-tuning these parameters and validating the results on a separate validation subset, the model's complexity and accuracy were balanced, and overfitting was prevented, ensuring that the model would generalize well to new data.

IV. RESULTS AND DISCUSSION

A. Experimental Setup

The experiment utilized Google Colab and the Python programming language to perform image processing techniques, while OpenCV was used to execute a variety of image processing operations such as Otsu thresholding, *findContour*, Canny edge detection, and contour detection for blemishes. The image dataset utilized in this study consisted of mango images with a uniform size of 640 pixels.

To assess the performance of the machine learning models, Scikit-learn (Sklearn) [20] was used to calculate various evaluation metrics such as accuracy, precision, recall, and *F₁score*. These metrics were computed for each grade of mangoes, including Grade I, Grade II, and Grade III, as well as for the overall performance of the models.

The experimental setup employed in the study ensured that the models were trained and evaluated using a standardized approach, thereby guaranteeing the validity and reliability of the results obtained.

B. Evaluation Metrics

Evaluation metrics play a crucial role in assessing the efficacy of image processing-based fruit grading methods. The selection of appropriate evaluation metrics is vital in determining the accuracy and reliability of the grading techniques employed. The *F₁score* is widely recognized as a key evaluation metric, as it offers a balanced measure of precision and recall, which are critical factors in fruit grading. The *F₁score* is a type of *Fscore*, commonly used in binary classification problems, which is calculated as the harmonic mean of *Precision* and *Recall* [26]. The *F₁score* is particularly useful when the dataset is imbalanced, a common scenario in fruit grading. The general formula (6) for the *Fscore* is:

$$Fscore = \frac{(1 + \beta^2) \cdot (Precision \cdot Recall)}{(\beta^2 \cdot Precision) + Recall} \quad (7)$$

Where β is a parameter that controls the relative weight of precision and recall. When β is set to 1, the formula reduces to the *F₁score*, which is often used as a default value.

In this study, the *F₁score* was selected as the primary metric and was calculated for each grade of mangoes by comparing the results of image processing techniques with the ground truth labels. Additionally, accuracy, precision, and recall were also computed to provide further insights into the performance of the image processing techniques. Accuracy measures the overall correctness of the predictions, while precision measures the proportion of true positives among all positive predictions, and recall measures the proportion of true positives that were correctly identified. To calculate accuracy, precision, and recall from the *F₁score*, the following formulas (8), (9), (10) were used:

$$Precision = \frac{TP}{TP + FP} \quad (8)$$

$$Recall = \frac{TP}{TP + FN} \quad (9)$$

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (10)$$

Where *TP* is true positive, *FP* is false positive, *TN* is true negative, and *FN* is false negative. These formulas can be used to provide additional insights into the performance of image processing techniques for fruit grading, along with the *F₁score*.

The *F₁score*, along with other evaluation metrics, provides a quantitative measure of the effectiveness of image processing techniques for grading mangoes. The use of appropriate evaluation metrics ensures that the grading techniques employed are accurate and reliable, providing insights into the potential of these techniques for streamlining the grading process and improving the accuracy and consistency of grading mangoes.

C. Numerical Results and Discussion

To evaluate the effectiveness of our mango grading methodology, we chose the Random Forest model, which is ideal for handling small datasets and making predictions on a test set for evaluation purposes. By utilizing this model, we obtained comprehensive evaluation results for our image processing techniques based on parameters such as Accuracy, Precision, Recall, and *F₁score*. The clear and compelling evidence of our methodology's ability to accurately grade mangoes is reflected in the numerical presentation of our findings in Table V, as well as their virtual representation in Fig. 9. The combination of these two forms of data visualization serves to underscore the robustness and reliability of our approach.

As shown in Table V and Fig. 9, the image processing techniques used in the study achieved a high level of accuracy, with an overall accuracy of 88%. Table V shown that the highest accuracy was achieved for Grade I, with a accuracy of 91.32%, indicating that the technique performed well in identifying the highest-quality mangoes. Grade II had a slightly

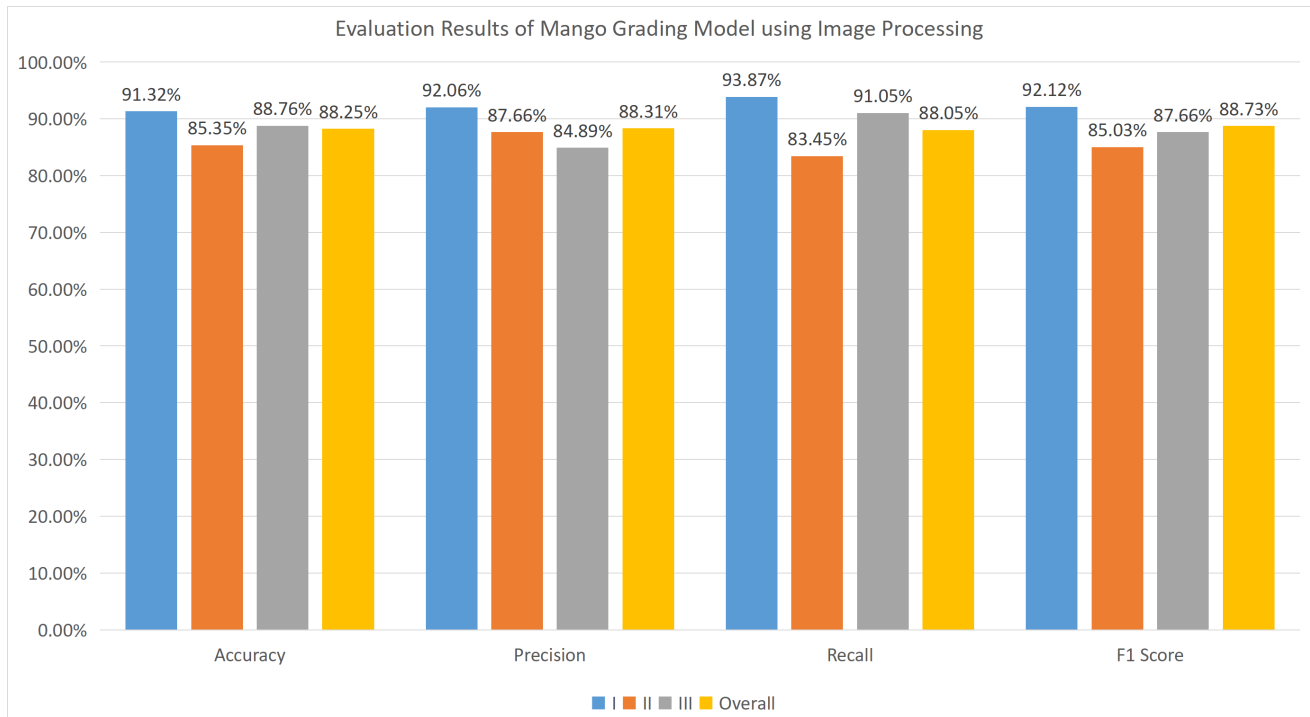


Fig. 9. Virtual evaluation results of mango grading model using image processing.

TABLE V. NUMERICAL EVALUATION RESULTS OF MANGO GRADING MODEL USING IMAGE PROCESSING

Grade	Accuracy	Precision	Recall	F1 Score
Grade I	91.32%	92.06%	93.87%	92.12%
Grade II	85.35%	87.66%	83.45%	85.03%
Grade III	88.76%	84.89%	91.05%	87.66%
Overall	88.25%	88.31%	88.05%	88.73%

lower accuracy of 85.35%, indicating that the technique was less successful in identifying the middle-quality mangoes. However, this accuracy score is still considered high and indicates that the technique is relatively robust. Grade III had an accuracy score of 88.76%, indicating that the technique performed well in identifying the lowest-quality mangoes.

The precision scores for the three mango grades were considerably elevated, with values between 84% and 92%. This signifies that the image processing technique accurately detected true positives, or the number of mangoes that were correctly identified for each grade while limiting the number of false positives, or the number of mangoes that were inaccurately identified. The highest precision score was observed for Grade I, indicating that the method was exceptionally precise in identifying the finest quality mangoes. Conversely, the lowest precision score was noted for Grade III, suggesting that the technique faced more difficulties in detecting the poorest quality mangoes.

Similarly, the recall scores for the three grades were also high, with values ranging from 83% to 93%. This implies that the technique was proficient in identifying all relevant occurrences, or the number of mangoes that were correctly identified for each grade while minimizing the number of false negatives, or the number of non-mangoes that were wrongly

identified as mangoes. The highest recall score was obtained for Grade I, indicating that the technique accurately identified the highest-quality mangoes. On the other hand, the lowest recall score was obtained for Grade II, suggesting that the technique faced more challenges in identifying middle-quality mangoes.

Moreover, the F_1 score for the three grades were also high, ranging from 85% to 92%. The F1 score is a measure of the harmonic mean of precision and recall, providing a balance between the two metrics. The highest F_1 score was achieved for Grade I, indicating that the technique was highly successful in identifying the highest quality mangoes with a balance between precision and recall. Conversely, the lowest F_1 score was observed for Grade II, implying that the technique experienced more difficulties in identifying middle-quality mangoes.

This study demonstrates the potential of image processing techniques to improve the precision and consistency of mango grading while streamlining the process. The implications of this study are noteworthy, as they imply that image processing techniques could be a reliable and effective means of grading mangoes. Furthermore, this study is in line with other research in the field, which also highlights the effectiveness of image-processing techniques for fruit grading. However, this study underscores the potential of utilizing a combination of techniques, such as Otsu thresholding, *findContour* of OpenCV, Canny edge detection, and contour detection for blemishes, to attain high levels of precision and consistency in grading mangoes. Therefore, this study provided valuable insights into the potential of image processing techniques for improving fruit grading's precision and consistency, and its implications could be instrumental in the fruit industry. The screenshot of the mango grading system is shown in Fig. 10.

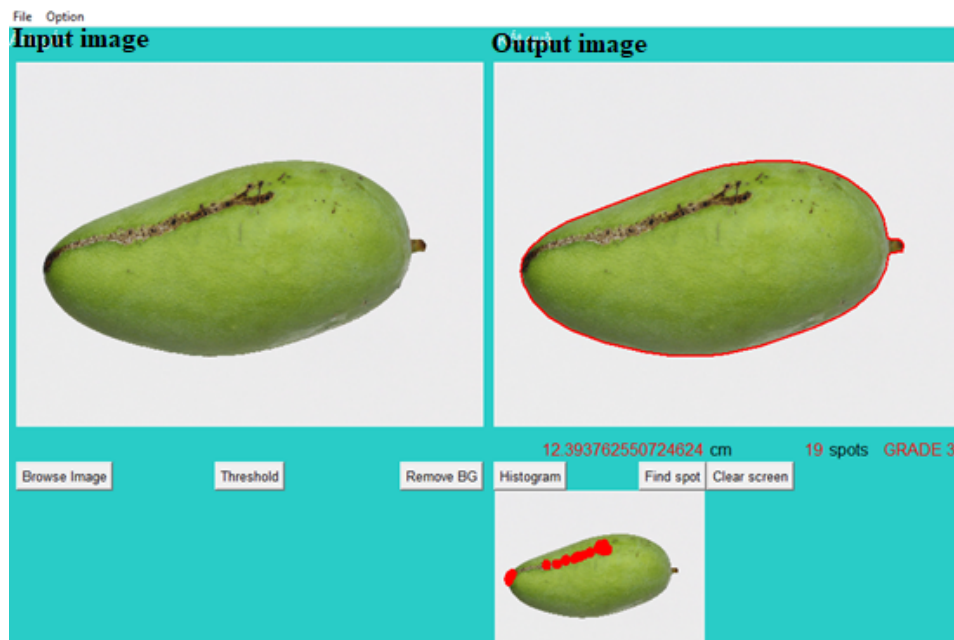


Fig. 10. The screenshot of the mango grading system.

V. CONCLUSIONS, LIMITATIONS, AND FUTURE RESEARCH

The proposed image processing system successfully has achieved the goal of automating the grading and sorting process of mangoes. By using the Otsu method for image segmentation and contour analysis for finding mango circumference, the system was able to accurately detect and classify mangoes based on their external quality features such as size, shape, and the presence of blemishes. The classification accuracy results showed that the proposed system is effective and efficient for grading mangoes, with an overall accuracy of 88%.

Despite the success of the proposed system, there are still some limitations and challenges that need to be addressed in future work. One of the limitations of the system is that it requires a controlled environment for image capturing, which can be challenging to achieve in real-world scenarios. Moreover, the system heavily relies on the quality of the input images, which can be affected by various factors such as lighting conditions and camera settings. Another challenge is the need for continuous updates and improvements to ensure the system's reliability and adaptability to new varieties of mangoes.

In future research, we aim to overcome the limitations and challenges outlined above and further enhance the accuracy and efficiency of the proposed system. To this end, research efforts should prioritize the development of more robust and precise image processing and analysis algorithms that can effectively handle variations in image quality, lighting, and camera calibration. Furthermore, we plan to explore various image segmentation and feature extraction techniques to augment the system's capacity to classify mangoes based on their quality features with greater accuracy. The use of advanced machine learning approaches, such as deep Convolutional neural networks, could also be explored to improve the grading

and sorting process's accuracy and efficiency. Additionally, we intend to investigate the feasibility of integrating the proposed system with other mango supply chain components, such as harvesting and packaging, to create a fully automated system. Lastly, it is crucial to consider the proposed system's potential impact on the livelihoods of small-scale mango farmers and ensure that the technology remains accessible and affordable for them. Therefore, future research should strive to develop solutions that can benefit all stakeholders in the mango supply chain, from farmers to processors and consumers.

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REFERENCES

- [1] Osama A. Alhashi; Fathey S. Almahjob; Abdelsalam A. Almarimi; Abdosllam M. Abobaker. Grading of apples and oranges by image processing. *International Journal of Electronics Communication and Computer Engineering*, 7.
- [2] Yiqin Bao, Qin Liu, and Yulu Bao. Citrus appearance quality grading system based on opencv image processing. 12 2022.
- [3] Jose Blasco, N. Aleixos, and Enrique Molto. Machine vision system for automatic quality grading of fruit. *Biosystems Engineering*, 85:415–423, 08 2003.
- [4] John Canny. A computational approach to edge detection. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, PAMI-8:679 – 698, 12 1986.
- [5] Dipali Chaudhari and Surendra Waghmare. Machine vision based fruit classification and grading—a review. pages 775–781, 2022.
- [6] Tin Kam Ho. Random decision forests. In *Proceedings of 3rd International Conference on Document Analysis and Recognition*, volume 1, pages 278–282 vol.1, 1995.
- [7] Tri Huynh and Son Dao. Highly efficient fruit mass and size estimation using only top view images. *Proceedings*, 42:6588, 11 2019.

- [8] Liu Junwei. Design of graphic recognition system based on opencv. *Electronic Technology and Software Engineering*, 2019.
- [9] Leena Kunttu, Jarno Nikkanen, and Matti Suksi. Blemish detection in camera production testing using fast difference filtering. *J. Electronic Imaging*, 18:020501, 04 2009.
- [10] Nguyen Truong Minh Long and Nguyen Truong Thinh. Using machine learning to grade the mango's quality based on external features captured by vision system. *Applied Sciences*, 10:5775, 2020.
- [11] Naveen Mahanti, Ravi Pandiselvam, Anjineyulu Kothakota, Padma S, Subir Chakraborty, Manoj Kumar, and Daniel Cozzolino. Emerging non-destructive imaging techniques for fruit damage detection: Image processing and analysis. *Trends in Food Science and Technology*, 120, 12 2021.
- [12] Agnieszka Mikołajczyk and Michał Grochowski. Data augmentation for improving deep learning in image classification problem. In *2018 International Interdisciplinary PhD Workshop (IIPhDW)*, pages 117–122, 2018.
- [13] Akira Mizushima and Renfu Lu. An image segmentation method for apple sorting and grading using support vector machine and otsu's method. *Computers and Electronics in Agriculture*, 94:29–37, 2013.
- [14] M.A. Momin, M.T. Rahman, M.S. Sultana, C. Igathinathane, A.T.M. Ziauddin, and T.E. Grift. Geometry-based mass grading of mango fruits using image processing. *Information Processing in Agriculture*, 4(2):150–160, 2017.
- [15] Chandra Sekhar Nandi, Bipan Tudu, and Chiranjib Koley. Computer vision based mango fruit grading system.
- [16] Bao T.Q; Vung N.V; and Dinh T.Q;. Identifying and discovering defects in mango peel. 2017.
- [17] Nobuyuki Otsu. A threshold selection method from gray-level histograms. *Systems, Man and Cybernetics, IEEE Transactions on*, 9:62–66, 01 1979.
- [18] Amber Pariona. The top mango producing countries in the world. *Worldatlas*.
- [19] Leo Pauly and Deepa Sankar. A new method for sorting and grading of mangos based on computer vision system. *2015 IEEE International Advance Computing Conference (IACC)*, pages 1191–1195, 2015.
- [20] Fabian Pedregosa, Gaël Varoquaux, Alexandre Gramfort, Vincent Michel, Bertrand Thirion, Olivier Grisel, Mathieu Blondel, Peter Prettenhofer, Ron Weiss, Vincent Dubourg, Jake Vanderplas, Alexandre Passos, David Cournapeau, Matthieu Brucher, Matthieu Perrot, and Édouard Duchesnay. Scikit-learn: Machine learning in python. *Journal of Machine Learning Research*, 12(85):2825–2830, 2011.
- [21] Van Huy Pham and Byung Ryong Lee. An image segmentation approach for fruit defect detection using k-means clustering and graph-based algorithm. *Vietnam Journal of Computer Science*, 2(1):25–33, February 2015.
- [22] Tajul Rosli, Bazilah Abd Razak, Mahmud Othman, and Ab Razak Mansor. Mango grading by using fuzzy image analysis. 2012.
- [23] Connor Shorten and Taghi Khoshgoftaar. A survey on image data augmentation for deep learning. *Journal of Big Data*, 6, 07 2019.
- [24] A. Supekar and M Wakode. Computer vision based automated mango grading – a review. *Journal of Postharvest Technology*, 8, 2020.
- [25] Prajwala T R. A comparative study on decision tree and random forest using r tool. *IJARCCCE*, pages 196–199, 01 2015.
- [26] Abdel Aziz Taha and Allan Hanbury. Metrics for evaluating 3d medical image segmentation: analysis, selection, and tool. *BMC Medical Imaging*, 15, 2015.
- [27] Lili Zhu and Petros Spachos. Support vector machine and yolo for a mobile food grading system. *Internet of Things*, 13:100359, 2021.

Mobile Module in Reconfigurable Intelligent Space: Applications and a Review of Developed Versions

Dinh Tuan Tran¹, Tatsuki Satooka², Joo-Ho Lee³

College of Information Science and Engineering, Ritsumeikan University, Kusatsu, Shiga, Japan^{1,3}

Graduate School of Information Science and Engineering, Ritsumeikan University, Kusatsu, Shiga, Japan²

Abstract—Due to the immobility of devices in conventional intelligent spaces, the quality and quantity of their applications (i.e., services) are thus restricted. To provide better and more applications, the devices in the spaces must be able to move autonomously to ideal positions. To solve this issue, the concepts of reconfigurable intelligent space (R+iSpace) and mobile modules (MoMos) have been introduced. Each device in the R+iSpace is carried by one or more MoMos that can freely move on the ceiling and walls. Consequently, the R+iSpace has evolved into a user-centered intelligent space, where devices can move to the user to provide services instead of the user having to move to where the devices are. In this work, several promising applications are introduced as open research challenges for the R+iSpace and the MoMo. In fact, various wall-climbing robots have been developed, however, their speed and carrying capacity are insufficient for adoption for the MoMo and the R+iSpace. Therefore, the development of MoMo requires the creation of entirely new designs and mechanisms. In addition to introducing promising applications, this work provides an overview of all versions of the MoMo that have been developed to gradually make it deployable in a realistic R+iSpace.

Keywords—Climbing Robot; intelligent space; iSpace; mobile module; MoMo; reconfigurable intelligent space; R+iSpace; smart home; ubiquitous environment

I. INTRODUCTION

Recently, terms such as smart homes, ubiquitous environment, and intelligent space (iSpace) have become popular [1]–[3]. This type of space is no longer merely an abstract concept realized in sophisticated research centers; it is being widely implemented even in ordinary homes. The fundamental premise of these spaces is to increase the intelligence of the devices contained within, allowing them to provide users with more valuable information and services. However, the methods by which devices interact with the users vary according to the space. For example, in an iSpace [1], each device is treated as a distributed intelligent network device (DIND) and is connected to the same local network. Here, a DIND can be either an input device (e.g., a camera or microphone) or an output device (e.g., a projector, light, television, or speaker). An input DIND is used to capture the demands of the user or the current state of the space. Then, the captured data are transmitted to a server computer. After processing the data and determining an appropriate service, the server distributes this result to all DINDs. Finally, a single or multiple output DINDs, as specified by the server, provide service to the users.

However, these spaces are either static or semi-dynamic and are not entirely oriented toward the users. In a static space, the poses (i.e., their positions and orientations) of all devices (e.g., DINDs in an iSpace) are fixed and do not

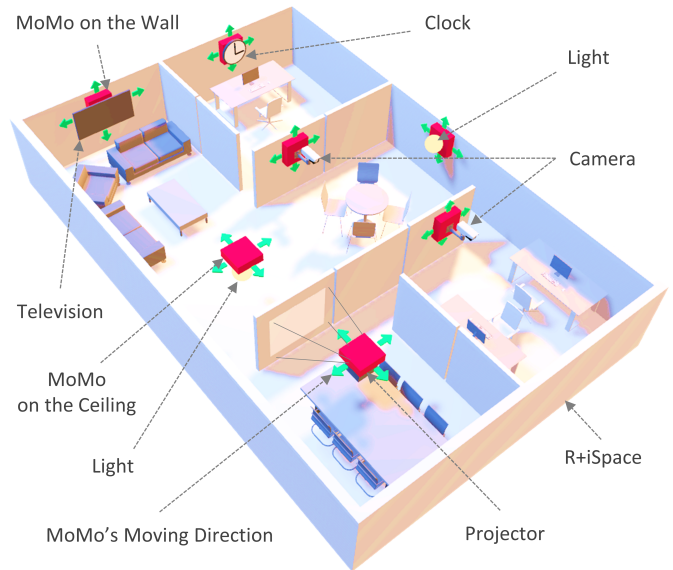


Fig. 1. A conceptual reconfigurable intelligent space with mobile modules (MoMos).

automatically change. In contrast, in semi-dynamic space, the positions of devices are fixed but their orientations are variable. The simplest approach to transform a static device into a semi-dynamic state is attaching it to an actuator. Typically, the users must arrange devices in such spaces into optimal positions manually. Each time requesting a service, the user must consider the location of the device to obtain the most effective service. For instance, to watch television, the user must walk in front of a television. Furthermore, multiple devices are required to provide greater services to the users. For example, a home with multiple rooms needs multiple televisions, and detecting the users in any situation requires multiple cameras.

Due to the reasons stated above, fully dynamic spaces are required to provide higher quality and quantity of services. A fully dynamic space is known as a reconfigurable iSpace (R+iSpace). For an R+iSpace to be completely user-oriented, its devices must be able to move and rotate autonomously. This can be accomplished by mounting the devices using an on-ground robot or a wall-climbing robot. This eliminates the need for the user to move in order to watch television; rather, the television will move closer to the user. Moreover, by transforming a space into one that is fully dynamic, the number of devices required to provide valuable services is minimized

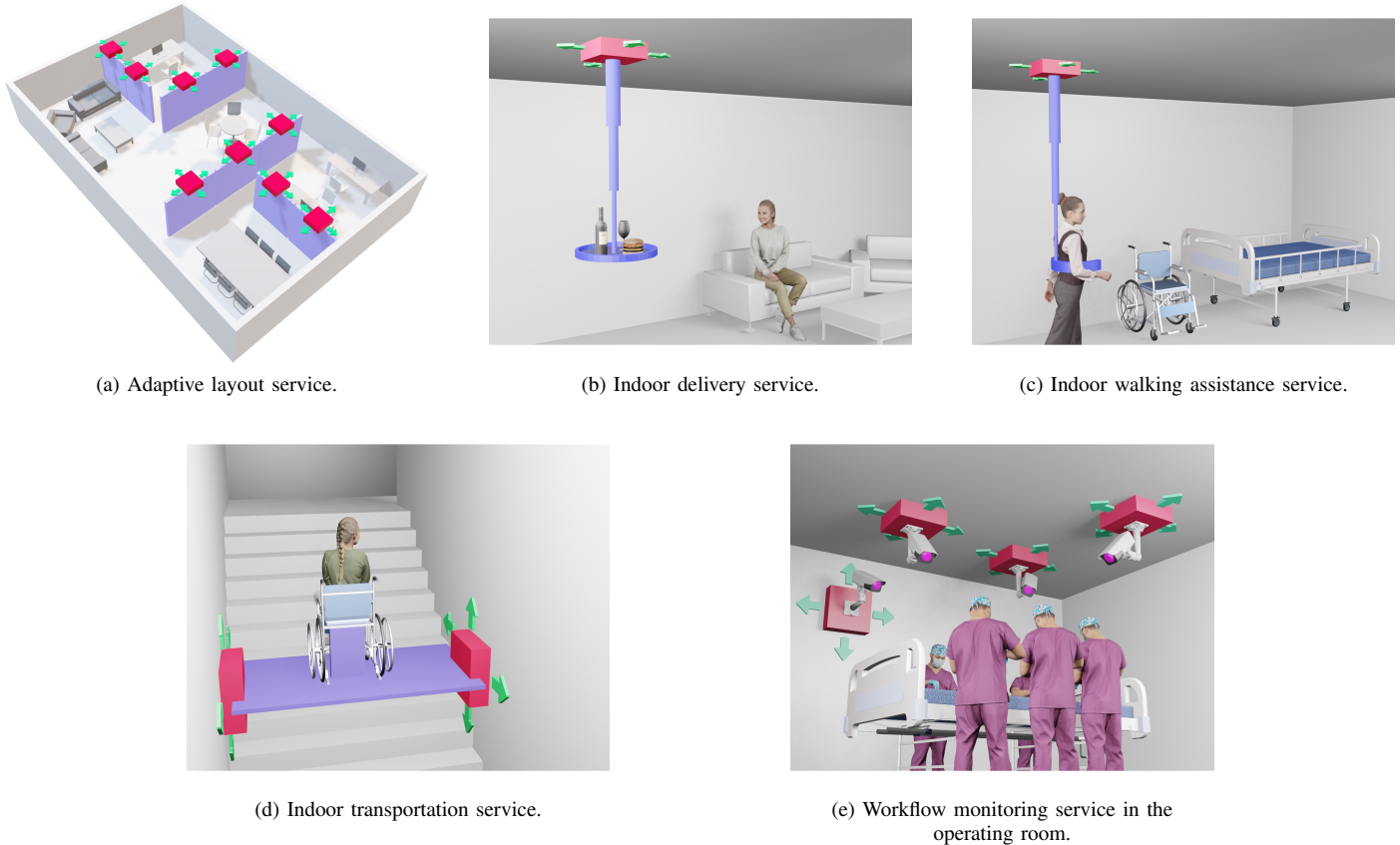


Fig. 2. Several promising applications of MoMo in the future.

[4], [5]. In an iSpace, for instance, only one television is required because it can be moved between rooms.

As previously mentioned, there are two methods to convert a space to an R+iSpace. The first is mounting the devices on on-ground robots. In this method, the devices move on the floor alongside the robots. On the ground, however, there are numerous obstacles, including humans. These obstacles are challenging for the robots to avoid, as they may be dynamic or frequently change. Consequently, the algorithm for robot movement becomes extremely complex. In addition, the robots may negatively impact the users by obstructing their movement. Remarkably, due to the limited height of a standard on-ground robot, devices such as cameras and lights cannot cover a large area when mounted on the robots. For these reasons, this approach was not adopted for the development of R+iSpace.

On the other hand, the second method is employing wall-climbing robots that are capable of carrying devices and moving along the ceiling and wall (hereafter referred to as the field). The greatest advantages of this method are that the robots and mounted devices do not occupy any floor space, do not need to avoid numerous obstacles, and do not impede the users. Thus, the movement algorithm for robots becomes simpler. Furthermore, the devices, such as cameras and lights, can be positioned anywhere, allowing them to monitor a larger area. In light of this, the second method was adopted for building the R+iSpace.

Numerous climbing robots have been developed previously [6]–[28]. These robots can be categorized based on their adhesion or movement techniques. According to the adhesion techniques, they can be classified into four types: magnetic force [6]–[11], suction force [12]–[18], use of adhesive material [19]–[24], and mechanical adhesion [25]–[28]. In contrast, they can be categorized based on three movement techniques: walking by raising each leg individually [6]–[8], [12]–[15], [19]–[21], [25], driving using wheels [9], [16]–[18], [22], [23], [28], and moving with crawlers [10], [11], [24], [26], [27]. These robots were experimentally demonstrated to be capable of moving across a field without falling. However, these robots have numerous limitations, including slow movement, energy expenditure during idle state, insufficient loading capacity, and difficulty in self-localization.

In order to establish the R+iSpace, a novel climbing robot must be developed. The new robot is called mobile module (MoMo), which can move on the field and to which a device can be mounted (Fig. 1). Nevertheless, developing such a robot is extremely challenging. The MoMo must move efficiently on the field, not fall off the field, have a sufficient moving speed, not consume electricity when in the idle mode, have a large loading capacity, and precisely and simply self-localize. In addition to introducing several promising applications of the R+iSpace, this work provides an overview of all developed MoMos.



Fig. 3. Previous versions of the MoMo.

II. PROMISING APPLICATIONS OF MOBILE MODULES (MoMos)

As mentioned in Section I, the MoMo is significantly important for creating a fully user-oriented R+iSpace. By proposing such an R+iSpace utilizing MoMos, numerous user-oriented applications can be provided in the future. Fig. 2 illustrates several of these anticipated applications.

A. Adaptive Layout Service

The first promising application of the MoMo is adaptively customizing the layout of the R+iSpace and the properties (e.g., location) of available devices within this space. For instance, by attaching partitions to multiple MoMos, users can change the design of a room at any time (Fig. 2a). Moreover, when a user enters the space, devices connected to the MoMos, such as cameras, projectors, lights, televisions, and wall clocks, can be repositioned optimally. Typically, cameras can be moved to situations where users and their requests can be easily detected and recognized. Similarly, the position, display size, and display resolution of a projector can be adjusted in response to the status of the user. During a conversation between two or more users, using the cameras to detect eye movements, the lights can be moved to appropriate positions that better emphasize the object on which the users

are focusing.

B. Indoor Delivery Service

Currently, conveyor belts and delivery robots are used in restaurants to deliver food and drinks directly from the kitchen to tables of customers. However, conveyor belts require space on the floor for installation. Moreover, delivery robots are predominantly ground-based. Such a robot must be capable of detecting humans, tables, and other obstacles placed on the ground to prevent collisions. Moreover, the appearance of such robots may annoy customers. Therefore, a robot that can move across the ceiling and walls without encountering obstacles to deliver food exhibits advantages such as ease of movement, conservation of floor space, and unobstructive operation. This robot can be developed using a single MoMo and an extendable robotic arm to pick up and drop off food (Fig. 2b).

C. Indoor Walking Assistance Service

The population in developed countries such as Japan is aging and declining. Consequently, many elderly people have problems with their spine, waist, or legs. These people have difficulty walking in everyday life and require devices to assist them in safely moving around. As a promising solution, a MoMo can be combined with an assistant module to aid elderly people in indoor environments (Fig. 2c). When compared to canes, crutches, walkers, and other walking mobility aids for older adults, a support device powered by MoMo will not require users to use their hands to control it. Sensors on the device can detect the direction of the user and transmit the acquired information to the MoMo. The MoMo then proceeds in this direction.

D. Indoor Transportation Service

Elevators and escalators are commonly used in commercial establishments, such as hotels, shopping centers, and high-rise structures. They are also used in private settings, such as private homes, particularly in homes with disabled residents. Given the size of a typical commercial space, the area required for an elevator or escalator is negligible. By contrast, individual locations are significantly smaller than commercial locations. Consequently, a relatively significant area is required to install a static elevator or escalator. Moreover, the installed devices are not as frequently used as they are in commercial spaces. Therefore, it is preferable to adopt a dynamic elevator in a private space rather than a fixed one. A dynamic elevator can be defined as a device that operates whenever users require it and frees the area in which it is located when not in use. As shown in Fig. 2d, two or more MoMos are utilized to construct such a flexible elevator. These MoMos carry a base plate on which the user can stand safely. With the ability of the MoMo to move on the field, the system can transport users in a manner similar to an elevator when in the active mode and move to the ceiling to free occupied space when in the inactive mode.

E. Workflow Monitoring Service in the Operating Room

For surveillance purposes, a minimal number of cameras can be attached to MoMos to allow them to move freely on the field (Fig. 2e). In this way, the camera system can monitor an R+iSpace, such as a private home, without encountering

TABLE I. PREVIOUS MOBILE MODULE (MoMo) SPECIFICATIONS

	MoMo 1	MoMo 2	MoMo 3	MoMo 4.1	MoMo 4.2
Weight (kg)	1.45	2.55	1.60	1.70	1.90
Size (mm)	190x255x110	210x318x129	200x280x129	200x300x125	200x420x120
Actuators	8	5	4	4	3
Moving Speed (cm/s)	0.33	2.05	2.8	6.82	7.3

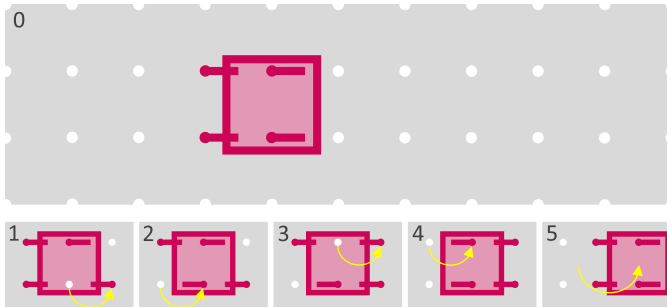


Fig. 4. Gait steps of MoMo 1.

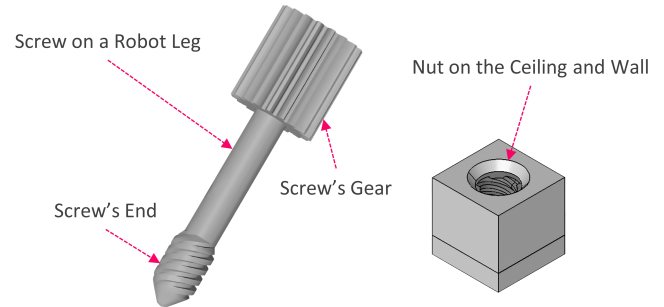


Fig. 5. Screw–nut mechanism in MoMos 1 and 2.

dead angles. Notably, such a system is more critical when monitoring the workflow in an operating room. For instance, the workflow monitoring systems in [4], [5], [29], [30] employed multiple cameras to capture every movement in the operating room. Then, the systems used these data to estimate the current workflow phase and detect unusual events that occurred during this phase. However, a surgical workflow is generally performed by a group of surgeons, with support staff gathered around a patient. Consequently, many dead angles may exist, and the critical motions that the cameras are unable to capture may be overlooked. By adopting MoMos in these situations, the attached cameras can be relocated to locations that provide a clearer view of both human and equipment movement.

III. PREVIOUS MoMo VERSIONS AND THEIR LIMITATIONS

Since 2012, the R+iSpace, specifically the MoMo, has been the subject of extensive research [31]–[35]. Consequently, four prototypes of the MoMo were developed, excluding the version introduced in this study (refer to Fig. 3 and Table 1). These MoMos were proposed according to the following six design requirements: they must be able to move on both the ceiling and wall, their fall must be prevented by using a fastening mechanism, they must move sufficiently quickly, they must consume no energy when fastened and idle, they must have a high loading capacity, and they must be accurate and straightforward in their self-localization, as discussed in Section I. Before delving into the details of the latest MoMo version, this section provides a brief overview of previous versions and their limitations.

A. Screw–nut Mechanism–based Four-legged MoMo 1

The first MoMo was a four-legged walking robot capable of moving across the field (Fig. 3a) [31]. Each leg was composed of two actuators. One, referred to as a pinning actuator, was used to fasten and unfasten a leg to and from the field. The

other, known as a panning actuator, was used to rotate the leg (gait steps 1, 2, 3, and 4) or the body (gait step 5) around the hip joint (refer to Fig. 4). This MoMo fastened and unfastened a leg to and from the field via a screw–nut mechanism controlled by the pinning actuator (Fig. 5). Each robot leg was equipped with a screw, and numerous nuts were evenly spaced across the vertical and horizontal axes of the field. The MoMo walked on the field by sequentially moving the four legs. Consequently, five gait steps were required to move from one position to the next, as illustrated in Fig. 4.

By adopting the screw–nut mechanism to fasten at least three of the four legs while in motion, the first MoMo was able to move on the field and effectively avoid falling. Additionally, once the robot tightened its screws into the nuts, it required no energy to maintain that position. This implies that the MoMo had zero energy consumption during any period of inactivity. Moreover, as each nut on the field had a fixed distance from the surrounding ones and the movement of each robot was restricted to this distance, the current location of the robot was measured quickly and accurately.

However, the first MoMo has several problems. The first and major limitation was the moving speed. In an experiment, it took 46 s for the robot to move 15 cm (approximately 0.33 cm/s) to the next position. This speed was insufficient for use in the R+iSpace. There are two possible explanations for this slow speed. The first and foremost reason was that the robot spent an inordinate amount of time fastening and unfastening the leg as a result of the screw–nut mechanism. The second reason was the length of time required to move the legs sequentially. The second limitation of the first MoMo was that the friction between a screw and a nut during fastening was experimentally shown to occasionally result in movement failure. The third was the high cost associated with the use of eight actuators.

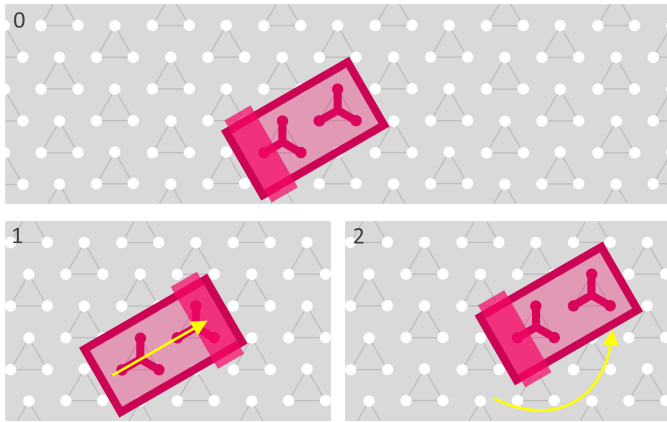


Fig. 6. Gait steps of MoMo 2.

B. Screw–nut Mechanism–based Two-legged MoMo 2

A second version was introduced to address the moving speed issue of the initial version (Fig. 3-b) [32]. Specifically, the number of legs was reduced to two. Each leg, similar to the legs in the first version, was equipped with two actuators called pinning and panning actuators. The screw–nut mechanism was also used in this version. Because of the limited number of legs in this robot, three screws in a triangular shape were attached to each leg to ensure that the robot had sufficient hinge force to free one leg and rotate its body around the other leg (gait step 2 in Fig. 6). The pinning actuator on each leg fastened or unfastened the screws simultaneously. The arrangement of the nuts on the field was thus altered to accommodate the screw structure. This MoMo added an additional component for mounting the device. A built-in actuator moved the component and device near one leg (gait step 1) before unfastening the other leg and rotating the body (gait step 2). Thus, the moment of inertia decreased dramatically with the rotation of the body. Consequently, MoMo 2 required only two gait steps to complete a movement (Fig. 6).

This version of the MoMo inherited all the advantages of MoMo 1, i.e., mobility without falling from the field, energy-free operation in the idle state, and efficient and precise localization. Moreover, by reducing the number of legs from four to two, the number of gait steps was reduced from five to two. Thus, the movement speed of the robot increased more than sixfold, from 0.33 cm/s to 2.05 cm/s. Additionally, this version utilized only five actuators, when compared to the eight required in MoMo 1, resulting in a decrease in the cost of the robot.

Although the movement speed of MoMo 2 was improved, it was extremely slow when deployed in practical applications. Apart from the reduction in speed caused by the screw–nut mechanism, the movement of the extra component between the two legs during gait step 1 also reduced the speed. Moreover, this version of MoMo lacked a device (e.g., a sensor) for tracking the location of screws on the legs in relation to nuts in the field. Experimentally, it was observed that a marginal error in positioning gradually resulted in screw abrasion. Consequently, incomplete leg fastening due to screw abrasion occurred occasionally. The incomplete fastening yielded a gap between the robot and the field. This gap led to an inability to

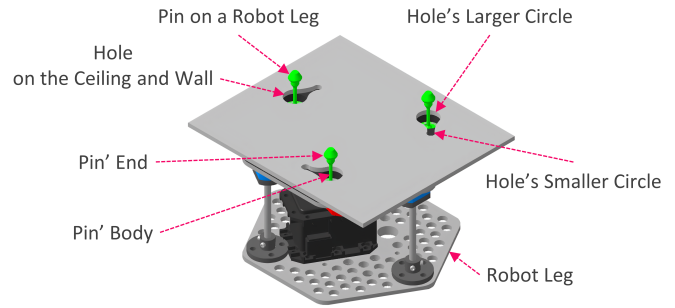


Fig. 7. Pin-lock mechanism in MoMo 3.

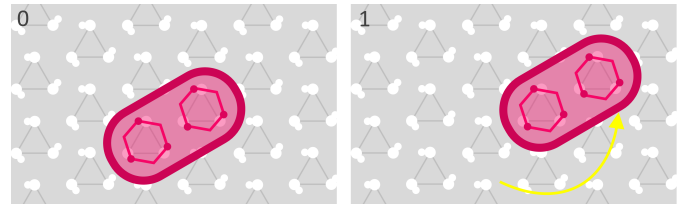


Fig. 8. Gait steps of MoMo 3.

fasten the other leg in the next gait step.

C. Pin-lock Mechanism–based Two-legged MoMo 3

The third version of the MoMo was developed to overcome the issues raised in the second version (Fig. 3c) [33]. Two significant changes from the second MoMo were observed in this version. First, the screw–nut mechanism was replaced with a new one called pin-lock, as shown in Fig. 7. Specifically, the three screws were replaced with three pins on each robot leg. Each pin had a larger end and a smaller body. Moreover, the nut on the field was replaced with a hole formed by two circles of varying sizes. The fundamental concept of the pin-lock mechanism was to use the pinning actuator on a leg to simultaneously push three pins into the larger circles of the holes and then use the panning actuator to rotate them into the smaller circles to lock (i.e., fasten) the leg. The unlocking (i.e., unfastening) procedure was performed in the reverse order. Thus, the panning actuator served two roles in MoMo 3: rotating the body around one leg (similar to MoMo 2) and rotating the pins from the larger circle into the smaller one. Owing to the larger diameter of the end of the pin in comparison with the smaller diameter of the hole, the MoMo could avoid falling out of the field when locked. Second, the extra movable component where the device was attached was eliminated. Instead, the device was positioned at the center of the MoMo. Thus, the number of gait steps was reduced from two to one (Fig. 8). However, the removal of the extra component increased the moment of inertia of the robot during body rotation. To adapt to this, MoMo 3 replaced the panning actuator with one that had a higher torque than that used in MoMo 2.

By substituting the screw–nut mechanism with the new pin-lock mechanism and omitting the extra movable component to reduce one gait step, the moving speed of this MoMo was increased significantly from 2.05 to 2.8 cm/s. Moreover, the extra component necessitated the use of an actuator to

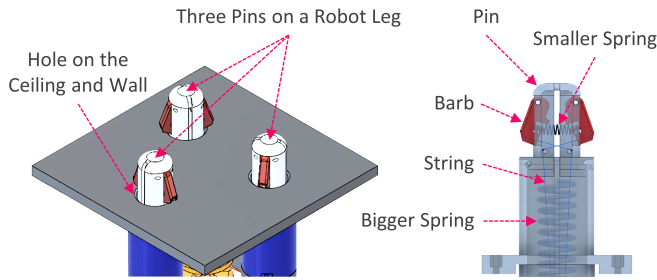


Fig. 9. Barb-spring mechanism in MoMo 4.

translate between the two legs. Consequently, by eliminating this component, the required number of actuators was reduced from five to four, resulting in a reduction in the cost of the robot. Moreover, by ensuring that the larger circle of the hole has a diameter greater than the end of the pin, the MoMo could handle misalignment between the pin and hole caused by marginal positioning errors during the movement of the robot without the use of additional sensors. Thus, movement failure that occasionally occurred in the first and second MoMos was thoroughly overcome experimentally.

