A Smart IoT System for Enhancing Safety in School Bus Transportation

Yousef H. Alfaifi[1], Tareq Alhmiedat[2]*, Emad Alharbi[3], Ahad Awadh Al Grais[4],
Maha Altalk[5], Abdelrahman Osman Elfaki[6]*
Faculty of Computers and Information Technology, University of Tabuk, Tabuk, 71491, Saudi Arabia[1, 2, 3, 6]
Artificial Intelligence and Sensing Technologies (AIST) Research Center, University of Tabuk, Tabuk, 71491, Saudi Arabia[2]
SEHA Virtual Hospital, Ministry of Health, Digital City, Riyadh, Saudi Arabia[4, 5]

***Abstract*—School districts globally implement comprehensive and expensive strategies to offer safe bus transportation to and from school. However, these technologies are unfeasible to schools with limited financial resources, thereby leaving students at risk of serious injury. This study focuses on five major obstacles to safe school transportation: 1) forgetting students on the bus unattended; 2) students' abnormal behavior; 3) overcrowding; 4) abnormal driver behavior; and 5) the risk of a bus running over children after they have disembarked. This paper developed an intelligent system using the Internet of Things, including rule-based and mathematical solutions to overcome the five transportation safety issues in student buses mentioned above, and to enhance student safety, using a bracelet system, short- and long-RFID sensors, and a processing unit to monitor the bus and its surrounding area. Therefore, in this paper, the proposed solution is superior to previous works in the same field. It is distinguished by its comprehensiveness and reasonable cost, making it affordable and easy to both install and maintain.**

Keywords—IoT; safety; RFID; school bus; transportation

I. INTRODUCTION

Keeping students safe on their journey to and from school is of great importance not only to parents, school officials, and administration, but to the entire local community. School buses play a crucial role in transporting students to and from school, serving as a prevalent and cost-effective mode of transportation in many educational communities and countries. Public institutions, communities, and nations aim to expand and improve their school bus services to lower transportation costs, alleviate traffic congestion, and decrease carbon emissions.

Despite these benefits, ensuring safe transportation for students can be difficult due to five safety issues that might harm their safety. The first is when children are forgotten and left on the bus. It is difficult to keep track of all the children to make sure everyone gets off the bus. Left unattended for long periods of time, these forgotten children can harm their health or even cause death [1, 2]. Second, student fights on school transport can hinder their and others' safety, as