Nevertheless, several issues from the previous MoMos persisted. For example, although MoMo 3 could move faster than the previous two, its speed remained insufficient for adoption in the R+iSpace. Intuitively, the robot required approximately 3 min to move to a position 5 m away from the current one. Moreover, as previously stated, the panning actuator was replaced with a higher torque to accommodate the expansion in the moment of inertia. However, this replacement was insufficient to cope with the considerable torque generated by a heavy device (e.g., a television) attached to the robot.

D. Barb-spring Mechanism-based Two-legged MoMo 4

The fourth version of the MoMo was developed to further improve the speed of movement [34]. This version of the MoMo has two subversions (Fig. 3-d and 3-e). The first subversion (MoMo 4.1) was nearly identical to MoMo 3, except for the addition of a new barb-spring mechanism in place of the pin-lock mechanism (Fig. 9). The panning actuator was retained to enable rotation of the body of the MoMo around one leg. Conversely, the second subversion (MoMo 4.2) retained the barb-spring mechanism used in MoMo 4.1 but omitted the panning actuators of the two legs. Instead, it employed a wheel mechanism comprising an omni wheel that was controlled by an actuator. The wheel mechanism was attached between the two legs to allow the body of the robot to rotate around one leg. This reduced the number of required actuators. However, the gravity force acting on the robot caused a small gap between the robot and the field during its body rotation. Hence, a compressed spring was incorporated into the wheel mechanism to ensure that the wheel was always in contact with the field. Both subversions were equipped with the newly developed barb-spring mechanism, which accelerated the fastening and unfastening processes.

As mentioned previously, MoMo 3 rotated the pinning and panning actuators sequentially to push the pins on the leg into the larger circles and then rotated the pins into the smaller circles. These sequential actions, combined with the

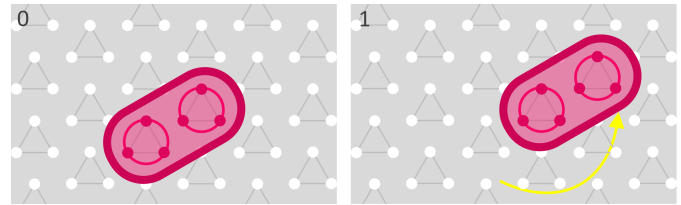


Fig. 10. Gait steps of MoMo 4.

slow rotation of the actuator, resulted in low-speed fastening and unfastening processes. To address this, the barb-spring mechanism in MoMo 4 utilized compressed springs inside the pins to immediately push (by bigger springs) and lock (by smaller springs) the pins into the holes without the need for the effort of an actuator. However, the pinning actuator was required to unlock the pins and their barbs from the holes and compress the springs inside the pins. During the rotation of the body of the robot, the compressive state of the springs was naturally maintained by the resistive force from the field. Once the pins reached the holes, the resistive force was lost, and the pins were pushed into the holes automatically. Both robot subversions moved on the field by repeating a single gait step, similar to the third robot (Fig. 10). However, the gait step required fewer actions, and each action was significantly faster than that of MoMo 3.

As mentioned earlier, although MoMo 4 required only one gait step, the speed of the gait step was significantly faster than in the previous version. Consequently, there was a nearly threefold increase in the moving speed of the MoMo. Experimentally, MoMo 4.1 that used the omni wheel to rotate the body and MoMo 4.2 that used the panning actuator achieved speeds of 7.91 and 6.82 cm/s, respectively. In comparison, MoMo 3 had a speed of only 2.8 cm/s. It was observed that substituting the panning actuator with the omni wheel resulted in a faster speed. Additionally, by adopting the barb-spring mechanism rather than the pin-lock mechanism, the legs could be automatically fastened without the assistance of an actuator. Therefore, the roles of each actuator were reduced, resulting in energy savings.

However, several issues remain unresolved or resurfaced in this version. First, the loadable weight of the MoMo remained small and constrained owing to the elimination of the extra movable component. Second, because the pin used two barbs to lock it to the field, the body of the pin was required to have a diameter that corresponded to the diameter of the hole in the field (Fig. 9). Consequently, any misalignment between the pin and the hole could result in a fastening failure. This implies that the movement failure issue that was resolved in MoMo 3 reappeared in MoMo 4. Third, the primary reason for replacing two panning actuators with an omni wheel controlled by an actuator in MoMo 4.2 was to reduce the number of actuators required. However, the aforementioned movement failure occurred more frequently in MoMo 4.2 than in MoMo 4.1. This can be explained as follows. The compressed spring within the wheel mechanism generates a pushing force that acts on the field. By contrast, a reaction force of equal magnitude acted on the robot. Moreover, one leg was fastened, and the other was left free during body rotation. As a result of the reaction force, the gap between the robot and the field became

more significant, and misalignment between the pins and holes occurred more frequently.

IV. CONCLUSION

Several future applications of R+iSpace and MoMo are presented in this paper to demonstrate that R+iSpace and MoMo research is extremely promising. Moreover, an overview of all developed MoMo versions was included. The developed MoMos satisfied four of the six design requirements. The robots were able to move on the field without collapsing. In addition, they required no electrical power to remain stationary in the field. Furthermore, they were able to precisely pinpoint their locations. However, the remaining two requirements (i.e., sufficient movement speed and large carrying capacity) were not met. Although the upgrade from the third to the fourth version of the MoMo significantly increased its speed, a faster MoMo was required for practical applications in the R+iSpace. Moreover, all versions of the MoMo were developed with the primary objective of increasing the speed of movement. The loading capacity was not taken into account during design or testing. None of the MoMos investigated the capacity of carrying weight. Additionally, movement failure due to pin-hole misalignment was a significant issue in these MoMos. These problems are open research questions for the future.

ACKNOWLEDGMENT

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REFERENCES

- [1] J.-H. Lee and H. Hashimoto, "Intelligent space — concept and contents," *Advanced Robotics*, vol. 16, no. 3, pp. 265–280, 2002. [Online]. Available: <https://doi.org/10.1163/156855302760121936>
- [2] B. Brumitt, B. Meyers, J. Krumm, A. Kern, and S. Shafer, "EasyLiving: Technologies for intelligent environments," in *Handheld and Ubiquitous Computing*, P. Thomas and H.-W. Gellersen, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2000, pp. 12–29.
- [3] H. Yoon, E. Kim, M. Lee, J. Lee, and T. Gatton, "A model of sharing based multi-agent to support adaptive service in ubiquitous environment," in *2008 International Conference on Information Security and Assurance (isa 2008)*, 2008, pp. 332–337.
- [4] D. T. Tran, R. Sakurai, H. Yamazoe, and J.-H. Lee, "Phase segmentation methods for an automatic surgical workflow analysis," *International Journal of Biomedical Imaging*, vol. 2017, p. 1985796, Mar 2017. [Online]. Available: <https://doi.org/10.1155/2017/1985796>
- [5] D. T. Tran, H. Yamazoe, and J.-H. Lee, "Multi-scale affinity-hof and dimension selection for view-unconstrained action recognition," *Applied Intelligence*, vol. 50, no. 5, pp. 1468–1486, May 2020. [Online]. Available: <https://doi.org/10.1007/s10489-019-01572-8>
- [6] J. Grieco, M. Prieto, M. Armada, and P. Gonzalez de Santos, "A six-legged climbing robot for high payloads," in *Proceedings of the 1998 IEEE International Conference on Control Applications (Cat. No.98CH36104)*, vol. 1, 1998, pp. 446–450 vol.1.
- [7] K. Kotay and D. Rus, "Navigating 3d steel web structures with an inchworm robot," in *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems. IROS '96*, vol. 1, 1996, pp. 368–375 vol.1.
- [8] A. Peidr , M. Tavakoli, J. M. Mar n, and  scar Reinoso, "Design of compact switchable magnetic grippers for the hyecro structure-climbing robot," *Mechatronics*, vol. 59, pp. 199–212, 2019. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0957415819300443>
- [9] M. Eich and T. V gele, "Design and control of a lightweight magnetic climbing robot for vessel inspection," in *2011 19th Mediterranean Conference on Control Automation (MED)*, 2011, pp. 1200–1205.
- [10] H. Eto and H. H. Asada, "Development of a wheeled wall-climbing robot with a shape-adaptive magnetic adhesion mechanism," in *2020 IEEE International Conference on Robotics and Automation (ICRA)*, 2020, pp. 9329–9335.
- [11] G. Lee, G. Wu, S. H. Kim, J. Kim, and T. Seo, "Combot: Compliant climbing robotic platform with transitioning capability and payload capacity," in *2012 IEEE International Conference on Robotics and Automation*, 2012, pp. 2737–2742.
- [12] I.-M. Chen and S. H. Yeo, "Locomotion of a two-dimensional walking-climbing robot using a closed-loop mechanism: From gait generation to navigation," *The International Journal of Robotics Research*, vol. 22, no. 1, pp. 21–40, 2003. [Online]. Available: <https://doi.org/10.1177/0278364903022001003>
- [13] H. Zhu, Y. Guan, W. Wu, L. Zhang, X. Zhou, and H. Zhang, "Autonomous pose detection and alignment of suction modules of a biped wall-climbing robot," *IEEE/ASME Transactions on Mechatronics*, vol. 20, no. 2, pp. 653–662, 2015.
- [14] M. Fujita, S. Ikeda, T. Fujimoto, T. Shimizu, S. Ikemoto, and T. Miyamoto, "Development of universal vacuum gripper for wall-climbing robot," *Advanced Robotics*, vol. 32, no. 6, pp. 283–296, 2018. [Online]. Available: <https://doi.org/10.1080/01691864.2018.1447238>
- [15] S. Hirose, A. Nagakubo, and R. Toyama, "Machine that can walk and climb on floors, walls and ceilings," in *Fifth International Conference on Advanced Robotics 'Robots in Unstructured Environments*, 1991, pp. 753–758 vol.1.
- [16] D. Schmidt, C. Hillenbrand, and K. Berns, "Omnidirectional locomotion and traction control of the wheel-driven, wall-climbing robot, cromsci," *Robotica*, vol. 29, no. 7, p. 991–1003, 2011.
- [17] G. Lee, H. Kim, K. Seo, J. Kim, and H. S. Kim, "Multitrack: A multi-linked track robot with suction adhesion for climbing and transition," *Robotics and Autonomous Systems*, vol. 72, pp. 207–216, 2015. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0921889015001256>
- [18] W. Morris, "City-climber : Development of a novel wall-climbing robot," in *Climbing and Walking Robots, Towards New Applications*, 2008.
- [19] H. Ko, H. Yi, and H. E. Jeong, "Wall and ceiling climbing quadruped robot with superior water repellency manufactured using 3d printing (uniclimb)," *International Journal of Precision Engineering and Manufacturing-Green Technology*, vol. 4, no. 3, pp. 273–280, Jul 2017. [Online]. Available: <https://doi.org/10.1007/s40684-017-0033-y>
- [20] M. P. Murphy, C. Kute, Y. Meng u , and M. Sitti, "Waalbot ii: Adhesion recovery and improved performance of a climbing robot using fibrillar adhesives," *The International Journal of Robotics Research*, vol. 30, no. 1, pp. 118–133, 2011. [Online]. Available: <https://doi.org/10.1177/0278364910382862>
- [21] S. Kim, M. Spenko, S. Trujillo, B. Heyneman, V. Mattoli, and M. R. Cutkosky, "Whole body adhesion: hierarchical, directional and distributed control of adhesive forces for a climbing robot," in *Proceedings 2007 IEEE International Conference on Robotics and Automation*, 2007, pp. 1268–1273.
- [22] K. Daltorio, A. Horchler, S. Gorb, R. Ritzmann, and R. Quinn, "A small wall-walking robot with compliant, adhesive feet," in *2005 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2005, pp. 3648–3653.
- [23] A. G. Dharmawan, P. Xavier, H. H. Hariri, G. S. Soh, A. Baji, R. Bouffanais, S. Foong, H. Y. Low, and K. L. Wood, "Design, Modeling, and Experimentation of a Bio-Inspired Miniature Climbing Robot With Bilayer Dry Adhesives," *Journal of Mechanisms and Robotics*, vol. 11, no. 2, 02 2019, 020902. [Online]. Available: <https://doi.org/10.1115/1.4042457>
- [24] J. Xu, L. Xu, J. Liu, X. Li, and X. Wu, "A multi-mode biomimetic wall-climbing robot," in *2018 IEEE 14th International Conference on Automation Science and Engineering (CASE)*, 2018, pp. 514–519.
- [25] R. Fukui, H. Morishita, T. Mori, and T. Sato, "Hangbot: A ceiling mobile robot with robust locomotion under a large payload (key mechanisms integration and performance experiments)," in *2011 IEEE International Conference on Robotics and Automation*, 2011, pp. 4601–4607.

- [26] R. Fukui, Y. Yamada, K. Mitsudome, K. Sano, and S. Warisawa, "Hangrawler: Large-payload and high-speed ceiling mobile robot using crawler," *IEEE Transactions on Robotics*, vol. 36, no. 4, pp. 1053–1066, 2020.
- [27] G. Stépán, A. Toth, L. L. Kovacs, G. Bolmsjö, G. Nikoleris, D. Surdilovic, A. Conrad, A. Gasteratos, N. Kyriakoulis, D. Chrysostomou, R. Kouskouridas, J. Canou, T. Smith, W. S. Harwin, R. C. V. Loureiro, R. López, and M. Moreno, "Acroboter: a ceiling based crawling, hoisting and swinging service robot platform," in *BCS HCI 2009 Workshop*, 2009.
- [28] M. Tavakoli, C. Viegas, L. Sgrigna, and A. T. de Almeida, "Scala: Scalable modular rail based multi-agent robotic system for fine manipulation over large workspaces," *Journal of Intelligent & Robotic Systems*, vol. 89, no. 3, pp. 421–438, Mar 2018. [Online]. Available: <https://doi.org/10.1007/s10846-017-0560-3>
- [29] D. T. Tran, R. Sakurai, and J.-H. Lee, "An improvement of surgical phase detection using latent dirichlet allocation and hidden markov model," in *Innovation in Medicine and Healthcare 2015*, Y.-W. Chen, C. Torro, S. Tanaka, R. J. Howlett, and L. C. Jain, Eds. Cham: Springer International Publishing, 2016, pp. 249–261.
- [30] D. T. Tran and J.-H. Lee, "Integration of a topic probability distribution into surgical phase estimation with a hidden markov model," in *IECON 2015 - 41st Annual Conference of the IEEE Industrial Electronics Society*, 2015, pp. 004766–004771.
- [31] J. Park and J.-H. Lee, "Reconfigurable intelligent space, r+ispace, and mobile module, momo," in *2012 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2012, pp. 3865–3866.
- [32] J. Park, T. Nunogaki, and J.-H. Lee, "The research on the algorithm for the optimal position and path for momo," in *IECON 2013 - 39th Annual Conference of the IEEE Industrial Electronics Society*, 2013, pp. 7849–7854.
- [33] —, "The mechanical structure of mobile module for new self-configurable intelligent environment," *ROBOMECH Journal*, vol. 2, no. 1, p. 14, Oct 2015. [Online]. Available: <https://doi.org/10.1186/s40648-015-0035-x>
- [34] T. Satooka, H. Yamazoe, and J.-H. Lee, "Barb based fast movement of mobile module for deploying devices in reconfigurable intelligent space," in *2018 15th International Conference on Ubiquitous Robots (UR)*, 2018, pp. 622–627.
- [35] —, "Development of mobile module ver.5.2 in reconfigurable intelligent space," in *2020 17th International Conference on Ubiquitous Robots (UR)*, 2020, pp. 159–164.

Blockchain-enabled Secure Privacy-preserving System for Public Health-center Data

Md. Shohidul Islam, Mohamed Ariff Bin Ameen, Husnul Ajra, Zahian Binti Ismail*
Faculty of Computing, Universiti Malaysia Pahang, Kuantan, Malaysia

Abstract—Health center data implicates a large scale of individual health records and is immensely concealment sensory. In the virtual era of large-size data, the increasingly different health informatization causes it important that health data needs to be stored precisely and securely. However, daily health data transactions carry the risk of privacy leaks that make sharing difficult. Moreover, the recently permitted blockchain applications suffer from deficient performance and lack of privacy. This study presents a privacy-preserving and secure sharing and storage system for public health centers based on the blockchain method to dispose of these issues. This system utilizes a hash-256-based access controller and transaction signature with the consensus policy and provides security to share and store health data in the blockchain. In this approach, blockchain guarantees scalability, privacy, integrity, and availability for data retention. Also, this paper measures the performance of transactions with supporting confidentiality-preserving and shows the average transaction time and acceptable latency when accessing health data.

Keywords—Blockchain; data; health; public; secure transaction

I. INTRODUCTION

Blockchain is currently inclining extensive importance and remarkable investment policy of shareholders across an exhaustive range of different initiatives [1]: sharing economy, digital currency, energy trades, financial security, copyright defense, and e-government. Blockchain, as a security defense technology, is evolving into a critical enabling approach for various organizations to create and deploy different decentralized applications and perform many digital sharing [2]. In order to make high-grade services to users, transactions in such applications must be high-speed, less latency, safe, and robust. In this regard, the integration of several emerging technologies in the health industry makes the processing of health information growingly knowledge [3], which defines the health record as the most creative and shareable resource. Nowadays, the medical records generated in the global health sector are growing explosively.

As the level of health information in health centers is increasing day by day, information systems are becoming increasingly complex, and the importance of information security and privacy [4] is increasing incredibly. Nowadays, the traditional paper-based health records of health sectors and their data management systems face serious risks to the privacy and integrity of storing patients' health information. Furthermore, as most health centers are sequestered from each other, long-term storage, sharing, and maintenance of health information are not facilitative to better treatment and counseling. As a result, there is potential for wastage of medical equipment and

key data in the healthcare sector. Furthermore, there has been some work on the security of data transactions in the health industry. This sector has some common work and authentication process issues that ignore health resource-controlled transactions and performance. Due to some conceptual issues, such as a lack of trusted transactions, data security, integrity, scalability, etc. The application development based on many technologies in the health sector for digital transactions is fairly slow. For these reasons, it is challenging to find a standard approach to preserve and manage humane and rational services on a large scale.

Fortunately, the recent rise of blockchain technology could open up new horizons for the secure data repository in the healthcare sector [5]. The blockchain approach can provide a trustworthy solution to health management as a rich database with features of decentralization, integrity, security, privacy, and transparency. The emergence of blockchain-based data management in the health sector has motivated the advancement of a rich data platform instead of traditional health record systems that revolutionizes the processing of health information privacy and integrity in health centers. The foremost intent of this paper is to design a secrecy-conserving and secure data storage system for health centers using blockchain [6]. Blockchain-based healthcare platform adds a timestamp to guarantee data immutability during data transactions, and user nodes access data through approved blockchains. Specifically, PoW consensus can accomplish entire decentralization in this design. All transaction records are imitated to all nodes over the blockchain [7] network.

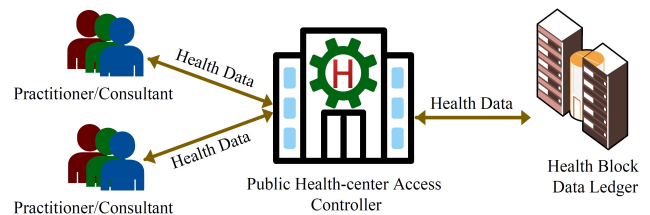


Fig. 1. General functions of public health center.

In Fig. 1, an operative scenario of the public health center exhibits how to conduct secure data transactions in the blockchain-enabled health center system. Authorized health practitioners and consultants can access public health centers and provide necessary health advice using health data. This system will ensure security, scalability, privacy, and integrity while storing and making health records accessible through blockchain technology [8]. Blockchain executes computational tasks and data mining through smart contracts on the chain

*Corresponding Authors.

using the consensus algorithm. All instructions, block size, and block confirmation precisely restrains the space resources available and time for the smart contract. Each node collects public health records and performs data transactions sequentially. The verifiable data is stored in the chain of systems that support privacy-preserving, including high performance. In this way, health records can be stored on the blockchain by a medical practitioner or user, improving the interoperability issues of current health record systems. With this blockchain-based framework, health records can be protected from malicious misuse and tampering. Hence, the applicability of health data and various use cases, blockchain can produce tamper-proof records while maintaining data privacy.

The key contributions of this study can be synopsised as follows:

- This paper provides a health center data repository and sharing system based on blockchain technology.
- This paper equips a system workflow to develop the proposed system and provides sequence diagram.
- This paper designs an evaluation measurement setting and demonstrates the performance of the proposed system.

The leftover of this study is as follows. In Section II, this study introduces the related work. Section III discusses the entire proposed model with design. In Section IV, this paper confers the results and discussion of the experimental appraisal of the proposed model. Lastly, Section V concludes the presented work with the conclusion of this paper.

II. EXISTING RELATED WORK

This segment briefly discusses the current studies related to the present work. This paper here surveys existing blockchain-based safe data storage and secure record-sharing issues. Typically, in healthcare resources, traditional systems suffer from some complications when storing and exchanging data to securely integrate interconnected networks. A lot of scholars have suggested various approaches to health record information sharing where in some cases, access control, secure storage, confidentiality, scalability, and integrity of information have not been considered or are deficient.

Through its decentralized standards in the healthcare sector, blockchain can accurately formulate medical functionality to monitor primary clinical data of human life, share secure patient data, and protect data storage [9]. Yang and Li [10] suggested a blockchain-based EHR construction. This construction controls the misuse and tampering of Electronic Health Records by pursuing entire circumstances in the blockchain network. Bowman et al. [11] demonstrated an approach called Private Data Object (PDO) that facilitates reciprocally unreliable groups to conduct intelligent contracts on personal information employing Intel SGX. PDO uses the interpreter enclave, and it executes an intelligent agreement composed in the structure. Cheng et al. [12] presented a system named Ekiden that incorporates secrecy-preserving contracts into a blockchain-enabled Trusted Execution Environment (TEE) as a common framework. By exploiting a Proof-of-Publication protocol, Ekiden can sustain blockchain designs, including indecisive consensus that depends on authorized timers. In this

case, such a system may add certain runtime overhead, induce security concerns and indicate an outsized attack surface.

Kushch et al. [13] introduced a particular data structure as a blockchain tree for reserving health records in the blockchain. The blockchain tree is designed by one or additional patient identity records and a sub-chain. As the primary blocks of the sub-chain, this sub-chain holds more critical facts and blocks. Tanzila Saba et al. [14] proposed a protected and energy-efficient Internet of Medical Things (IoMT) framework for e-healthcare over a wireless body area network in clinics. Through this, necessary actions can be taken by tracing the health of remote patients and required monitoring of the data. Moreover, sensitive health records are likely to be disclosed due to biased energy-efficient data transfer and limited sensor capabilities. Ashutosh Sharma et al. [15] described a blockchain-based IoMT scheme with smart contracts for e-healthcare management, which is based on the preset code short script that will enrich agreement execution and eliminate intermediaries for delivering trust, security, and certification among its stakeholders.

D'Arienzo et al. [16] and Yu et al. [17] discoursed the benchmarking scheme named BLOCKBENCH for assessing the execution of private blockchain on behalf of required information processing workloads. This technique works on energy-efficient persistent data security and fault-tolerant storage systems. Zhang et al. [18] introduced a scheme named OpTrak that concentrated extensively on employing blockchain to deal with the U.S. opioid concern. The intent of this system was to permit direct control of records in an access control method for the prescription database to prevent overprescription. Fan et al. [19] offered a secure radio frequency identification (RFID) system based on a lightweight cloud authentication framework for IoT-based ecosystems. The system is constructed to perform at less computational power. Liu et al. [20] introduced a cloud-based scheme called CloudDTH constructed on digital twin medical care prescriptions. The scheme is developed to encourage the convergence and interaction of the digital twin in the medical sector based on various clinical procedures.

According to the aforementioned context, research in this sector has some general and authentication process problems which ignore resource-controlled transactions and the performance of health tasks. This paper offers possible solutions to maintain secure transactions and healthy data integrity. The proposed architecture can deliver optimal transaction times and low latency for different user nodes.

III. MATERIALS AND METHODS

This section presents a proposed determination based on blockchain technology to overcome the current complexity of storing sensitive records of public health centers, especially guaranteeing a safe healthcare process. It illustrates the coordination process of healthcare activities, sequence diagrams, and block-generated flow results.

A. Public Health Center Modeling using Blockchain

In this portion, this paper mainly presents a framework to enhance system performance for health centers to support the privacy, integrity, verifiability, and security of authorized health records, and it also introduces the workflow of the scheme.

Fig. 2 depicts a secure storage architecture for the health center using blockchain. The functions and methods used in a health center data security storage scheme based on blockchain and access control are expressed here. Constructing such a new blockchain-based secure data cloud architecture for any health center can meet the goals of executing high-performance, privacy, and integrity authorization frameworks. The security and scalability of health information in this model can produce satisfaction and rightfulness of data services among any clinic's stakeholders. This system will build stakeholders' confidence in the need to use blockchain-based secure and professional services in this sector. The key design concept and functions of this platform are based on the health data user or consultant, health center controller, and secure data repository.

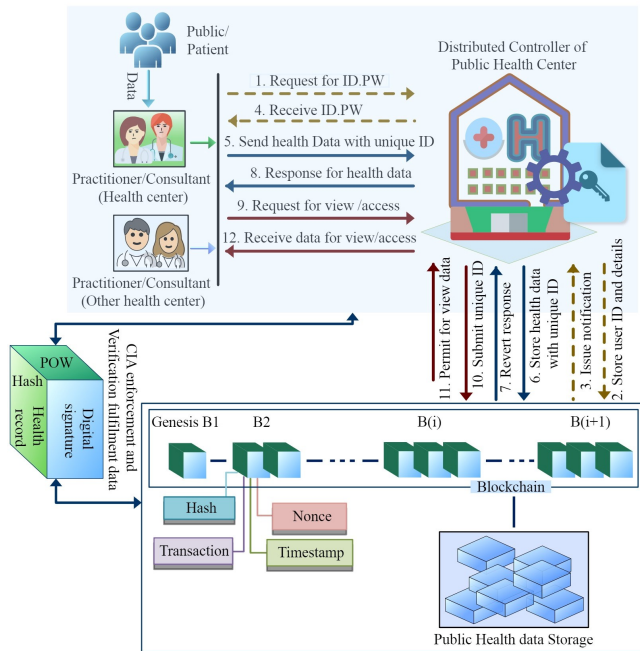


Fig. 2. Blockchain-based public health center model.

The functionality of the data user or consultant of the blockchain-based health center model is operated by the health center controller. The respective users or consultants perform the health care functions existing on this platform as data privacy-keepers. In this scheme, only relevant users or consultants can individually access health data and create or update health data smart contracts on the blockchain. Health data users or consultants collect all health information from patients or individuals under treatment and record it in the blockchain by generating public keys. Consultants can generate a set of private keys for each patient or individual's unique health record.

In this scheme, the health center controller initially allows respective health data users or consultants to generate their own unique identity to register. Then for registration at a health center, the controller issues a unique digital ID with a password individually to users or consultants through this framework. In this case, the Bcrypt algorithm is used to create the digital identity of users or consultants. All this information is stored in data storage. Then, registered authorized health

information users or consultants can access the blockchain network using their unique digital keys. In this case, verification and authentication processes must be followed to access the blockchain network. This framework can create a unique data identity for each patient or individual's unique health record. In a blockchain-based secure framework, accessing data from the database, such as adding, viewing, or sharing data, must communicate with the blockchain to ensure system confidentiality, security, and availability.

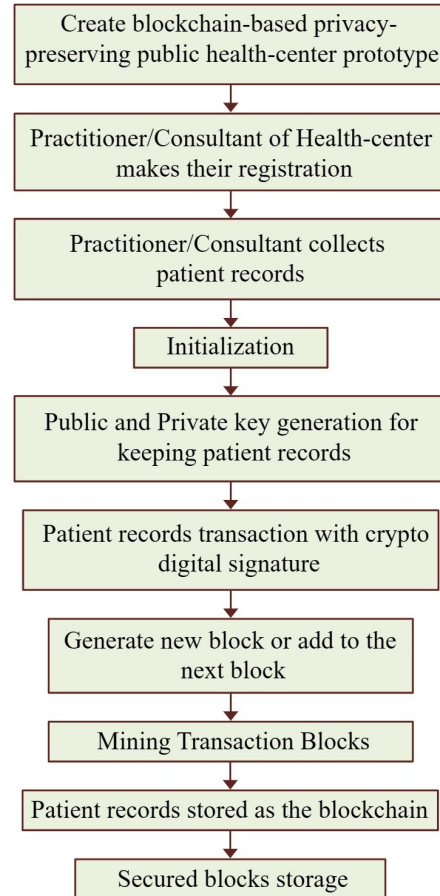


Fig. 3. Workflow for blockchain-based public health center system.

The blockchain network ensures the preservation, accuracy, and security of health records in the storage system through trusted and authorized user or consultant nodes. In this platform, health data is uploaded to the blockchain for immutable storage based on transaction signatures. Entire data is cross-referenced by generating the SHA-256 hash to securely store health data under integrity and confidentiality. PoW consensus policy is executed to conduct the full decentralization of health data in this blockchain network. Sequencing of each SHA256 hash inspects and verifies any tampering of transaction data by hash, nonce, timestamp, and encoding value. Transaction block history is effectively verified by miners. Otherwise, the data chain will logically be declared invalid if any kind of interruption is encountered.

The process of transmitting and receiving records is mentioned in public health center model. Users or consultants need to provide valid Identity (ID) and Password (PW) to access

the scheme of the health center. Through authentication, they can request the controller of the health center to access the blockchain storage. In this case, they can send encrypted health data to storage for accumulating purposes. If necessary, they can receive data from blockchain storage. When encrypted health data is stored in the block, a unique data identity (DID) will be generated for each patient or person under treatment. The controller supports storing or retrieving patient data in the database through DID. The workflow of the proposed system based on the blockchain technique is presented in Fig. 3. Each process and operation of building the approved blockchain-based health center model is manipulated. Based on this workflow, various functional interactions and functions of the user or consultant are programmed with the blockchain.

B. Coordination Process

As indicated by the proposed model, the distributed controller of the public health centers allows medical practitioners or consultants to access health data on the blockchain. It comprises practitioners or consultants as the user, distributed controller as the registration process and access task, and a blockchain ledger. Here the blockchain governs the highly distributed ledger to store various information about the health of the public or patients and to conduct timely transactions, to which only authorized participants to have access or permission. Participating network nodes are engaged in inputting, storing, viewing, and verifying different health data. The sequence diagram of the proposed model for user activities is illustrated in Fig. 4. This sequence diagram is designed to show the sequence of activities of the proposed model. The performing operations of this framework are briefly introduced as follows.

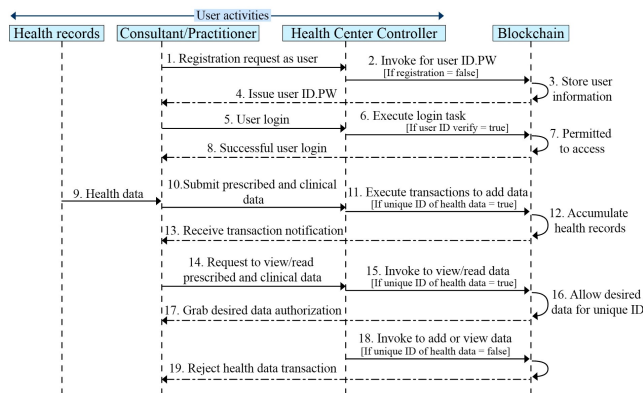


Fig. 4. Sequence diagram of user activities for blockchain-based public health center.

Step1: In this case, each medical practitioner or consultant sends a request for registration to the public health center controller with all their information. The health center controller receives all the information and verifies whether the doctors or consultants have already registered in the system. After verification, it takes the registration decision and invokes storing all user information in the blockchain. After storing the information of the doctors or consultants, the blockchain user login credentials and issues them a unique identity with a password through the distributed controller for login. Consultants

can successfully login into the system at any time through verification and get data access.

Step2: After login, each medical practitioners or consultant collects information from the public or patients and submits the prescribed and clinical data to the health center controller. The health center controller calls for creating unique identities of individual health information in the context of public or patient health information received from consultants. Blockchain produces and accumulates unique identities with hash-based values of individual health records. Only those consultants or doctors who have been permitted access rights to this blockchain platform can add or transact patient medical records. After publishing the health record in the blockchain, participants receive the confirmation notification of the data transaction.

Step3: Each medical doctor or consultant can interact with the blockchain through the health center controller to at look public health records. If each medical doctor or consultant wishes to view and read the prior health data from the blockchain, first, they need to login into the system using their unique identity with a password through the distributed controller. In this case, they must have unique identities of individual health information of their prescribed people or patient. Then, they use the unique identities of patients to request access to the public health center’s controller to view prior prescribing and clinical data. The health center controller receives their requests and verifies whether the unique identities of patients are already generated in the system. After verification, it allows to visit and read the pre-prescribed health information of the unique identity of those people from the blockchain. Finally, medical doctors or consultants get the opportunity and authorization to view and read the prior prescribed health information. The medical doctor can monitor the current health data along with the previous health information of the prescribed patient to make new prescriptions and add them to the data block of the system. But in this case, the blockchain system will reject the transaction to view the health data if it is found to be incorrect/false while verifying the unique identity of the patients collected by the doctors or consultants.

The various activities that take place between different actors for health data processing within the proposed platform, authorize combining blockchain technology with public health data. The sequence diagram norms of blockchain transaction process are depicted in Fig. 5. The sequence diagram of blockchain transaction process consists of medical practitioners or consultants, security enforcement and blockchain process. Medical doctors or consultants collect public or patient health records and interact with the blockchain to complete the transaction. Separate public key and private key pairs are generated by employing key generation algorithms to able health data processing within the proposed platform. This system randomly generates these keys.

The blockchain process includes hashing and signing algorithms to enforce robust security on health data. When a medical practitioner or consultant shares a patient’s health records with another, no assets are actually being sent to anyone. In this case, instead of sending data, the customer has to announce new data allocation by reallocating an amount of data to the blockchain. To reassign data, each data transaction

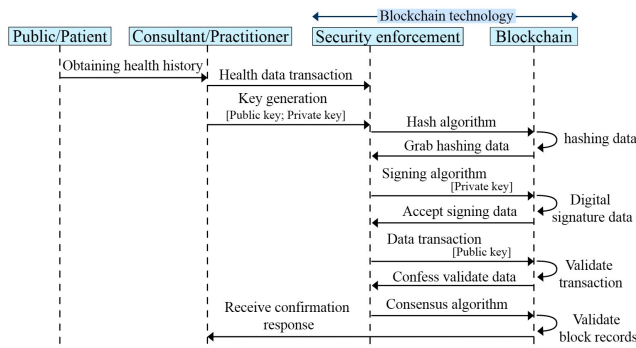


Fig. 5. Sequence diagram of blockchain transaction process.

must be signed by the sender's private key and verifiable using the sender's public key. Hash-256 function is used for data processing operations in this network. It retrieves health data by making a unique hash value while accessing health records through URLs in the web system.



Fig. 6. Consequence of block generated flow.

In addition, it allows user nodes to process health data within the platform to sign their transactions with private keys, and it can assure the integrity of stored data through verification to make secure share between the participants. As a PoW consensus algorithm, nodes select miners for the next block generation of the system and ensure continuity by synchronizing data. Due to the presence of this consensus procedure, the blockchain network achieves block record verification and reliability and establishes trust during data distribution. The consequence of block generated flow for data transactions on the blockchain after the mining process in this system are shown in Fig. 6. In this case, implementing RSA and SHA-256 in the system ensures the health data confidentiality of the blockchain storage and protects the published records. It also

delivers timely data to the blockchain repository and ensures maximum availability.

In the proposed model, it shows the process of generating the cryptographic hash SHA-256 associated with the data structure of the blockchain, which is an explicit means of enforcing data integrity. Blockchain's data structure forms a hierarchical set of blocks for secure access where the current block accumulates values such as hash, block transaction, timestamp, nonce, blockchain address, and so on. The blockchain's header holds the block number, and then the previous block's hash value provides the reliability of the transaction data chain. In this case, the block body can incorporate one or more transactions of health data.

Algorithm 1 Generate transaction key-pair

```

1: if health data user start transaction then
2:   procedure set(transactionKeyGenerate)
3:   RNG ← generate random(cryptographic value)
4:   Kpr ← generate(RSA(1024, RNG))
5:   Kpb ← Kpr · Kpb(i)
6:   decode in PEM, ascii (Kpr, Kpb)
7:   get Kpr, Kpb
8: else
9:   do nothing
10: end if
11: end procedure

```

The asymmetric cryptographic algorithm RSA PKCS is operated for digital signatures and transactional matters from a provable security perspective with the aim of establishing trust between users and cloud servers. Also, digital signature verifiability is checked using the Elliptic Curve Digital Signature Algorithm (ECDSA) from both the user side and server side for data security. Failing this verification on tampering and altered data values will automatically discard the adversary message. Due to two-party verifiability, the selected transaction is unable to forge signatures on the data and will not be authenticated as a legitimate user. The process facts of the generated transaction signatures relative to the user nodes are shown in the sequence diagram of the blockchain transaction process mentioned.

Algorithm 2 Digital signature generation for health data transaction

```

1: procedure signature(transaction)
2: if health data user Uh requests transaction T over BC then
3:   T ← makes T exclude sender's Kpr
4:   Kpr ← create RSA.key(sender's Kpr)
5:   Tsigner ← create crypto-sign.new(Kpr)
6:   H ← compute hash.encode(standard value)
7:   return Tsigner.sign(H).decode(ascii)
8: else
9:   not creating signature for T
10: end if
11: end procedure

```

When health practitioners and consultants desire to initiate public health data transactions in this platform, a key pair as a public key (K_{pb}) and a private key (K_{pr}) is generated, which is illustrated in Algorithm 1. Accordingly, the RSA technique is

utilized for public health data encryption or data decryption, and the PEM method is mapped with ASCII to decode the transactions. The process of digital signature generation during health data transactions is shown in Algorithm 2, which will ensure confidentiality while accessing data on the network.

Algorithm 3 Creating and Adding a new block for hash-based health data transactions

```
1: procedure createNewBlock(health data)
2: Initialize health transaction (empty set)
3: set in  $block \leftarrow (block_n, healthtransaction, nonce, timestamp, prehash)$ ;
4: if  $block_n \leftarrow len(chain) + 1$  then
5:   append the  $block$  for a new health transaction in  $chain$ ;
6:   re-set regarding the running  $transaction$ ;
7:   add health  $blocks$  to  $chain$ ;
8: end if
9: if  $block_s \leftarrow json.block.encode(standard\ value)$  as a file then
10:   $hash256 \leftarrow hash.new(SHA256)$ 
11:  update  $hash256.block_s$ 
12:  return encoded  $hash256$  in hexadecimal
13: else
14:  do nothing;
15: end if
16: end procedure
```

Algorithm 4 Append node to health blockchain network

```
1: procedure registration request(node)
2: if health data user request for a node then
3:   create a registration node
4: end if
5: Initialize parameters: ( $healthtransaction, chain, nodes, genesis_{block}$ )
6:  $urlNodeparse \leftarrow parse.urlNode$ 
7: if sets  $urlNodeparse.Netloc$  and  $urlNodeparse.path$ . then
8:   add  $urlNodeparse.Netloc$  and  $urlNodeparse.path$  to  $nodes$ ;
9:   append a new node to  $nodes$ ;
10: else
11:   not make to append;
12: end if
13: end procedure
```

The process of creating and adding a new block for hash-based health data transactions is exhibited in Algorithm 3. Here, block data transaction contains blockn, health transaction data, nonce, timestamp, and hash value which are important to ensure the integrity and immutability of public health records. In the blockchain-based public health center network, the process of adding the new node is introduced in Algorithm 4. This framework allows new nodes to be added to ensure transactions in a distributed or decentralized network. The procedure of accumulating and accessing public health-center data over the blockchain is ascertained in Algorithm 5. In this case, the digital signature process in the transactional health data is employed and verified by defining the PKCS1 standard based on the RSA technique. The Proof of Work method is performed to accomplish the valid proof conditions of mining requirements, and the health transaction records are validated

to share or access from one network node to another network node. The consensus Proof of Work process in the blockchain-based public health center system network will automatically adjust the number of new participating nodes and maintain the scalability of the network by speeding up the data transaction process. Finally, this model publishes the transactional data blocks of public health centers on the healthcare blockchain ledger.

Algorithm 5 Accumulating and accessing public health-center data over blockchain

```
1: procedure accumulating and publishing
2: Initialize transaction parameters for health data
3: generate health transaction block
4: verify digital transaction signature
5:  $K_{pb} \leftarrow RSA.sender's\ K_{pb}$ 
6:  $signverifier \leftarrow PKCS1.new(K_{pb})$ 
7:  $hash = SHA.new(health\ transaction.encode(utf8))$ 
8: verify( $hash$ , hex transaction Signature)
9: perform proof-of-work method
10: accomplish mining valid proof conditions
11: synchronise blockchain's nodes
12: check the health transaction blockchain is valid
13: transmit health data to transaction chain array
14: if verify transaction signature then
15:   transaction or share from one node to another node
16:   access health data
17: end if
18: end procedure
```

IV. RESULTS AND DISCUSSIONS

In this segment, this paper evaluates the performance of the presented secure storage management system with respect to user nodes for health centers using blockchain. The performance evaluation of this framework supports achieving the safety goals of the scheme. Experimental arrangement and qualitative analysis of this framework have been carried out to achieve data privacy and security objectives. It has been set a procedure evaluation environment to assemble the system demonstration and investigation using an Intel(R) Pentium(R) N5000 laptop (CPU -1.10GHz), x64-based processor, Windows 10, 4 GB RAM, 64-bit operating system. In the evaluation method, data access user or consultant node and blockchain node are embedded to investigate the underlying operations of the health scheme. To design the proposed model, it has been employed Python 3.9.0 (64-bit), Flask 1.1.1, and DevTools, including the web server gateway interface.

In order to evaluate and exhibit the health center's performance, multiple user or consultant nodes communicate with the blockchain server in this architecture. In this case, the average transaction time in milliseconds (ms) and latency in ms are evaluated for several data transactions on the blockchain by user nodes. In this case, the performance of each node is recorded by performing different data transmissions of this proposed system. In this scheme, it has been set nodes 1 to 5 to execute transactions. User nodes mine all transmitted blocks containing 1, 5, 10, and 15 transactions (T1, T5, T10, and T15) and propagate them to the blockchain-based public health center system. The specific results of the average transaction

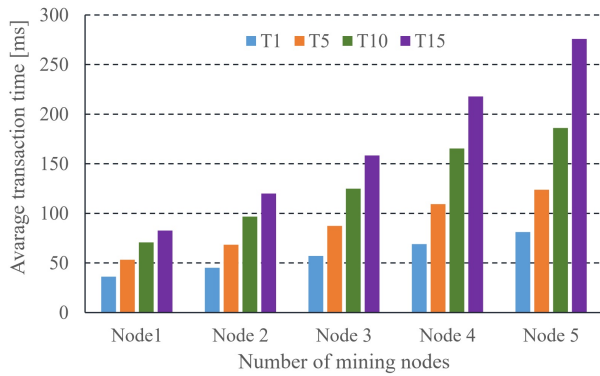


Fig. 7. Average transaction time for different user nodes.

time for different user nodes are shown in Fig. 7. As this test demonstration, by user or consultant node1, the health center scheme reaches 36.31 ms for T1 and 82.7 ms for T15. Again accordingly, by user node 5, the health center scheme reaches 81.11 ms for T1 and gradually reaches a maximum of 275.76 ms for T15. The corresponding average transaction time across network nodes is expected in this system for different block transactions.

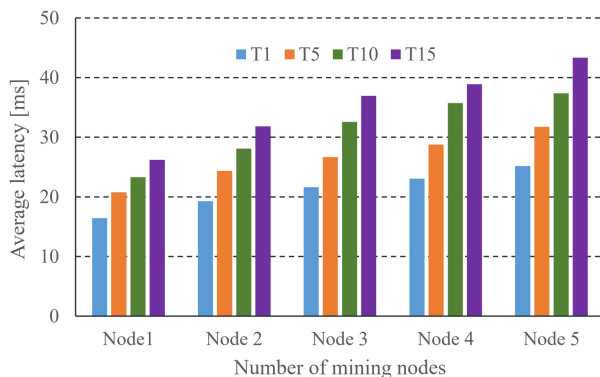


Fig. 8. Latency for different number of user nodes.

Next, it has been measured various transaction-based latencies across the setup nodes in this scheme. For this scheme, the precise consequences of latency for the different numbers of user nodes are shown in Fig. 8. As the work demonstration, it measures the latency of 16.42 ms through the user or consultant node1 for T1 to transmit and receive data block to the blockchain server. It also measures a latency of 26.21 ms for T15 using node 1. Moreover, for a capacity of user node5, the system observes a latency of 25.18 ms for T1 and a maximum latency of 43.35 ms for T15.

Finally, the overall performance induced by this scheme is analyzed by comparing the latency of several nodes. In this case, it sends and receives a data block for 10 transactions to each node in the blockchain server. It measures system latency under different nodes as a benchmark performance. The observation analysis of Latency per client node for publishing transactions between the native blockchain [21] and the proposed work is shown in Fig. 9. According to the exposition of this analysis, the latency of the proposed system compared

to the native blockchain is 23.7 ms for node 1. Accordingly, the latency of the proposed system is found to be 48.7 ms compared to the native blockchain for node 8. It can be observed that the proposed system exhibits the most promising consequences in terms of latency than the native blockchain. Therefore, it exposes relatively good scalability in health center data transactions.



Fig. 9. Comparative analysis of latency per client node for publishing transaction.

This paper exhibits the functionalities comparison of the presented scheme with some other existing works on blockchain-based data storage in Table 1. For this comparison, by using available (✓) and not available (×), This paper includes some different technical functionalities such as availability (A), Confidentiality (C), Integrity (I), server-side verifiability (SSV), and user-side verifiability (USV). However, most relevant schemes lack many other significant technical features that are not committed to securely storing health data. The comparison consequences exhibit that the mentioned structure accomplishes better than the recent systems and hence can afford an optimistic determination for enhancing existing health data storage applications.

TABLE I. FUNCTIONALITIES COMPARISON

Ref.	A	C	I	SSV	USV
[22]	×	✓	✓	×	×
[23]	✓	✓	✓	×	×
[24]	✓	×	✓	×	×
[25]	×	×	✓	×	×
[26]	×	×	✓	×	×
[27]	×	✓	✓	×	×
Our work	✓	✓	✓	✓	✓

V. CONCLUSION

Encouraged by the demand for health center digitalization, this paper designed a secure storage system for data management by deploying a privacy-preserving and performance-enhanced blockchain. In this study, a trusted access control strategy based on blockchain is designed to control user access to confirm secure and efficient health record sharing. The proposed system specifies functional units and follows a systematic process for blockchain-enabled decentralized data

repository and record sharing. This scheme may allow consultants or users to store data more securely than conventional schemes, particularly by ensuring confidentiality, availability, scalability, and integrity. Then, this work has exhibited the performance evaluation of the system by measuring the publishing transaction time cost and its latency on the blockchain employing different user nodes. Compared to traditional schemes, the presented framework can be a reliable and promising determinant in the health center industry towards efficient and secure management of health records. It may consume a significant amount of energy during data transactions and storage in the system, which is enough to raise environmental concerns and can be considered a system limitation. In future work, this work will extend and study this scheme toward auditing the metadata of the cloud storage.

ACKNOWLEDGMENT

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REFERENCES

- [1] M. Pourvahab and G. Ekbatanifard, "An efficient forensics architecture in software-defined networking-IoT using blockchain technology," *IEEE Access*, vol. 7, pp. 99573–99588, 2019.
- [2] S. Kim, "Two-phase cooperative bargaining game approach for shard-based blockchain consensus scheme," *IEEE Access*, vol. 7, pp. 127772–127780, 2019.
- [3] R. Srivastava and D. Prashar, "A Secure Block-chain Enabled Approach for E-Health-care System," In 2021 International Conference on Computing Sciences (ICCS) IEEE, pp. 194–201, 2021.
- [4] M. Hema Kumar, V. Mohanraj, Y. Suresh, J. Senthilkumar, and G. Nagalalli, "Real time two hop neighbour strategic secure routing with attribute specific blockchain encryption scheme for improved security in wireless sensor networks," *Int. J. Comput. Networks Appl.*, vol. 8, no. 4, pp. 300–310, 2021.
- [5] M.S. Islam, M.A.B. Ameen, M.A. Rahman, H. Ajra, and Z.B. Ismail, "Healthcare-Chain: Blockchain-Enabled Decentralized Trustworthy System in Healthcare Management Industry 4.0 with Cyber Safeguard," *Computers*, MDPI, vol. 12(2), pp.46, 2023.
- [6] K. M. S. Khan and S. S. Nisha, "BTDEC: Blockchain-Based Tribble Data Elliptic Curve Cryptosystem with Fine-Grained Access Control for Personal Data," *Int. J. Comput. Networks Appl.*, vol. 9, no. 2, pp. 214–228, 2022.
- [7] A. Johari and R. Alsaqour, "Blockchain-Based Model for Smart Home Network Security," *Int. J. Comput. Networks Appl.*, vol. 9, no. 4, pp. 497–509, 2022.
- [8] M.A. Rahman, M.S. Abuludun, L.X. Yuan, M.S. Islam and A.T. Asyhari, "EduChain: CIA-compliant blockchain for intelligent cyber defense of microservices in education industry 4.0," *IEEE Transactions on Industrial Informatics*, vol. 18(3), pp.1930-1938, 2021.
- [9] A. Khatoon, "A blockchain-based smart contract system for healthcare management," *Electron.*, vol. 9, no. 1, 2020.
- [10] G. Yang and C. Li, "A design of blockchain-based architecture for the security of electronic health record (EHR) systems," *Proc. Int. Conf. Cloud Comput. Technol. Sci. CloudCom*, vol. 2018-December, pp. 261–265, 2018.
- [11] M. Bowman, A. Miele, M. Steiner, and B. Vavala, "Private Data Objects: an Overview," *arXiv preprint arXiv:1807.05686*, 2018.
- [12] R. Cheng et al., "Ekiden: A platform for confidentiality-preserving, trustworthy, and performant smart contracts," *Proc. - 4th IEEE Eur. Symp. Secur. Privacy, EURO S P 2019*, pp. 185–200, 2019.
- [13] S. Kushch, S. Ranise, and G. Sciarretta, "Blockchain Tree for eHealth," *2019 IEEE Glob. Conf. Internet Things, GCIoT 2019, IEEE*, pp. 1-5, 2019.
- [14] T. Saba, K. Haseeb, I. Ahmed, and A. Rehman, "Secure and energy-efficient framework using Internet of Medical Things for e-healthcare," *J. Infect. Public Health*, vol. 13, no. 10, pp. 1567–1575, 2020.
- [15] A. Sharma, Sarishma, R. Tomar, N. Chilamkurti, and B. G. Kim, "Blockchain based smart contracts for internet of medical things in e-healthcare," *Electron.*, vol. 9, no. 10, pp. 1–14, 2020.
- [16] M. P. D'Arienzo, A. N. Dudin, S. A. Dudin, and R. Manzo, "Analysis of a retrial queue with group service of impatient customers," *J. Ambient Intell. Humaniz. Comput.*, vol. 11, no. 6, pp. 2591–2599, 2020.
- [17] X. Yu, Y. an Tan, Z. Sun, J. Liu, C. Liang, and Q. Zhang, "A fault-tolerant and energy-efficient continuous data protection system," *J. Ambient Intell. Humaniz. Comput.*, vol. 10, no. 8, pp. 2945–2954, 2019.
- [18] P. Zhang et al., "OpTrak: Tracking Opioid Prescriptions via Distributed Ledger Technology," *Int. J. Inf. Syst. Soc. Chang.*, vol. 10, no. 2, pp. 45–61, 2019.
- [19] K. Fan, S. Zhu, K. Zhang, H. Li, and Y. Yang, "A Lightweight Authentication Scheme for Cloud-Based RFID Healthcare Systems," *IEEE Netw.*, vol. 33, no. 2, pp. 44–49, 2019.
- [20] Y. Liu et al., "A Novel Cloud-Based Framework for the Elderly Healthcare Services Using Digital Twin," *IEEE Access*, vol. 7, pp. 49088–49101, 2019.
- [21] M. Brandenburger, C. Cachin, R. Kapitza, and A. Sorniotti, "Trusted computing meets blockchain: Rollback attacks and a solution for hyperledger fabric," In 2019 38th Symposium on Reliable Distributed Systems (SRDS), IEEE, pp. 324–32409, 2019.
- [22] Z. Ying, L. Wei, Q. Li, X. Liu, and J. Cui, "A Lightweight Policy Preserving EHR Sharing Scheme in the Cloud," *IEEE Access*, vol. 6, pp. 53698–53708, 2018.
- [23] H. Wang and Y. Song, "Secure Cloud-Based EHR System Using Attribute-Based Cryptosystem and Blockchain," *Journal of medical systems*, vol. 42, no. 8, pp. 152, 2018.
- [24] A. R. Lee, M. G. Kim, and I. K. Kim, "SHAREChain: Healthcare data sharing framework using Blockchain-registry and FHIR," *Proc. - 2019 IEEE Int. Conf. Bioinforma. Biomed. BIBM 2019*, pp. 1087–1090, 2019.
- [25] C. D. Parameswari and V. Mandadi, "Healthcare data protection based on blockchain using solidity", *Fourth World Conference on Smart Trends in Systems Security and Sustainability (WorldS4)*, IEEE, pp. 577-580, 2020.
- [26] N. Al Asad, MT. Elahi, A. Al Hasan and MA. Yousuf, "Permission-Based Blockchain with Proof of Authority for Secured Healthcare Data Sharing," in 2020 2nd International Conference on Advanced Information and Communication Technology (ICAICT) 2020 Nov 28, IEEE, Dhaka, Bangladesh, pp. 35–40, 2020.
- [27] V. Ramani, T. Kumar, A. Bracken, M. Liyanage, and M. Ylianttila, "Secure and Efficient Data Accessibility in Blockchain Based Healthcare Systems," *2018 IEEE Glob. Commun. Conf. GLOBECOM 2018 - Proc.*, 2018.

Video-based Heart Rate Estimation using Embedded Architectures

Hoda El Boussaki*, Rachid Latif, Amine Saddik

Laboratory of Systems Engineering and Information Technology LISTI
National School of Applied Sciences, Ibn Zohr University, Agadir 80000, Morocco

Abstract—Monitoring a driver’s heart rate is an important determinant to his health condition. The monitoring system must be accurate and non restrictive to the user’s actions. Estimating the driver’s change in his usual heart beat pattern can prevent undesirable outcomes. Several methods exist to estimate heart rate without any contact. In this paper, we are focusing on a method that uses remote photoplethysmography (rPPG). rPPG is a technique where heart rate is extracted from a PPG signal. The signal is extracted from the changes in blood flow that corresponds to the color variations recorded through an RGB camera. In this work, a different study that was based on an existing algorithm is presented to determine its processing time. The algorithm we proposed was divided into different global blocks and each block into different functional blocks (FBs). Though evaluating all the blocks’ processing time, it was possible to determine the most time consuming functional blocks. The results are implemented on different architectures: Desktop, Odroid XU4 and Jetson Nano to provide a higher performance.

Keywords—Heart rate; driver; photoplethysmography; non-contact; embedded architectures

I. INTRODUCTION

Monitoring Vital signs can be life saving. When it comes to driving, it could save the driver’s life as well as anyone who could be affected by a potential accident. People suffering from cardiovascular diseases (CVD), like cardiomyopathy or coronary heart disease (CHD), can become a danger to themselves and any passerby. A rapid heart rate and palpitations can also be caused by a low blood sugar. It can indicate a hypoglycemia for example. Therefore, heart rate is an indicator of several health conditions as it is the first response of the body to a threat. According to the world health organization, an estimated of 17.9 million people died from CVDs in 2019, representing 32% of all global deaths. Heart attacks and strokes were responsible for 85% of these deaths [1]. The death of a driver due to a disease attack is a reasonably common cause of death on the road [2]. As reported by the Center for Disease Control and Prevention (CDC), 1.35 million people are killed every year on the road around the world. Injuries on the road is the eight leading cause of death globally [3]. Therefore, a continuous heart rate monitoring in this context is of great importance as it can save lives.

Measuring heart rate usually requires an ECG that records the electrical heart activity caused by the repolarization and depolarization of the muscle [4], [5]. Different methods exist to estimate heart rate in vehicles. They can be divided into five types depending on what kind of system is used. There is the heart rate monitor integrated into the steering wheel, the seat, the rear-view mirror or the seat-belt or a heart rate monitor

using a camera. As an example, J. Priya et al. 2020 used a pulse sensor, GPS and GSM modules are combined to the steering wheel to assess the driver’s pulse rate in real time [6]. Using also a steering wheel, Arakawa et al. 2018 developed a system that measures heart rate through a transmitter and a red LED as a receiver [7]. S. Mitani 2018 developed an in-vehicle pulse sensor using the microwave sensor where the sensor is in the driver’s seat [8]. Texas instruments developed in 2019 the AWR1642 sensor placed on the rear-view mirror that estimates the heart rate of all the passengers [9]. There are also devices situated in the seat-belt as in the HARKEN concept [10]. Another method is to extract heart rate from the changes of hemoglobin concentration on the surface of the face captured by an RGB camera [11]. Y. lee et al. 2018 used Impulse-Radio Ultra-Wideband (IR-UWB) Radar Technology to monitor vital signs [12]. W. Lv et al. 2021 also used radar technology. They used a frequency-modulated continuous-wave (FMCW) Millimeter Wave Radar in the 120 GHz band [13].

In our work, we propose an algorithm that estimates heart rate through an RGB camera. It is divided into four parts. The first part focuses on the face detection and the forehead extraction. We used the box blurring filter, the edge sobel edge detection technique and morphological operations for face detection and the extraction of the region of interest. The second part extracts the raw signal by calculating the average of each of the channels (red, green and blue). The third part uses only the green channel of the image to estimate the final signal. The result is obtained by normalizing and denoising the signal and also using a detrending filter and a moving average filter. Finally, the fourth part calculates the heart rate based on a frequency analysis. The three latter parts were based on the work of P. rouast et al. 2016 [14]. The summary of our contribution is as follows:

- The proposition of a new algorithm for face detection and forehead extraction.
- The examination of the temporal constraints based on a Hardware/Software Co-Design approach.
- The evaluation of the algorithm on different embedded architectures.

The algorithm based on C/C++ was validated then was accelerated using OpenMP, MPI and CUDA. We chose a hybrid implementation of OpenMP or MPI and CUDA due to the requirements of the algorithm. CUDA uses NVIDIA’s Graphics Processing Unit (GPU) to achieve a higher performance time-wise. Using parallel programming gives better results than the naive implementation. We first tested the algorithm on a desktop, but the desktop is not adequate to monitor heart

rate when driving because of its size and power consumption. Therefore, we tried implementing the algorithm on embedded architectures such as Odroid XU4 and Jetson Nano.

This paper is structured as follows: Section I describes the recent works on contactless heart rate monitoring. Section II describes our methodology. Then, Section III highlights the results obtained by implementing the algorithm on different architectures. Finally, a conclusion summarizes this work and gives some future perspectives.

II. RELATED WORK

Various studies were made to estimate heart rate from an RGB camera. It was possible to monitor heart rate by monitoring the variation of the RGB colors of an image induced by the changes of blood flow in the capillaries. The signal extracted from those variations is known as a photoplethysmography (PPG) signal. The human skin is illuminated with a light source and a camera captures the variations of color [15]. The skin's RGB values change with time and are estimated through the reflection of the light [16]. There are two types of reflection: specular and diffuse as shown in Fig. 1. The reflection of a skin pixel is defined in Eq. 1 [16].

$$C_k(t) = I(t) \cdot (v_s(t) + v_d(t) + v_n(t)) \quad (1)$$

Where k is the k th pixel, $I(t)$ is the luminance intensity, $v_s(t)$ is the specular reflection that occurs on the surface, $v_d(t)$ is the diffuse reflection on the blood vessels and $v_n(t)$ is the noise.

The specular reflection is a mirror-like reflection and does not contain information of the pulse. It can be expressed in Eq. 2 [16].

$$v_s(t) = u_s \cdot (s_0 + s(t)) \quad (2)$$

Where u_s is the unit color vector of the light spectrum and s_0 and $s(t)$ are the stationary and changing parts of the specular reflection.

The diffuse reflection is related to the absorption of the light. It is defined in Eq. 3 [16].

$$v_d(t) = u_d \cdot d_0 + u_p \cdot p(t) \quad (3)$$

Where u_d is the unit color vector of the skin, d_0 is the stationary reflection, u_p is the relative strength of the pulse in the channels and $p(t)$ is the signal.

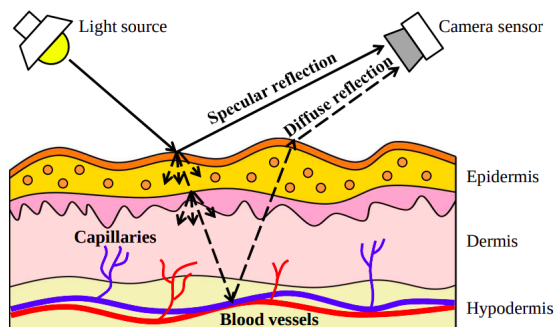


Fig. 1. Reflection of the light on the skin [16].

Different methods were proposed to extract the PPG signal like the green spectrum method where the signal is extracted

from the G channel only [17], the Blind source Separation-based (BSS) methods that uses all three channels [18], the CHROM technique that is chrominance-based [19], the Plane-Orthogonal-To-Skin (POS) that defines an orthogonal plane to a normalized skin [16] and the Spatial Subspace Rotation (2SR or SSR) that measures the rotation of the spatial subspace of the pixels [20].

H. Rahman et al. 2016 used an RGB camera to monitor heart rate [21]. They used an Independent Component Analysis (ICA) to extract the PPG signal and the Fast Fourier Transform to convert the signal to the frequency domain. M. A. Hassan et al. 2016 also used an RGB camera using only the green spectrum [22]. V. Jeanne et al. 2013 used an infrared camera instead of a regular RGB camera that requires certain light conditions [23]. Other methods for non-contact heart rate monitoring include radar systems. K. J. Lee et al. 2016 used continuous-wave Doppler Radar to estimation a driver's heart rate. The radar is installed in the seat. The emitted signal gets reflected and contains information about the heart activity. The spectral peak of the reflected signal represents the value of the heart rate. Instead of using a Fast Fourier Transform (FFT), they proposed a method using multiple signal classification (MUSIC) because the contamination of the signal caused by movement of the driver and the vehicle [24]. H. Xu et al. 2021 also used radar technology to estimate heart rate. They used an ultra-wideband (UWB) radar with a mean absolute error (MAE) of 1.32 [25].

This work focuses on the algorithm proposed by P. Rouast et al. 2016 [14]. They used the green spectrum method. The face is detected using the Viola-Jones algorithm as the first method and a deep neural network (dnn) as the second method. Then, it is captured by a camera in order to determine facial landmarks. After that, the forehead, where most of the blood vessels are concentrated, is selected as the region of interest. The average of each pixel color (Red, Green, Blue) of the region is measured over time to extract the PPG signal. Afterwards, the signal is filtered and its peaks are detected to estimate the heart rate. However, the processing time of their work is significant and needs improving. Furthermore, the face detection part is the most time consuming.

III. METHODOLOGY

Estimating heart rate is defined in this paper as a four steps methodology: face detection, raw signal extraction, signal filtering and heart rate estimation. Each step represents a block and every block is going to be divided into different functional blocks (FBs).

A. Face Detection

In this work, heart rate is being extracted from the face. The face is the most visible part on the body when a person is captured by a camera. And since the forehead is a surface that has a visible subcutaneous vascular structure, the forehead is the region of interest. Therefore, face detection is an important phase of the algorithm. Different methods exists to detect and track the face. The most used in contactless monitoring are machine learning based methods. They are capable of recognizing facial features through comparing them with an existing database. The main issue with these kind of methods

is that they are time-consuming. Consequently, we propose a different approach for face detection.

1) *Original approach:* The original algorithm on which this work was based used the Viola-Jones algorithm to detect the face. It's a haar classifier that is trained to detect faces. The OpenCV cascade classifier was used. Once the face is detected, the region of interest (ROI), known as the forehead, is selected. The algorithm can track faces and that means that it works when there is movement but it takes an important amount of time to be executed, approximately 1s. The Haar cascade uses Haar-like features represented by rectangles. Each rectangle is used to detect a region of the face [26]. These features help identifying where pixel intensity suddenly changes. The darker areas have a pixel value of 1 and the lighter areas have a pixel value of 0. When the difference of the sum of the first area's pixels and the sum of the second area's pixels is close to 1, then an edge was detected.

2) *First method:* The problem encountered in the beginning of this work is that a trained haar classifier cannot be accelerated using parallel computing to reduce its processing time as it is an OpenCV function. The first approach to this problem was to use a sequence of images instead of a video. The processing time decreased but was still significant. The second approach was to use a sequence of images, but instead of detecting the face for each images the region of interest is defined manually. The face is static and so is the ROI. If the ROI's emplacement in the image is known, it can be extracted without going through a trained classifier. The processing time of the ROI extraction using this method was 0,02 ms instead of 1s with a haar classifier.

3) *Second method:* The second method was proposed because of how limited is the previous one is. Even if the processing time is significantly low, it is not practical to manually set the ROI each time. This method works through three steps: image preprocessing, face identification and forehead extraction.

Fig. 2 represents the ROI extraction algorithm. The algorithm that represents the first block is divided into different functional blocks. In the first functional block, the RGB image is converted to grayscale and a box blurring filter is applied in order to apply to sobel filter. In the second functional block, the resulting image is converted to a binary image to be able to detect the contours. Once the contours are detected, in the third functional block, inside the contours is filled in white and morphological operations are applied. After that, in the last functional block the new contours are found to determine the top extreme point that represents the top of the head.

a) *Preprocessing:* In this step, the colored image is turned into a gray scale image because the edge detection technique works with gray scale images only. Then, the image is blurred. Fig. 3 represents the original image and Fig. 4 represents the grayscale image.

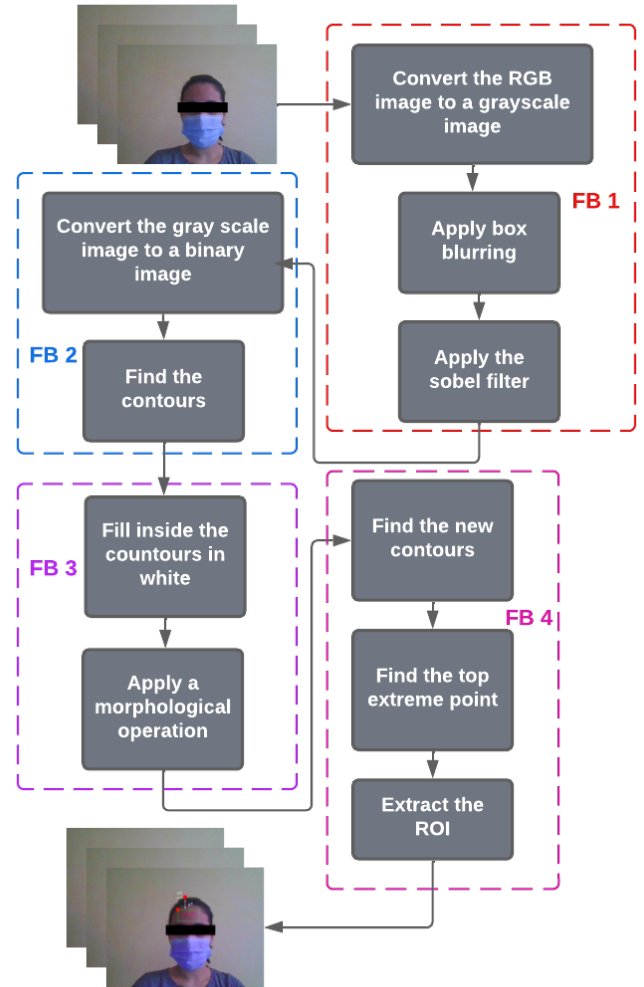


Fig. 2. ROI extraction (Block 1).



Fig. 3. Original image.



Fig. 4. Gray scale image.

Box blurring is a low-pass filter where an image's pixel has a value close to the average value of the pixels surrounding it. It allows the suppression of as much noise as possible. A 3x3 matrix K is applied on the image to blur it. The convolution technique is shown in Eq. 5. The center of matrix K corresponds in the image to the pixel's value that's going to change. The value is calculated by adding the product of each

neighboring value with the corresponding kernel's value.

$$K = \frac{1}{3 \times 3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \quad (4)$$

$$B = A \oplus K \quad (5)$$

Where A is the input image and B is the blurred image. The blurred image is obtained using Eq. 6 [27].

$$B(i, j) = A(i, j) \oplus K(i, j) = \sum_{m=0}^2 \sum_{n=0}^2 A(2, 2) F(i - m, j - n) \quad (6)$$

Where $0 \leq i, m \leq 2$ and $0 \leq j, n \leq 2$

b) Face identification: In order to detect the face, the sobel filter is used to detect the edges of the face by calculating the gradient of the image. According to Himani et al. 2020, the sobel filter is more precise and time-efficient than the canny filter [28]. The filter highlights the edges. It uses two 3x3 matrix Sx and Sy also known as convolution kernels or masks.

$$Sx = \begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix} \quad (7)$$

$$Sy = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \quad (8)$$

Sx is the horizontal mask used for the changes in the horizontal direction and Sy is the vertical mask used for the changes in the vertical direction. Sy is a rotation of the second kernel Sx by 90°. The kernels are applied separately on the image to produce separate calculations of the gradient component in each orientation [29].

$$Gx = Sx \oplus A \quad (9)$$

$$Gy = Sy \oplus A \quad (10)$$

Where A is the input image.

The separate gradients are combined to produce one image using Eq. 11.

$$G = \sqrt{Gx^2 + Gy^2} \quad (11)$$

An approximation of the combined gradients is given by Eq. 12.

$$G = Gx + Gy \quad (12)$$

The edges obtained are shown in Fig. 5.

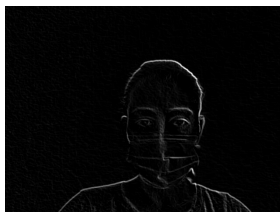


Fig. 5. Image filtered using sobel edge filter.

After using the sobel edge filter, a thresholding is applied on the filtered image. It converts the image from a gray scale one to a binary image. It's an OpenCV technique where a pixel's value becomes 0 if the initial value is smaller than the threshold, otherwise it becomes 255 which is the maximum value a pixel can have. It turns the edges completely white while the rest is black. This technique thickens the edges and make them more visible. Fig. 6 represents the image after using the thresholding technique.



Fig. 6. Image after using the thresholding technique.

Algorithm 1 describes how the sobel edge filter is performed.

Algorithm 1 Box blurring and sobel edge filter (FB1)

Input: Image

Output: Image after using the sobel filter

Function cvtcolor:

| GrayImage \leftarrow 0.299.R + 0.587.G + 0.114.B

Function blur:

| Create a 3x3 kernel

| Apply the kernel to the image

Create the horizontal mask Sx

Function filter2D:

| Compute correlation between Sx and the GrayImage

| Get Gx

Create the vertical mask Sy

Function filter2D:

| Compute correlation between Sy and the GrayImage

| Get Gy

G \leftarrow Gx + Gy

c) Forehead extraction: The first step to detect the forehead is to find the coordinates of the contours. They are found using the OpenCV function: findcontours. The function detects the sudden changes in the image's color. Once the change is detected, the coordinate are retrieved. The function implements an algorithm introduced in 1985 by S. Suzuki et al. [30].

When the contours are retrieved, it becomes possible to color the face in white with the OpenCV function fillpoly. Now, we want to delete the forms left on the background but also leave only the upper part of the face. For this purpose, a mathematical operation, known as an opening, is applied on the filled image to make the image more clear. The image contains small white filled forms that need to be removed, hence darkened. An opening is the process of applying erosion followed by dilatation on an image [31]. These two operations are achieved by using a 5x5 structuring element x on an image A as shown in the following formula.

$$B = (A \ominus x) \oplus x \quad (13)$$

Where the first operation represents the erosion and the second represents the dilatation.

The dilatation and erosion give a new binary image. In the dilatation, the pixel's value of image A is set to 1 when any of the neighboring pixels is equal to 1. Whereas in the erosion, the pixel's value of A is set to 0 when any of the neighboring pixels is equal to 0.

Now that only some parts of the image are left and the forehead is very visible, it is possible to detect the forehead by finding the top extreme point on the image which is the top of the head.

In order to find the coordinates of the top extreme point, we apply the OpenCV function findcontours. The use of this function for a second time gives us the new contour's values because the image have been modified. Then, a loop is used to compare between all the new coordinates of the contours to find the top point. Algorithm 2 describes these steps.

Algorithm 2 Finding the top extreme point (FB4).

```

Input: Image after using the opening operation
Output: The Top extreme point
Function findcontours:
| Retrieve the contours from the image
Create a point Top
for  $i = 0$  to  $Contours.size()$  do
| Create a point P
| Create a vector NewContours
|  $NewContours \leftarrow Contours[i]$ 
| for  $j = 0$  to  $NewContours.size()$  do
| | Create a point CurrentP
| |  $CurrentP \leftarrow NewContours[j]$ 
| | if  $y$  coordinate of  $CurrentP$  ;  $y$  coordinate of  $P$  then
| | |  $P \leftarrow CurrentP$ 
| | end
| end
|  $Top \leftarrow P$ 
end
    
```

The top extreme point is represented in red in Fig. 7. The last step is to subtract a value $x1$ to the x coordinate of the top point and add a value $y1$ to the y coordinate. It allows us to get an ROI that starts from these new coordinates a little below the top of the head where the forehead is situated. Fig. 8 represents this step.



Fig. 7. The Top extreme point on the original image



Fig. 8. Roi extraction.

B. Raw Signal Extraction

The raw signal is extracted from the image by using a function that calculates the average of each channel's pixels. An image contains 3 channels: red, green and blue. The average of each channel is added to the signal. And, for every frame, new values are added to it. At this stage, the signal represents the changes of the pixel's values from one frame to another. Fig. 9 represents the raw signal extraction algorithm.

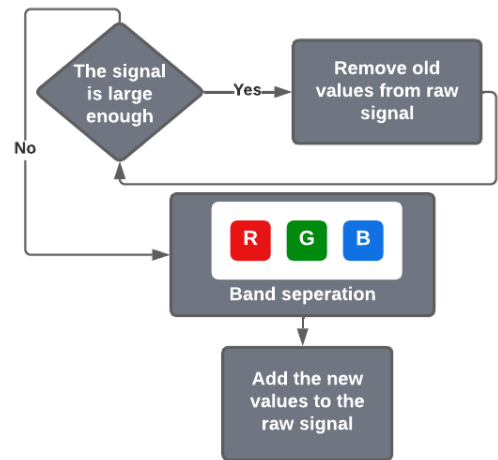


Fig. 9. Raw signal extraction (Block 2).

C. Signal Filtering

Different methods exist to obtain the final signal. After extracting the average of each channel, only the green channel is left. W. Verkruyssen et al. 2008 explained that the green channel contains the most information about a PPG signal. The main reason for that is the better absorption of green light than red and blue by hemoglobin [32]. Fig. 10 represents the signal filtering algorithm which represents the second block of the algorithm.

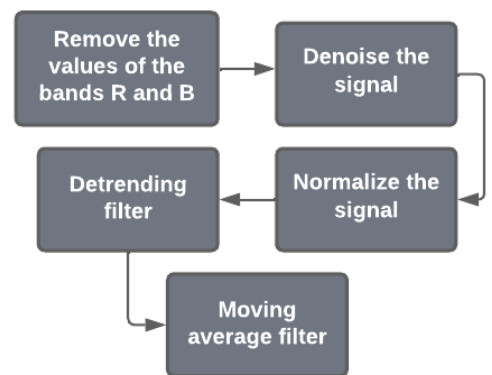


Fig. 10. Signal filtering (Block 3).

This block is executed only if the signal is large enough. There is enough data after exactly 35 frames. The block, represented in Fig. 11, contains four steps. First, a filter is used to remove unwanted spikes from the signal. Then, normalize the signal and apply a high pass and a low pass filter to cut off low and high frequencies corresponding to 0.7 and 3 Hz [33]. These frequencies are generally caused by noise and sudden light change. P. rouast et al. 2016 used detrending filter as an equivalent to the high pass filter and a moving average filter as an equivalent to the low pass filter.

D. Heart Rate Estimation

The HR is measured using a frequency analysis. This block remained the same as the original algorithm and is executed only if the signal is large enough. In this case, the discrete Fourier transform (DFT) is used. The heart rate is calculated with Eq. 14.

$$BPM = (MaxFr * fps * 60) / Size \quad (14)$$

Where:

MaxFr is the maximum frequency

fps is the number of frames per second

Size is the size of the signal

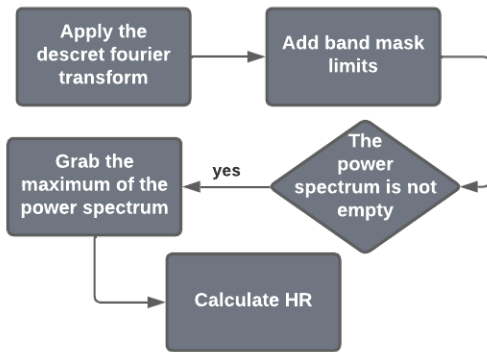


Fig. 11. Heart rate estimation (Block 4).

IV. HARDWARE AND SOFTWARE RESULTS

The algorithm was first validated using the C/C++ language. Then, in order to achieve better results in term of time consumption, we separated the algorithm into four blocks, each with a specific function. This step was essential to estimate the processing time of the blocks and to determine the blocks that consume the most. The first block is for face detection and forehead extraction, the second is for the raw signal extraction, the third is for signal filtering and finally the fourth block calculates the heart rate. In our case, the first block was the most consuming, hence its separation into four functional blocks. The second temporal evaluation on the algorithm revealed that the first functional block (FB1) takes most of the block's processing time.

A. System Specification

This work was implemented on an Intel i7-1165G7 desktop that has a NVIDIA GeForce MX330 GPU based on a Pascal architecture and that supports CUDA. It was also implemented on two different embedded architectures: Odroid XU4 and NVIDIA Jetson Nano. The Odroid XU4 has an exynos 5422 processor, an ARM A15 CPU with 2 Ghz and an ARM A7 with 1.4 Ghz. Finally, the NVIDIA Jetson Nano has an ARM A57 CPU with 1.43 Ghz and a Maxwell based GPU. Table I represents the systems' specifications.

TABLE I. SPECIFICATION OF THE SYSTEMS USED

Type	Desktop	Odroid XU4	Jetson Nano
Processor	11th Gen Intel Core™	Exynos 5422	Tegra SoC
CPU	Intel i7	ARM Cortex A15/A7	ARM A57
GPU	NVIDIA GeForce MX330	Advanced Mali	Nvidia Maxwell
Support language	C/MPI/OpenMP/Cuda/OpenCL	C/MPI/OpenMP/OpenCL	C/MPI/OpenMP/Cuda
Frequency	2.8GHz	2GHz/1.4GHz	1.43Ghz
Weight	1,78kg	60g	136G
Energy	90W	5W	10W

B. Sequential Implementation of the Algorithm

The algorithm was implemented on each of the different architectures based on the C/C++ language. It contains four blocks and the processing time of each block was calculated. Table II summarizes the time evaluation.

TABLE II. PROCESSING TIME OF EACH BLOCK

Blocks	Desktop	Odroid XU4	Jetson Nano
B1	50,41 ms	503,21 ms	16,56 ms
B2	0.51 ms	0.52 ms	0.033 ms
B3	0.86 ms	2.22 ms	0.1 ms
B4	0.52 ms	0.5 ms	0.07 ms
Total	52.3 ms	506.45 ms	17.39 ms

The time evaluation in Table II shows that the Jetson Nano consumes the less when compared to the other architectures with a global processing time of 16.76 ms. The desktop consumes 52.3 ms and the Odroid XU4 consumes 506.45 ms. Fig. 12 to 15 represent the processing time of block 1 to block 4 respectively on three different architectures. The Jetson Nano has a lower processing time for all blocks. Block 1 consumes the most for all architectures. For that reason, the functional blocks of Block 1 are going to be evaluated. Block 1 is about 50.41 ms for the desktop, 503.21 ms for the Odroid XU4 and 16.56 ms for the Jetson Nano. The next step is to evaluate

the processing time of the functional blocks of B1 and use OpenMP, MPI and CUDA in order to accelerate the global processing time of the algorithm.

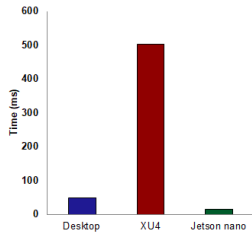


Fig. 12. Processing Time of Block 1.

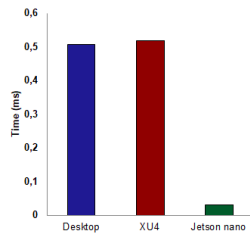


Fig. 13. Processing Time of Block 2.

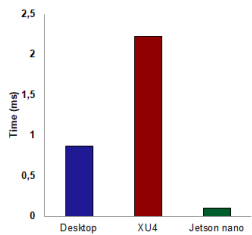


Fig. 14. Processing Time of Block 3.

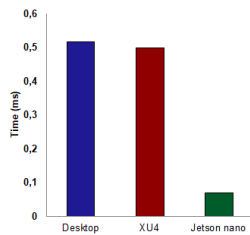


Fig. 15. Processing Time of Block 4.

C. OpenMP and MPI based Implementation

In this, we are going to use both OpenMP and MPI to accelerate the algorithm and determine which one gives better results. However, the main issue we encountered is the difficulty of accelerating the first block using directives. The reason for that is the fact that Block 1 contains mainly OpenCV functions, we couldn't reduce its processing time using OpenMP and MPI. OpenMP and MPI directives wouldn't be effective. On the contrary the processing time increased. Therefore, the implementation of the algorithm using OpenMP and MPI was done only on Blocks 2, 3 and 4. Table III represents the processing time of blocks 2, 3 and 4 with OpenMP and MPI.

The temporal evaluation in Fig. 16 represents the processing time of Block 2, Block 3 and Block 4 with C/C++, OpenMP and MPI implemented on the desktop. It shows better results with MPI as the time is significantly lower than with OpenMP and even more when compared with C/C++. MPI is 6.2 times faster than OpenMP for Block 2, 2.2 times faster for Block 3 and Block 4. Fig. 17 and 18 represent the comparison between the processing time of same blocks using C/C++, OpenMP and MPI but implemented on Odroid XU4 and Jetson Nano.

TABLE III. PROCESSING TIME OF EACH BLOCK WITH OPENMP AND MPI

Blocks	Desktop	Odroid XU4	Jetson Nano
OpenMP			
B2	0.42 ms	0.52 ms	0.03 ms
B3	0.28 ms	1.55 ms	0.092 ms
B4	0.27 ms	0.31 ms	0.067 ms
Total	1.24 ms	2.38 ms	0.19 ms
MPI			
B2	0.069 ms	0.59 ms	0.03 ms
B3	0.12 ms	2.037 ms	0.093 ms
B4	0.12 ms	0.34 ms	0.067 ms
Total	0.31 ms	2.97 ms	0.19 ms

For the Odroid XU4, the results show a nearly same processing time for Block 2. OpenMP was found to be 1.4 times faster for Block 3 and 1.6 times faster for Block 4. MPI was found to be 1.1 times faster for Block 3 and 1.4 times faster for Block 4. This concludes that OpenMP shows a better result than MPI on XU4 with an improvement in global processing time of all the blocks of x1.4 for OpenMP and x1.1 for MPI. In regards to the Jetson Nano, the results show the same results for OpenMP and MPI. However, MPI shows a better result on the desktop with an improvement in global processing time of x6 when OpenMP shows an improvement of x2.

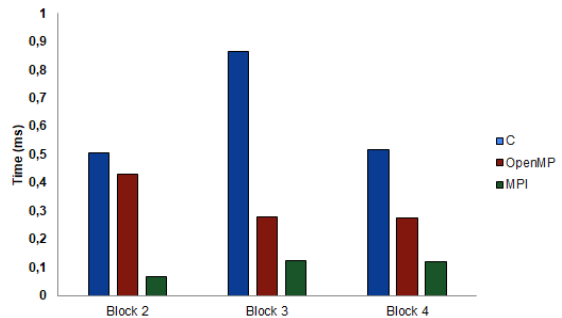


Fig. 16. Improved processing time on desktop.

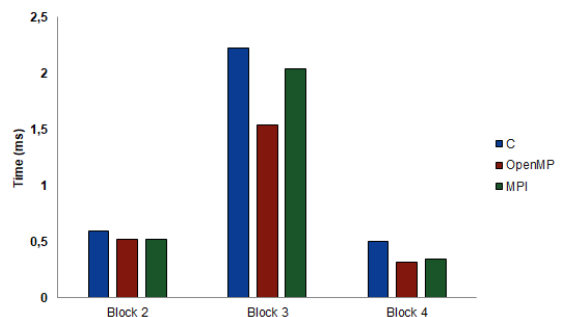


Fig. 17. Improved processing time on Odroid XU4.

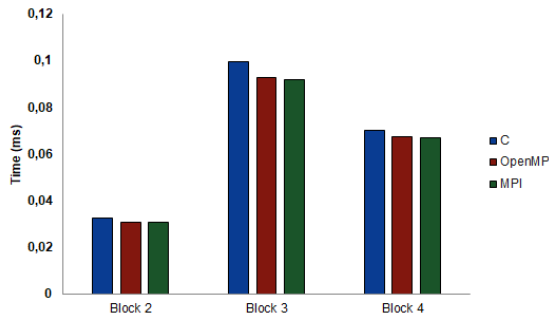


Fig. 18. Improved processing time on Jetson Nano.

D. Cuda based Implementation

In this part, we focused only on the first block. Block 1 was divided into five functional blocks (FBs) as previously shown in Fig. 2. Since we couldn't improve its processing time using OpenMP or MPI, we opted for CUDA to exploit the advantages of a GPU. Table IV represents the processing time of the four different functional blocks of Block 1 on the desktop and the Jetson Nano.

TABLE IV. PROCESSING TIME OF B1'S FUNCTIONAL BLOCKS

Blocks	Desktop	Jetson Nano
FB1	23,21 ms	7,56 ms
FB2	9,8 ms	2,47 ms
FB3	7,41 ms	5,23 ms
FB4	3,07 ms	1,18 ms

For both the desktop and the Jetson Nano, the first functional block is the most consuming. FB1 consumes a time of 23,21 ms for the desktop and 7,56 ms for the Jetson Nano. Consequently, FB1 will be accelerated using CUDA. Fig. 19 summarizes the processing times of the different functional blocks.

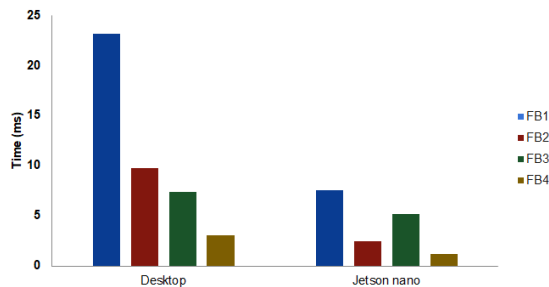


Fig. 19. Processing time of the different functional blocks of B1 in desktop and Jetson Nano.

FB1 contains three sub-blocks (SBs). The first one converts an image from RGB to grayscale, it takes an average of 5.12 ms for the desktop and 1.25 ms for the Jetson Nano. The second applies a blurring filter with an average of 3.6 ms for the desktop and 1 ms for the Jetson Nano. The last sub-block filters the image using a sobel filter and takes 14.49 ms for

the desktop and 5.3 ms for the Jetson Nano. We then opted to accelerate the first and the last sub-blocks as shown in Fig. 20 for both architectures.

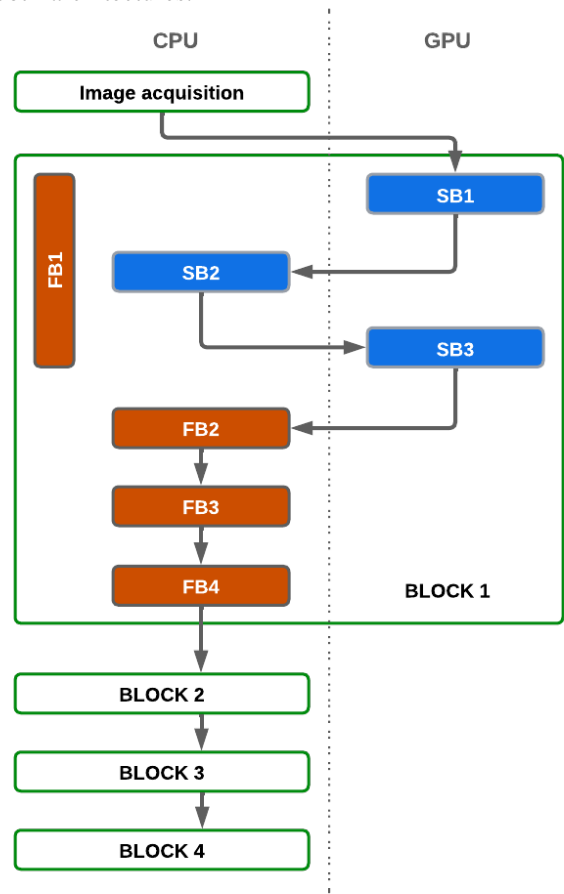


Fig. 20. CPU-GPU implementation based on CUDA.

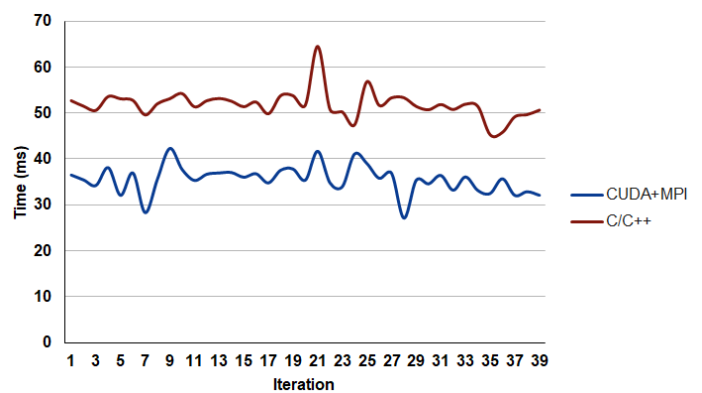


Fig. 21. Improved global processing time on desktop.

Fig. 21 shows the improved global processing of the algorithm on the desktop and Fig. 22 shows the improved global processing on the Jetson Nano. We obtained an average improved time 35.54 ms for the desktop, hence an overall improvement of x 1.5. For the Jetson Nano, we achieved an improved time of 12.7 ms which is 1.32 times faster. We

used a hybrid implementation of CUDA for the first block and OpenMP/MPI for the other three blocks.

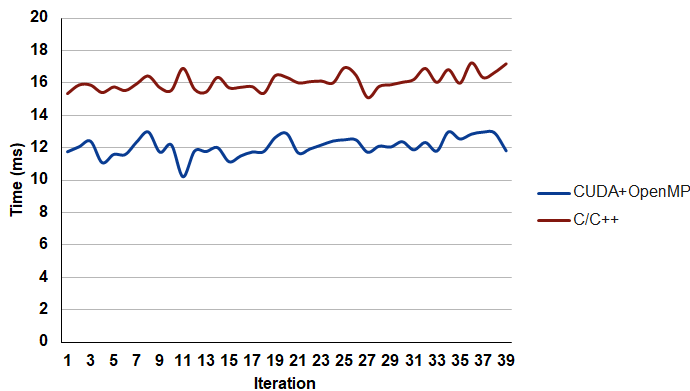


Fig. 22. Improved global processing time on Jetson Nano.

V. CONCLUSION

In this paper, a non contact heart rate monitoring algorithm is proposed to measure the driver's heart rate. The algorithm was studied to be implemented on different architectures such as Odroid XU4 and Jetson Nano. The time evaluation of the C/C++ implementation showed better results on the Jetson Nano than the other architectures. We were able to exploit the advantages that presents a Nvidia GPU in CPU-GPU architectures by using CUDA. A hardware/software co-design approach was implemented and showed that the Jetson Nano remains the best choice. The sequential implementation consumes a lot of time. Hence, it is not real-time. For this reason, an acceleration of the algorithm was proposed. The acceleration is based on OpenMP, MPI and CUDA on the different architectures used. Future works consist of improving the face detection algorithm when there is movement and further accelerating the algorithm based on CUDA.

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REFERENCES

- [1] World health organisation Homepage [Online] Retrieved 2022-06-15 from <https://www.who.int>.
- [2] T. Tervo, E. Rätty, P. Sulander, J. M. Holopainen, T. Jaakkola, and K. Parkkari, "Sudden death at the wheel due to a disease attack," *Sudden death at the wheel due to a disease attack*, 14(2), pp.138-144, 2013.
- [3] Road Traffic Injuries and Deaths—A Global Problem. (2020, December 14). Centers for Disease Control and Prevention. Retrieved October 12, 2022, from <https://www.cdc.gov/injury/features/global-road-safety/index.html>
- [4] S. Mejhoudi, R. Latif, W. Jenkal, A. Saddik, and A. Elouardi, "Hardware Architecture for Adaptive Dual Threshold Filter and Discrete Wavelet Transform based ECG Signal Denoising," *International Journal of Advanced Computer Science and Applications*, 12(11), 2021.
- [5] S. Mejhoudi, R. Latif, A. Saddik, W. Jenkal, and A. Elouardi, "Speeding up an Adaptive Filter based ECG Signal Pre-processing on Embedded Architectures," *International Journal of Advanced Computer Science and Applications*, 12(5), 2021.

- [6] J. Priya, T. S. Reshmi, and M. Gunasekaran, "Smart Steering Wheel for Real-Time Heart Rate Monitoring of Drivers," *International Journal of Innovative Technology and Exploring Engineering*, 9(4), pp.3040–3043, 2020.
- [7] T. Arakawa, N. Sakakibara, and S. Kondo, "Development of Non-Invasive Steering-Type Blood Pressure Sensor for Driver State Detection," *Int. J. Innov. Comput. Inf. Control*, 14, pp.1301–1310, 2018.
- [8] OMRON, Development of the in-vehicle pulse sensor [Online] Retrieved 2022-06-15 from <https://www.omron.com/global/en/assets/file/technology/omrontechnics/vol50/OMT\verb|\Vol50\verb|\006.pdf>
- [9] TEXAS INSTRUMENTS, Using TI mmWave Sensors for Heart-Rate Monitoring [Online] Retrieved 2022-06-15 from <https://e2e.ti.com/blogs\verb|\b/behind\verb|\the\verb|\wheel/posts/ti-mmwave-technology-for-car-interior-sensing>.
- [10] HARKEN [Online] Retrieved 2022-06-15 from <https://harken.ibv.org/index.php/about>
- [11] G. Okada, T. Yonezawa, K. Kurita, and N. Tsumura, "Monitoring Emotion by Remote Measurement of Physiological Signals Using an RGB Camera," *ITE Trans. MTA*, 6, pp.131–137, 2018.
- [12] Y. Lee, J.Y. Park, and Y.W. Choi, "A Novel Non-contact Heart Rate Monitor Using Impulse-Radio Ultra-Wideband (IR-UWB) Radar Technology," *Sci Rep* 8, 13053, 2018.
- [13] W. Lv, W. He, X. Lin, and J. Miao, "Non-Contact Monitoring of Human Vital Signs Using FMCW Millimeter Wave Radar in the 120 GHz Band," *Sensors (Basel, Switzerland)*, 21(8), 2732, 2021.
- [14] P. V. Rouast, M. T. P. Adam, R. Chiong, D. Cornforth, and E. Lux, "Remote heart rate measurement using low-cost RGB face video: a technical literature review," *Frontiers of Computer Science*, 12(5), pp.858-872, 2018.
- [15] A. Bella, R. Latif, A. Saddik, and F. Z. Guerrouj, "Monitoring of Physiological Signs and Their Impact on The Covid-19 Pandemic: Review," *E3S Web of Conferences*, 229, 01030, 2021.
- [16] W. Wang, A. C. den Brinker, S. Stuijk, and G. de Haan, "Algorithmic Principles of Remote PPG," *IEEE Transactions on Biomedical Engineering*, 64(7), pp.1479–1491, 2017.
- [17] T. Ysehak Abay, K. Shafqat, and P. A. Kyriacou, "Perfusion Changes at the Forehead Measured by Photoplethysmography during a Head-Down Tilt Protocol," *Biosensors*, 9(2), 71, 2019.
- [18] R. H. Goudarzi, S. Somayyeh Mousavi, and M. Charimi, "Using imaging Photoplethysmography (iPPG) Signal for Blood Pressure Estimation," *2020 International Conference on Machine Vision and Image Processing (MVIP)*, 2020.
- [19] G. De Haan, and V. Jeanne, "Robust Pulse Rate From Chrominance-Based rPPG," *IEEE Transactions on Biomedical Engineering*, 60(10), pp.2878-2886, 2013.
- [20] W. Wang, S. Stuijk, G. de Haan, "A Novel Algorithm for Remote Photoplethysmography: Spatial Subspace Rotation," *IEEE Transactions on Biomedical Engineering*, 63(9), pp.1974–1984, 2016.
- [21] H. Rahman, M. U. Ahmed, S. Begum, and P. Funk, "Real Time Heart Rate Monitoring from Facial RGB Color Video using Webcam," *The 29th Annual Workshop of the Swedish Artificial Intelligence Society SAIS 2016*, 129.
- [22] M. K. Hassan, A. B. Malik, D. Fofi, N. M. Saad, and F. Meriaudeau, "Novel health monitoring method using an RGB camera," *Biomedical Optics Express*, 8(11), 4838, 2017.
- [23] V. Jeanne, M. Asselman, B. den Brinker and M. Bulut, "Camera-based heart rate monitoring in highly dynamic light conditions," *2013 International Conference on Connected Vehicles and Expo (ICCVE)*, Las Vegas, NV, USA, pp. 798-799, 2013.
- [24] K. Y. Lee, C. Park, and B. Lee, "Tracking driver's heart rate by continuous-wave Doppler radar," *International Conference of the IEEE Engineering in Medicine and Biology Society*, 2016.
- [25] H. Xu, M.P. Ebrahim, K. Hasan, F. Heydari, P. Howley, and M.R. Yuce, "Accurate Heart Rate and Respiration Rate Detection Based on a Higher-Order Harmonics Peak Selection Method Using Radar Non-Contact Sensors," *Sensors* 2022, 22, 83.
- [26] A. B. Shetty, Bhoomika, Deeksha, J. Rebeiro, and Ramyashree, "Facial recognition using Haar cascade and LBP classifiers," *Global Transitions Proceedings*, 2(2), pp.330–335, 2021. <https://doi.org/10.1016/j.gltp.2021.08.044>

- [27] A. Saddik, R. Latif, A. Elouardi, M. A. Alghamdi, and M. Elhoseny, "Improving Sustainable Vegetation Indices Processing on Low-Cost Architectures," *Sustainability*, 2022.
- [28] H. Rana, and H. Sirohia, "Comparative Study Between Canny and Sobel Edge Detection Techniques," 2022.
- [29] X. J. Jiang, and P. J. Scott, "Characterization of free-form structured surfaces," *Advanced Metrology*, pp.281–317, 2020.
- [30] S.Suzuki, and K. be, "Topological structural analysis of digitized binary images by border following," *Computer Vision, Graphics, and Image Processing*, 30(1), pp.32–46, 1985.
- [31] A. M. S. Khairul, and B. J. Asral, "A study of image processing using morphological opening and closing processes," *International Journal of Control Theory and Applications*, 9, pp.15-21, 2016.
- [32] W. Verkruysse, L. O. Svaasand, J. S. Nelson, "Remote plethysmographic imaging using ambient light," *Optics Express*, 16(26), 21434, 2008.
- [33] A. Saddik, R. Latif, and A. Bella, "ECG signal monitoring based on Covid-19 patients: Overview," *Journal of Intelligent Systems and Internet of Things*, Vol. 2 , No. 2 , pp.45-54, 2021.

Prediction of Death Counts Based on Short-term Mortality Fluctuations Data Series using Multi-output Regression Models

Md Imtiaz Ahmed*, Nurjahan[†], Md. Mahbub-Or-Rashid[‡], and Farhana Islam[§]

*Department of Computer Science and Engineering, Prime University

[†]Department of Internet of Things and Robotics Engineering, Bangabandhu Sheikh Mujibur Rahman Digital University, Bangladesh

[‡]Department of Computer Science and Engineering, Bangladesh University of Business and Technology

[§]Department of Educational Technology, Bangabandhu Sheikh Mujibur Rahman Digital University, Bangladesh

Abstract—Effective public health responses to unexpected epidemiological hazards or disasters need rapid and reliable monitoring. But, monitoring fast-changing situations and acquiring timely, accurate, and cross-national statistics to address short-term mortality fluctuations due to these hazards is very challenging. Estimating weekly excess deaths is the most solid and accurate way to measure the mortality burden caused by short-term risk factors. The Short-term Mortality Fluctuations (STMF) data series is one of the significant collections of the Human Mortality Database (HMD) that provides the weekly death counts and rates by age and sex of a country. Sometimes, the data collected from the sources are not always represented in specific age groups rather represented by the the total number of individual death records per week. However, the researchers reclassified their dataset based on the ranges of age and sex distributions of every country so that one can easily find out how many people died in per week of each country based on an equation and earlier distribution data. The paper focuses on the implementation of multi-output regression models such as logistic regression, decision tree, random forest, k nearest neighbors, lasso, support vector regressor, artificial neural network, and recurrent neural network to correctly predict death counts for specific age groups. According to the results, random forest delivered the highest performance with an R squared coefficient value of 0.9975, root mean square error of 43.2263, and mean absolute error of 16.4069.

Keywords—Multi-output regression model; short-term mortality fluctuations; machine learning; deep learning

I. INTRODUCTION

In the past few years, there have been many outbreaks of natural or man-made hazards which eventually turned into a pandemic situation. For instance, influenza outbreaks in 2014–15, 2016–17, and 2017–18, as well as the recent COVID-19 pandemic. These hazards induced significant increases in short-term mortality in several countries [1]. Accurate and statistical data is important to analyze the mortality rates and to provide an immediate response to short-term health concerns for reducing life loss. However, the recent COVID-19 pandemic pointed out the scarcity of reliable, accurate, and comparable international data required to track the spread of epidemics [2]. In May 2020, the Human Mortality Database (HMD, [3]) team released the Short-term Mortality Fluctuations (STMF) data series to meet the increasing need for such

data. The information on how many people died in a calendar year has been kept in this dataset on a weekly basis. However, the researchers built their dataset on age-specific deaths in each country so that one can find out how many children, youth, or adults die in each country per week. In many cases, researchers have already stated that they cannot get accurate data into different ranges of ages but they can get the total death number of a city, a country, or a state. To mitigate these problems, researchers normally use the below Eq. 1 for distributing the total number of deaths to age-specific numbers. They use the equation 1 and use the earlier distribution that they already deposited into the database. However, the observed or forecasted death counts from annual age-specific groups are then converted to standard age groups using the following formula:

$$\hat{M}_b^s(x, x+m) = M_b^s(x, x+n) * \frac{M_b(x, x+m)}{M_b(x, x+n)} \quad (1)$$

In the above equation, $M_b^s(x, x+n)$ indicates the number of death according to the original data in the interval of age $[x, x+n]$ in s week of year b and n is the age interval length of original data. On the other hand, $\hat{M}_b^s(x, x+m)$ indicates the predicted number of death in the interval of age $[x, x+m]$ in s week of b year and m is the age interval length of estimated data. $M_b(x, x+m)$ and $M_b(x, x+n)$ represents the number of death in the whole year b .

Similar to the age specific distributions, they have calculated the specific groups based on sex by using the annual data stated in the following Eq. 2 when the age-specific sex group data is unavailable.

$$\hat{M}_b^{s,males}(x, x+m) = M_b^{s,total}(x, x+m) * \frac{M_b^{males}(x, x+m)}{M_b^{total}(x, x+m)} \quad (2)$$

The death rate according to the age groups has been estimated using total number of death in s week of b year and total population $P_b(x, x+m)$ of specific age groups using the following Eq. 3:

$$R_b^s(x, x + m) = \frac{M_b^s(x, x + m)}{P_b(x, x + m)/52} \quad (3)$$

However, The accuracy of the prediction of weekly age or sex group specific data from the combined data using the above distribution equation is not calculated or proved. As an efficient and easy alternative to the equation to solve the problem, we have proposed a system that uses several multi-output regression models. Compared to developing separate five single-output models for predicting five output features, multi-output regression has multiple advantages. Multi-output regression provides reduced training time, a unified prediction rule, and improved predictive generalization. As a result, much more complicated decision-making problems can be solved easily [4]. In this work, the prime objective of this research is to propose a model using multioutput regression to correctly perform the prediction of mortality data based on combined weekly mortality data. After collecting the dataset, we applied six ML models as well as two DL models named Linear Regression (LR), Decision Tree (DT), Random Forest (RF), K-nearest Neighbour (KNN), Least Absolute Shrinkage and Selection Operator (LASSO), Support Vector Regressor (SVR), Artificial Neural Network (ANN) and Recurrent Neural Network (RNN). After then, we have compared the output of each model. Finally, we have explored the best-performing model for the problem.

The remainder part of the paper is organized as follows: the recent relevant works is shown on Section II, the materials and methods is described on Section III, the result of the experiment is shown on Section IV, discussion is demonstrated on Section V and finally the conclusion and future works on Section VI.

II. RELATED WORKS

Some researchers already exploited the benefit of multi-output regression in their work. For example, in [5], Cui et al. jointly predicted two healthcare resource utilization measures such as length of stay and cost using multi-output regression models. They used four regression models such as NN, DT, RF, and multi-task Lasso for the prediction. They have achieved best performance with RF model when features generated through skip-gram feature vectors according to the R^2 coefficient, RMSE, Mean-Absolute error (MAE), Median Absolute Error (Median-AE) among the uninterpretable methods. Boumezoued et al. [6] utilized linear regression and neural network model to the correction of the mortality data while birth by month data is not available. They worked on the database of human mortality. In [7], Shahid et al. used seven regression models including decision tree, random forest, linear regression, support vector regression, ridge regression, gradient boosting, and multi-layer perceptron to efficiently forecast road traffic flow. Before implementing the models, they have utilized five dimensionality reduction methods. Han et al. [8] applied multi-output least square support vector regressor (M-LSSVM) to predict the levels of gas in a multi-tank LDG system in real time. It encompasses both the individual fitting errors as well as the combined ones for each output. Tuia et al. [9] employed an multioutput support vector regressor

(MSVR) model to estimate biophysical parameters such as fractional vegetation cover, chlorophyll content, and leaf area index from remote sensing images in a simultaneous manner. The study demonstrated that M-SVR is a viable substitute for nonparametric estimation of biophysical parameters and model inversion, compared to the single-output regression method. Li et al. [10] developed a system that utilizes multi-target regression models to predict the time series value of blood-drug efficacy in traditional chinese medicine datasets. The proposed system utilized the correlation between targets to enhance the performance of four learning techniques such as LR, Partial Least Squares, SVR, and ANN. SVR exhibits the best performance among the applied models. Meyer et al. [11] investigated the use of multi-target machine learning models for wind turbine normal behavior monitoring. The authors assessed 6 multi-target models such as DT, RF, KNN, MLP, CNN, and LSTM in a wind turbine case study and found that these models offer benefits over single-target modeling. Specifically, multi-target models can significantly decrease the effort required for the lifecycle management of normal behavior models while maintaining model accuracy. Kucuk et al. [12] predicted soil moisture through applying nine multi-output regression models such as LR, ridge regression, Lasso, RF, adaptive boosting, extreme gradient boosting, gradient boosting, histogram-based gradient boosting and extra tree regressor (ETR). They have shown that ETR delivers best performance with 0.81 r-squared coefficient value.

III. METHODOLOGY

The whole procedure has been subdivided into several parts such as dataset description, data preprocessing, implementation of multi-output regression models and finally the comparison of the performance of the algorithms. The conceptual flow of the procedure has been demonstrated on Fig. 1. At first, we have gathered the dataset in csv format. The data values has been scrubbed with the necessary features, and the final dataset has the features named Country Code, Year, Week, Sex, D_Total, D0_14, D15_64, D65_74, D75_84, and D85p. To handle multiple target features, we have utilized several regression models that perform better in multi-output regression problems such as LR, DT, RF, KNN, Lasso, SVR, ANN, and RNN. All the implementation were performed on python. Finally, the the performance of the model has been evaluated based on performance metrics.

A. Dataset Description

The STMF data series, a part of HMD, contains the records of human mortality rate according to every week of a year. The data has been stored both in the csv and excel file formats. There are total 19 features in the dataset such as CountryCode, Year, Week, Sex, next five features (5-9) includes death counts by age group (0-14, 15-64, 65-74, 75-84, 85+), total death counts through combining all age groups, next five features (11-15) such as death rates by age group (0-14, 15-64, 65-74, 75-84, 85+), total death rates through combining all sex groups, finally 17-19 attributes are explanatory indicators such as split, splitsex and forecast (see Table I). The four columns of the dataset are country in ISO-3 code format, year, week, sex of the the people who has died. It maintains the guidelines of ISO 8601-2004 to arrange the week. Generally, a year is

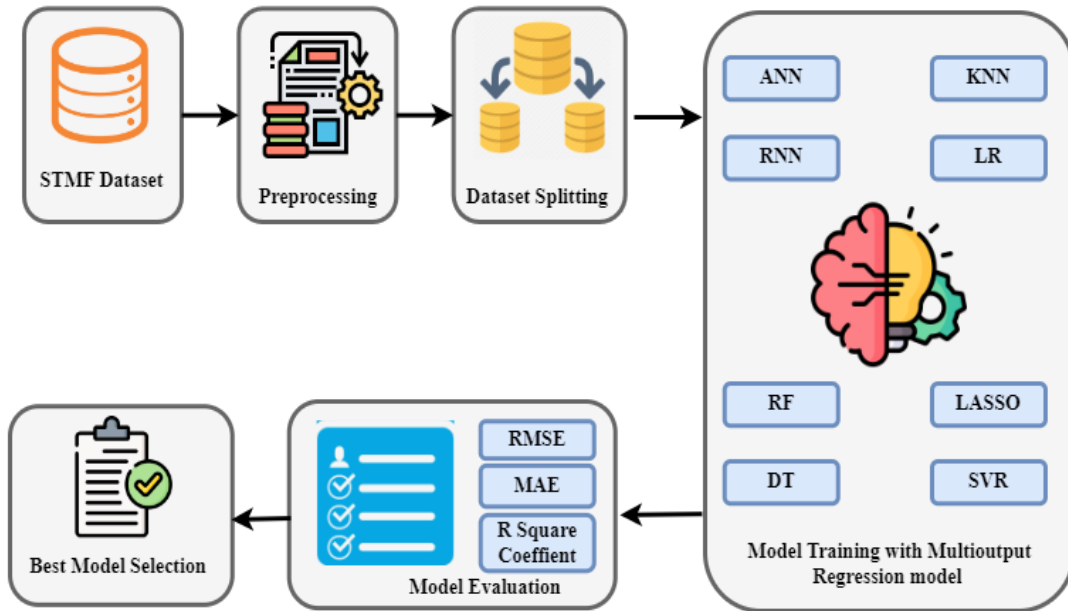


Fig. 1. Conceptual flow of the proposed model.

divided to 52 weeks except for some years of 53 weeks like 1992, 1998, 2004, 2009, 2015, and 2020. However, this paper focuses on the dataset with ten features where the five features such as country code, year, week, sex, D_Total were used as independent features and the five features such as D0_14, D15_64, D65_74, D75_84, and D85p were used as dependent features. On the other hand, there are 107211 records in the table.

B. Data Preprocessing

Data preprocessing is performed to remove any abnormalities in the dataset, identifying missing values as well as to prepare the data for further analysis. In this work, the dataset was checked whether it has any null values or not and it was replaced with zero using the fillna() option of python. After that, the character values changed using the encoder of python as the character or word data cannot be used for the application.

C. Multi-output Regression Models

Multi-output regression involves concurrently predicting multivariate output feature space from a given multivariate input feature space [13], [14]. Suppose $a \in R^u$ is a u -dimensional input feature space and $b \in R^v$ is a v -dimensional output feature space. So, multi-output regression can be stated as mapping from R^u to R^v [15]. In this work, we simultaneously predicted five output features using multi-output regression models. We have implemented eight different regression models namely ANN, RNN, LR, DT, RF, KNN, Lasso, and SVR to the data.

1) *Artificial Neural Network (ANN)*: ANN [16] is a computational network, which is motivated by the structure and function of biological neural networks in the brain [17]. The neural networks have several's neurons that are interconnected to each layer named as nodes similar to biological neural networks. The basic objective is to simulate the neural network that makes up the human brain so that computers can be capable of comprehending information and making decisions in the same way humans do. There are major three layers of ANN.

- **Input Layer**: The input layers receive input in various formats from multiple sources provided by researchers. Inputs are provided in the form of a pattern and vector from those external sources.
- **Hidden Layer**: The hidden layer lies in the middle of the input and output layers. This layer extracts all hidden features and patterns based on a given weight.
- **Output Layer**: Each input is multiplied by its associated weight. If the summed-up weighted input is zero then a bias is added to make a non-zero or different output. After that an activation function is applied to the summed-up weighted inputs to get the desired output. The Eq. 4 displays the standard format of a transfer function.

$$y = \sum_{i=1}^n W_i * X_i + c \quad (4)$$

Here, the variable y represents the weighted sum, where X_i represents the input values, W_i represents their respective

TABLE I. DIFFERENT ATTRIBUTES OF THE DATASETS

S.N.	Attributes	Type of Attribute	Attribute Value
1	CountryCode	Nominal	Australia, Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, England and Wales, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Israel, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Norway, Poland, Portugal, Russia, Scotland, Slovenia, Slovakia, Spain, Switzerland, Sweden, USA
2	Year	Numerical	1990-2022
3	Week	Numerical	1-53
4	Sex	Nominal	Male(m), Female(f), Both(b)
5	Death counts by age group (0-14), D0_14	Numerical	Mean: 24.48840206
6	Death counts by age group (15-64), D15_64	Numerical	Mean: 741.2852896
7	Death counts by age group (65-74), D65_74	Numerical	Mean: 574.2379793
8	Death counts by age group (75-84), D75_84	Numerical	Mean: 860.7234414
9	Death counts by age group (84+), D85p	Numerical	Mean: 874.3757614
10	The total death counts of all ages combined, DTotal	Numerical	Mean: 3075.110874
11	Death rates by age group (0-14), R0_14	Numerical	Mean: 0.000410215
12	Death rates by age group (15-64), R15_64	Numerical	Mean: 0.003046857
13	Death rates by age group (65-74), R65_74	Numerical	Mean: 0.020856924
14	Death rates by age group (75-84), R75_84	Numerical	Mean: 0.055437482
15	Death rates by age group (84+), R85p	Numerical	Mean: 0.166329407
16	The total death rates of all ages combined, RTTotal	Numerical	Mean: 0.009862773
17	Split	Nominal	0,1
18	SplitSex	Nominal	0,1
19	Forecast	Nominal	0,1

weights, and c represents the bias term. The output is then produced by passing the weighted total through an activation function. The training of the model has been performed in 100 epochs with relu activation function as well as Adam optimizer.

2) *Recurrent Neural Network (RNN)*: RNN is a type of artificial neural network in which the output from one phase is fed back as input for the subsequent phase. It possesses hidden layers that utilize RNN memory to preserve information from prior computations, thereby facilitating the extraction of significant information for the purpose of sequential data processing. Thus, many applications with sequential data such as speech recognition [18], language translation [19], and human activity recognition can be benefited from RNNs. RNN converts independent activations into dependent ones by giving each layer the same amount of weights and biases. This reduces the complexity of increasing parameters and helps to memorize each previous output, which will be used as input for the subsequent hidden layer. After then, each set of three layers can be connected to form a single recurrent layer. The Eq. 5 represents the formula for determining the current state:

$$S_t = f(S_{t-1}, X_t) \quad (5)$$

Here, S_t denotes the present state, S_{t-1} denotes the preceding state, and X_t denotes the input state. The Eq. 6 represents the formula for using the activation function:

$$S_t = f(W_{ss}S_{t-1} + W_{sx}X_t) \quad (6)$$

Here f is the activation function, W_{ss} represents the weight assigned to the recurrent neuron, and W_{sx} represents the weight assigned to the input neuron. The Eq. 7 represents the formula to determine output:

$$Y_t = W_{sy}S_t \quad (7)$$

Here Y_t represents the output and W_{sy} represents the weight assigned to the output layer.

3) *Linear Regression (LR)*: LR is one of the widely used machine learning methods which estimates the linear relationship between dependent and independent variables. It demonstrates how the value of the dependent variable changes based on the value of the independent variable. Basically, it is employed in predictive analysis. It forecasts factors that are real or numerical, such as birthday, sales, salary, age, and product price. The main goal of linear regression is to determine the best-fitting linear equation that reduces the disparity between the anticipated and actual values of the dependent variable. The Eq. 8 represents the formula of the model.

$$y = b_0 + b_1x_1 + b_2x_2 \dots b_nx_n \quad (8)$$

Here y denotes the dependent variable, also termed as target variable, $x_1, x_2 \dots x_n$ denotes the independent variables, which are known as predictor variables. $b_0, b_1, b_2 \dots b_n$ denotes the coefficients associated with each independent variable. b_0 is the line's intercept, and a_1 is the linear regression coefficient.

4) *Decision Tree (DT)*: DT is a supervised learning algorithm applied to both classification and regression problems. It is a tree-like structured approach where the internal nodes indicate input features or attributes, branches indicate the decision-making process that is based on those features, and leaf nodes indicate the output or prediction of the model. The algorithm starts at the root node of the tree and at every decision node, the algorithm selects the branch to pursue by evaluating the present record's values with associated decision node values. Based on this comparison, the algorithm follows the corresponding branch to the next node. One of the main issues in DT algorithms is to determine the best attribute for the root node and subsequent sub-nodes. An attribute selection measure (ASM) can be used to find solutions to these issues. There are two widely used ASM techniques that are described in the following sections.

- **Information Gain**: After dividing the data depending on an attribute, it calculates the reduction in entropy or uncertainty in the target variable. The splitting attribute is selected based on the attribute that has the highest information gain. The Eq. 9 represents the formula to calculate Information Gain (IG).

$$IG = Entropy(s) - \sum \frac{|S_v|}{|S|} * Entropy(S_v) \quad (9)$$

Here, $Entropy(s)$ represents the entropy of the original dataset S . $|S_v|$ represents the instance number in S that have the value v for attribute, $|S|$ represents the total instance number in S , and $Entropy(S_v)$ is the entropy of the subset S_v after splitting the data based on the attribute value v .

- Gini Index: Gini index quantifies the impurity or dissimilarity of a dataset's value while creating a decision tree. The objective of the Gini index is to reduce impurities from the root nodes to the leaf nodes. The attribute with the lowest Gini index should be chosen as the splitting attribute. Gini index can be calculated using the below formula stated in Eq. 10.

$$GI(S) = 1 - \sum p_i^2 \quad (10)$$

Here, p_i is the proportion of instances in S that belong to class i .

5) *Random Forest (RF)*: RF is another popular supervised algorithm that integrates the power of decision trees and ensemble learning for solving classification and regression problems [20]. It functions by randomly choosing subsets of the training data and features known as bootstrap samples from the original dataset. Each decision tree is then created independently using these subsets through a recursive process. During prediction, each tree generates an independent prediction and the final prediction is then determined by taking the average prediction of all the trees. There should be a chance that certain decision trees may generate incorrect predictions, but when all the trees are combined, it provides an accurate prediction. RF also provides several other benefits, including the ability to handle nonlinear relationships, capture complex interactions among features, and improved accuracy, and robustness against outliers and noise compared to individual decision trees [21].

6) *K Nearest Neighbour (KNN)*: KNN is one of the simplest yet versatile algorithms applied to both classification and regression tasks [22]. This algorithm is non-parametric, instance-based, and makes no assumptions on the distribution of the underlying data. KNN algorithm assigns labels to previously unlabeled data based on the features and labels of its K nearest neighbors in the training data. The process involves computing the distance between the new unseen input data and each training sample using a certain distance metric such as Euclidean distance, Minkowski distance, Manhattan distance, hamming distance. In the classification process, KNNs are used to assigning labels to a new data point based on the dominant class label among the neighbors. In regression, the predicted value is calculated by averaging the target values of K 's nearest neighbors. The choice of K may have impact on the algorithm's performance. If the value of K is smaller, it may lead to a potentially more flexible and noisier prediction and if the value of K is larger, it may lead to potentially smoother but biased predictions. In order to identify the K nearest neighbors, Euclidean distance is used most of the time as a distance metric. The Eq. 11 represents the formula to determine the nearest neighbors between two data sets, p and q .

$$d(p, q) = \sqrt{\sum_{i=1}^n (q_i - p_i)^2} \quad (11)$$

Here, p and q denote the coordinates of data points in each dimension, and n represents the total number of dimensions or features.

7) *Least Absolute Shrinkage and Selection Operator (LASSO)*: LASSO is a type of linear regression model that employs shrinkage to select the variables. It is beneficial in analyzing datasets with high dimensions, specifically those with many features and fewer observations [23]. During prediction, the linear regression model provides equal importance to all features. However, when there are many features, including irrelevant or redundant ones, the model may become complicated and overfit the training data, which results in poor generalization of new data. Lasso Regression addresses this problem by adding an L1 penalty term to the cost function. The L1 penalty promotes sparsity and facilitates efficient feature selection by shrinking the coefficients of irrelevant features toward zero, thereby eliminating the corresponding features from the model. The generic form of the cost function in LASSO regression is presented on Eq. 12.

$$J = \frac{1}{m} \sum_{i=1}^m \left(y^{(i)} - h \left(x^{(i)} \right) \right)^2 + \lambda \sum_{j=1}^n |w_j| \quad (12)$$

Here, the variable m denotes the count of training examples. The variable $y^{(i)}$ represents the target variable's value for the i -th training example. The expression $h(x^{(i)})$ denotes the hypothesis function's for prediction, while n denotes the total number of features. The weight assigned to the j th feature is represented by w_j .

8) *Support Vector Regression (SVR)*: SVR is a supervised learning algorithm used for classification and regression problems [24], [25], [26]. It is an expansion of the Support Vector Machine (SVM) algorithm. The aim of SVR is to select a hyperplane with a maximum margin while allowing a certain level of error (epsilon) for data points that lie within that margin. The SVR algorithm tries to identify the optimal hyperplane by solving an optimization problem that minimizes the training data error and maximizes the margin. In the prediction phase, SVR applies the learned hyperplane to predict the values for new data points. The predicted values are defined by the position of the data points with respect to the hyperplane. SVR can handle non-linear relationships and high-dimensional data effectively with the help of kernel functions. Kernel functions are applied to convert the input data into a higher-dimensional space, where it can find a linear regression function. The selection of the kernel function depends on the type of data and the problem at hand. The three kernels that SVM most frequently uses are.

- Linear kernel: It deals with large sparse data and is used in text categorization. It measures the linearity between the input data and the target variable.
- Polynomial kernel: This kernel, known as a polynomial kernel, introduces polynomial features to capture nonlinear relationships.

- Radial Basis Function (RBF): It maps the input data into an infinite-dimensional feature space applying Gaussian functions.

D. Performance Metric

The purpose of accuracy metrics is to determine the performance of any model. In this section, we used three evaluation metrics such as R Square coefficient, RMSE, and MAE to measure the prediction accuracy of the regression models.

1) *R Square Coefficient*: R square coefficient is an evaluation metric that measures the fitness of a regression model [7]. It can be expressed as using Eq. 13.

$$R^2 = 1 - \frac{\sum_i (x_i - \hat{x}_i)^2}{\sum_i (x_i - \bar{x})^2} \quad (13)$$

Where, x_i and \hat{x}_i are the actual and predicted output of i -th sample respectively, \bar{x} is the average output. The highest value of R^2 is 1, indicating that the closer the value to 1 the better fitted the model is.

2) *Root Mean Square Error(RMSE)*: RMSE is a general-purpose error metric used to measure the performance of a model according to prediction accuracy [27]. The smaller the RMSE value the higher the prediction accuracy. It can be expressed as the square root of the mean squared error. The equation to calculate MSE and RMSE for multi-output regression model is provided in Eq. 14 and 15, respectively.

$$MSE = \frac{1}{m} \frac{\sum_i (x_i - \hat{x}_i)^2}{N} \quad (14)$$

$$RMSE = \sqrt{MSE} \quad (15)$$

In the above equation stated in 14, N denotes the number of samples.

3) *Mean Absolute Error(MAE)*: MAE calculates the difference between actual output and predicted output. MAE for multi-output regression model expressed in the Eq. 16.

$$MAE = \frac{1}{m} \frac{1}{n} \sum_{i=1}^n |(x_i - \hat{x}_i)| \quad (16)$$

IV. EXPERIMENTAL RESULTS

The main objective of the proposed model is to predict the weekly death count based on age-specific user group. To perform the task, we have implemented several regression models. The dataset was divided into 80% to 20% where 80% data is used for training and 20% data for testing purposes. All the experiments were performed in Python. The performance of these models is evaluated based on three different metrics such as MSE, MAE and R squared coefficient. The higher value of the R squared coefficient is found with RF algorithm (0.9975), which is followed by DT (0.9958), RNN (0.9529), KNN (0.9430), ANN (0.9427), LR (0.8937), Lasso (0.8937), SVR (0.8438) which is shown on Table II. The higher value of the R squared coefficient, the lower value of RMSE and MAE indicates good fitted model for the task. It is evident that the value of MAE is lower with RF (16.4069) that is

TABLE II. COMPARISON AMONG THE REGRESSION MODELS BASED ON RMSE, MAE AND R SQUARED COEFFICIENT

	RMSE	MAE	R Squared
RF	43.2263	16.4069	0.9975
DT	56.4134	21.7217	0.9958
RNN	333.8810	124.3763	0.9529
KNN	386.2374	106.2851	0.9430
ANN	389.7136	114.8771	0.9427
LR	525.6425	212.0527	0.8937
Lasso	525.6477	211.7925	0.8937
SVR	656.4845	245.8620	0.8438

followed by DT (21.7217), KNN (106.2851), ANN (114.8771), RNN (124.3763), Lasso (211.7925), LR (212.0527) and SVR (245.8620). The lowest RMSE value is found on RF with 43.2263 which is followed by DT, RNN, KNN, ANN, LR, Lasso, and SVR. Therefore, it can be concluded that RF is the best-performing model for the task and after then DT showed almost similar types of prediction.

V. DISCUSSION

In this research, we figured out that, instead of using the distribution equation, the construction of a model with random forest and decision tree algorithms to perform the count of mortality in absence of age specific data from the total count of all ages is much easier and better solution. It is evident that the use of the multi-output regression model has proved its efficiency to perform the prediction. To the best of our knowledge, this work is the first attempt to propose a multi-output regression model as a solution to the distribution problem on the mentioned dataset. It can be summarised that ML techniques provide better output for multi-output regression than DL methods. Among the classifiers, RF showed the best performance based on RMSE, MAE, and R squared coefficient.

However, the performance of several algorithms can further be improved through tuning the hyper-parameters of the model. In addition, the utilization of these regression models can be applied to the similar domains through extending their potentiality.

VI. CONCLUSION

STMF data series is one of the most valuable data series of HMD. Various types of analysis can be performed using the weekly records according to the information of their age group and gender. However, the data that are collected from various countries sometimes lack the weekly death information. Currently, researchers used the distribution equation to calculate the age-specific weekly data. Multi output regression models are getting popularity in prediction related problems over the last few years. In this work, we have implemented such regression models because of the benefits over single output model. In this work, RF is selected as the best performing model based on R-square coefficient, RMSE and MAE.

REFERENCES

- [1] D. A. Jdanov, A. A. Galarza, V. M. Shkolnikov, D. Jasilionis, L. Németh, D. A. Leon, C. Boe, and M. Barbieri, "The short-term mortality fluctuation data series, monitoring mortality shocks across time and space," *Scientific Data*, vol. 8, no. 1, p. 235, Dec. 2021. [Online]. Available: <https://www.nature.com/articles/s41597-021-01019-1>

- [2] L. Németh, D. A. Jdanov, and V. M. Shkolnikov, "An open-sourced, web-based application to analyze weekly excess mortality based on the short-term mortality fluctuations data series," *Plos One*, vol. 16(2), no. e0246663, 2021. [Online]. Available: <https://doi.org/10.1371/journal.pone.0246663>
- [3] "Hmd," *The Human Mortality Database*, 2020. [Online]. Available: <http://www.mortality.org/>.
- [4] D. Xu, Y. Shi, I. W. Tsang, Y.-S. Ong, C. Gong, and X. Shen, "Survey on Multi-Output Learning," *IEEE Transactions on Neural Networks and Learning Systems*, pp. 1–21, 2019. [Online]. Available: <https://ieeexplore.ieee.org/document/8892612/>
- [5] L. Cui, X. Xie, Z. Shen, R. Lu, and H. Wang, "Prediction of the healthcare resource utilization using multi-output regression models," *IIEE Transactions on Healthcare Systems Engineering*, vol. 8, no. 4, pp. 291–302, Oct. 2018. [Online]. Available: <https://doi.org/10.1080/24725579.2018.1512537>
- [6] A. Boumezoued and A. Elfassihi, "Mortality data correction in the absence of monthly fertility records," *Insurance: Mathematics and Economics*, vol. 99, pp. 486–508, 2021. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0167668721000536>
- [7] N. Shahid, M. A. Shah, A. Khan, C. Maple, and G. Jeon, "Towards greener smart cities and road traffic forecasting using air pollution data," *Sustainable Cities and Society*, vol. 72, p. 103062, 2021. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S2210670721003462>
- [8] Z. Han, Y. Liu, J. Zhao, and W. Wang, "Real time prediction for converter gas tank levels based on multi-output least square support vector regressor," *Control Engineering Practice*, vol. 20, no. 12, pp. 1400–1409, Dec. 2012. [Online]. Available: <https://linkinghub.elsevier.com/retrieve/pii/S0967066112001670>
- [9] D. Tuia, J. Verrelst, L. Alonso, F. Perez-Cruz, and G. Camps-Valls, "Multioutput Support Vector Regression for Remote Sensing Biophysical Parameter Estimation," *IEEE Geoscience and Remote Sensing Letters*, vol. 8, no. 4, pp. 804–808, Jul. 2011. [Online]. Available: <http://ieeexplore.ieee.org/document/5735189/>
- [10] H. Li, W. Zhang, Y. Chen, Y. Guo, G.-Z. Li, and X. Zhu, "A novel multi-target regression framework for time-series prediction of drug efficacy," *Scientific Reports*, vol. 7, no. 1, p. 40652, Jan. 2017. [Online]. Available: <https://www.nature.com/articles/srep40652>
- [11] A. Meyer, "Multi-target normal behaviour models for wind farm condition monitoring," *Applied Energy*, vol. 300, p. 117342, Oct. 2021. [Online]. Available: <https://linkinghub.elsevier.com/retrieve/pii/S0306261921007509>
- [12] C. Kucuk, D. Birant, and P. Yildirim Taser, "An intelligent multi-output regression model for soil moisture prediction," in *Intelligent and Fuzzy Techniques for Emerging Conditions and Digital Transformation*, C. Kahraman, S. Cebi, S. Cevik Onar, B. Oztaysi, A. C. Tolga, and I. U. Sari, Eds. Cham: Springer International Publishing, 2022, pp. 474–481.
- [13] S. Xu, X. An, X. Qiao, L. Zhu, and L. Li, "Multi-output least-squares support vector regression machines," *Pattern Recognition Letters*, vol. 34, no. 9, pp. 1078–1084, 2013. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0167865513000196>
- [14] G. Liu, Z. Lin, and Y. Yu, "Multi-output regression on the output manifold," *Pattern Recognition*, vol. 42, no. 11, pp. 2737–2743, 2009. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0031320309001691>
- [15] D. Xu, Y. Shi, I. W. Tsang, Y.-S. Ong, C. Gong, and X. Shen, "Survey on multi-output learning," *IEEE Transactions on Neural Networks and Learning Systems*, vol. 31, no. 7, pp. 2409–2429, 2020.
- [16] S.-C. Wang, *Artificial Neural Network*. Boston, MA: Springer US, 2003, pp. 81–100. [Online]. Available: https://doi.org/10.1007/978-1-4615-0377-4_5
- [17] W. S. McCulloch and W. Pitts, "A logical calculus of the ideas immanent in nervous activity," *The Bulletin of Mathematical Biophysics*, vol. 5, no. 4, pp. 115–133, Dec. 1943. [Online]. Available: <http://link.springer.com/10.1007/BF02478259>
- [18] A. Graves, A.-r. Mohamed, and G. Hinton, "Speech recognition with deep recurrent neural networks," in *2013 IEEE international conference on acoustics, speech and signal processing*. Ieee, 2013, pp. 6645–6649.
- [19] I. Sutskever, O. Vinyals, and Q. V. Le, "Sequence to sequence learning with neural networks," *Advances in neural information processing systems*, vol. 27, 2014.
- [20] L. Breiman, "Random Forests," *Machine Learning*, vol. 45, no. 1, pp. 5–32, 2001. [Online]. Available: <http://link.springer.com/10.1023/A:1010933404324>
- [21] J. Ali, R. Khan, N. Ahmad, and I. Maqsood, "Random forests and decision trees," *International Journal of Computer Science Issues (IJCSI)*, vol. 9, no. 5, p. 272, 2012.
- [22] V. Iswarya Kumari, M. Bhavya, N. Kasi Mounika, and M. Yoshitha, "Sales Prediction using Linear Regression," *International Journal of Advanced Research in Science, Communication and Technology*, pp. 139–141, Nov. 2022. [Online]. Available: <http://ijarsct.co.in/Paper7611.pdf>
- [23] S. Kwon, S. Han, and S. Lee, "A small review and further studies on the lasso," *Journal of the Korean Data and Information Science Society*, vol. 24, no. 5, pp. 1077–1088, 2013.
- [24] M. Sajjad, S. U. Khan, N. Khan, I. U. Haq, A. Ullah, M. Y. Lee, and S. W. Baik, "Towards Efficient Building Designing: Heating and Cooling Load Prediction via Multi-Output Model," *Sensors*, vol. 20, no. 22, p. 6419, Nov. 2020. [Online]. Available: <https://www.mdpi.com/1424-8220/20/22/6419>
- [25] C. Cortes and V. Vapnik, "Support-vector networks," *Machine Learning*, vol. 20, no. 3, pp. 273–297, Sep. 1995. [Online]. Available: <http://link.springer.com/10.1007/BF00994018>
- [26] P. Lu, L. Ye, W. Zhong, Y. Qu, B. Zhai, Y. Tang, and Y. Zhao, "A novel spatio-temporal wind power forecasting framework based on multi-output support vector machine and optimization strategy," *Journal of Cleaner Production*, vol. 254, p. 119993, May 2020. [Online]. Available: <https://linkinghub.elsevier.com/retrieve/pii/S0959652620300408>
- [27] T. O. Hodson, "Root-mean-square error (rmse) or mean absolute error (mae): when to use them or not," *Geoscientific Model Development*, vol. 15, no. 14, pp. 5481–5487, 2022. [Online]. Available: <https://gmd.copernicus.org/articles/15/5481/2022/>

Opportunities in Real Time Fraud Detection: An Explainable Artificial Intelligence (XAI) Research Agenda

Eleanor Mill, Wolfgang Garn, Nick Ryman-Tubb, Chris Turner
Surrey Business School, University of Surrey, Guildford, GU2 7XH

Abstract—Regulatory and technological changes have recently transformed the digital footprint of credit card transactions, providing at least ten times the amount of data available for fraud detection practices that were previously available for analysis. This newly enhanced dataset challenges the scalability of traditional rule-based fraud detection methods and creates an opportunity for wider adoption of artificial intelligence (AI) techniques. However, the opacity of AI models, combined with the high stakes involved in the finance industry, means practitioners have been slow to adapt. In response, this paper argues for more researchers to engage with investigations into the use of Explainable Artificial Intelligence (XAI) techniques for credit card fraud detection. Firstly, it sheds light on recent regulatory changes which are pivotal in driving the adoption of new machine learning (ML) techniques. Secondly, it examines the operating environment for credit card transactions, an understanding of which is crucial for the ability to operationalise solutions. Finally, it proposes a research agenda comprised of four key areas of investigation for XAI, arguing that further work would contribute towards a step-change in fraud detection practices.

Keywords—Artificial intelligence; explainable AI; machine learning; credit card fraud

I. INTRODUCTION

Europol's Serious and Organised Crime Threat Assessment identifies non-cash payment fraud as one of the most concerning criminal activities in the European Union [1]. In the UK alone, fraud losses on UK issued cards totalled £567 million in 2020 [2]. UK losses, however, are dwarfed in comparison to global losses which were estimated to be \$32.39 billion in 2020, extending to over \$40 billion by 2027 [3]. It is argued that as the use of non-cash payment cards increases year on year, perpetrators of these frauds are likely to see a continual increase in their illegal funding unless industry and academics can come together to create a significant step-change in the way in which fraudulent transactions are intercepted.

A. Changing Landscape

The volumes and velocity of credit card transactions means that financial institutions cannot rely on human expertise alone to identify fraudulent transactions. Fraud Management Systems (FMS) complement other internal processes to help automate fraud detection and decision-making. FMSs are traditionally rule based, meaning every single transaction is checked against a catalogue of pre-determined rules. This is an approach favoured by industry fraud experts because of the ease with which they can understand the inputs, modify the rules and interpret the results. However, whilst the relative simplicity of

rule-based systems ensures the results are easily understood, this fixed approach does not scale well and limits the ability of the FMS to recognise or adapt to evolving patterns of fraud. Moreover, recent regulatory and technological developments threaten the effectiveness of traditional rule-based fraud management systems. As a consequence the payments industry, and therefore payment card fraud detection, is facing a once-in-a-generation need for radical change.

1) *Regulatory developments:* As part of the Payment Services Directive 2 (PSD2) regulation, Strong Customer Authentication (SCA) has recently been enforced in Europe and the United Kingdom [4]. SCA employs new Regulatory Technical Standards (implemented through an initiative called 3-D Secure 2.0) which enhance the current practices of processing customer transaction data. One of the pre-SCA challenges for issuers in fraud detection was the limited amount of data they received from the retailer – typically less than 10 variables per transaction. In contrast, the new Regulatory Technical Standards describe “Authentication Enrichment” data that a retailer should now provide to an issuer in addition to the usual transaction data. The Authentication Enrichment data increases the original 10 variables to over 100 variables (known as “security features”) [5], [6] as shown in Fig. 1 .

The ten-fold increase in the security features necessitates a step-change in traditional rule-based fraud detection methodologies. Whilst rule-based engines will continue to perform initial screening of transactions to eliminate the most common fraud approaches, machine learning (ML) will be required to perform the majority of the analysis. Synergistically, the results of those ML models must be easily translated by the fraud analysts and management teams in order to interpret and act upon any newly derived insights.

Additionally, the Regulatory Technical Standards dictate the need to perform the analysis of transactions using these data points in real-time. The adoption of Authentication Enrichment data and enforcement of real-time analysis makes improvements to the automated processing of transactions increasingly urgent: It is claimed that “Approximately 80% of issuers plan to invest in machine-learning (ML) and rule-based engines to facilitate SCA processes by the end of 2021” [7].

2) *Technology developments:* Technology is revolutionising the way society pays for its goods and services. Contactless technology has become mainstream [8] and digital wallets such as Apple Pay, Google Pay or Samsung Pay have significantly increased their user base, especially in the younger generations

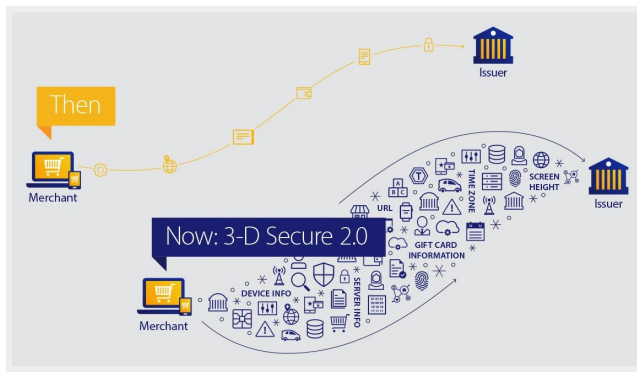


Fig. 1. Additional security features to be provided from the merchant (retailer) to the issuer as a result of new SCA regulatory technical standards (implemented through an initiative called 3-D Secure 2.0) [6].

[9]. Using this technology, payments can now be made through physical cards, mobile phones and even jewellery such as rings or watches which use Near Field Communication (NFC) technology. In addition, Open Banking has facilitated the entrance of a myriad of new payments service providers and the introduction of account-to-account payments [10].

These innovations not only transform the footprint of a traditional payment transaction but also highlight the flexibility needed to address the future transaction landscape. Traditional rule-based fraud detection methodologies which rely on a user's consistent and repetitive behaviours are less effective when payments can be made through any device, piece of clothing or jewellery in any location and at any time. Similarly, changes to the way payments are conducted means a re-evaluation of a retailer's payment infrastructure [11] which, in turn, will also affect their traditional fraud detection methodologies.

Finally, recent advances in technology enable fraudsters to work en masse, causing disruption at an ever faster pace. In [12], Dvorsky reported on the already-present ability of criminals to launch AI-based attacks, enabling much faster and more widespread disruption than previous human manual led strikes. Fraudsters are agile. They do not have the restraints of customer privacy, regulation and legacy applications to accommodate. In a recent industry report [13], Mike Haley, CIFAS CEO said "fraud is ever evolving, and criminals continue to collaborate. As a community, we must do the same".

Hence the need for the FMS to be able to adapt at pace becomes even more critical. Rule-based systems may have been sufficiently refined over the past 30 years to effectively seek out known fraud patterns or traits, yet it is suggested that they are no match for the dynamics of this modern fraud landscape. As a consequence, the accuracy of the traditional FMS over the medium-to-long term will decline.

B. Current Status

To address the challenges of escalating transaction volumes, changes in regulation, technological advancements and a more sophisticated and technology-savvy criminal fraternity, researchers are exploring the opportunities of employing ML techniques in credit card fraud detection. However, adoption

of ML techniques in financial settings have been slow to materialise [14]. The running hypothesis is that organisations perceive ML techniques as "black box" solutions which lack transparency and are therefore difficult to trust. Some domains, for example movie recommendation engines, are able to tolerate the opacity which accompanies black box solutions since the consequences of an incorrect outcome (for example a poor movie recommendation), whilst potentially irritating, present a low risk to the user.

In financial domains the consequences of an incorrect decision on a data subject are more impactful. In the case of credit card fraud detection, a consumer is likely to have the transaction rejected, and potentially the credit card subsequently withheld or cancelled. At the very least this will result in annoyance or embarrassment, but it may also impact the consumer's ability to buy groceries or keep up with payments on more substantial items. The existence of these risks places a much stronger onus on practitioners to ensure they can trust in the outputs of these ML models. For the finance industry, the inability to understand or justify the outcomes of the black box ML models has consequentially become a strong barrier to change.

To counter this challenge, scholars have begun investigating ways in which ML techniques can be leveraged whilst simultaneously providing transparency to engender trust in the models and therefore encourage more ubiquitous adoption. An emerging and increasingly popular technique to create this transparency is Explainable Artificial Intelligence (XAI).

C. Terminology

Scholarly research of nascent fields often begins with the difficulty of achieving a consensus on normative terminology. This is especially pertinent for the discourse surrounding XAI. As noted by both [15] and [16], many authors avoid committing themselves to a definition of an XAI system. This may be because, as a nascent field, the community have yet to come together to agree upon a clear definition. Yet without open discussion, how can consensus be reached? Those same authors suggest that this avoidance exposes the discipline to criticism that the field lacks rigour, noting that the community cannot justify claims of delivering XAI without agreement as to what XAI is.

To complicate matters further, there is also discord between authors regarding use of the terms "explainable" (usually followed by "artificial intelligence" and denoted XAI) and "interpretable" (usually followed by "machine learning" and denoted IML) with some authors considering the two terms analogous [17], [18] and other authors seeing a clear distinction between them.

One suggestion [19] is that the term "explainable" should be considered an umbrella term which has the goal to "... summarise the reasons for neural network behaviour, gain the trust of users, or produce insights about the causes of their decisions". The authors then perceive interpretability as a sub-goal to shed light on "what a model did or might have done" – answering the question of "how" the system came to its conclusion, yet stopping short of providing the complete response which a system audit may require. An explainable model is therefore, by definition, inherently interpretable yet

the reverse is not true – an interpretable model does not necessarily satisfy all the requirements of being explainable.

Similarly, [20] provide an holistic definition of XAI as “AI systems that can explain their rationale to a human user, characterize their strengths and weaknesses, and convey an understanding of how they will behave in the future.” Their concept of interpretability, analogous with the perspective of [19], is also subservient to the concept of being explainable. However the authors are more precise in their description, suggesting that “Interpretable models are machine learning techniques that learn more structured, interpretable, or causal models.”

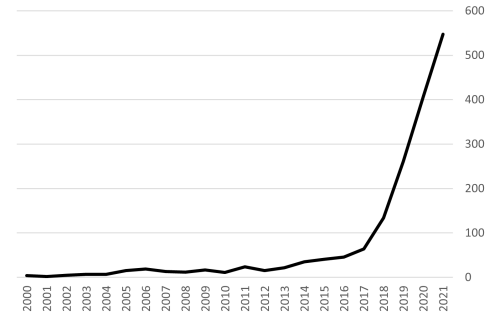
This concept of interpretability representing models that can be decomposed by an appropriately skilled audience is becoming more widely recognised amongst contemporary authors. Specifically, authors identify linear models, decision trees, rule-based models and constrained variants of black-box models as interpretable models [21]–[25]. Such models are often referred to as “inherently” interpretable [22], [23], [26], [27] or “intrinsic” [28], with the advantage that they are able to provide accurate and undistorted [26] explanations for the model output.

In contrast, black box models are often defined as models which are not interpretable, that is their complexity is so acute that the intended audience are unable to unravel their inner workings. When presented with such a model, it is increasingly commonplace for those seeking an explanation of the output to implement a subsequent interpretable model in a post-hoc fashion, the purpose of which is to find an approximate and human-understandable explanation to the original model’s output. Obscuring the holistic definitions of both [19] and [20], authors frequently refer to these post-hoc models as explainable models [15], [22], [29] or explainable AI [23], [27], although others employ the term post-hoc interpretability [21], [30].

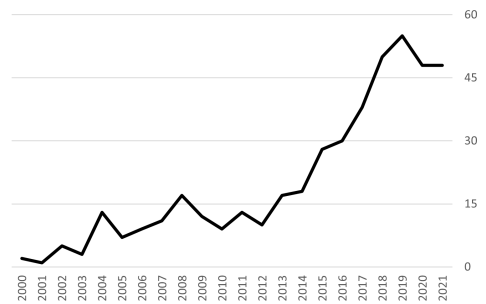
In an effort to reconcile the discourse, this paper leverages the holistic perspectives of both [19] and [20] to suggest XAI should be considered as an umbrella term. Specifically, it adopts the definition put forward by [20] (see above) which emphasises the importance of producing an explanation that is human-understandable, including transparency of the working parameters of the system. Where necessary, it differentiates XAI models through use of the terms “intrinsic” and “post-hoc”. The former term describes models that are inherently interpretable. Decision trees and linear regressions are well studied examples of intrinsic models. Section III-B discusses intrinsic models in more detail and highlights some of their perceived challenges. Other models are built to prioritise alternative desiderata such as precision, accuracy or speed. In that circumstance, explanations are obtained “post-hoc”, i.e. derived as part of an additional process after the model has delivered the outcome.

D. Scholarly Focus

Despite the ongoing debate as to the exact terminology and definitions pertaining to XAI, many scholars are undeterred in their investigations. XAI models are an increasingly popular research topic within the ML community (see Fig. 2a), and the techniques to develop, present and categorise the explanations



(a) Web of science core collection articles or proceedings papers focusing on XAI 2000 to 2021.



(b) Web of science core collection articles or proceedings papers focusing on credit card fraud 2000 to 2021.

Fig. 2. Scholarly focus for XAI and credit card fraud 2000 to 2021.

are many and varied. Likewise, investigations into credit card fraud detection are enjoying renewed attention (Fig. 2b). However, analysis of this joint population reveals just one paper published over the past 21 years which specifically investigates the application of XAI within a credit card fraud context [31].

Within that paper the authors initially propose a black box solution to distinguish between fraudulent and legitimate transactions. They subsequently acknowledge the difficulty that a human being would have in understanding the resulting output and propose an overlay to translate the results into human-understandable format. The explanation is therefore positioned as an afterthought, rather than central to the paper.

One additional paper of note explores the ability to extract generalised rules from a neural network within the domain of credit card fraud [32]. Despite no specific reference to XAI, it makes an early contribution to the field by introducing SOAR (Sparse Oracle-based Adaptive Rule extraction) which makes complex rule-sets more comprehensible by exploiting key decision boundaries.

Hence fraud – XAI cross-disciplinary research has so far lacked focus. This paper seeks to address the gap by arguing that techniques attributed to the field of XAI have the ability to accelerate a step-change in the detection of fraud in the credit card industry. This research agenda suggests ways in which XAI can improve the adoption of complex models, such as neural networks, in credit card fraud detection. Section II begins with a discussion of the credit card fraud operating landscape and key challenges which must be overcome for

successful model adoption. Section III then lists four significant focus areas which would benefit from increased scholarly attention. Finally, Section IV provides concluding remarks.

II. FUNDAMENTAL CONCEPTS AND BACKGROUND

A. Credit Card Operating Environment

Credit card transactions are bifurcated into Cardholder Present (CP) and Cardholder Not Present (CNP) transactions. For CP transactions the customer is physically present at the purchase point and offers a physical card to the retailer for payment. For CNP transactions the purchase is carried out remotely, for example over an e-commerce website. It is this latter scenario which will be the focus of this paper.

The speed and simplicity with which an individual can execute a credit card transaction disguises the complexity of its operating environment. There are multiple key organisations which have to interact seamlessly to deliver a smooth consumer experience. Fig. 3 shows the five key parties involved and the general timings used to execute and settle a credit card transaction.

The customer initiates the process by providing credit card payment details to the retailer in exchange for a product or service (step (1)). In real-time, the retailer requests permission from the issuer through both the acquirer and the payment card association [steps (2) to (4)] and receives an authorisation code back [steps (5) to (7)], at which point the transaction is either authorised or declined. Readers will be familiar with this entire request and response process being completed in a matter of seconds.

Following the transaction approval, the retailer receives funds from the issuer up to three days later [steps (8) to (13)]. The issuer then places the transaction on the credit card statement and issues the statement up to thirty days post transaction [step (14)]. The cardholder then has up to another thirty days to settle the bill either in full or through the use of a credit facility [step (15)].

Real-time fraud analysis focuses on confirming the authenticity of a single credit card transaction before the transaction is completed (see step (1) to step (7) in Fig. 3). The retailer, acquirer, card association and issuer all have roles to play. They perform similar types of analyses in order to ensure they are comfortable with the validity of the transaction, yet their fraud detection datasets are substantially different (Table I), enabling a multi-dimensional view of both the transaction and the context within which the transaction is being executed [33].

TABLE I. ORGANISATIONS AND THEIR CREDIT CARD FRAUD DETECTION DATASETS

Organisation	Fraud Dataset
Retailer	Previous customers and purchases
Acquirer	Transactions from all retailers who bank with them
Card Association	Transactions using the card association brand
Issuer	Transactions from all customers using issuer cards

To minimise repetition, this paper will assume the perspective of the retailer / e-commerce gateway in its discussions of fraud identification strategies and where XAI can improve the status quo. However, the strategies discussed are equally as relevant to acquirers, card associations and issuers in the real-time environment.

B. Key Challenges

FMS which enable the retailer's detection of illegitimate credit card transactions are hindered by four key challenges which will be described below. These challenges complicate the fraud identification process yet must be catered for in order to provide an operationally effective solution. Since intrinsic XAI models need to incorporate both the underlying ML algorithm and the explanation, any intrinsic XAI model will have to accommodate for all of these challenges in order to deliver an effective fraud detection explanation. In contrast, the first challenge is the only challenge relevant for a post-hoc XAI model, since its underlying AI model should operationally satisfy all key challenges.

1) *Real-time analysis*: Modern technology allows for the accumulation of hundreds of security features to provide information about the legitimacy of a transaction, as illustrated in Fig. 1. However, to ensure adherence to new regulations, deliver a smooth checkout experience for the customer and to minimise losses at the e-Commerce gateway those security features also need to be processed in real time. The real-time credit card transaction process illustrated by points (1) to (7) in Fig. 3 typically takes less than two seconds [34].

The foremost concern for the retailer is the provision of a seamless checkout experience for all legitimate transactions. A recent survey indicated that almost 20% of online shopping cart abandonment experiences were as a result of a "sticky" checkout experience [35]. The negative experience also reduces the likelihood of individuals visiting the store in the future thereby also impacting future sales revenue. Retailers' determination to protect their seamless checkout process is one of the key drivers behind the slow adoption of 3D Secure¹ checkouts [36].

2) *Concept drift*: A further advantage of real-time fraud analysis and explanation is the ability to detect emerging fraud trends and enable timely decision-making. Historically, the behaviour of fraudsters has been moderately consistent, enabling the cataloguing of fraud vectors which allows for rule-based analysis [37]. However, recent technological advances have enabled a more sophisticated and agile offender. *Concept drift* is the term used to describe this changing circumstance. Unforeseen, changing patterns in the fraud vectors results in the rules catalogue becoming either outdated or unmanageably large as more rules are added to try to keep pace with the new patterns of fraud. As a consequence, the fraud identification becomes less effective.

Examples of XAI models addressing concept drift in the domain of financial fraud are scant. However, the field could benefit from advances made in other fields. In particular, recent years have cemented the importance of addressing concept drift in the medical field of pandemic / epidemic response. In this field, authors have proposed various explainable models to support a real-time decision support model. Notably, [38] analyse Covid-19 symptomatic data using their DeepCOVID post-hoc XAI model. The result is a real-time graphical representation

¹3D Secure (3DS) requires customers to complete an additional verification step with the card issuer when paying, for example being directed to an authentication page on their bank's website, where they enter a password associated with the card or a code sent to their phone.

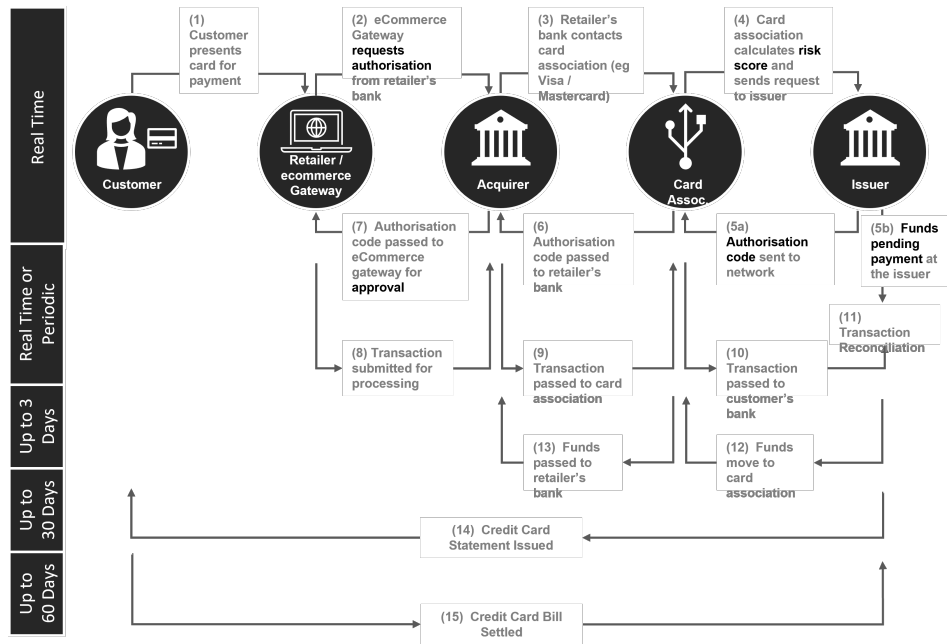


Fig. 3. CNP Credit card transaction life-cycle.

of the variables providing the most significant contributions to the prediction of Covid-19 diagnosis.

3) *Minimising false positives:* A model will sometimes incorrectly indicate a positive (e.g. fraudulent) result. This is known as a false positive result. Maximising the opportunities for a seamless checkout experience requires fraud investigators to minimise the occurrence of false positives when identifying fraudulent transactions.

False positives create friction in the process by either slowing down the real-time approval whilst manual assessment is required or cancelling the valid transaction altogether. In the latter case, the retailer loses both the goodwill of the customer and the value of the sale [39]. In addition to the negative experience of the customer, the occurrence of false positives creates further expense for the retailer as manual intervention is required to investigate the queried transactions. In an empirical survey of contemporaneous neural networks applied in credit card fraud detection, [14] suggested all but eight of the fifty-one (51%) ML methods in their literature population would be operationally ineffective. This is due to the high numbers of false positives in the results, requiring costly and inefficient manual oversight.

Whilst obtaining the proportion of false positive results on a test dataset helps to understand the efficacy of an AI model, it does little to provide transparency as to why incorrect predictions are being made. In contrast, XAI solutions have the advantage of being able to provide transparency to explain the reasoning for a false positive result. Saliency plots, for example, have been used by researchers to understand why an image-processing model was mistaking the picture of a husky for a wolf on a test dataset despite working with good accuracy on the training dataset [21].

4) *Dealing with class imbalance:* Fraudulent transactions are anomalous data points which exist within a large popula-

tion of genuine transactions. Mark Nelson, Visa's Senior Vice President of Risk Products and Business Intelligence, reports that Visa operates at a fraud rate of 0.1% of transactions [40]. Having an unbalanced dataset such as this creates difficulties for training ML models with the data since many algorithms assume an equal distribution of each class. When the minority class is the most important class, as it is in fraud detection, it typically results in a poor predictive performance.

A variety of approaches are available to scholars working with class imbalance. One option is to employ a weighted loss function which penalises the misclassification of the minority class thereby boosting its performance. Other popular approaches involve either undersampling the majority class or oversampling the minority class. Undersampling involves removing a proportion of the majority class in order to create a more balanced population. This is either done through random sampling or in a more structured way, often using nearest neighbour techniques. In contrast, oversampling the minority class increases the occurrence of the minority class in the dataset. This can either be done through making copies of existing minority transactions or creating additional synthetic transactions. SMOTE (Synthetic Minority Oversampling Technique) [41] remains a popular oversampling approach which has spawned an array of derivative oversampling techniques.

C. Fraud Risk Scoring

Fig. 1 illustrates the many data points which are available to the retailer for the purposes of performing a transaction fraud assessment. These data points are employed in a number of AI profiling algorithms to be used as inputs to generate an aggregated risk score. Fig. 4 represents a drill-down into the fraud detection process for a retailer / e-commerce gateway and highlights some of the most common inputs to the risk score such as product profiling, customer profiling, geo-location profiling and analysis of spending patterns [42]. The aggregated

fraud risk score is then compared to a fraud risk threshold determined by the retailer. Scores over the threshold identify transactions which the retailer considers worthy of challenge.

1) *Product profiling*: When retailers list a product for sale, they make an assessment of how appealing the product is likely to be to a fraudster. Typically, fraudsters steal products which are high value and high demand and can easily be resold on a secondary market. Retailers would identify these products in their portfolio as “High-Risk” and therefore apply a high-risk score to any sale of this product. The risk score is magnified when the number of high-risk products in a single transaction increase. In a recent survey of over 1,000 retail fraud professionals, the product profile (also referred to as the “Order Content”) was the key fraud indicator for 34% of survey respondents [42].

Shopping trends are in constant flux, depending upon the availability of new technology releases, changes due to seasonal trends, product availability and even media or social media influences. Consequently, it is difficult to implement an effective rule-based solution for determining high-risk products. However, ML provides retailers with an ability to adapt to new trends in a timely manner. Analogous with the discussion on *concept drift* in the paragraphs above, XAI solutions will provide real-time transparency of emerging trends enabling a retailer to understand why specific products are designated as high-risk. Graph Convolutional Networks are a popular tool in the detection of emerging trends due to their interpretability, enhanced performance and flexibility [43].

2) *Customer profiling*: It is important that retailers know their customer. This is not only relevant from a loyalty perspective, building a strong customer-retailer relationship, but it also provides useful knowledge in the fight against fraud. The above mentioned survey [42] identified the customer profile as the second most important fraud indicator for the survey respondents.

In respect of CNP transactions, the retailer needs to have confidence that the customer is genuine, and that they are dispatching the product to the right person at the correct address. This is much easier if they already have a prior transaction history with the customer, and far more difficult if the customer is new onto their platform. In order to establish a customer profile, they reference a number of key pieces of information which includes, but is not restricted to:

- Name and delivery address
- Usual mode of ordering (e.g. mobile or desktop)
- Frequently used IP Addresses
- Frequently used payment details
- History of returns or disputes
- Email address
- Email account history

Changes to any of the above profile factors can increase the customer’s risk score.

The lowest risk for the retailer is a customer with whom they have a regular transaction history, no reported disputes,

consistent behavioural patterns (e.g. mode of ordering and use of IP Address) and delivery to the same dispatch address. Any transactions with a customer in this category would be given a low-risk score for their customer profiling.

The highest risk for the retailer is a new customer. In this case they have no prior relationship data to build a customer profile. Instead, they leverage existing banking protocols alongside using other available data. At a minimum they ensure the shipping address reconciles with the billing address provided at checkout. Any deviations further increase the risk score of the customer profile. Other tactics involve ensuring the email address is not duplicated across their systems and looking at the account history of the email address.

The author in [44] explored user profiling to detect fraudulent cellular usage. Their work used an intrinsic XAI rule-learning technique to determine whether or not a customer was making a phone call from a cloned or genuine account. However, the flexibility and adaptability of clustering and classification ML algorithms have become increasingly popular in recent profiling studies. In particular, [45] demonstrated the effectiveness of the WIBL (Weighted Instance Based Learning) algorithm compared to more traditional clustering methods. WIBL improves explainability over existing clustering methods by using weighted features to indicate feature importance.

3) *Geo-location profiling*: The IP address also enables the retailer to access location details from where the order originates. This information is useful to the retailer in a number of ways. First, there may be certain locations which the retailer knows from prior experience have high risk of fraudulent activity. Retailers are able to use rule-based filters to exclude sales to those areas if they wish. Second, the location given by the IP address can be reconciled against the shipping and billing addresses. Although not a conclusive assessment, incongruence may indicate a higher risk of fraudulent activity.

4) *Spending patterns*: Finally, the retailer can also look for unusual or tell-tale spending patterns. They do this both at an individual customer level, and also holistically across their customer base. As above, this is much easier at an individual level if they have an established relationship with the customer. In that case they may be concerned with behaviours such as cancellations of orders followed by purchases of high-risk items, large volumes of high-risk products in a single transaction or unusual purchases for the customer profile, for example, an 80-year-old suddenly purchasing five flat-screen televisions. Looking across their customer base, they may see an unusual volume of high-risk products being purchased by different people but delivered to the same address, a common tactic when using “mules” to disguise fraudulent purchases.

III. RESEARCH AGENDA

The sections above articulate the motivation for change and describe the challenges encountered so far in the improvement of credit card fraud detection. In particular, Section II provides details regarding the context within which an effective fraud detection solution must operate. In this section we introduce a number of key concepts and developments within XAI that the authors argue would contribute towards a step-change in its adoption for credit card fraud investigations.

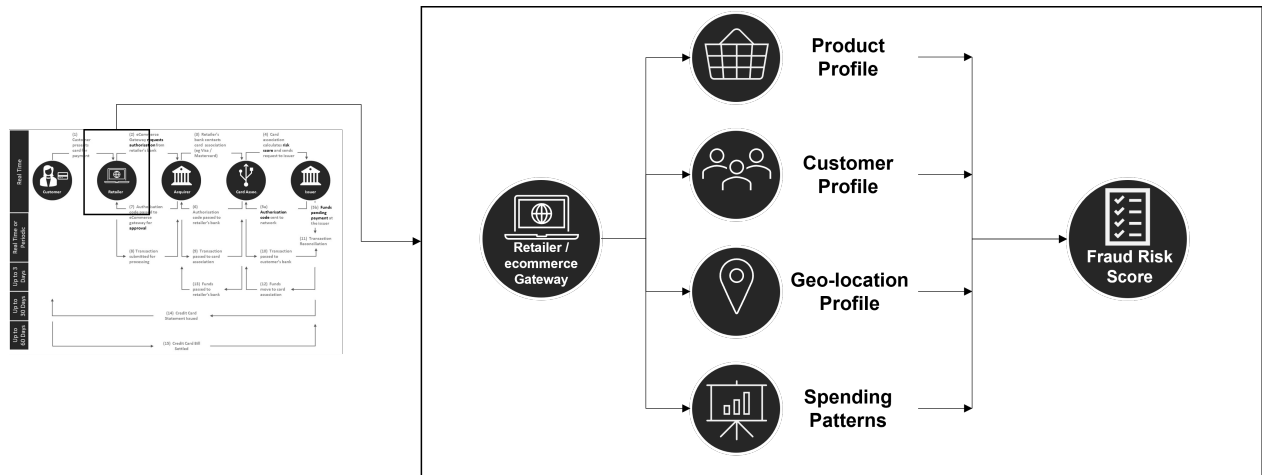


Fig. 4. Drill-down into the Retailer / e-commerce gateway process for fraud risk scoring.

To ascertain current trends in this domain, the Scopus database was employed as a primary source for gathering literature. A query identified computer science articles which were written in English and used the phrase "credit card fraud" in their key words. The resulting population of 181 articles were then filtered using reviews of the (1) title (2) abstract and (3) textual detail to focus on papers that are specifically concerned with the implementation of models in the domain of credit card fraud detection. In particular, papers which primarily focused on the generic development of models, only using a credit card fraud dataset as illustration of their techniques, were excluded from the survey. This filtering process resulted in a population of fifty-three papers, which subsequently grew to fifty-six following the addition of three papers identified by means of a snowballing technique.

Table II provides a selection of papers extracted from the full dataset. These papers consider at least two of the aforementioned operational challenges in their work. For completeness, the full table can be made available by contacting the authors of this paper. The table is complemented by Fig. 5a and 5b which summarise the full dataset.

A. Explanations within a Specific Context

Section II-B introduces the practical constraints of real-time analysis, managing unbalanced data and concept drift and minimising false positives which need to be considered in order for a model to be operationalisable. These contextual requirements of credit card fraud detection are perhaps more complex and multi-faceted than many fields. Additionally, Section II-C highlights a variety of fraud investigation approaches which provide transparency on the root causes of the fraud detection. Unfortunately, it is rare for scholars to acknowledge or clarify the timing and perspective within which their model is intended to operate, and the field of credit card fraud detection is no exception.

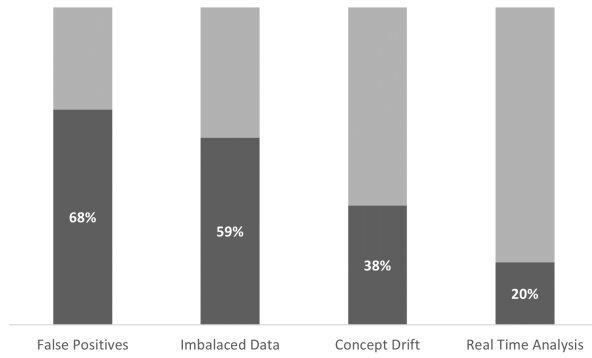
Fig. 5a and 5b show the resulting analysis of the literature population, with a view to understanding the extent of its coverage of the real world challenges discussed in Section II-B. Scholars demonstrate a strong awareness for incorporating the challenges of false positives and imbalanced data in their

TABLE II. LITERATURE COVERAGE OF REAL WORLD CREDIT CARD FRAUD CHALLENGES, BY PAPER - A SELECTION OF PAPERS WHICH CONSIDER AT LEAST TWO OF THE FOUR KEY CHALLENGES

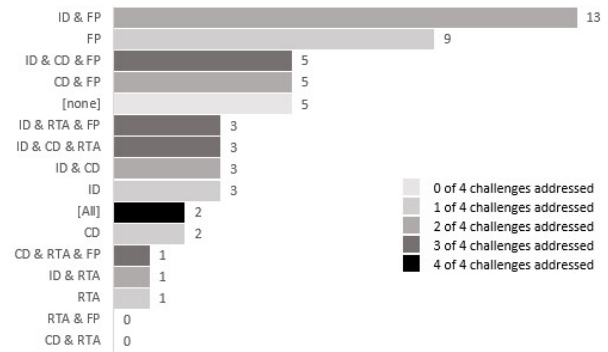
Reference	Managing False Positives	Imbalanced Data	Concept Drift	Real Time Analysis
[46]	✓	✓	✓	✓
[47]	✓	✓	✓	✓
[48]	✓	✓		✓
[49]	✓	✓		✓
[50]	✓	✓		✓
[51]	✓	✓	✓	
[52]	✓	✓	✓	
[53]	✓	✓	✓	
[54]	✓	✓	✓	
[55]	✓	✓	✓	
[56]		✓	✓	✓
[57]		✓	✓	✓
[58]		✓	✓	✓
[59]	✓		✓	✓
[60]	✓	✓		
[61]	✓	✓		
[62]	✓	✓		
[63]	✓	✓		
[64]	✓	✓		
[65]	✓	✓		
[66]	✓	✓		
[67]	✓	✓		
[68]	✓	✓		
[69]	✓	✓		
[70]	✓	✓		
[71]	✓	✓		
[72]	✓	✓		
[73]	✓		✓	
[74]	✓		✓	
[75]	✓		✓	
[76]	✓		✓	
[77]	✓		✓	
[78]		✓	✓	
[79]		✓	✓	
[80]		✓	✓	
[81]		✓		✓

papers (Fig. 5a) yet the majority fail to account for the difficulties brought about by the need to consider concept drift and real time analysis.

Fig. 5b particularly draws attention to the fact that the literature has so far failed to address any of these challenges, or even combinations of these challenges, in a consistent manner. In fact, five papers within the literature corpus failed to recog-



(a) Summary analysis of literature coverage of real world credit card fraud challenges.



(b) Detailed analysis of literature coverage of real world credit card fraud challenges, using the following abbreviations: Imbalanced Data (ID); False Positives (FP); Concept Drift (CD) and Real Time Analysis (RTA).

Fig. 5. Literature coverage of real world credit card fraud challenges.

nise any of the aforementioned challenges, whilst professing to deliver an implementable solution. In contrast, only two papers addressed all four of the aforementioned challenges [46], [47], with forty-two papers (75%) acknowledging two or fewer than two of them.

This analysis supports the argument that the current population of literature fails to take the contextual requirements of the credit card fraud operating environment into account when designing AI solutions. To encourage more ubiquitous adoption, scholars need to demonstrate an understanding of operational challenges and incorporate innovative solutions into their models. Authors also suggest that more rigour can be achieved by partnering with practitioners to deliver a testing strategy that mimics the operational environment [16].

Whilst scholars seeking to apply ML techniques in this domain might choose to specialise on a single challenge such as having unbalanced data or concept drift, demonstrating that the model is implementable in an operational environment (i.e. meets *usability* requirements) is key to achieving rigour and therefore ensuring more widespread acceptance [16].

Just as the contextual considerations of ML models are necessary for improving organisational adoption, the overarching consensus for XAI is that explanations are also contextual [82]. That is, in order for an agent to deliver a successful explanation, the context of the question must first be determined, and then addressed within the explanation itself. But what is meant by context, in the field of XAI, and how can it be achieved?

Whilst the literature contains a panoply of papers suggesting frameworks for the context of an explanation [18], [83]–[86], few provide an initial definition of what context means in the domain of XAI. Yet it is clear that the domain would benefit from a common vocabulary in order to move forward [15], [16]. In the absence of a normative definition, this paper proposes the following:

Context in XAI is any information needed by the explanation system to satisfy the explanation goals, trust and usability expectations of the audience.

This definition brings together four key elements of context frequently discussed in the literature. First it leverages the centrality of the audience [25], [87]–[90] since it is the audience who determines whether the explanation is a good one or not [16]. Second it captures the importance of understanding the goals of the audience, [85], [91] since it is the goals that drive the ML model design [85], [91], [92]. Third it recognises the value of ensuring trust in the explanation [17], [21], [93] since trust enables the audience to decide whether or not to have confidence in the results [21], [22]. Finally, by acknowledging the importance of usability [15], [82], [94], [95] the definition ensures that the system is more likely to be successful in an operational context [16], [94], [96].

Hence, the first recommendation for contributing towards a step-change in credit card fraud is to ensure that XAI models are designed with the context in mind. Demonstrating adherence to usability constraints such as real-time delivery, minimising false positives and supporting concept drift will encourage practitioners to see the potential rewards that XAI can bring over extant rule-based methods. An understanding of the audience goals will help scholars to develop XAI models that target practitioner desiderata and reflect the needs of real problems.

B. Increase Focus on Intrinsic Models

Section I-C introduces the concepts of intrinsic and post-hoc XAI models. For credit card fraud, the determination of fraudulent transactions can have a significant impact on a person's life and well-being. A false positive result could cause emotional distress such as shame or embarrassment as well as practical difficulties such as being unable to purchase goods. On the other hand, a false negative result fails to identify a transaction as fraudulent and results in financial consequences for the credit card holder, retailer or issuer. The serious consequences that could arise as a result of the fraud detection model forces the need for absolute trust that the explanation correctly interprets the decision-making within the model. Some authors suggest that models used for high stakes circumstances such as these should employ an intrinsic rather than post-hoc design [23].

Arguments supporting the use of intrinsic models leverage their ability to overcome the difficulties associated with black box models and their post-hoc explanations. The overriding challenge of black box models is their inherent opacity which undermines the ability of an individual to decide whether or not they can trust the model’s output. Moreover, the layering of a post-hoc explanation over the black box model introduces additional trust challenges. Since the post-hoc model, by definition, cannot provide a true 100% explanation of its underlying black box model, then there must be an element of uncertainty as to whether or not the explanation is correct. An individual faced with a black box model and post-hoc explanation therefore has two trust challenges to overcome:

- 1) Can the model be trusted to produce an accurate output?
- 2) Can the explanation be trusted to be faithful to the model?

In contrast, intrinsic models are sufficiently transparent that an individual can understand not only the most influential variables in the dataset, but also how those variables interact with other variables. Furthermore, the explanation, by design, directly reflects the model machinations, thereby enabling an easier decision as to whether or not to trust the output.

Unfortunately, there is a strong bias in the extant literature against the development of intrinsic models, meaning that focus is not forthcoming. Analysis of Guidotti’s [97] comprehensive survey of explainability methods identifies a slim population of 10 papers devoted to this approach, compared to 130 using post-hoc methods. Those findings are consistent with the analysis of literature conducted in this survey. Only seven of the fifty-six papers focus on the development of models which are inherently interpretable. The remaining forty-nine either propose black box models, or complex ensemble models without any attempt to explain the resulting outcomes.

There may be many reasons for this. Some authors suggest intrinsic models sacrifice accuracy for interpretability, [20], although other authors vehemently contest the notion [23]. Perhaps some scholars take pride in the complexity of black-box models ignoring the practical advantages that a transparent model would bring. Alternatively, authors designing models without a specific use-case in mind may prefer the advantages of flexibility that accompany a post-hoc, model-agnostic design.

Despite the cloak of simplicity that accompanies intrinsic models, they have many operational challenges that would benefit from scholarly focus [23]. It is not the intention of this discourse to argue a preference for intrinsic models over post-hoc techniques but to highlight that the field would benefit from increased focus and visibility. More work needs to be done to investigate the opportunities of intrinsic models in the fields of high-stakes decision-making where faithfulness to the underlying model has both an academic and moral imperative.

1) *Interpretable scoring systems:* A noteworthy subgroup of intrinsic models are interpretable scoring systems, used in decision-making and risk evaluation. Decision-making typically involves the careful evaluation of a number of diverse facts in order to arrive at a balanced decision. For example, medical professionals often weigh-up a number of discrete

Physiological parameter	Score						
	3	2	1	0	1	2	3
Respiration rate (per minute)	≤8		9–11	12–20		21–24	≥25
SpO ₂ Scale 1 (%)	≤91	92–93	94–95	≥96			
SpO ₂ Scale 2 (%)	≤83	84–85	86–87	88–92 ≥93 on air	93–94 on oxygen	95–96 on oxygen	≥97 on oxygen
Air or oxygen?		Oxygen		Air			
Systolic blood pressure (mmHg)	≤90	91–100	101–110	111–219			≥220
Pulse (per minute)	≤40		41–50	51–90	91–110	111–130	≥131
Consciousness				Alert			CVPU
Temperature (°C)	≤35.0		35.1–36.0	36.1–38.0	38.1–39.0	≥39.1	

NEW score	Clinical risk	Response
Aggregate score 0–4	Low	Ward-based response
Red score Score of 3 in any individual parameter	Low-medium	Urgent ward-based response*
Aggregate score 5–6	Medium	Key threshold for urgent response*
Aggregate score 7 or more	High	Urgent or emergency response**

Fig. 6. National Early Warning Scores (NEWS2) for assessing and responding to acute illness severity in the NHS [100].

facts about a patient before suggesting or even investigating a potential medical diagnosis, or finance professionals might weigh-up a number of different factors about a client before deciding on whether or not to offer them a loan. The accumulation and evaluation of these discrete facts are synonymous with domains requiring expert judgment. Heuristics are established through experience and expertise with simple techniques such as linear regression often being used to establish relationships between these pre-defined features and their classifier.

These aforementioned heuristics are known as “scoring systems”. Their popularity stems from the fact that decision-makers find them easy to understand and interpret [98]. Moreover, the input variables can easily be flexed to reveal the consequential impact on the predictor variable, and the model presents a common language for standardisation of reporting and comparison of results. Fig. 6 shows the scoring system mandated by NHS England for the assessment of patients presenting to, or being monitored in hospital. The lower table indicates the response that a patient should receive depending upon the medical staff’s assessment of the eight key variables in the upper table.

The transparency and uniformity of this approach has the added incentive of enabling the model to be transferable to other similar circumstances, as shown by [99] who demonstrated its effectiveness at also predicting short-term mortality as a result of Covid-19. However, the challenge of employing expert-led heuristic risk scores lies in the lack of a *formal guarantee* [101] that the heuristics are the right ones.

Recent experiences in AI demonstrate that oftentimes it is beneficial to ignore human experiences and instincts, and to instead be open to new discoveries and findings. One such example is the application of reinforcement learning to playing strategy games such as chess and Go. The initial approach was to use supervised learning techniques to “teach” the AI the strategies which had been learned by generations

of experts, but this only resulted in minimal improvements upon human levels of expertise. The step-change occurred when reinforcement learning techniques allowed the AI to learn for itself without human interference [102], resulting in significantly improved performance and the discovery of some novel game-winning strategies.

With this in mind, [103] introduce RiskSLIM (Risk-calibrated Supersparse Linear Integer Model) which learns from data, rather than experience and heuristics, to deliver a risk scoring system. The model not only works efficiently but is also able to be sensitive to organisational constraints such as minimising false positive results. Meanwhile it retains interpretability and enables expert decision-makers to flex the model prior to concluding on the overall risk assessment.

There are clear parallels to be drawn between the domains of medical risk assessment and credit card fraud detection. Both domains suffer from issues with unbalanced data, need to prioritise model efficiency and minimise false positives. Moreover, they require experts to have a full understanding of the drivers influencing the risk assessment.

Section II-C describes the four key dimensions which contribute to the holistic picture of a credit card transaction. Each dimension would be expected to have a risk score of its own and then be accumulated to produce an overall transaction risk score, in a similar manner to that presented in Fig. 6 [55], [57]. From the surveyed articles, six papers proposed a risk score as a decision-making tool as opposed to a binary classification approach. These papers were also more likely to have collaborated with industrial partners in their research, demonstrating the validity of risk scores being more aligned to a real-world perspective.

The survey also shows evidence that authors are increasingly looking beyond the single dimension of transaction spending patterns. Of the fifty-six surveyed papers, twenty-two of them incorporated customer profiling within their work. However, the inclusion of product profiles and geo-location profiles remains elusive.

Unfortunately, research into risk scoring systems which learn for themselves is scant. There are very few competitors to RiskSLIM to enable a sufficiently rigorous discourse. This is despite the successful practical applications which have been achieved by contemporary authors in the medical domain. For example, [104] collaborated with the World Health Organisation (WHO) to demonstrate its effectiveness in screening for adult attention-deficit/hyperactivity disorder and more recently [105] showed its effectiveness in screening for seizures in hospitalised patients. Given the ubiquity of scoring systems in use across multiple industries, and specifically their aforementioned relevance in fraud detection, the domain would benefit from more attention from scholars. In particular, it would be beneficial to explore applications for RiskSLIM outside of the medical domain, in addition to the development of alternative models to challenge the hegemony of RiskSLIM as a self-learning risk scoring system.

C. Measure the Faithfulness of Explanations

Assuming a researcher chooses to engage in the development of a post-hoc explanation technique, then common

sense dictates that the explanation must accurately represent the reasoning process behind the model's prediction. This close relationship between the explanation and the underlying reasoning process is often referred to as faithfulness [19], [21], [106] or fidelity [97].

It has been shown that without some measure of faithfulness of an explanation, an audience may be prone to over-trust and misuse explanation tools. This circumstance was exemplified by [107] who performed a contextual inquiry and survey of data scientists using the InterpretML implementation of Generalised Additive Models (GAMs) and the SHAP Python software package. Their investigation found that some users were using the tool to rationalise suspicious observations instead of just understanding the underlying model. Others were taking the visualisations at face value instead of using them to identify issues with the dataset. Moreover, the open-source nature of both tools led individuals to trust the explanations without fully understanding them.

Efforts to measure faithfulness are nascent, with few works in publication more than five years ago. In [108] the authors used a Natural Language Processing (NLP) model called NILE (Natural language Inference over Label-specific Explanations) to demonstrate that model faithfulness and model accuracy can co-exist. Their paper used a sensitivity analysis to evidence the faithfulness of their model. Building on that concept, [109] suggest that sensitivity should be accompanied by stability to determine whether or not an explanation is faithful.

In an effort to extract consistency from the diverse literature, [106] perform a review of faithfulness works. They identify (but do not necessarily endorse) three assumptions that they say researchers are making in order to determine faithfulness:

- 1) **The model assumption** Two models will make the same prediction if and only if they use the same reasoning process.
- 2) **The prediction assumption** On similar inputs, the model makes similar decisions if and only if it provides different interpretations for similar inputs and outputs.
- 3) **The linearity assumption** Certain parts of the input are more important to the model reasoning than others. Moreover, the contributions of different parts of the input are independent from each other.

In their discourse, [106] argue that the binary approach to determining faithfulness is fraught with difficulty since counter-examples will likely always exist. Instead, they suggest that authors should consider degrees of faithfulness to give an indication of how close an explanation is to the reasoning process of the underlying model.

Section III-B suggests there are two trust challenges that need to be overcome in order to be comfortable with the output of a black box model and its explanation. The issue of faithfulness is central to the second trust challenge. Nowhere is that trust more necessary than in high-stakes industries where the consequences of an incorrect or mis-interpreted explanation can be highly damaging. Whilst explanations may only be required under certain circumstances (for example in the event of an unexpected model outcome), there exists a moral

obligation to associate an explainable model in high stakes decision-making with some measure regarding the expected accuracy of the explanation to the ground truth.

D. Human Interaction with Explanations

In a recent call for closer integration between the Human-Computer Interaction (HCI) and ML communities, [90] cites the advantages to intelligible machine learning of leveraging the well-established human-centered research community. The cornerstone of HCI philosophy begins with understanding the needs of the audience, recognising that different audiences may have different requirements of the same system.

In the context of fraudulent transactions this paper adapts the work of [86] to suggest there are three key audiences for the explanation system:

- 1) The operator / executor i.e., the fraud analysts, whose role it is to determine the validity of the positive “red flag” transactions identified as potentially fraudulent.
- 2) The creator i.e., the technical support responsible for the internal operation of the system.
- 3) The examiners i.e., the senior management teams, who are focused on both the changing trends of fraud patterns and the integrity of the fraud identification process.

Critically, in the event of a transaction being deemed to be likely fraud, the cardholder should not be informed of the entire explanation without operator oversight, hence the omission of decision-subjects and data-subjects. This is because organisations within this process must take care not to advise fraudsters of the parameters in place to detect fraudulent transactions. It would therefore be incorrect to consider the cardholder as one of the parties requiring the direct explanation.

For the fraud analyst, the explanation is in place to ensure they fully understand, and agree with, the reasoning for the FMS to identify the transaction as fraudulent. They are detecting and looking for causal reasoning of an event which has already occurred. Hence their dialogue centres around local, causal explanations and the fitness of the attributes contributing towards each individual “red flag”.

Technical specialists meanwhile are interested in “how”, rather than “why” [110]. Their role is to ensure the system is operating effectively, for which they need transparency of the process rather than justification of an outcome. These teams will therefore look towards a causal attribution explanation in order to understand the internal workings of the explanation agent.

On the other hand, senior management teams are interested in fraud preventative measures [111]; explanations which shed light on predictive patterns. They may be searching for insight on emerging trends of fraud, in order to support future decision-making. Alternatively, they may be interested in validation that the models treat all data subjects equitably. Hence they need both local and global explanations; local to explain specific predictions and global to understand the model as a whole.

Identifying such diverse audiences and their corresponding perspectives provides a wealth of opportunities for researchers

to explore a variety of targeted explanations in fraud detection. Yet the HCI community, and increasingly the ML community too, suggest that scholars should go a step further in their quest to satisfy audience desiderata. In particular, the explanation should also reflect contemporary understandings of how an audience engages with an explanation [87].

Miller’s [87] seminal paper makes the case for ensuring researchers design explanations with an appreciation of human cognition in mind. It builds upon an earlier paper [82] which articulates the importance of comprehension in order to ensure the explanation is useful to the intended user in a practical setting. This view is widely held [16], [17], [93], [112].

Cognitive scientists claim that prior knowledge is widely recognised to have a profound influence on understanding new concepts [113]. Hence for an effective explanation, the explainer must first understand the audience’s initial level of existing knowledge. Any subsequent new information then builds upon that baseline [114], [115], incrementally constructing a bridge to a new knowledge state. This individualised layering of new knowledge on old becomes synonymous with explanation as a dialogue, wherein the audience repeatedly questions the explanation agent until a point of understanding is reached.

However, building knowledge in this way only allows for the audience to learn from the explanation agent. In fields such as fraud detection, there are also likely to be instances where experts have more knowledge than the explainer, resulting in them outperforming the system-generated explanation [116]. In this circumstance, explanations should therefore be a two-way concept. Whilst we look to XAI to communicate unknown patterns and influences extracted from the prescribed data, the expert audience adds breadth, supplementing the explanation with their own peripheral knowledge and undocumented experiences. Hence in expert systems, designing explanation with an interactive dialogue in mind allows for the development of a “learning loop”, which ultimately enhances the performance of both the XAI agent and the audience [116].

IV. CONCLUSION

Credit card fraud is widely acknowledged as a key contributor to the persistence of organised crime in the European Union. Moreover, the recent Covid-19 pandemic has accelerated the switch to digital payments and revealed the potential of a future cashless global society. As the use of payment cards continues to overtake the use of cash in our economy, the ability of payments providers to reduce the value and volume of fraudulent transactions becomes ever more crucial.

Regulators acknowledge this danger and are working to introduce increasingly stringent legislation to counteract the trend. In particular, they are leveraging the vast quantities of data available in our modern society to encourage more effective financial defences. As part of the PSD2 regulation, SCA has recently been enforced in Europe and the United Kingdom. SCA mandates real-time data analysis and the introduction of authentication enrichment data, both of which combine with recent developments in open banking and payment technologies to create an urgent need for change in the detection of fraudulent credit card transactions.

The overarching consensus is that established rule-based fraud detection methodologies are no longer scalable to the extent that modern society needs them to be. Moreover, they struggle to provide the flexibility or agility to adapt to either the rapidly changing operating environment or dynamic modus operandi of modern fraudsters. ML models have the ability to provide a solution to these challenges, yet their opacity has impeded their adoption in this domain.

In response, this paper argues for more researchers to engage with investigations into the use of XAI techniques for credit card fraud detection. It contributes to the discourse in three key ways:

- 1) It sheds light on recent regulatory changes which are pivotal in driving the adoption of new ML techniques.
- 2) It examines the operating environment pertaining to CNP credit card transactions, an understanding of which is crucial for the ability to operationalise ML solutions.
- 3) Using a survey of contemporary literature, it sets out a research agenda, arguing that further work would contribute towards a step-change in the adoption of ML into this industry.

The research agenda first suggests that the current literature fails to consistently accommodate the key contextual challenges of real-time analysis, concept drift, minimising false positives and dealing with class imbalance. These omissions lead to solutions which are not operationalisable, thereby undermining the relevancy of the work. Incorporating context fully into an XAI solution would support more wider adoption, yet recent papers in XAI have struggled to articulate the full meaning of context in this field. The first agenda point therefore provides a novel definition of the term "context" in relation to XAI and goes on to suggest that researchers should always design XAI models with context in mind.

Second, it recommends that more work should be done to examine the utility of intrinsic models and in particular focus on the under-researched area of self-learning risk scoring systems. Contemporary literature generally demonstrates a bias towards the development of post-hoc rather than intrinsic models. A popular argument suggests this is because black box models are more accurate than their interpretable counterparts. Yet this statement remains controversial for some authors, especially in light of the need for trust and transparency in high-stakes decision-making. Increased attention from scholars will help to progress this debate and may help to challenge the hegemony of incumbent risk scoring systems.

Third, it recognises that authors should consider implementing measures of faithfulness to give an indication of how close an explanation is to the reasoning process of the underlying model, and thereby help to establish trust in the explanation. Previous authors have demonstrated the tendency for an audience to over-trust and mis-use explanation tools without some measure of faithfulness. Its inclusion as an evaluation tool is particularly pertinent in the field of high-stakes decision-making such as fraud detection, where the consequences of an incorrect decision can be damaging to multiple parties.

Finally, it suggests recognising the value of human expert knowledge in this domain and incorporating an ability

to provide a "learning loop" which ultimately enhances the performance of both the XAI agent and the audience. The current corpus of literature recommends that explanations should not only be designed with the audience in mind, but also recognise the nuances of human cognition in order to deliver an explanation that is useful to the intended user in a practical setting. The explanation should subsequently evolve into a dialogue, wherein the audience can repeatedly question the explanation agent until a point of understanding is reached, and likewise contribute expert knowledge into the model to enhance mutual understanding.

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REFERENCES

- [1] Europol, "Serious and Organised Crime Threat Assessment," 2021.
- [2] UK Finance, "Fraud - The Facts, 2021," 2021.
- [3] S. Nilson, "The Nilson Report: Card Fraud Losses Reach \$27.85 Billion," 2019.
- [4] European Central Bank, "The revised payment services directive (psd2) and the transition to stronger payments security," https://www.ecb.europa.eu/paym/intro/mip-online/2018/html/1803_revisedpsd.en.html Accessed: July 27, 2022, 2018.
- [5] J. Allen, "What is authentication enrichment and why should you do it?" <https://www.ravelin.com/blog/what-is-authentication-enrichment-and-why-should-you-do-it> Accessed: November 30, 2021, 2020.
- [6] Visa, "New and improved 3-d secure," 2019. [Online]. Available: <https://usa.visa.com/content/dam/VCOM/global/visa-everywhere/documents/visa-3d-secure-2-program-infographic.pdf>
- [7] T. Cray, "How will sca adoption impact chargebacks?" <https://www.ukfinance.org.uk/news-and-insight/blogs/how-will-sca-adoption-impact-chargebacks>, 2021.
- [8] K. Dowd, "The war on cash is about much more than cash," *Economic Affairs*, vol. 39, no. 3, pp. 391–399, 2019.
- [9] UK Finance, "UK Payments Market Summary 2021," 2021.
- [10] Open Banking Limited, "Open Banking Impact Report, 2022," <https://openbanking.foleon.com/live-publications/the-open-banking-impact-report-june-2022/> Accessed 28 July, 2022, 2022.
- [11] The International Bank for Reconstruction and Development, "Payment systems worldwide - a snapshot," <https://documents1.worldbank.org/curated/en/115211594375402373/pdf/A-Snapshot.pdf>, 2020.
- [12] G. Dvorsky, "Hackers have already started to weaponise artificial intelligence," <https://gizmodo.com/hackers-have-already-started-to-weaponize-artificial-in-1797688425>, 2017.
- [13] CIFAS, "Fraudscape 2020," <https://www.fraudscape.co.uk/>, 2020.
- [14] N. F. Ryman-Tubb, P. Krause, and W. Garn, "How artificial intelligence and machine learning research impacts payment card fraud detection: A survey and industry benchmark," *Engineering Applications of Artificial Intelligence*, vol. 76, pp. 130–157, 2018.
- [15] Z. C. Lipton, "The mythos of model interpretability: In machine learning, the concept of interpretability is both important and slippery," *Queue*, vol. 16, no. 3, pp. 31–57, 2018.
- [16] F. Doshi-Velez and B. Kim, "A roadmap for a rigorous science of interpretability," *arXiv preprint arXiv:1702.08608*, vol. 2, p. 1, 2017.
- [17] O. Biran and C. Cotton, "Explanation and justification in machine learning: A survey," in *IJCAI-17 workshop on explainable AI (XAI)*, vol. 8, 2017, pp. 8–13.

- [18] W. J. Murdoch, C. Singh, K. Kumbier, R. Abbasi-Asl, and B. Yu, "Definitions, methods, and applications in interpretable machine learning," *Proceedings of the National Academy of Sciences*, vol. 116, no. 44, pp. 22071–22080, 2019.
- [19] L. H. Gilpin, D. Bau, B. Z. Yuan, A. Bajwa, M. Specter, and L. Kagal, "Explaining explanations: An overview of interpretability of machine learning," in *2018 IEEE 5th International Conference on data science and advanced analytics (DSAA)*. IEEE, 2018, pp. 80–89.
- [20] D. Gunning and D. Aha, "Darpa's explainable artificial intelligence (xai) program," *AI magazine*, vol. 40, no. 2, pp. 44–58, 2019.
- [21] M. T. Ribeiro, S. Singh, and C. Guestrin, "Why should i trust you?" explaining the predictions of any classifier," in *Proceedings of the 22nd ACM SIGKDD international conference on knowledge discovery and data mining*, 2016, pp. 1135–1144.
- [22] A. Adadi and M. Berrada, "Peeking inside the black-box: a survey on explainable artificial intelligence (xai)," *IEEE access*, vol. 6, pp. 52138–52160, 2018.
- [23] C. Rudin, "Stop explaining black box machine learning models for high stakes decisions and use interpretable models instead," *Nature Machine Intelligence*, vol. 1, no. 5, pp. 206–215, 2019.
- [24] P. Hall, N. Gill, and N. Schmidt, "Proposed guidelines for the responsible use of explainable machine learning," *arXiv preprint arXiv:1906.03533*, 2019.
- [25] S. Atakishiyev, H. Babiker, N. Farruque, R. Goebel, M. Kima, M. H. Motallebi, J. Rabelo, T. Syed, and O. R. Zai'ane, "A multi-component framework for the analysis and design of explainable artificial intelligence," *arXiv preprint arXiv:2005.01908*, 2020.
- [26] M. Du, N. Liu, and X. Hu, "Techniques for interpretable machine learning," *Communications of the ACM*, vol. 63, no. 1, pp. 68–77, 2019.
- [27] S. Mohseni, N. Zarei, and E. D. Ragan, "A multidisciplinary survey and framework for design and evaluation of explainable ai systems," *ACM Transactions on Interactive Intelligent Systems (TiIS)*, vol. 11, no. 3-4, pp. 1–45, 2021.
- [28] D. V. Carvalho, E. M. Pereira, and J. S. Cardoso, "Machine learning interpretability: A survey on methods and metrics," *Electronics*, vol. 8, no. 8, p. 832, 2019.
- [29] S. M. Lundberg and S.-I. Lee, "A unified approach to interpreting model predictions," *Advances in neural information processing systems*, vol. 30, 2017.
- [30] F. Bodria, F. Giannotti, R. Guidotti, F. Naretto, D. Pedreschi, and S. Rinzivillo, "Benchmarking and survey of explanation methods for black box models," *arXiv preprint arXiv:2102.13076*, 2021.
- [31] D. Sinanc, U. Demirezen, Ş. Sağıroğlu *et al.*, *Explainable Credit Card Fraud Detection with Image Conversion*. Ediciones Universidad de Salamanca (España), 2021.
- [32] N. F. Ryman-Tubb and A. d. Garcez, "Soar—sparse oracle-based adaptive rule extraction: knowledge extraction from large-scale datasets to detect credit card fraud," in *The 2010 International Joint Conference on Neural Networks (IJCNN)*. IEEE, 2010, pp. 1–9.
- [33] Gartner, "Market guide for online fraud detection." 2021. [Online]. Available: <https://www.gartner.com/doc/reprints?id=1-27FWBFD0&ct=210915&st=sfb>
- [34] Fisglobal, "What is credit card processing?" <https://www.fisglobal.com/en-gb/insights/merchant-solutions-worldpay/article/what-is-credit-card-processing> Accessed: March 23, 2022, 2019.
- [35] Baymard Institute, "Main reasons why consumers in the united states abandoned their orders during the checkout process in 2021." <https://www-statista-com.surrey.idm.oclc.org/statistics/1228452/reasons-for-abandonments-during-checkout-united-states/> Statista Inc.. Accessed: November 30, 2021., 2021.
- [36] 3dSecure2, "Why was 3-d secure 1.0 not successful in some countries?" <https://3dsecure2.com/blog/why-was-3-d-secure-1-0-not-successful-in-some-countries/> Accessed: November 30, 2021, 2019.
- [37] A. Shen, R. Tong, and Y. Deng, "Application of classification models on credit card fraud detection," in *2007 International conference on service systems and service management*. IEEE, 2007, pp. 1–4.
- [38] A. Rodriguez, A. Tabassum, J. Cui, J. Xie, J. Ho, P. Agarwal, B. Adhikari, and B. A. Prakash, "Deepcovid: An operational deep learning-driven framework for explainable real-time covid-19 forecasting," in *Proceedings of the AAAI Conference on Artificial Intelligence*, vol. 35, 2021, pp. 15393–15400.
- [39] Ethoca, "Solving the cnp false decline puzzle: Collaboration is key," <https://hs.ethoca.com/solving-the-cnp-false-decline-puzzle-collaboration-is-key> Accessed: July 28, 2022, 2017.
- [40] M. Nelson, "Outsmarting fraudsters with advanced analytics," <https://usa.visa.com/visa-everywhere/security/outsmarting-fraudsters-with-advanced-analytics.html> Accessed: March 23, 2022, no date.
- [41] N. V. Chawla, K. W. Bowyer, L. O. Hall, and W. P. Kegelmeyer, "Smote: synthetic minority over-sampling technique," *Journal of artificial intelligence research*, vol. 16, pp. 321–357, 2002.
- [42] Ravelin, "Retail eCommerce Fraud and Payments Survey," <https://pages.ravelin.com/retail-fraud-payments-report> Accessed 28 July, 2022, 2021.
- [43] Z. Zhang, P. Cui, and W. Zhu, "Deep learning on graphs: A survey," *IEEE Transactions on Knowledge and Data Engineering*, 2020.
- [44] T. Fawcett and F. Provost, "Adaptive fraud detection," *Data mining and knowledge discovery*, vol. 1, no. 3, pp. 291–316, 1997.
- [45] A. Cufoglu, "User profiling—a short review," *International Journal of Computer Applications*, vol. 108, no. 3, 2014.
- [46] I. Sadgali, N. Sael, and F. Benabbou, "Adaptive model for credit card fraud detection," 2020.
- [47] R. Van Belle, B. Baesens, and J. De Weerd, "Catchm: A novel network-based credit card fraud detection method using node representation learning," *Decision Support Systems*, p. 113866, 2022.
- [48] V. Van Vlasselaer, C. Bravo, O. Caelen, T. Eliassi-Rad, L. Akoglu, M. Snoeck, and B. Baesens, "Apatate: A novel approach for automated credit card transaction fraud detection using network-based extensions," *Decision Support Systems*, vol. 75, pp. 38–48, 2015.
- [49] M. Arya and H. Sastry G, "Deal—'deep ensemble algorithm' framework for credit card fraud detection in real-time data stream with google tensorflow," *Smart Science*, vol. 8, no. 2, pp. 71–83, 2020.
- [50] A. F. Ghahfarokhi, T. Mansouri, M. R. S. Moghaddam, N. Bahrambeik, R. Yavari, and M. F. Sani, "Credit card fraud detection using asexual reproduction optimization," *Kybernetes*, 2021.
- [51] A. Dal Pozzolo, G. Boracchi, O. Caelen, C. Alippi, and G. Bontempi, "Credit card fraud detection: a realistic modeling and a novel learning strategy," *IEEE transactions on neural networks and learning systems*, vol. 29, no. 8, pp. 3784–3797, 2017.
- [52] S. M. Darwish, "A bio-inspired credit card fraud detection model based on user behavior analysis suitable for business management in electronic banking," *Journal of Ambient Intelligence and Humanized Computing*, vol. 11, no. 11, pp. 4873–4887, 2020.
- [53] J. Forough and S. Momtazi, "Sequential credit card fraud detection: A joint deep neural network and probabilistic graphical model approach," *Expert Systems*, vol. 39, no. 1, p. e12795, 2022.
- [54] V. Plakandaras, P. Gogas, T. Papadimitriou, and I. Tsamardinos, "Credit card fraud detection with automated machine learning systems," *Applied Artificial Intelligence*, vol. 36, no. 1, p. 2086354, 2022.
- [55] J. N. Dharwa and A. R. Patel, "A data mining with hybrid approach based transaction risk score generation model (trsgm) for fraud detection of online financial transaction," *International Journal of Computer Applications*, vol. 16, no. 1, pp. 18–25, 2011.
- [56] F. Carcillo, A. Dal Pozzolo, Y.-A. Le Borgne, O. Caelen, Y. Mazzer, and G. Bontempi, "Scarf: a scalable framework for streaming credit card fraud detection with spark," *Information fusion*, vol. 41, pp. 182–194, 2018.
- [57] I. Mekterović, M. Karan, D. Pintar, and L. Brkić, "Credit card fraud detection in card-not-present transactions: Where to invest?" *Applied Sciences*, vol. 11, no. 15, p. 6766, 2021.
- [58] I. Sadgali, N. Sael, and F. Benabbou, "Human behavior scoring in credit card fraud detection," *IAES International Journal of Artificial Intelligence*, vol. 10, no. 3, p. 698, 2021.
- [59] S. Ounacer, H. A. El Bour, Y. Oubrahim, M. Y. Ghomari, and M. Azzouzi, "Using isolation forest in anomaly detection: the case of credit card transactions," *Periodicals of Engineering and Natural Sciences (PEN)*, vol. 6, no. 2, pp. 394–400, 2018.

- [60] Y. Sahin, S. Bulkan, and E. Duman, "A cost-sensitive decision tree approach for fraud detection," *Expert Systems with Applications*, vol. 40, no. 15, pp. 5916–5923, 2013.
- [61] E. Duman and M. H. Ozcelik, "Detecting credit card fraud by genetic algorithm and scatter search," *Expert Systems with Applications*, vol. 38, no. 10, pp. 13 057–13 063, 2011.
- [62] S. Jha, M. Guillen, and J. C. Westland, "Employing transaction aggregation strategy to detect credit card fraud," *Expert systems with applications*, vol. 39, no. 16, pp. 12 650–12 657, 2012.
- [63] A. G. de Sá, A. C. Pereira, and G. L. Pappa, "A customized classification algorithm for credit card fraud detection," *Engineering Applications of Artificial Intelligence*, vol. 72, pp. 21–29, 2018.
- [64] J. A. Gómez, J. Arévalo, R. Paredes, and J. Nin, "End-to-end neural network architecture for fraud scoring in card payments," *Pattern Recognition Letters*, vol. 105, pp. 175–181, 2018.
- [65] E. Kim, J. Lee, H. Shin, H. Yang, S. Cho, S.-k. Nam, Y. Song, J.-a. Yoon, and J.-i. Kim, "Champion-challenger analysis for credit card fraud detection: Hybrid ensemble and deep learning," *Expert Systems with Applications*, vol. 128, pp. 214–224, 2019.
- [66] N. Rtayli and N. Enneya, "Enhanced credit card fraud detection based on svm-recursive feature elimination and hyper-parameters optimization," *Journal of Information Security and Applications*, vol. 55, p. 102596, 2020.
- [67] S. Akila and U. S. Reddy, "Cost-sensitive risk induced bayesian inference bagging (ribib) for credit card fraud detection," *Journal of computational science*, vol. 27, pp. 247–254, 2018.
- [68] N. K. Trivedi, S. Simaiya, U. K. Lilhore, and S. K. Sharma, "An efficient credit card fraud detection model based on machine learning methods," *International Journal of Advanced Science and Technology*, vol. 29, no. 5, pp. 3414–3424, 2020.
- [69] C. Wang and D. Han, "Credit card fraud forecasting model based on clustering analysis and integrated support vector machine," *Cluster Computing*, vol. 22, no. 6, pp. 13 861–13 866, 2019.
- [70] M. Rezapour, "Anomaly detection using unsupervised methods: credit card fraud case study," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 11, 2019.
- [71] E. Esenogho, I. D. Mienye, T. G. Swart, K. Aruleba, and G. Obaido, "A neural network ensemble with feature engineering for improved credit card fraud detection," *IEEE Access*, vol. 10, pp. 16 400–16 407, 2022.
- [72] J. F. Roseline, G. Naidu, V. S. Pandi, S. A. alias Rajasree, and N. Mageswari, "Autonomous credit card fraud detection using machine learning approach," *Computers and Electrical Engineering*, vol. 102, p. 108132, 2022.
- [73] A. Pumsirirat and Y. Liu, "Credit card fraud detection using deep learning based on auto-encoder and restricted boltzmann machine," *International Journal of advanced computer science and applications*, vol. 9, no. 1, 2018.
- [74] F. Carcillo, Y.-A. Le Borgne, O. Caelen, Y. Kessaci, F. Oblé, and G. Bontempi, "Combining unsupervised and supervised learning in credit card fraud detection," *Information sciences*, vol. 557, pp. 317–331, 2021.
- [75] L. Zheng, G. Liu, C. Yan, and C. Jiang, "Transaction fraud detection based on total order relation and behavior diversity," *IEEE Transactions on Computational Social Systems*, vol. 5, no. 3, pp. 796–806, 2018.
- [76] Y. Xie, G. Liu, C. Yan, C. Jiang, and M. Zhou, "Time-aware attention-based gated network for credit card fraud detection by extracting transactional behaviors," *IEEE Transactions on Computational Social Systems*, 2022.
- [77] M. Krivko, "A hybrid model for plastic card fraud detection systems," *Expert Systems with Applications*, vol. 37, no. 8, pp. 6070–6076, 2010.
- [78] F. Carcillo, Y.-A. Le Borgne, O. Caelen, and G. Bontempi, "Streaming active learning strategies for real-life credit card fraud detection: assessment and visualization," *International Journal of Data Science and Analytics*, vol. 5, no. 4, pp. 285–300, 2018.
- [79] I. Sadgali, N. Sael, and F. Benabbou, "Bidirectional gated recurrent unit for improving classification in credit card fraud detection," *Indonesian Journal of Electrical Engineering and Computer Science (IJECS)*, vol. 21, no. 3, pp. 1704–1712, 2021.
- [80] H. Z. Alenzi and N. O. Aljehane, "Fraud detection in credit cards using logistic regression," *International Journal of Advanced Computer Science and Applications*, vol. 11, no. 12, 2020.
- [81] A. Q. Zainab K., Dhandu N., "Adoca: A novel technique to defraud credit card using an optimized catboost algorithm," *Journal of Theoretical and Applied Information Technology*, 2022.
- [82] T. Miller, P. Howe, and L. Sonenberg, "Explainable ai: Beware of inmates running the asylum or: How i learnt to stop worrying and love the social and behavioural sciences," *arXiv preprint arXiv:1712.00547*, 2017.
- [83] F. Sørmø, J. Cassens, and A. Aamodt, "Explanation in case-based reasoning—perspectives and goals," *Artificial Intelligence Review*, vol. 24, no. 2, pp. 109–143, 2005.
- [84] D. Wang, Q. Yang, A. Abdul, and B. Y. Lim, "Designing theory-driven user-centric explainable ai," in *Proceedings of the 2019 CHI conference on human factors in computing systems*, 2019, pp. 1–15.
- [85] V. Arya, R. K. Bellamy, P.-Y. Chen, A. Dhurandhar, M. Hind, S. C. Hoffman, S. Houde, Q. V. Liao, R. Luss, A. Mojsilović *et al.*, "One explanation does not fit all: A toolkit and taxonomy of ai explainability techniques," *arXiv preprint arXiv:1909.03012*, 2019.
- [86] R. Tomsett, D. Braines, D. Harborne, A. Preece, and S. Chakraborty, "Interpretable to whom? a role-based model for analyzing interpretable machine learning systems," *arXiv preprint arXiv:1806.07552*, 2018.
- [87] T. Miller, "Explanation in artificial intelligence: Insights from the social sciences," *Artificial intelligence*, vol. 267, pp. 1–38, 2019.
- [88] M. Ribera and A. Lapedriza, "Can we do better explanations? a proposal of user-centered explainable ai." in *IUI Workshops*, vol. 2327, 2019, p. 38.
- [89] S. Rüping, "Learning interpretable models," 10 2006.
- [90] J. W. Vaughan and H. Wallach, "A human-centered agenda for intelligible machine learning," *Machines We Trust: Getting Along with Artificial Intelligence*, 2020.
- [91] Y. Zhang, K. Song, Y. Sun, S. Tan, and M. Udell, "Why Should You Trust My Explanation?" Understanding Uncertainty in LIME Explanations," *arXiv preprint arXiv:1904.12991*, 2019.
- [92] S. R. Haynes, M. A. Cohen, and F. E. Ritter, "Designs for explaining intelligent agents," *International Journal of Human-Computer Studies*, vol. 67, no. 1, pp. 90–110, 2009.
- [93] R. R. Hoffman, G. Klein, and S. T. Mueller, "Explaining explanation for "explainable ai"," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 62. SAGE Publications Sage CA: Los Angeles, CA, 2018, pp. 197–201.
- [94] A. Abdul, J. Vermeulen, D. Wang, B. Y. Lim, and M. Kankanhalli, "Trends and trajectories for explainable, accountable and intelligible systems: An hci research agenda," in *Proceedings of the 2018 CHI conference on human factors in computing systems*, 2018, pp. 1–18.
- [95] T. Kulesza, S. Stumpf, M. Burnett, and I. Kwan, "Tell me more? the effects of mental model soundness on personalizing an intelligent agent," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2012, pp. 1–10.
- [96] T. Kulesza, M. Burnett, W.-K. Wong, and S. Stumpf, "Principles of explanatory debugging to personalize interactive machine learning," in *Proceedings of the 20th international conference on intelligent user interfaces*, 2015, pp. 126–137.
- [97] R. Guidotti, A. Monreale, S. Ruggieri, F. Turini, F. Giannotti, and D. Pedreschi, "A survey of methods for explaining black box models," *ACM computing surveys (CSUR)*, vol. 51, no. 5, pp. 1–42, 2018.
- [98] B. Ustun and C. Rudin, "Supersparse linear integer models for optimized medical scoring systems," *Machine Learning*, vol. 102, no. 3, pp. 349–391, 2016.
- [99] L. J. Scott, A. Tavaré, E. M. Hill, L. Jordan, M. Juniper, S. Srivastava, E. Redfern, H. Little, and A. Pullyblank, "Prognostic value of national early warning scores (news2) and component physiology in hospitalised patients with covid-19: a multicentre study," *Emergency Medicine Journal*, 2022.
- [100] Royal College of Physicians, "National early warning score (news) 2: Standardising the assessment of acute-illness severity in the nhs," 2017. [Online]. Available: <https://www.rcplondon.ac.uk/projects/outputs/national-early-warning-score-news-2>

- [101] B. Ustun and C. Rudin, "Learning optimized risk scores." *J. Mach. Learn. Res.*, vol. 20, no. 150, pp. 1–75, 2019.
- [102] D. Silver, J. Schrittwieser, K. Simonyan, I. Antonoglou, A. Huang, A. Guez, T. Hubert, L. Baker, M. Lai, A. Bolton *et al.*, "Mastering the game of go without human knowledge," *nature*, vol. 550, no. 7676, pp. 354–359, 2017.
- [103] C. Rudin and B. Ustun, "Optimized scoring systems: Toward trust in machine learning for healthcare and criminal justice," *Interfaces*, vol. 48, no. 5, pp. 449–466, 2018.
- [104] B. Ustun, L. A. Adler, C. Rudin, S. V. Faraone, T. J. Spencer, P. Berglund, M. J. Gruber, and R. C. Kessler, "The world health organization adult attention-deficit/hyperactivity disorder self-report screening scale for dsm-5," *Jama psychiatry*, vol. 74, no. 5, pp. 520–526, 2017.
- [105] A. F. Struck, A. A. Rodriguez-Ruiz, G. Osman, E. J. Gilmore, H. A. Haider, M. B. Dhakar, M. Schrettnner, J. W. Lee, N. Gaspard, L. J. Hirsch *et al.*, "Comparison of machine learning models for seizure prediction in hospitalized patients," *Annals of clinical and translational neurology*, vol. 6, no. 7, pp. 1239–1247, 2019.
- [106] A. Jacovi and Y. Goldberg, "Towards faithfully interpretable nlp systems: How should we define and evaluate faithfulness?" *arXiv preprint arXiv:2004.03685*, 2020.
- [107] H. Kaur, H. Nori, S. Jenkins, R. Caruana, H. Wallach, and J. Wortman Vaughan, "Interpreting interpretability: understanding data scientists' use of interpretability tools for machine learning," in *Proceedings of the 2020 CHI conference on human factors in computing systems*, 2020, pp. 1–14.
- [108] S. Kumar and P. Talukdar, "Nile: Natural language inference with faithful natural language explanations," *arXiv preprint arXiv:2005.12116*, 2020.
- [109] F. Yin, Z. Shi, C.-J. Hsieh, and K.-W. Chang, "On the faithfulness measurements for model interpretations," *arXiv preprint arXiv:2104.08782*, 2021.
- [110] M. R. Wick, P. Dutta, T. Wineinger, and J. Conner, "Reconstructive explanation: A case study in integral calculus," *Expert Systems with Applications*, vol. 8, no. 4, pp. 463–473, 1995.
- [111] E. Gianotti and E. D. da Silva, "Strategic management of credit card fraud: stakeholder mapping of a card issuer," *Journal of Financial Crime*, 2021.
- [112] K. Sokol and P. Flach, "Explainability fact sheets: a framework for systematic assessment of explainable approaches," in *Proceedings of the 2020 Conference on Fairness, Accountability, and Transparency*, 2020, pp. 56–67.
- [113] T. Lombrozo, "The structure and function of explanations," *Trends in cognitive sciences*, vol. 10, no. 10, pp. 464–470, 2006.
- [114] G. Carenini and J. D. Moore, "Generating explanations in context," in *Proceedings of the 1st international conference on Intelligent user interfaces*, 1993, pp. 175–182.
- [115] P. Brézillon, "Context in problem solving: A survey," *The Knowledge Engineering Review*, vol. 14, no. 1, pp. 47–80, 1999.
- [116] G. Klein, B. Shneiderman, R. R. Hoffman, and K. M. Ford, "Why expertise matters: A response to the challenges," *Ieee Intelligent Systems*, vol. 32, no. 6, pp. 67–73, 2017.

Detecting Pneumonia with a Deep Learning Model and Random Data Augmentation Techniques

Tawfik Guesmi

Department of Electrical Engineering, College of Engineering University of Ha'il
Ha'il 2240, Saudi Arabia

Abstract—This research paper presents an investigation into the detection of pneumonia using deep learning models and data augmentation techniques. The study compares and evaluates the performance of different models based on experimental results. The proposed model consists of multiple convolutional layers and maxpooling layers. Extensive experiments were conducted on a dataset, and the results demonstrate the efficiency and accuracy of our approach. The findings highlight the potential of deep learning in pneumonia detection and contribute to the existing body of knowledge in this field. The implications of this research can have a significant impact on improving diagnostic accuracy and patient outcomes. Future research directions could explore further enhancements in the model architecture, investigate additional data augmentation techniques, and consider larger datasets for more comprehensive evaluations.

Keywords—Deep learning; pneumonia detection; convolutional neural network; random data augmentation

I. INTRODUCTION

The capabilities of e-health tools have been recently boosted and improved by advances in artificial intelligence (AI) that allows the detection and diagnosis of diseases. Artificial intelligence is not a newly-invented technique. In fact, it was prefigured in a chess computer program that was generated by Alan Turing in 1950 [1]. The health sector has not been deprived of these technological advances. Indeed, there has been considerable and growing interest in this health sector and especially in the automatic detection of diseases from medical images. As a subdomain of AI, machine learning makes use of algorithms so as to parse data, gain an understanding from the results, and apply the learning to make decisions and predictions. Thanks to the rise in computing power and the availability of huge datasets, researchers have proposed many new approaches of smart healthcare disease diagnosis and patient management by using machine learning and especially deep learning algorithms. We note that machine learning algorithms have been developed to detect objects or faces, to assist in healthcare, traffic prediction, natural disasters prediction, etc. In our research work, we are focused on the healthcare services by incorporating AI through disease detection and prediction using machine learning and deep learning. The proposed approach harnesses the benefits of AI-based systems in the medical diagnosis field by replicating human brain function for simple tasks and providing innovative solutions for more complex ones. Towards reaching our objective, we recommend implementing AI-based solutions. Our primary algorithmic approach includes machine learning, particularly deep learning algorithms, which provide computational models for learning data representations. We note that these algorithms have greatly

improved previous disease detection and recognition efforts [2].

Deep learning reveals a complex structure in high-dimensional data such as images and videos by using the back-propagation algorithm. The goal is to help a machine regulate its internal parameters to enable it to generate a configuration in each layer from the previous one. Being the most representative model of deep learning, CNN has been broadly put in application in many research areas, such as image classification, face recognition and object detection. It's composed of the input layer, hidden layers (at least one), and an output layer. Constructing a typical CNN takes some steps. The starting phase involves two types of layers: convolutional layers and pooling layers. In the proposed approach, a convolutional layer contains filters characterized with parameters that should be learned. Thus, the filters' height and weight tend to be inferior to those of the input volume. Then an activation map based on neurons is computed by convolving each filter with the input volume. The concluding phase consists in obtaining the convolutional layer's output volume. This is achieved by stacking all filters' activation maps along the depth dimension [3].

The proposed CNN architecture, along with the well-known pre-trained models DenseNet and MobileNet, is evaluated and compared in terms of their matching performance and computational cost. Furthermore, the incorporation of random data augmentation techniques enhances the model's ability to generalize to new and unseen images, improving its robustness and reducing the risk of overfitting. The experimental results demonstrate that the proposed CNN model outperforms the existing models in terms of accuracy and provides a promising solution for accurate and efficient pneumonia detection. By highlighting the value of this paper, we contribute to the advancement of AI-based systems in medical diagnosis, specifically in the detection and diagnosis of pneumonia, which can lead to improved healthcare outcomes, more timely treatments, and ultimately, saving lives.

The main objective of the proposed approach is to detect pneumonia from chest X-ray datasets. Convolutional neural networks (CNNs) are effective tools for image understanding and are widely used in medical image analysis. For these reasons, we have used two very well known and very successful CNNs which are: DenseNet and MobileNet in order to test them to detect pneumonia disease. The results obtained were compared to our CNN model. For this, we used four different datasets to validate the results. Note that we have used different data augmentation techniques to overcome the problem of limited datasets [4]. In many computer vision tasks,

the original dataset may be limited in size and may not reflect the variability of the real-world scenarios. For example, in an image classification task, the model may only see pictures of dogs taken from one angle and with a specific resolution. This lack of diversity in the training data can lead to poor performance when the model encounters new, unseen data. The main contribution and results are:

- The proposed CNN model, DenseNet and MobileNet showed performance improvements on augmented datasets.
- Our CNN model performed better than the other models.
- The results were validated on four different datasets. A comparative table has been drawn up for this purpose.
- We used random data augmentation techniques such as randomly flipping, zooming, shifting, and rotating images which can be highly beneficial for training image processing and computer vision models. These techniques can help to artificially increase the size of the training dataset and expose the model to a wider variety of image variations. It improves the model's ability to generalize to new images, making it more robust and less prone to overfitting.

In fact, using the classic techniques of data augmentation can be less beneficial as the model will be exposed only to the flipped version and it may not generalize well to the original version of the image in the case of the flipping technique. However, randomly flipping images can be more beneficial. It is important to expose the model to a diverse set of training data. Randomly flipping images horizontally or vertically can be a way to artificially increase the diversity of the training dataset by creating new images from existing ones. By randomly flipping images, the model is exposed to both the original image and its flipped version, which can help it learn to recognize objects regardless of their orientation.

Previous research in pneumonia detection has primarily focused on traditional machine learning algorithms and a limited set of image features. These approaches often struggle to capture the complex patterns and variations present in chest X-ray images, resulting in suboptimal performance and limited generalization capabilities. Furthermore, the use of pre-trained convolutional neural networks (CNNs) in this domain has been limited, and their potential for pneumonia detection remains underexplored. In this paper, we aim to address the gap between the existing approaches and the potential for leveraging deep learning techniques, specifically CNNs, for improved pneumonia detection. Our proposed work presents a detailed review of various CNN architectures, including well-known models such as DenseNet and MobileNet, and their characteristics. We then introduce an efficient CNN architecture for pneumonia detection using X-ray images, incorporating random data augmentation techniques. By leveraging the power of deep learning and exploring the potential of CNN models, we aim to overcome the limitations of existing approaches and achieve enhanced performance in pneumonia detection.

This paper is organized as follows: Section II explores the related research done in the same field. In Section III,

there is a brief description of the two deep convolutional neural networks: DenseNet and MobileNet. In Section IV, the description of the applied methodology and the proposed CNN architecture. Section V presents the experimental result and performance analysis. Finally, Section VI shows the results and discussion and Section VII concludes this paper.

II. RELATED WORKS

In recent years, deep learning has opened up horizons for researchers in the field of medical sciences. Published research is promising. These studies were done to test the detection, prediction and diagnosis of disease. Today, the enormous progress and advances of CNNs have attracted the attention of researchers to apply them in many fields. Medical research is one of the most sought-after fields. All the details and features in a medical image are of high importance in the machine learning pipeline. The problem is that most known ML algorithms used classical features to develop detection and recognition systems [5]–[7]. In contrast, the use of deep learning (DL) models, in particular convolutional neural networks (CNN), has demonstrated a strong ability to extract relevant features in the image classification framework [8], [9]. Image classification can be significantly improved if we have a very rich set of extracted features. Indeed, the availability of pre-trained CNN models like MobileNet [10], AlexNet [11], ResNet [12] and DenseNet [13] speeds up and improves the relevant feature extraction procedure. Several interesting research papers on the disease of pneumonia have been published with the aim of classifying chest X-ray images [14]–[19]. In [20], authors implemented a deep convolution neural network on more than 100 thousand x-ray images of approximately 32,000 in order to analyze and recognize pulmonary infection and its subtypes. In [21], Amit Kumar et al. implemented a Mask-RCNN which performed a combination of pulmonary image segmentation and an image augmentation. They started by testing known detection techniques such as YOLO 3 and U-Net but the results were not motivating. They then proposed their own model based on Mask-RCNN and showed in the experimental results that the proposed identification model achieves better performance.

In order to take advantage of the characteristics of the Inception V3 model, authors, in [22], have implemented a CNN model based on Inception V3. The authors were able to successfully classify various types of pneumonia infections on pediatric patients. They developed a new CNN model not only to classify images into class of sick people and non-sick people but also to classify images showing pneumonia disease into two categories: pneumonia caused by bacteria and pneumonia caused by a virus.

A novel approach for automatic detection of pneumonia was proposed by Anuja Kumar et al. in [23]. In fact, they proposed a deep Siamese neural network by analyzing the amount of white substance presence on both the right and the left chest of X-ray image. In their approach, Paras et al. [24] were inspired by pre-trained AlexNet and GoogleNet data models as well as data augmentation. The authors in [25], developed numerous models in order to validate an accurate result in detecting pneumonia. They trained AlexNet, LeNet, GoogleNet, ResNet, and VGGNet on a dataset of over 26 thousand images of a resolution of 1024x1024. Vikash et

al. proposed a novel approach for detection of pneumonia based on transfer learning and ImageNet model [26]. In [27], pneumonia was one of 14 different diseases that were detected using a 121-layer CNN on chest x-rays. In [28], authors developed an automated diagnosis of pneumonia by classifying X-ray images using deep CNN. They showed that the proposed model reached 91% of accuracy. In [29], authors proposed a novel deep convolutional neural network architecture to extract relevant features from chest X-ray images and classify them into two classes. They also studied in their paper, the influence of the size of the dataset on the performance of the model. They used the original dataset as well as its augmented version.

III. DEEP CONVOLUTIONAL NEURAL NETWORKS

A Convolutional Neural Network (CNN) is composed of neurons with varying weights and biases. These neurons receive inputs from preceding layers, producing a fast and precise algorithm [30], [31]. CNNs have proven to outperform traditional neural networks in detection and classification tasks, as seen in their successful classification of well-known image databases such as MNIST [32], [33] and CIFAR 10 [34], [35].

A. Convolution Layer

A convolution layer in deep learning is a layer in a neural network that performs a mathematical operation called convolution on the input data. The convolution operation involves sliding a small matrix (the "filter" or "kernel") over the input data and computing a dot product at each position, producing a feature map that represents important information from the input. This operation is repeated with multiple filters, effectively learning different features at different scales, and allowing the network to learn complex representations of the data. Convolution layers are commonly used in computer vision tasks, such as image classification and object detection. The formula for computing a single output element in a convolution operation is given as follows.

$$O_{i,j} = \sum_{m=0}^{k-1} \sum_{n=0}^{k-1} I_{i+m,j+n} \cdot F_{m,n} \quad (1)$$

where $O_{i,j}$ is the (i, j) th element of the output feature map, $I_{i,j}$ is the (i, j) th element of the input feature map, $F_{m,n}$ is the (m, n) th element of the filter (also called kernel) matrix and k is the size of the filter. This formula is applied element-wise for each position of the filter over the input feature map, with the result being a new output feature map that represents the filtered version of the input.

B. Activation Function

An activation function in deep learning is a non-linear function applied to the output of each neuron in a neural network. The activation function is used to introduce non-linearity into the model, allowing it to model complex relationships in the data. There are several commonly used activation functions, including (Fig. 1):

- Sigmoid: $f(x) = \frac{1}{1+e^{-x}}$
- Tanh: $f(x) = \tanh(x)$
- ReLU (Rectified Linear Unit): $f(x) = \max(0, x)$

- Leaky ReLU: $f(x) = \max(0.01x, x)$
- Softmax: used for multiclass classification, maps inputs to a probability distribution over the classes.

C. DenseNet

DenseNet is a network architecture characterized by the fact that each layer is directly connected to all the others. Feature maps from all layers that precede another are treated as separate inputs. On the other hand, the layers following any layer, are fed by its own feature maps. This connectivity model gives state-of-the-art accuracies on CIFAR10/100 (with or without data augmentation) [13], [36]. It's architecture is detailed in Table I.

TABLE I. DENSENET ARCHITECTURE

Layers	Output Size
Convolution	112x112
Pooling	56x56
DenseBlock (1)	56x56
Transition Layer (1)	56x56—28x28
Dense Block (2)	28x28
Transition Layer (2)	28x28—14x14
Dense Block (3)	14x14
Transition Layer (3)	14x14—7x7
Dense Block (4)	7x7
Classification Layer	1x1

D. MobileNet

MobileNet is a CNN architecture that is among the first CNN models that aims to be deployed on mobile applications. The main innovation is that the convolutions are separable according to the depth. A separable convolution transforms a classical convolution kernel into two separate kernels. For example, a 4x4 kernel turns into a 4x1 kernel and a 1x4 kernel. The objective behind this separation is to minimize the number of operations needed to perform the convolution. Therefore, the model becomes more efficient. This model is, today, a reference for object detection, face detection, and for object classification. MobileNet model has 27 Convolution layers which includes 13 depthwise Convolution, 1 Average Pool layer, 1 Fully Connected layer and 1 Softmax Layer. This model was developed by Andrew G. Howard and other researchers from Google [10]. It's architecture is detailed in Fig. 2.

IV. THE PROPOSED CNN ARCHITECTURE

A. Layers Description

a new approach of drawing a CNN model has been proposed in order to classify chest X-ray images. The goal is to classify images into two classes: Normal X-ray image and X-ray image with pneumonia. The CNN architecture is based on:

- Convolutional layers
- Maxpooling layers

The resulting image after the last convolution/maxpooling layer is first flattened and then inserted into a dense layer.

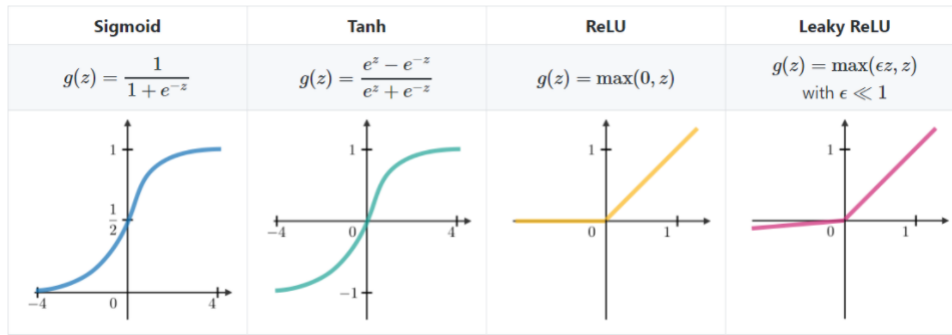


Fig. 1. Activation functions.

Type (Stride)	Filter Shape	Input Size
Conv (s2)	3 x 3 x 3 x 32	224 x 224 x 3
Conv dw(s1)	3 x 3 x 32 dw	112 x 112 x 32
Conv (s1)	1 x 1 x 32 x 64	112 x 112 x 32
Conv dw(s1)	3 x 3 x 64 dw	112 x 112 x 64
Conv (s1)	1 x 1 x 64 x 128	56 x 56 x 64
Conv dw (s1)	3 x 3 x 128 dw	56 x 56 x 128
Conv (s1)	1 x 1 x 128 x 128	56 x 56 x 128
Conv dw (s2)	3 x 3 x 128 dw	56 x 56 x 128
Conv (s1)	1 x 1 x 128 x 256	28 x 28 x 128
Conv dw (s1)	3 x 3 x 256 dw	28 x 28 x 256
Conv (s1)	1 x 1 x 256 x 256	28 x 28 x 256
Conv dw (s2)	3 x 3 x 256 dw	28 x 28 x 256
Conv (s1)	1 x 1 x 256 x 512	14 x 14 x 256
	3 x 3 x 512 dw	14 x 14 x 512
5X	1 x 1 x 512 x 512	14 x 14 x 512
Conv dw (s2)	3 x 3 x 512 dw	14 x 14 x 512
Conv (s1)	1 x 1 x 512 x 1024	7 x 7 x 512
Conv dw (s2)	3 x 3 x 1024 dw	7 x 7 x 1024
Conv (s1)	1 x 1 x 1024 x 1024	7 x 7 x 1024
Avg Pool (s1)	Pool 7 x 7	7 x 7 x 1024
FC (s1)	1024 x 1000	1 x 1 x 1024
Softmax (s1)	Classifier	1 x 1 x 1000

Fig. 2. The detailed MobileNet architecture.

The sigmoid function is used to activate the layer where the output was introduced. Note also that the sigmoid function was used in the last layer since the classification is binary. Fig. 3 illustrates the architecture of the proposed CNN. The architecture of the proposed CNN is carefully designed to learn and classify pneumonia patterns in chest X-ray images effectively. It utilizes the hierarchical structure of convolutional and pooling layers to capture both local and global features, enabling accurate and robust predictions. The combination of convolutional and dense layers allows the network to learn complex relationships and make informed decisions based on the extracted features. Overall, the proposed CNN architecture offers a powerful tool for pneumonia detection and showcases

promising potential in medical image analysis.

Initially, the image is resized to the size of (150x150). It is then integrated into a first layer (3x3x16) of sixteen filters and dimensions (3x3). The convolutional layer is then used to decompose the image to have new dimensions of (75x75x32). The latter is integrated into the Maxpooling layer having a window size of (2x2). We finally have an image with a new size. Different layers are listed below.

- The image crosses the second dimension convolutional layer (3x3x32). We will have as output of this layer an image (38x38x64). Shape Maxpooling layer (2x2) is introduced and gives as output an image with a new shape.
- The resulting image is passed through another convolutional layer of the same dimension and which has the same shape as the previous one. In order to detect more relevant details of the image, the latter is again processed by the convolutional layer. Thus, the image reaches a new shape of (19x19x128) and it is introduced through a Maxpooling layer of dimension (2x2).
- 64 filters make up the final layer which is of the shape of (3x3x64). The resulting image has the shape (5x5x256) and will once again be introduced into the maxpooling layer. The end result is a set of finer instances of the image which will help in better classification.

In the following, we move on to the description of the second phase: the deep neural network. After passing through the last layer, the output is flattened and inserted into the Deep Neural Network (DNN). Then, it is introduced into a 128 neurons layer in order to detect the key data of the image and its relevant characteristics. The ReLU function is used as an activation function. The last dense layer of the DNN is a single output neuron. The aim is to classify the chest X-ray images into two classes: images with pneumonia and images without pneumonia.

B. Summary of the CNN Model

The proposed CNN model is summarized as follows:

- Four convolutional layers.

TABLE II. DESCRIPTION OF THE CNN MODEL.

Layer	Filter	Kernel Size	Strid	Size of feautre Maps
Input	-	3 x 3	-	150 x 150 x 3
Conv(1)	64	3 x 3	1 x 1	150 x 150 x 3
Conv (2)	64	3 x 3	3 x 3	150 x 150 x 3
Batch normalization	-	-	-	150 x 150 x 3
Pooling	-	2 x 2	2 x 2	75 x 75 x 3
Conv(3)	64	3 x 3	1	75 x 75 x 3
Dropout	-	-	-	75 x 75 x 3
Batch normalization	-	-	-	75 x 75 x 3
pooling	-	2 x 2	2 x 2	38 x 38 x 3
Conv(4)	128	3 x 3	1 x 1	38 x 38 x 3
Batch normalization	-	-	-	38 x 38 x 3
pooling	-	2 x 2	2 x 2	19 x 19 x 3
Conv(5)	128	3 x 3	3 x 3	19 x 19 x 3
dropout	-	-	-	19 x 19 x 3
Batch normalization	-	-	-	19 x 19 x 3
pooling	-	2 x 2	2 x 2	10 x 10 x 3
Conv(6)	256	3 x 3	3 x 3	10 x 10 x 3
Dropout	-	-	-	10 x 10 x 3
Batch normalization	-	-	-	10 x 10 x 3
pooling	-	2 x 2	2 x 2	5x 5 x 3

- Four Maxpooling layers.
- flattened layer of zero parameters.
- Dense layers of about 819328 parameters.
- The total number of parameters that can be trained in the network is 1,246,401 parameters.

Our model is based on the CNN model described in Table II and its architecture is detailed in Fig. 3.

C. Random Data Augmentation

In order to properly implement a CNN, a large dataset is required. In case we have a limited amount of data, we can use random data augmentation techniques which are a solution to artificially increase the amount of existing data. In the case of medical image datasets, the data is not available in large quantities. Random data augmentation is often considered to be better than classic data augmentation because it can increase the diversity of the training data in a more controlled manner. In classic data augmentation, the same transformation is applied to all instances of the data, which can lead to overfitting to the augmented data and decreased performance on the original data. On the other hand, in random data augmentation, different transformations are randomly applied to each instance of the data. This increases the diversity of the training data in a more controlled manner and can help prevent overfitting to the augmented data. By applying different transformations to different instances of the data, random data augmentation can help the model learn to recognize objects regardless of their orientation, scale, and deformation. This can improve the model's generalization ability and increase its robustness to changes in the input data. This is why we applied the data augmentation technique on our training data set. An example of random data augmentation is shown in Fig. 4, 5, 6 and 7. In fact, we added changes to our images by making minor changes, such as:

- Random rotating data: it consists of applying random rotations to images in a dataset in order to increase the diversity of the training data and reduce overfitting. This can be done by specifying a range of rotation

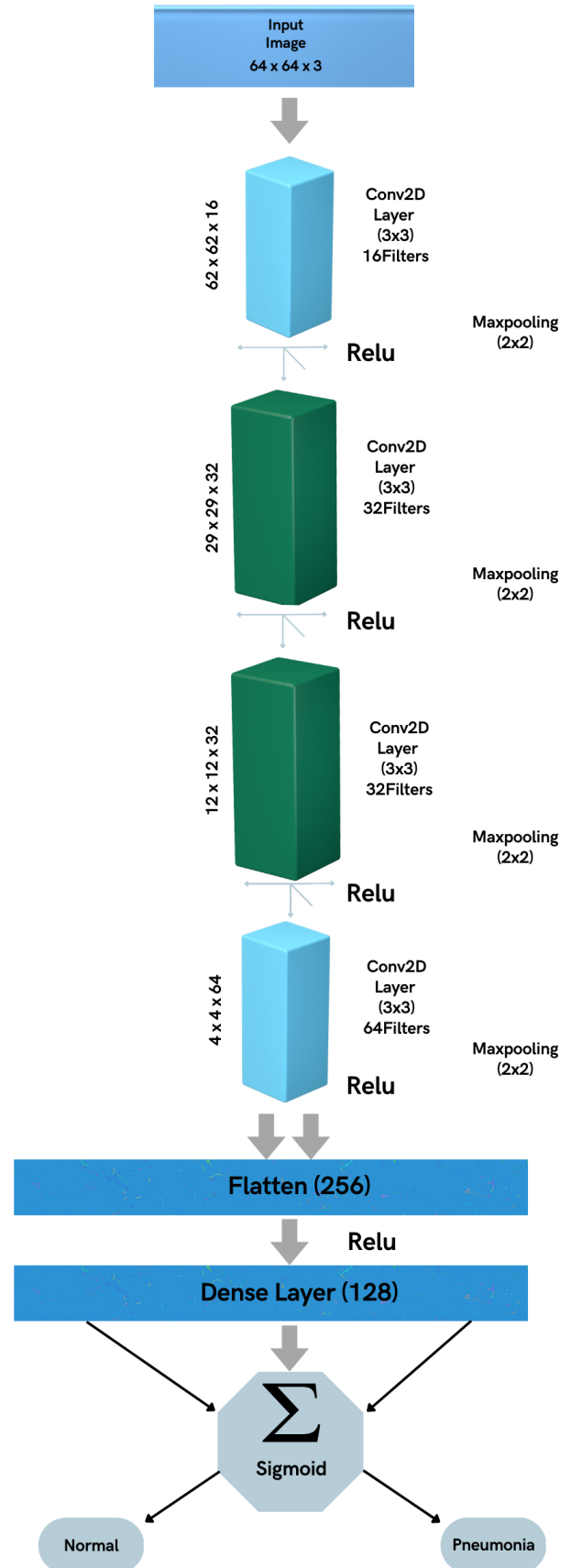


Fig. 3. Architecture of the CNN model.

angles, and then applying a random rotation within that range to each image in the dataset before it is used for training. This technique can be useful for image classification tasks, as it allows the model to learn to recognize objects in different orientations.

- **Random Zoom:** it involves randomly zooming in or out of an image by a certain percentage, while maintaining the aspect ratio of the original image. This technique can help increase the diversity of the training data and improve the robustness of the model by exposing it to different scales and perspectives of the same object. It can also help to prevent overfitting by making the model more generalizable to new images.
- **Random shifting images horizontally or vertically:** it consists of randomly shifting the position of an image by a certain number of pixels horizontally or vertically. This technique is used to simulate the effect of objects being slightly misaligned or translated in real-world scenarios. In such scenarios, a model trained on perfectly aligned images may not perform well when presented with images that are not perfectly aligned. However, by training the model on images that have been randomly shifted, the model can learn to be more robust to small changes in position and handle misalignment better.
- **Random flipping images horizontally:** the left and right sides of the image are switched. This can be done by reflecting the image across a vertical axis. The idea behind this technique is to artificially increase the diversity of the training data by exposing the model to both the original image and its flipped version. Flipping images horizontally can also be useful when the model needs to recognize objects that are symmetric across a vertical axis. For example, in object detection tasks, flipping the image horizontally and training the model on both the original and the flipped images can make the model more robust to detect the object in the image regardless of its orientation.
- **Random cropping:** the basic idea is to randomly select a rectangular region of an image, and then crop the image to that region. The cropped region is then resized to the original size of the image. We randomly select the starting and ending coordinates of the cropped region within the original image's dimensions. The cropped region is then resized to the original size of the image using interpolation to avoid distorting the image. the cropping parameters such as the size of the cropped region and the aspect ratio can be adjusted. For example, if the model is trained for object detection, the cropping area should be adjusted to keep the object of interest within the crop area. Also, when using random cropping, it is important to make sure that the entire image is covered by the crop area, otherwise important information may be lost.

We note that some data augmentation techniques are domain-specific, for example, in medical images rotating images can be harmful. In general, using a combination of different data augmentation techniques can be more effective

than using a single technique, as it can provide the model with a more diverse set of training data. This will increase the size of our training data and our model will consider each of these small changes as a separate picture. In our work we applied the data augmentation Algorithm 1.

Algorithm 1: Random Data Augmentation

```
Input : Training dataset  
Output: Augmented dataset  
Procedure  
| DataAugmentation  
end  
for each image  $x$  in the training dataset do  
|  $r \leftarrow \text{Random}(0, 1)$ ;  
| if  $r < p_{rotate}$  then  
| |  $x \leftarrow \text{Rotate}(x, \text{angle})$ ;  
| end  
| if  $r < p_{zoom}$  then  
| |  $x \leftarrow \text{Zoom}(x, \text{zoom})$ ;  
| end  
| if  $r < p_{h\_shift}$  then  
| |  $x \leftarrow \text{Shift}(x, h\_shift \times \text{width})$ ;  
| end  
| if  $r < p_{v\_shift}$  then  
| |  $x \leftarrow \text{Shift}(x, v\_shift \times \text{height})$ ;  
| end  
| if  $r < p_{flip}$  then  
| |  $x \leftarrow \text{Flip}(x)$ ;  
| end  
end  
Model.fit(Dataset);
```

In this work, we selected four different datasets where in each one we find a train folder, test folder and validation folder. Table III lists the number of images in each dataset. The datasets were selected from Guangzhou Women and Children's Medical Center [37] and they are images from pediatric patients of one to five years old.

V. EXPERIMENTAL RESULTS AND PERFORMANCE OF THE CNN MODEL

A. Hyperparameter Optimization (HPO)

To search for optimal hyperparameters of the model, random search was performed [38]. It is a method for searching for optimal hyperparameters of a training model that involves randomly sampling hyperparameter combinations from a pre-defined search space. The search space is defined by specifying a range or distribution for each hyperparameter. The outline of the algorithm for random search is as follows.

- Define the hyperparameter search space: it consists of specifying the range or distribution of possible values

TABLE III. DIFFERENT DATASETS OF CHEST X-RAY IMAGES

Data	Number of images	Training	Testing	Validation
Dataset 1	5872	4770	551	551
Dataset 2	5856	4762	612	482
Dataset 3	6896	5532	720	644
Dataset 4	4665	3672	474	519

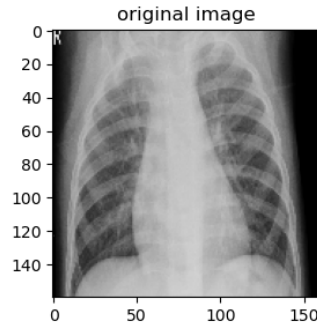


Fig. 4. Images without augmentation.

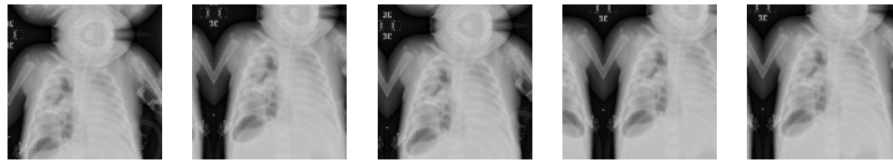


Fig. 5. Image augmented by random translation technique.



Fig. 6. Image augmented by random flipping technique.

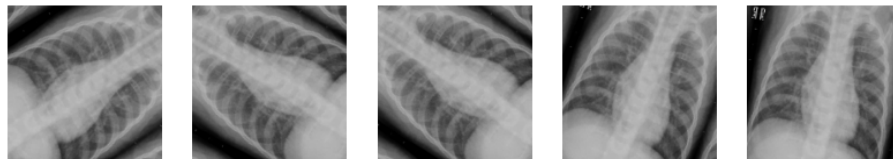


Fig. 7. Image augmented by random rotation technique.

for each hyperparameter.

- Initialize the random search object by creating an instance of the random search function, such as `RandomizedSearchCV` in `scikit-learn`, and specifying the model, the hyperparameter search space, the number of iterations, and other parameters such as the number of cross-validation folds.
- Generate random samples of hyperparameters by randomly sampling hyperparameter combinations from the defined search space. The number of samples is controlled by the number of iterations specified in step 2.
- Train the model with each sample of hyperparameters: For each generated sample of hyperparameters, train the model using the corresponding sample of hyperparameters and evaluate its performance using a performance metric such as accuracy or F1-score on

the validation set.

- Select the best set of hyperparameters by selecting the set of hyperparameters that results in the best performance on the validation set as the best set of hyperparameters.
- Validate the model on unseen data by using the best set of hyperparameters to train a final model and evaluate its performance on unseen data.

Hyperparameters obtained by the random search of the model were as follows. The model was trained using a batch size of 32, where 32 data samples are used to update the model's parameters in each iteration. The training process continued for 12 iterations. The early stopping technique was used to avoid overfitting, where the training process is stopped if the validation loss does not decrease for 7 consecutive iterations. This is done to ensure that the model generalizes well on unseen data.

B. Evaluation and Results

The training accuracy of a model is a measure of how well the model is able to predict the correct labels for the training data. The validation accuracy is a measure of how well the model is able to predict the correct labels for the validation data, which is a subset of the data that is held out from the training process and used to evaluate the model's performance. In general, the training accuracy of a model will be higher than the validation accuracy, because the model has seen the training data during the training process and has learned to predict the labels for those data points accurately. The validation accuracy is a more realistic measure of the model's performance, because it reflects the model's ability to generalize to unseen data. In order to determine the performance of the proposed method, we examined the accuracy, precision, recall, and F1 score. Accuracy is the proportion of correctly classified instances (True Positives and True Negatives) out of all instances. It is computed as follows:

$$Accuracy = (TP + TN) / (TP + TN + FP + FN) \quad (2)$$

Where True Positives (TP) are the number of instances where the model correctly predicted the positive class, True Negatives (TN) are the number of instances where the model correctly predicted the negative class, False Positives (FP) are the number of instances where the model incorrectly predicted the positive class and False Negatives (FN) are the number of instances where the model incorrectly predicted the negative class. Precision is the proportion of correctly classified positive instances out of all positive instances predicted by the model. It is calculated as:

$$Precision = TP / (TP + FP) \quad (3)$$

Recall is the proportion of correctly classified positive instances out of all actual positive instances. It is calculated as follows:

$$Recall = TP / (TP + FN) \quad (4)$$

F1 Score is the harmonic mean of precision and recall. It is calculated as follows:

$$F1-score = \frac{2 \cdot TP}{2 \cdot TP + (FP + FN)} \quad (5)$$

All values of accuracy, precision, recall and F1 score are listed in Table IV.

In order to assess the influence of the size of the dataset on the performance of the CNN model, we plotted the curves of Training accuracy/Validation accuracy and Training loss/Validation loss. The tests were carried out, first, on four original datasets. Fig. 8 show that the training and validation accuracy varies with the epoch count. In fact, the model is learning efficiently, the training and validation accuracy reach a plateau after the end of the 20th epoch indicating that the model has reached its maximum performance. The Training accuracy curve demonstrates the progression of the model's accuracy on the training set over successive epochs. As the training progresses, the accuracy steadily increases, indicating that the model is effectively learning the patterns and features of the pneumonia dataset. The upward trend in the curve signifies the successful optimization of the model's parameters, leading to improved classification accuracy. Similarly, the

Training loss curve illustrates the decline in the loss function during the training phase. The loss function measures the discrepancy between the predicted and actual values, and the decreasing trend of the curve indicates that the model is converging towards a better approximation of the ground truth labels. A lower loss value indicates that the model is becoming more proficient at minimizing errors and making more precise predictions. The Validation accuracy and loss curves provide insights into the model's generalization performance on unseen data. The Validation accuracy curve tracks the accuracy of the model on a separate validation dataset that was not used for training. A rising validation accuracy curve indicates that the model is not overfitting and can generalize well to new data.

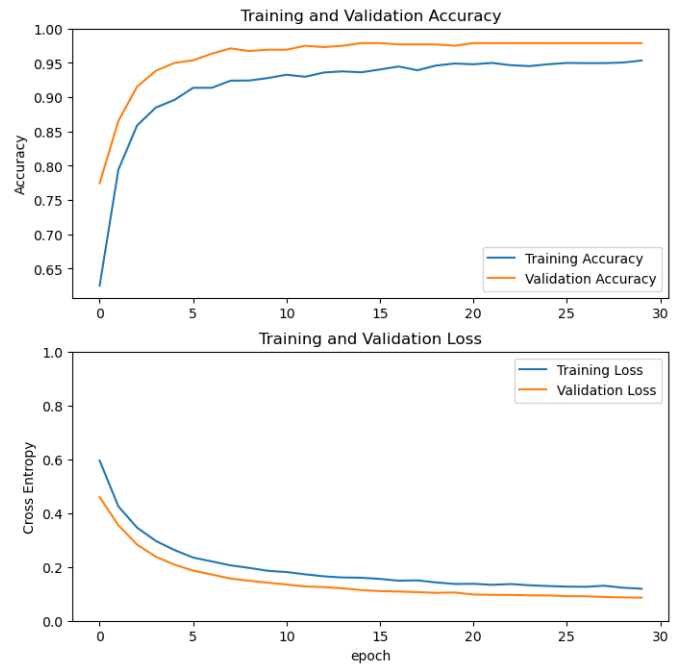


Fig. 8. Training and validation accuracy/loss curves of our CNN model applied on dataset 1.

A comparison of the obtained metrics our solution with those of known models has been summarized in the Table V.

VI. RESULTS AND DISCUSSION

Note that the proposed model comprises four convolutional layers accompanied by four additional Maxpooling layers. The flattened layer of zero parameters and dense layers of about 819328 parameters come next. We thus have a total number of parameters which amounts to 1,246,401 parameters. We used two well-known and very powerful models to test the effectiveness of the proposed model. The CNN model was able to accomplish good values of Accuracy. After the augmentation of data, there was a clear improvement in the performance of all models and especially our CNN model (Table VI).

Four Chest X-ray images datasets served as the basis for our experiment. The datasets is publicly available on Kaggle, a shared data platform, and consists of 23289 real images

TABLE IV. PERFORMANCE OF THE PROPOSED METHOD

Model	Accuracy	Precision	Recall	F1-score
Our model	0.92	0.92	0.91	0.91

TABLE V. COMPARISON TABLE BETWEEN DIFFERENT MODELS

Model	Accuracy	Precision	Recall	F1-score
VGG16	0.96	0.93	1.0	0.97
ResNet-50	0.89	0.87	0.93	0.90
VGG-19	0.93	0.94	0.93	0.93
Inception-V3	0.75	0.77	0.71	0.74
ResNet-101	0.74	0.74	0.74	0.73
DenseNet121	0.49	0.50	0.48	0.49
Our model	0.92	0.92	0.91	0.91

TABLE VI. COMPARISON OF ACCURACY VALUES BETWEEN DIFFERENT MODELS

Data/Model	CNN		MobileNet		DenseNet	
	With aug	Without aug	With aug	Without aug	With aug	Without aug
Data1	97.88	80.64	99.99	62.50	80.76	80.76
Data2	95.34	80.41	97.11	62.50	87.78	78.39
Data3	95.04	81.02	96.05	61.18	87.78	79.89
Data4	94.99	80.70	98.26	61.18	87.78	79.89

developed by radiologists using data from real affected patients. We split our data into training, validation, and testing. First, data augmentation is done to enhance our dataset by doing minor changes in our images. We trained the models for 15 epochs with a batch size of 32 and a learning rate equal to 0.01. Our model showed a considerable improvement of performance between the basic and augmented images. We evaluated also the MobileNet and DenseNet models on data without and with augmentation and we find that augmenting data gives good results and enhanced the accuracy of different models. By applying data augmentation techniques, such as random cropping, flipping, rotation, and scaling, a larger and more diverse training dataset can be created from the original data. This increased diversity in the training data can lead to improved performance of the model on the test set, as it has seen similar variations during training. Additionally, data augmentation can also act as a regularization technique, preventing the model from overfitting to the training data. However, it's important to note that too much data augmentation can lead to overfitting to the augmented data and decreased performance on the original data. It's also important to find the right balance between the degree of augmentation and the quality of the augmented data to prevent information loss or degradation. In general, it's a good practice to experiment with different augmentation techniques and evaluate their effect on the model's performance. The results indicated that random data augmentation can be considered better than classic data augmentation because it increases the diversity of the training data in a more controlled manner, preventing overfitting to the augmented data and increasing the generalization ability of the model.

VII. CONCLUSIONS

This paper presents a comparative study of Deep Learning Models for the detection of Pneumonia, incorporating data augmentation techniques. The experimental results validate the effectiveness and accuracy of our proposed model. It

showed good results compared to MobileNet and DenseNet. A remarkable improvement was noticed after applying the data augmentation techniques on the different datasets. Data augmentation can be a powerful technique for improving the performance of deep learning models. By artificially increasing the size and diversity of the training data, data augmentation can prevent overfitting and increase the generalization ability of the model. This can lead to enhanced results on the test set, and improved performance in real-world scenarios.

While our research has presented valuable insights into the detection of pneumonia using deep learning models and data augmentation techniques, there are a few aspects that merit further consideration. Firstly, it is important to acknowledge the limitations of our study, such as the reliance on a specific dataset and the need for further validation on larger and more diverse datasets. Additionally, exploring the impact of different data augmentation strategies and their effects on model performance could be an interesting avenue for future investigation. Moreover, investigating the generalizability of our proposed model to other medical imaging tasks and assessing its performance in real-world clinical settings could provide valuable insights. Lastly, incorporating interpretability techniques to understand the model's decision-making process and exploring ways to address any potential biases are important directions for future research. By addressing these questions and focusing on these areas, we believe that further advancements can be made in the field of pneumonia detection using deep learning techniques.

REFERENCES

- [1] A. Turing, "Faster than thought," *Pitman, New York*, vol. 4, no. 1, pp. 286–310, 1953.
- [2] M. Arsenovic, M. Karanovic, S. Sladojevic, A. Anderla, and D. Stefanovic, "Solving current limitations of deep learning based approaches for plant disease detection," *Symmetry*, vol. 11, no. 7, p. 939, 2019.
- [3] Y. LeCun, Y. Bengio, and G. Hinton, "Deep learning," *nature*, vol. 521, no. 7553, pp. 436–444, 2015.

- [4] P. Chlap, H. Min, N. Vandenberg, J. Dowling, L. Holloway, and A. Harworth, "A review of medical image data augmentation techniques for deep learning applications," *Journal of Medical Imaging and Radiation Oncology*, vol. 65, no. 5, pp. 545–563, 2021.
- [5] D. K. Das, M. Ghosh, M. Pal, A. K. Maiti, and C. Chakraborty, "Machine learning approach for automated screening of malaria parasite using light microscopic images," *Micron*, vol. 45, pp. 97–106, 2013.
- [6] M. Poostchi, K. Silamut, R. J. Maude, S. Jaeger, and G. Thoma, "Image analysis and machine learning for detecting malaria," *Translational Research*, vol. 194, pp. 36–55, 2018.
- [7] N. E. Ross, C. J. Pritchard, D. M. Rubin, and A. G. Duse, "Automated image processing method for the diagnosis and classification of malaria on thin blood smears," *Medical and Biological Engineering and Computing*, vol. 44, no. 5, pp. 427–436, 2006.
- [8] A. Sharif Razavian, H. Azizpour, J. Sullivan, and S. Carlsson, "Cnn features off-the-shelf: an astounding baseline for recognition," in *Proceedings of the IEEE conference on computer vision and pattern recognition workshops*, 2014, pp. 806–813.
- [9] R. Nijhawan, R. Verma, S. Bhushan, R. Dua, A. Mittal *et al.*, "An integrated deep learning framework approach for nail disease identification," in *2017 13th International Conference on Signal-Image Technology & Internet-Based Systems (SITIS)*. IEEE, 2017, pp. 197–202.
- [10] A. G. Howard, M. Zhu, B. Chen, D. Kalenichenko, W. Wang, T. Weyand, M. Andreetto, and H. Adam, "Mobilenets: Efficient convolutional neural networks for mobile vision applications," *arXiv preprint arXiv:1704.04861*, 2017.
- [11] A. Krizhevsky, I. Sutskever, and G. E. Hinton, "Imagenet classification with deep convolutional neural networks," *Communications of the ACM*, vol. 60, no. 6, pp. 84–90, 2017.
- [12] K. He, X. Zhang, S. Ren, and J. Sun, "Deep residual learning for image recognition," in *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2016, pp. 770–778.
- [13] G. Huang, Z. Liu, L. Van Der Maaten, and K. Q. Weinberger, "Densely connected convolutional networks," in *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2017, pp. 4700–4708.
- [14] O. Ronneberger, P. Fischer, and T. Brox, "U-net: Convolutional networks for biomedical image segmentation," in *International Conference on Medical image computing and computer-assisted intervention*. Springer, 2015, pp. 234–241.
- [15] M. Woźniak, D. Połap, G. Capizzi, G. L. Sciuto, L. Kośmider, and K. Frankiewicz, "Small lung nodules detection based on local variance analysis and probabilistic neural network," *Computer methods and programs in biomedicine*, vol. 161, pp. 173–180, 2018.
- [16] Y. Gu, X. Lu, L. Yang, B. Zhang, D. Yu, Y. Zhao, L. Gao, L. Wu, and T. Zhou, "Automatic lung nodule detection using a 3d deep convolutional neural network combined with a multi-scale prediction strategy in chest cts," *Computers in biology and medicine*, vol. 103, pp. 220–231, 2018.
- [17] T. K. Khanh Ho and J. Gwak, "Multiple feature integration for classification of thoracic disease in chest radiography," *Applied Sciences*, vol. 9, no. 19, p. 4130, 2019.
- [18] G. Liang and L. Zheng, "A transfer learning method with deep residual network for pediatric pneumonia diagnosis," *Computer methods and programs in biomedicine*, vol. 187, p. 104964, 2020.
- [19] A. A. Saraiva, D. Santos, N. J. C. Costa, J. V. M. Sousa, N. M. F. Ferreira, A. Valente, and S. Soares, "Models of learning to classify x-ray images for the detection of pneumonia using neural networks," in *Bioimaging*, 2019, pp. 76–83.
- [20] X. Wang, Y. Peng, L. Lu, Z. Lu, M. Bagheri, and R. M. Summers, "Chestx-ray8: Hospital-scale chest x-ray database and benchmarks on weakly-supervised classification and localization of common thorax diseases," in *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2017, pp. 2097–2106.
- [21] A. K. Jaiswal, P. Tiwari, S. Kumar, D. Gupta, A. Khanna, and J. J. Rodrigues, "Identifying pneumonia in chest x-rays: A deep learning approach," *Measurement*, vol. 145, pp. 511–518, 2019.
- [22] D. S. Kermany, M. Goldbaum, W. Cai, C. C. Valentim, H. Liang, S. L. Baxter, A. McKeown, G. Yang, X. Wu, F. Yan *et al.*, "Identifying medical diagnoses and treatable diseases by image-based deep learning," *Cell*, vol. 172, no. 5, pp. 1122–1131, 2018.
- [23] A. K. Acharya and R. Satapathy, "A deep learning based approach towards the automatic diagnosis of pneumonia from chest radio-graphs," *Biomedical and Pharmacology Journal*, vol. 13, no. 1, pp. 449–455, 2020.
- [24] P. Lakhani and B. Sundaram, "Deep learning at chest radiography: automated classification of pulmonary tuberculosis by using convolutional neural networks," *Radiology*, vol. 284, no. 2, pp. 574–582, 2017.
- [25] S. V. Militante, N. V. Dionisio, and B. G. Sibbaluca, "Pneumonia detection through adaptive deep learning models of convolutional neural networks," in *2020 11th IEEE Control and System Graduate Research Colloquium (ICSGRC)*. IEEE, 2020, pp. 88–93.
- [26] V. Chouhan, S. K. Singh, A. Khamparia, D. Gupta, P. Tiwari, C. Moreira, R. Damaševičius, and V. H. C. De Albuquerque, "A novel transfer learning based approach for pneumonia detection in chest x-ray images," *Applied Sciences*, vol. 10, no. 2, p. 559, 2020.
- [27] P. Rajpurkar, J. Irvin, R. L. Ball, K. Zhu, B. Yang, H. Mehta, T. Duan, D. Ding, A. Bagul, C. P. Langlotz *et al.*, "Deep learning for chest radiograph diagnosis: A retrospective comparison of the cheXnet algorithm to practicing radiologists," *PLoS medicine*, vol. 15, no. 11, p. e1002686, 2018.
- [28] S. Bangare, H. Rajankar, P. Patil, K. Nakum, and G. Paraskar, "Pneumonia detection and classification using cnn and vgg16," *International Journal of Advanced Research in Science, Communication and Technology*, vol. 12, pp. 771–779, 2022.
- [29] H. Sharma, J. S. Jain, P. Bansal, and S. Gupta, "Feature extraction and classification of chest x-ray images using cnn to detect pneumonia," in *2020 10th International Conference on Cloud Computing, Data Science & Engineering (Confluence)*. IEEE, 2020, pp. 227–231.
- [30] N. Wang, Y. Li, and H. Liu, "Reinforced neighbour feature fusion object detection with deep learning," *Symmetry*, vol. 13, no. 9, p. 1623, 2021.
- [31] J. Zhang, J. Liu, and Z. Wang, "Convolutional neural network for crowd counting on metro platforms," *Symmetry*, vol. 13, no. 4, p. 703, 2021.
- [32] Y. LeCun, L. D. Jackel, L. Bottou, C. Cortes, J. S. Denker, H. Drucker, I. Guyon, U. A. Muller, E. Sackinger, P. Simard *et al.*, "Learning algorithms for classification: A comparison on handwritten digit recognition," *Neural networks: the statistical mechanics perspective*, vol. 261, no. 276, p. 2, 1995.
- [33] L. Deng, "The mnist database of handwritten digit images for machine learning research [best of the web]," *IEEE Signal Processing Magazine*, vol. 29, no. 6, pp. 141–142, 2012.
- [34] X. Zhu and M. Bain, "B-cnn: branch convolutional neural network for hierarchical classification," *arXiv preprint arXiv:1709.09890*, 2017.
- [35] K. Kanwal, K. T. Ahmad, R. Khan, A. T. Abbasi, and J. Li, "Deep learning using symmetry, fast scores, shape-based filtering and spatial mapping integrated with cnn for large scale image retrieval," *Symmetry*, vol. 12, no. 4, p. 612, 2020.
- [36] G. Huang, Z. Liu, G. Pleiss, L. Van Der Maaten, and K. Weinberger, "Convolutional networks with dense connectivity," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 2019.
- [37] D. Kermany, K. Zhang, M. Goldbaum *et al.*, "Labeled optical coherence tomography (oct) and chest x-ray images for classification," *Mendeley data*, vol. 2, no. 2, 2018.
- [38] J. Bergstra and Y. Bengio, "Random search for hyper-parameter optimization," *Journal of machine learning research*, vol. 13, no. 2, 2012.

Cross-age Face Image Similarity Measurement Based on Deep Learning Algorithms

Jing Zhang*, Ningyu Hu

Computer Department, Xinzhou Normal University, Xinzhou, 034000, China

Abstract—In this study, a multi-feature fusion and decoupling solution based on the RNN is proposed from a discriminative perspective. This method can address the identity and age information extraction losses in cross-age face recognition. This method not only constrains the correlation between identity and age using correlation loss but also optimizes identity feature restoration using feature decoupling. The model was trained and simulated in CACD and CACD-VS datasets. The single-task learning model stabilized after 125 iterations of training, while the multi-task learning model reached a stable and convergent state after 75 iterations. In terms of performance analysis, the DE-RNN model had the highest recognition accuracy with a mAP of 92.4%. The Human Voting model had a value of 90.2%. The mAP of the Human Average model was 81.8%, whereas the mAP of the DAL model was the lowest at 78.1%. Experiments proved that the model constructed in this study has effective recognition and application value in the cross-age face recognition scenario.

Keywords—Cross-age; image recognition; RNN; feature fusion; decoupling; loss function

I. INTRODUCTION

Nowadays, the universal facial recognition technology, which refers to facial recognition performed at small age intervals, has reached or even surpassed human performance. However, in specific scenarios such as cross age facial recognition across larger age intervals, the performance of universal facial recognition technology is limited because as individuals age, the facial features, including textures, bones, etc., gradually change. The facial feature changes with age seriously affect the performance of face recognition, resulting in unrecognizability or recognition errors. How to suppress age factors and extract age invariant facial features are the keys to cross age face recognition. The studies of cross age facial recognition algorithms not only compensate for the performance shortcomings of general facial recognition algorithms in large age interval facial recognition, but also has practical significance in criminal investigation, document and other scenarios. Scholar Ali et al. [1] emphasized the main applications, challenges, and trends of facial recognition systems in social and scientific fields in their research. At the same time, this article summarizes recent facial recognition technologies and introduces the future aspects of facial recognition technology and its potential significance in the upcoming digital society. Jin et al. [2] conducted facial image recognition analysis from RGB-D technology, proposing a pseudo RGB-D facial recognition framework and providing a data-driven method for generating depth maps from 2D facial images. The research results indicate that with image fusion

technology cooperating, the accuracy of facial recognition is significantly improved. Andrejevic and Selwyn [3] considered applying facial recognition technology to campus safety and emotion detection. And they analyzed the positive and negative impacts of this technology in campus applications. To provide a new approach for current cross age facial recognition and help face recognition overcome the information loss during feature fusion and decoupling, a feature fusion and feature decoupling model based on RNN is proposed.

This study proposes the application of RNN based feature fusion and feature decoupling models in cross age facial recognition. To further separate the age and identity features obtained from the decoupling process, this article also utilizes correlation loss to constrain the correlation between the two. And to ensure the effective identity features restoration during the feature decoupling, this article further designs feature restoration losses, so that the restored features can effectively represent the identity information of the face.

II. RELATED WORK

Chen and Lau [4] proposed an identity-level angle triplet loss and used Euclidean distance to calculate similarity for cross-age FR. They also adopted a moderately positive mining strategy. The results on FR datasets showed the effectiveness of this method. Bahmani and Schuckers [5] studied the impact of short-term changes in children facial features on recognition. They used a quality-aware face matcher (MagFace) to analyze the decay relationship between age gaps and matching performance. This study demonstrated that the accuracy of children's FR was 98% within 6 months. And the accuracy only dropped to 94% within 36 months, indicating that this method had high accuracy in children's FR within three years. Sajid et al. [6] evaluated different backbone structures of deep convolutional neural networks in FR at different age stages. This method used fine-tuning models for face image feature extraction and transfer learning for matching. Experiments showed that this method had application value. Rizwan et al. [7] combined facial expression and age recognition to develop a recognition system. This system not only considered indoor and outdoor applications but also used landmark positioning to avoid the obstruction of FR by masks. The experiment showed that the system had superior performance in recognition accuracy and computation time. Riaz et al. [8] proposed a 3D aging FR model for facial age-related factors such as line and wrinkle changes. This model also paid attention to gender differentiation, and dataset verification showed that this model had high recognition performance with an accuracy of 83.89% in simulation experiments. Kavita and Chhillar [9] analyzed the application of various technologies in face detection, FR, facial

expression, and age estimation. And they investigated the application background of FR technology in recent years. Based on the survey results, they summarized the research directions and future trends of FR technology.

Apart from the RNN used in this study, Long Short-Term Memory (LSTM) is also capable of memorizing sequential information. Therefore, Sepas-Moghaddam et al. [10] applied it in the context of FR, and also conducted multi-task learning using different frameworks. The application scenario was multi-view light field image FR. The experiment showed that the LSTM cell structure had higher accuracy in FR than the existing light field recognition methods. Dubey and Jain [11] used an improved VGG16 model for facial expression recognition and matched facial features by using transfer learning. In the simulation experiment, the recognition rate of this method on the validation dataset reached 93.7%, and the facial expression recognition accuracy was higher. Liu et al. [12] used Markov decision and attention control methods to model unordered images and process FR. Meanwhile, pose-guided methods were used for image recognition optimization. In simulation experiments, the model was proven to be effective. Zhang et al. [13] found that regional differences in facial features and environmental differences had an impact on feature extraction in FR. Therefore, they proposed a model that combined deep CNN network and reinforced attention mechanism for FR. After training the model, this method showed high recognition accuracy in mainstream FR scenarios.

In summary, as more and more researchers have focused on cross-age FR and proposed many solutions, cross-age FR has achieved certain results. However, there are still some issues. How to propose an effective solution that preserves not only facial identity information but also has relatively little correlation with age factors is still a challenging problem. Therefore, this study uses feature fusion and feature decoupling to constrain the correlation between facial identity and age feature information. It is hoped to compensate for the cross-age FR technology shortcomings in specific application scenarios.

III. MULTI-FEATURE FUSION AND DECOUPLING METHOD FOR CROSS AGE FR

A. Cross Age Facial Feature Fusion based on RNN

Cross-age FR is one of the important research branches of general FR. Similar to general FR tasks, it can also be divided into two sub-tasks: cross-age face identification and cross-age face verification. The cross-age face identification task involves inputting a given face query image, and then comparing each image in the database with the input query image, one by one, to determine whether they are the same person. It is worth noting that some images in the database may have a large age gap with the query image, which poses a challenge to the general FR algorithm. In the cross-age face identification task, cross-age face verification involves comparing each image with the query image and then determining whether they are the same person. The cross-age face detection and recognition is shown in Fig. 1.

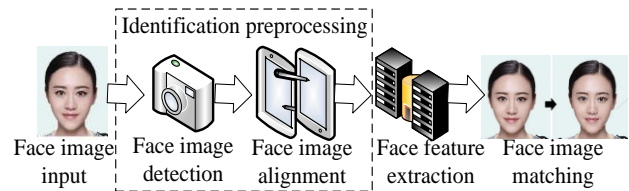


Fig. 1. Process of cross age face detection and recognition.

As shown in Fig. 1, cross-age face detection and recognition usually includes the following steps: face detection, face alignment, face feature extraction, and face matching. Face detection and face alignment are preprocessing steps in FR, which are similar in both general FR algorithms and discriminative-based cross-age FR algorithms. However, the differences are as follows. Firstly, the cross-age FR model uses a cross-age face dataset for training. Secondly, the face features extracted by the discriminative-based cross-age FR algorithm need to have strong anti-interference ability to age factors, that is, only the face features related to the identity need to be extracted. Based on the above steps, each face image can be represented as a feature vector. Face matching is based on the similarity measurement of the extracted face feature vectors, with 1:1 or 1:N matching. And the more similar or exceeding the set threshold, the more likely it is the same person. In face matching, cosine similarity is commonly used. And this study also uses cosine similarity to represent the face similarity. The calculation for cosine similarity is shown in Formula (1).

$$\cos(A, B) = \frac{A \cdot B}{\|A\|_2 \cdot \|B\|_2} \quad (1)$$

In Formula (1), A and B represent the feature vectors of two face images, while $\|A\|_2$ and $\|B\|_2$ represent the Euclidean norms of the feature vectors. Deep learning is an important branch of machine learning, which has received widespread attention from researchers in recent years and has made significant progress in applications such as speech recognition, natural language processing, and computer vision [14, 15]. In this study, recurrent neural networks (RNN) in deep learning algorithms are used for feature fusion in cross-age FR. Unlike traditional neural networks, RNN utilizes sequential information within the network. It not only considers the input from the previous moment, but also has a memory of the previous content. So the current sequence output is also related to the previous output. This feature is very important in many application scenarios, as the embedded structure in the data sequence can transmit useful knowledge information. RNN can be regarded as a short-term memory unit including input layer, hidden layer and output layer. And the nodes between hidden layers are no longer connected. The value of hidden layer depends not only on the input at the current time but also on the output value of the hidden layer at the previous time. When training the RNN network for face feature fusion, given that there can be several facial images for each individual in the sample datasets, depicting different ages yet sharing the same identity, such images are initially organized into a sequence of faces, represented by Formula (2).

$$\{F_1^p, F_2^p, \dots, F_l^p\} \in \{F_1^p, F_2^p, \dots, F_l^p, \dots, F_N^p\} \quad (2)$$

In Formula (2), F denotes a face image, l denotes an identity number, P denotes the face sequence length, and N denotes all face images of this identity in a data set. Formula (2) indicates that the sampling strategy for the face sequence is continuous and uninterrupted sampling. The initial face features are extracted from the face images using the RNN backbone network, as shown in Formula (3).

$$x_i^p = G(F_i^p), i \in \{1, 2, \dots, l\} \quad (3)$$

In Formula (3), x_i^p denotes the feature extracted from the face image, and G denotes the backbone network of RNN. The RNN network not only considers the input at the previous moment but also has the memory ability for input content. With this characteristic, we treat the face feature sequence of the same identity as a sequence of facial appearance changes with age. And we stack the face feature sequence length and use it as input to the RNN. In order to give different attentions, the attention mechanism of RNN is used to weight the each time step's outcome. The process of RNN face feature fusion is shown in Fig. 2.

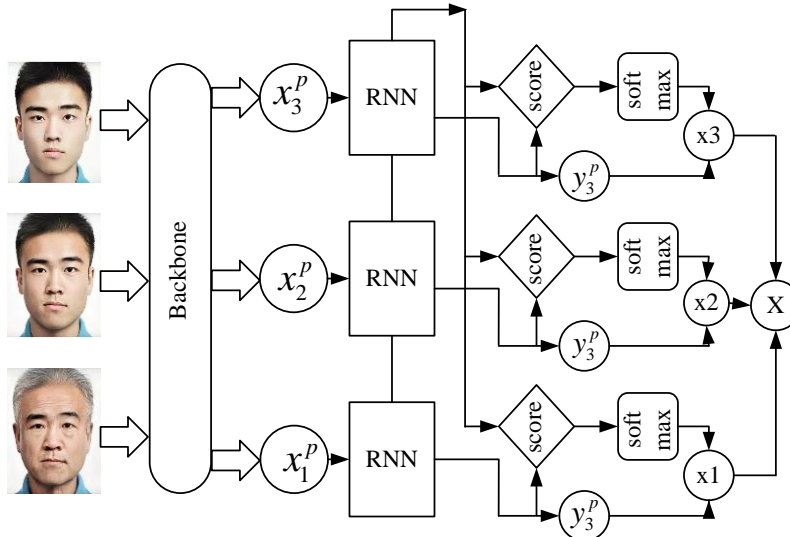


Fig. 2. RNN face feature fusion process.

As shown in Fig. 2, RNN is used to remember features from multiple time periods. X represents the fused face image feature while x_1 , x_2 , and x_3 represent feature extraction of images at different age stages. This scheme fuses the facial features of the same person at different age stages, thereby achieving feature fusion and making the fused face features have strong robustness against age interference.

B. Optimization Research on Cross Age Face Feature Fusion and Decoupling

Due to the influence of age, a same individual's face is very different at different ages. On occasions, the similarity gap between subjects of the same class surpasses that from different classes [16, 17]. If only the extracted face features are used for cross-age FR, a good performance is hard to obtain. It is necessary to eliminate the age factors influence on FR. Therefore, in this study, feature decoupling is used to optimize the feature fusion. The facial feature decomposition is represented by Formula (4).

$$x^p = x_{age}^p + x_{id}^p \quad (4)$$

In Formula (4), x_{age}^p represents the age feature, while x_{id}^p represents the face identity features. In facial feature decomposition, given the face feature x^p , the RNN fully connected layer is first linearly transformed to obtain age-

related features x_{age}^p . In order to reduce the identity information loss in the feature decomposition, this study projects the age-related features in the direction of x^p to obtain the corresponding age projection features, which are used as the final age features, as shown in Formula (5).

$$x_{proj}^p = \frac{x^p x_{r-age}^p}{\|x^p\|_2} \quad (5)$$

In Formula (5), x_{proj}^p represents the age projection feature in the direction of x^p , while x_{r-age}^p represents the age-related feature. Even after simple feature decoupling, the identity and age feature obtained may still have implicit correlations. Through the above feature decoupling, the study could acquire the features. In order to avoid the recognition degradation caused by the correlation of identity and age features, this study evaluates the correlation between identity and age features, and designs a loss function to minimize the correlation between them, achieving accurate constraint of feature decoupling, as shown in Formula (6).

$$\varphi = \frac{\left\| \frac{1}{m} \sum_{i=1}^m (Y_{age}^i - \mu_{age})(Y_{id}^i - \mu_{id}) \right\|}{\sqrt{\sigma_{age}^2 + \varepsilon} \sqrt{\sigma_{id}^2 + \varepsilon}} \quad (6)$$

In Formula (6), φ represents the correlation, μ_{age} and σ_{age}^2 are the mean and variance of Y_{age}^i . μ_{id} and σ_{id}^2 are the mean and variance of Y_{id}^i . ε represents a constant used to ensure numerical stability. Y_{age}^i and Y_{id}^i represent identity variables and age variables, respectively, and their definitions are given in Formula (7).

$$\begin{cases} Y_{age} = w_{age}^T x_{age} \\ Y_{id} = w_{id}^T x_{id} \end{cases} \quad (7)$$

In Formula (7), w represents trainable parameters, x_{age} and x_{id} represent age features and identity features, respectively. Therefore, the correlation loss function between them is represented by $L_c = \exp(|p|)$. FR based on discriminant cross-age is actually a multitask learning method. So besides correlation loss function, this study also needs to construct identity loss function and age loss function for RNN multi-feature fusion and decoupling cross-age FR. The approach taken in this study involves utilizing CosFace Loss as the primary identity loss function, which guides the model in learning essential identity-related information. The calculation is shown in Formula (8).

$$L_{id} = -\frac{1}{N} \sum_i \log \left(\frac{e^{s(\cos(\theta_{s,i})-c)}}{e^{s(\cos(\theta_{s,i})-c)} + \sum_{j \neq y_i} e^{s \cos(\theta_{j,i})}} \right) \quad (8)$$

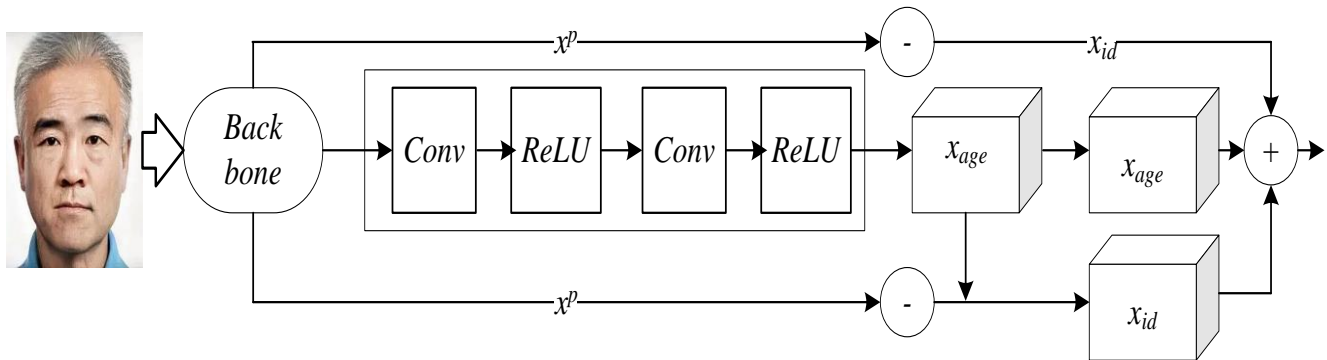


Fig. 3. Facial image feature decoupling and feature restoration.

From Fig. 3, the face features fused by RNN are first reshaped into a feature map. In order to enhance the fitting ability of feature decoupling, this study uses convolution combined with ReLU activation to optimize the decoupling. When decoupling, further recovering the identity feature from the age feature is equivalent to further decomposing the identity-related feature and identity-unrelated feature, which is the final age feature. This process is represented by Formula (10).

$$\begin{cases} \tilde{x}_{id}^p = kx_{age}^p \\ \tilde{x}_{age}^p = x_{age}^p - kx_{age}^p \end{cases} \quad (10)$$

In Formula (8), N represents the samples number in the training set, while $\cos(\theta_{j,i}) = W_j^T x_{id,i}$ represents the classes number. W represents the weight vector corresponding classifier category j . $x_{id,i}$ represents the identity feature vector corresponding to the face identity label y_i , while $\theta_{j,i}$ represents the angle between the weight vector and the identity feature vector. c, s represent the hyper parameters of the CosFace Loss function. Therefore, this identity loss function improves the model's identity recognition ability by maximizing the inter-class difference and minimizing the intra-class difference. The age loss function is constructed by using the cross-entropy loss function and its calculation is shown in Formula (9).

$$L_{age} = -\log \left(\frac{e^{t^p}}{\sum_{j=1}^m e^{t^j}} \right) \quad (9)$$

In Formula (9), m represents the categories for age labels, and e^{t^p} and e^{t^j} respectively represent the i -th and j -th term values output by the classifier. Finally, combining the correlation loss function, identity loss function, and age loss function, this study constructs the overall objective function of the supervised learning. It is defined as $L = L_{id} + \alpha L_{age} + \beta L_c$, where α and β are hyper parameters that balance the three loss functions. Finally, to reduce the information loss caused by the feature decoupling process, this study adds the lost face identity information back to the decoupled identity feature. The process of feature recovery is shown in Fig. 3.

In Formula (10), \tilde{x}_{age}^p and \tilde{x}_{id}^p are the features obtained after decoupling. k represents a learnable vector with a range of 0-1. The calculation of this vector is shown in Formula (11).

$$k = g(\omega_2 f(\omega_1 \text{GAP}(x_{age}^p))) \quad (11)$$

In Formula (11), g represents the sigmoid activation function. ω_2 and ω_1 represent the parameters of the fully connected layer. f represents the ReLU activation function. GAP represents global average pooling. The identity-related features extracted from the age feature to the decoupled identity feature are added, and the final recovered identity feature is available, as shown in Formula (12).

$$\hat{x}_{id}^p = x_{id}^p + \tilde{x}_{id}^p \quad (12)$$

The algorithm flow of the face image recognition model constructed in this study is shown in Fig. 4.

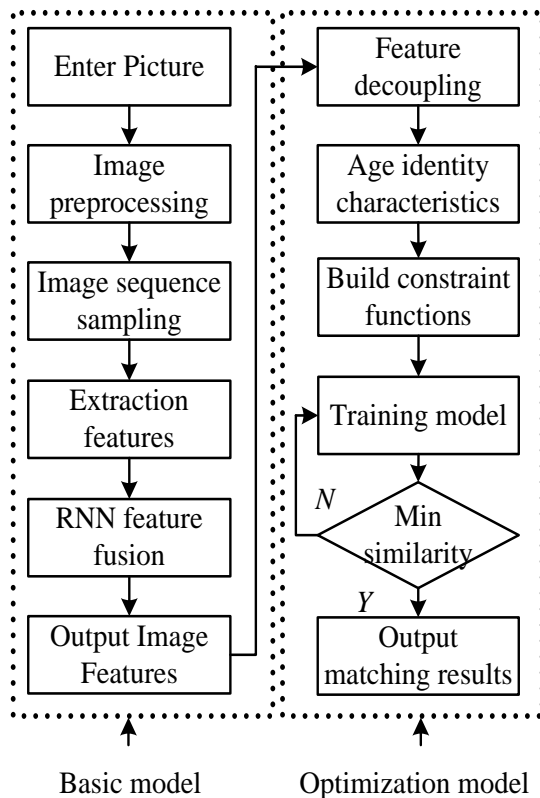


Fig. 4. RNN feature fusion decoupling optimized cross age FR model process.

As shown in Fig. 4, the cross-age face feature fusion and decoupling optimization model constructed in this study mainly uses the RNN and loss function for optimization. The model inputs a sequence of face images obtained by sampling (i.e., face images of the same person at different ages), as well as corresponding identity labels and age labels. Then, the backbone network is used to perform initial feature extraction on the face image sequence to obtain the face feature sequence. After obtaining the face feature sequence, it is fed into the feature fusion module to ensure that the fused face features can contain the adults' identity information to a certain extent.

Although the fused features contain rich face identity information, feature decoupling is still necessary to obtain age-related and identity-related features. Finally, the identity recognition loss function is used to supervise the identity feature, the age estimation loss function is used to supervise the age feature. And the correlation loss function is used to constrain the correlation between the age feature and the identity feature.

IV. APPLICATION SIMULATION ANALYSIS OF CROSS AGE FR MODEL UNDER RNN FUSION FEATURE DECONSTRUCTION OPTIMIZATION

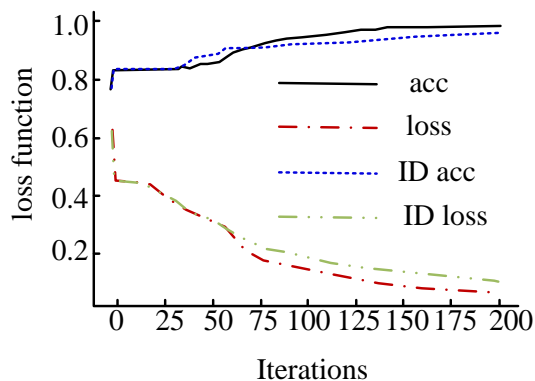
A. Parameter and Training Analysis of IDE-RNN Model

This study used RNN network feature fusion and feature decoupling, as well as related constraint functions optimization, to perform cross-age FR and construct the DE-RNN model. To verify the model, the CACD (Cross Age Celebrity Dataset) and its subset, CACD-VS, were used for simulation validation in this study. The CACD data set is a large-scale face aging data set for cross-age FR tasks. The collected images vary with changes in age, lighting, makeup, and other factors, which improves the simulation. The CACD-VS subset is meticulously annotated by cross-referencing associated images and web content. As for the face verification, each fold of the data set comprises of 200 positive sample pairs and 200 negative sample pairs. In the experiment, the hybrid matrix index and mean Average Precision (mAP) index were used. First, the parameters of the model constructed in this study were set as shown in Table I, and the model was simulated trained on the PyTorch platform.

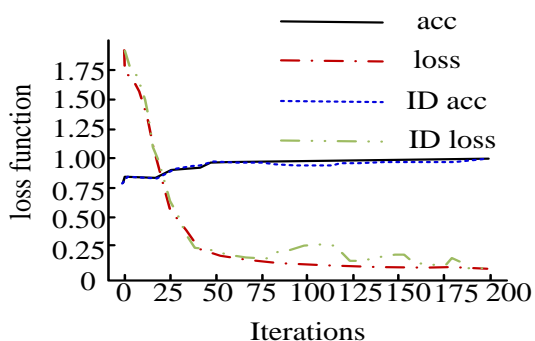
TABLE I. DE-RNN MODEL PARAMETER SETTINGS AND TRAINING PARAMETERS

Parameter name	Character	Value
Length of face sequence	l	3
CosFace Loss Hyperparameter	c	0.35
	s	64
Loss function equilibrium coefficient	α	0.3
	β	0.3
Pytorch Batch size	/	64
Maximum number of workouts	/	200

After obtaining the above model parameters, this study verified the effectiveness of the proposed method on both cross-age and general face datasets. When testing, Principal Component Analysis (PCA) was used in this study to obtain feature vectors with high discriminability for classification. Cosine distance was used to measure face similarity. The comprehensive loss function during the training process is shown in Fig. 5.



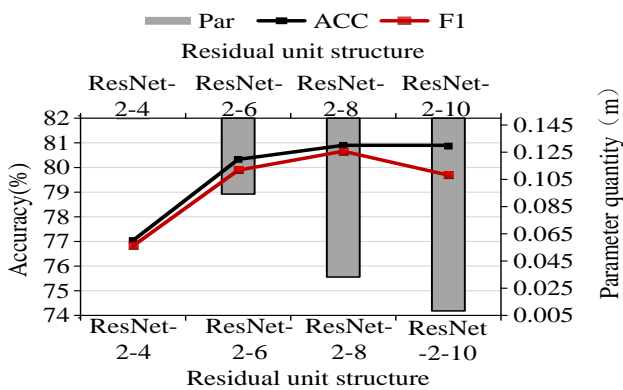
(a)Single-task damage identification model



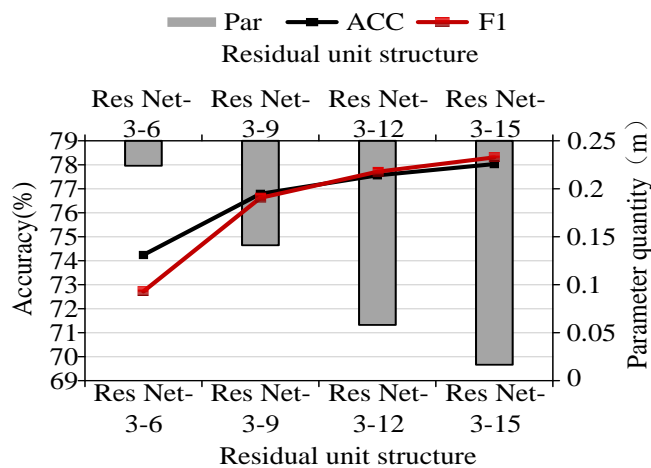
(b)Multi-task damage identification model

Fig. 5. Iterative comparison between single-task model and multi-task learning model.

The training curves in Fig. 5 include the age feature recognition accuracy and identity feature recognition for face matching, represented by acc and ID acc, respectively. From the training curves in Fig. 5, it can be observed that the single-task face image recognition model reaches full convergence after 125 iterations. While the single-task face identity recognition model has not yet reached full convergence. The multi-task learning model reaches a stable convergence state after 75 iterations. It can be seen that by utilizing multi-task learning to simultaneously optimize multiple tasks, the learning efficiency of the model is improved greatly, and the convergence speed of the model is significantly accelerated.



(a)2 Accumulation layer training results



(b)3 Accumulation layer training results

Fig. 6. Effect of different stack layer structure parameters on residual element performance.

In this study, the RNN backbone network was a residual network structure. The simulation tests were conducted to compare the face image recognition capabilities of different residual structures. Fig. 6 shows the effect of the residual blocks on the residual units with 2 and 3 layers of residual network stacks. As shown in Fig. 6, regardless of whether the residual network stack has 2 or 3 layers, the overall performance of the residual unit motion detection accuracy exhibits an increasing trend as the number of residual blocks increases. However, the overall accuracy in the residual network stack with three layers is lower than that in the stack with two layers. The average accuracy and F1 value in the two-layer stack structure were 79.785% and 79.265%, respectively. And in the three-layer structure, they were 76.555% and 76.34%, respectively. In terms of parameter calculation, the computing time of the residual network is negatively correlated with residual blocks. The residual blocks are more, the computation parameters are less. The average parameter for the two-layer stack structure was 0.0711 m, while that for the three-layer structure was 0.109 m. Therefore, the optimal number of residual network stack layers is two. And the best detection performance in the two-layer structure is the unit structure with four residual blocks, with accuracy and F1 values of 80.9% and 80.66%, respectively, which is higher than other structures. The experiment shows that the optimal value for parameter iteration of the RNN backbone network structure is the four residual blocks in the stack with 2 layers. After obtaining the parameters of the locally error-correcting joint residual network algorithm, this study compared the recognition accuracy and training time of 5 traditional CNN network structures. The experimental test data set selected the publicly available CACD data set, and the experimental results are shown in Table II.

TABLE III. TRAINING ACCURACY PERFORMANCE AND TRAINING TIME OF DIFFERENT ALGORITHMS IN CACD DATASET

Network structure	Accuracy (%)	Training time
LeNet5	60.21	50 m 12 s
AlexNet	72.83	47 m 34 s
Vgg16	78.36	24 m 20 s
GoogleNet	82.94	24 m 12 s
ResNet	88.82	22 m 10 s
DE-RNN	91.93	20 m 34 s

The table shows that LeNet5, AlexNet, Vgg16 are classic CNN network structures for image recognition, GoogleNet is the original basic network, ResNet is a single residual network, and DE-RNN is the proposed feature fusion and decoupling RNN model in this study. As shown in the table, the motion image recognition detection accuracy of individual classical CNN networks is decreasing, with accuracy below 80%. The recognition accuracies of GoogleNet and single residual network were 82.94% and 88.82%, respectively. While the proposed algorithm model had a higher accuracy of 91.93% compared to the first five CNN network structures. Moreover, its training time was the shortest, taking only 20 minutes and 34 seconds to train 500 image data.

B. Performance Analysis Parameters and Training Analysis of Cross Age FR using DE-RNN based on IDE-RNN Model

This study analyzed the performance of the DE-RNN cross age FR model on the CACD and CACD-VS datasets. Firstly, this study will compare other face verification methods and use a ten fold cross validation method to report ACC and AUC indicators. The specific experimental results are shown in Table III.

TABLE IV. ANALYSIS OF ACC AND AUC METRICS FOR DIFFERENT CROSS AGE FR MODELS IN CACD-VS DATASET

Methods	ACC	AUC
High-Dimensional LBplia	81.60%	88.80%
HFA	84.40%	91.70%
CARC	87.60%	94.20%
CAN	92.30%	N/A
Center Loss	97.50%	N/A
DAL	99.40%	99.60%
Human Average	85.70%	94.60%
Human Voting	94.20%	99.00%
DE-RNN	97.80%	99.60%

From Table III, the model proposed in this chapter is still competitive compared to other methods. In ACC indicators, DE-RNN performs better, but is lower than DAL. Among the AUC indicators, the AUC value of the DE-RNN model is 99.60%, higher than other algorithm models. In this study, four models with the highest AUC value will be selected for further

performance analysis. First, the mAP indicators of the model will be evaluated. The specific results are shown in Fig. 7.

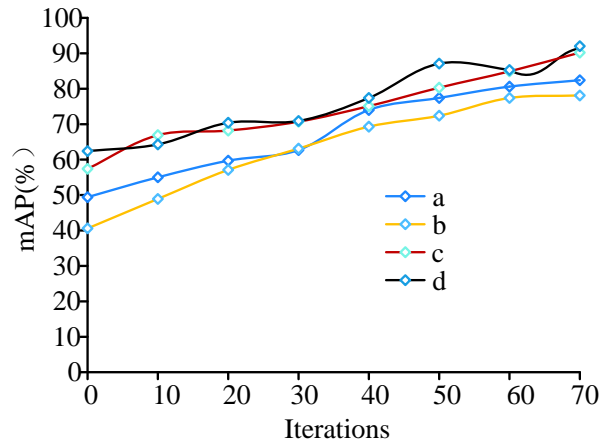
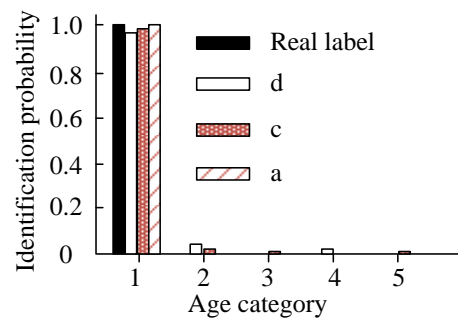
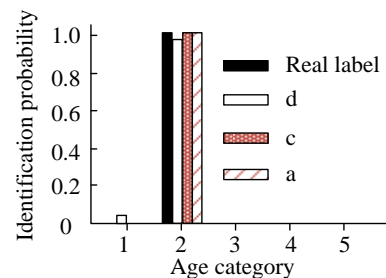


Fig. 7. Comparative analysis of different algorithms for map.

In Fig. 7, a, b, c, and d represent the Human Average model, DAL, the Human Voting model, and the proposed DE-RNN model, respectively. It can be observed from Fig. 6 that the mAP of different models is positively correlated with the number of iterations. When the number of iterations for the test sample was 70, the DE-RNN model had the highest recognition accuracy, with a mAP of 92.4%. The Human Voting model had the second highest recognition accuracy, with a value of 90.2%. The mAP of the Human Average model was 81.8%, while the mAP value of the DAL model was the lowest, at 78.1%. Therefore, in the following experiments, the DAL model will not be considered due to its low mAP value below 80%.



(a) Cross age identification of CACD dataset



(b) Cross age identification of CACD-VS dataset

Fig. 8. Application of MTL-1DCNN model for damage identification of double-storey buildings.

This experiment aimed to validate the FR performance of different algorithms for different age groups in the CACD and CACD-VS datasets. The images of different age groups, 0-20, 20-30, 30-45, 45-60, and over 60 years old, in the datasets were used to verify the recognition accuracy. The specific experimental results are shown in Fig. 8, where the horizontal axis represents the age classification, numbered 1-5 from the lowest to the highest. The number of validation samples in both datasets was 200. From Fig. 8, it can be seen that in the face image recognition of the first stage, age 0-20, in the CACD-VS dataset, the DE-RNN model had an accuracy of 96%, higher than other algorithms. In the second stage, age 20-30 of FR in the CACD dataset, the accuracy of the DE-RNN model reached 98%, higher than that of the Human Voting model. Regarding the comparative methods, the Human Average model had better performance than the Human Voting model but was inferior to the DE-RNN model built in this study.

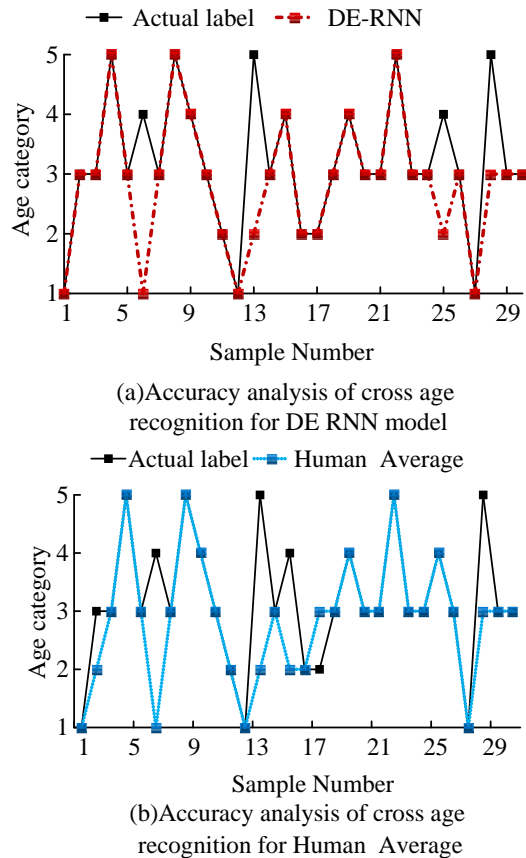


Fig. 9. Accuracy of cross age FR using different methods.

Finally, this study combined the CACD and CACD-VS datasets to compare the cross-age face image recognition performance of the two methods in the integrated data set. As shown in Fig. 9, out of the 30 training samples, the model built in this study only had four recognition errors, while the Human Average model had six misjudgments.

V. RESULT AND DISCUSSION

The technology that brings the most convenience to people's daily lives in artificial intelligence is facial recognition technology. As one of the representative artificial intelligence

technologies, facial recognition technology has naturally attracted a large number of researchers to conduct research. Since face includes a lot of useful semantic information, such as face, gender, expression, age and identity, face recognition also includes many research directions: face identity recognition, face age estimation, face expression recognition, etc.

In cross age facial recognition, feature fusion and feature decoupling can filter out age independent information in images. Yan et al. [18] proposed a new multi feature fusion and decomposition (MFD) framework for age invariant facial recognition. Based on facial time series, this method could combine feature decomposition and fusion to ensure that the final age independent features effectively represent the face identity information. And it has stronger robustness to the aging process. Huang et al. [19] first utilized attention mechanisms to divide the fused facial information into two parts: identity and age information. Then, they used methods such as multitasking learning and continuous domain adjustment to de correlate the two parts. Unlike conventional single Hot codes, the study aims to use a new identity state model to complete the identity state, and enhances the age smoothness of combined faces through a weighted allocation mechanism. The existing discrimination methods for cross age facial recognition mainly focus on decomposing facial features in images into age related and independent identity features, and then performing facial recognition. In fact, it is inevitable that facial identity information will be lost when feature decoupling. To address this issue, this article first proposes a cross age facial recognition framework based on multi feature fusion and decoupling, which fully learns facial feature representations with high discrimination ability, thereby alleviating intra class differences in cross age facial recognition [20, 21]. Therefore, this study also adopted this approach to optimize the face cross age recognition technology of RNN models. And CACD and CACD-VS datasets are used for validation analysis. In the experiment, it was found that the single task facial image recognition model reached a complete convergence state after 125 iterations. While the multi task learning training model reached a stable convergence state after 75 iterations. Therefore, the multi task optimization project proposed in this study is effective. In addition, through experiments, the research determines the RNN backbone network structure. That is, the best detection performance is the unit structure with two layers of stacked four residual blocks, whose precision and F1 value are 80.9% and 80.66% respectively, higher than other structures.

In performance analysis, the experimental results of facial image recognition between the ages of 0 and 20 in the first stage of CACD-VS data set show that the accuracy of the DE-RNN model is 96%, which is higher than other algorithms. In the second stage of facial recognition between the ages of 20 and 30 in CACD, the accuracy of the DE-RNN model is 98%, which is higher than the Human Voting model. At the same time, this study synthesized CACD and CACD-VS into a data set. And the performance of two methods in cross age facial image recognition was compared in the comprehensive data set. The results showed that out of 30 training samples, the model constructed in the study had only four recognition

errors, while the Human Average model had six judgment errors. The experiment shows that the improved recurrent neural network facial cross age recognition model proposed in this study has excellent accuracy and recognition speed.

VI. CONCLUSION

In this study, RNN network was used to construct a face cross-age recognition model with feature fusion and decoupling. The parameters and performance of the model were analyzed on a simulation platform. The experimental results show that the single-task learning model reached convergence after 125 iterations, while the multi-task model built in this study stabilized at 75 iterations. Meanwhile, in the data set analysis, the performance and structure of the backbone networks were compared. And the DE-RNN model had the highest accuracy of 91.93% and the shortest training time, which was 20 minutes and 34 seconds to train 500 image data. Regarding performance analysis, the DE-RNN model had the highest recognition accuracy, with a mAP of 92.4%, followed by the Human Voting model, with a value of 90.2%, and the Human Average model had a mAP of 81.8%. The performance of the three algorithms was compared and analyzed. In the first face image recognition stage, age 0-20, in the CACD-VS dataset, the accuracy of the DE-RNN model was 96%, higher than other algorithms. In the second stage, age 20-30 of FR in the CACD data set, the accuracy of the DE-RNN model reached 98%, higher than that of the Human Voting model. Regarding the integrated data set comparison, out of 30 training samples, the model built in this study only had four recognition errors, while the Human Average model had six misjudgments. The experimental data shows that the model built in this study has superior recognition performance and cross-age face image classification ability. However, the limitation of this study is that the sample classification is based on age stage labels, which still have some noise. For the multi feature fusion in this article, it is necessary to first sample a facial sequence and then fuse the features of the facial sequence. Therefore, this process increases model training and inference time. Therefore, in future experiments, the feature extraction optimization of age attributes will be considered.

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REFERENCES

- [1] W. Ali, W. H. Tian, S. U. Din, D. Iradukunda, and A. A. Khan, "Classical and modern face recognition approaches: A complete review," *Multimedia Tools Appl.*, vol. 80, pp. 4825-4880, October 2021.
- [2] B. Jin, L. Cruz, and N. Gonçalves, "Pseudo RGB-D face recognition," *IEEE Sens. J.*, vol. 22, no. 22, pp. 21780-21794, November 2022.
- [3] M. Andrejevic and N. Selwyn, "Facial recognition technology in schools: critical questions and concerns," *Learn., Media Tech.*, vol. 45, no. 2, pp. 115-128, November 2020.
- [4] X. Y. Chen and H. Y. K. Lau, "The identity-level angular triplet loss for cross-age face recognition," *Appl. Intell.*, vol. 52, no. 6, pp. 6330-6339, September 2022.
- [5] K. Bahmani and S. Schuckers, "Face recognition in children: A longitudinal study," *2022 International Workshop on Biometrics and Forensics*, pp. 1-6, June 2022.
- [6] M. Sajid, N. Ali, N. I. Ratal, M. Usman, F. M. Butt, I. Riaz, U. Musaddiq, M. J. A. Baig, S. Baig, and U. A. Salaria, "Deep learning in age-invariant face recognition: A comparative study," *Comput. J.*, vol. 64, no. 4, pp. 940-972, April 2022.
- [7] S. A. Rizwan, Y. Y. Ghadi, A. Jalal, and K. Kim, "Automated facial expression recognition and age estimation using deep learning," *Comput. Mater. & Continuum.*, vol. 71, no. 3, pp. 5235-5252, January 2022.
- [8] S. Riaz, Z. Ali, U. Park, J. Choi, I. Masi, and P. Natarajan, "Age-invariant face recognition using gender specific 3D aging modeling," *Multimedia Tools Appl.*, vol. 78, pp. 25163-25183, May 2019.
- [9] K. Kavita and R. S. Chhillar, "Human face recognition and age estimation with machine learning: A critical review and future perspective," *Int. J. Elec. Comput. Eng. Syst.*, vol. 13, no. 10, pp. 945-952, 2022.
- [10] A. Sepas-Moghaddam, A. Etemad, F. Pereira, and P. L. Correia, "Long short-term memory with gate and state level fusion for light field-based face recognition," *IEEE Trans. Inform. Forensics Secur.*, vol. 16, pp. 1365-1379, November 2020.
- [11] A. K. Dubey and V. Jain, "Automatic facial recognition using VGG16 based transfer learning model," *J. Inform. Opt. Sci.*, vol. 41, no. 7, pp. 1589-1596, September 2020.
- [12] X. F. Liu, Z. H. Guo, J. You, and B. V. K. Vijaya Kumar, "Dependency-aware attention control for image set-based face recognition," *IEEE Trans. Inf. Forensics Security*, vol. 15, pp. 1501-1512, August 2019.
- [13] L. P. Zhang, L. J. Sun, L. N. Yu, X. L. Dong, J. C. Chen, W. W. Cai, C. Wang, and X. Ning, "AR face: Attention-aware and regularization for face recognition with reinforcement learning," *IEEE Trans. Biometrics, Behav., Identity Sci.*, vol. 4, no. 1, pp. 30-42, August 2021.
- [14] X. Zhou, Y. Li, and W. Liang, "CNN-RNN based intelligent recommendation for online medical pre-diagnosis support," *IEEE/ACM Trans. Comput. Biol. Bioinformatics*, vol. 18, no. 3, pp. 912-921, May 2020.
- [15] R. Sudharsan and E. N. Ganesh, "A swish RNN based customer churn prediction for the telecom industry with a novel feature selection strategy," *Connect. Sci.*, vol. 34, no. 1, pp. 1855-1876, June 2022.
- [16] X. L. Xiao, Y. Y. Chen, Y. J. Gong, and Y. C. Zhou, "Low-rank preserving t-linear projection for robust image feature extraction," *IEEE Trans. Image Process.*, vol. 30, pp. 108-120, October 2020.
- [17] M. T. H. Fuad, A. A. Fime, D. Sikder, M. A. R. Iftee, J. Rabbi, M. S. Al-Rakhami, A. Gumaie, O. Sen, M. Fuad, and M. N. Islam, "Recent advances in deep learning techniques for face recognition," *IEEE Access*, vol. 9, pp. 99112-99142, July 2021.
- [18] C. G. Yan, L. X. Meng, L. Li, J. H. Zhang, Z. Wang, J. Yin, J. Y. Zhang, Y. Q. Sun, and B. L. Zheng, "Age-invariant face recognition by multi-feature fusion and decomposition with self-attention," *ACM Trans. Multimedia Comput., Commun., Appl. (TOMM)*, vol. 18, pp. 7-18, January 2022.
- [19] Z. Huang, J. Zhang, and H. Shan, "When age-invariant face recognition meets face age synthesis: A multi-task learning framework," *Proc. IEEE/CVF Conf. Comp. Vis. Patt. Recognit*, pp. 7282-7291, October 2021.
- [20] Y. Zhong, W. Deng, J. Hu, D. Zhao, X. Li, and D. Wen, "SFace: Sigmoid-constrained hypersphere loss for robust face recognition," *IEEE Trans. Image Process.*, vol. 30, pp. 2587-2598, January 2021.
- [21] L. P. Zhang, L. J. Sun, L. N. Yu, X. L. Dong, J. C. Chen, W. W. Cai, C. Wang, and X. Ning, "ARFace: attention-aware and regularization for face recognition with reinforcement learning," *IEEE Trans. Biometrics, Behav., Identity Sci.*, vol. 4, no. 1, pp. 30-42, August 2021.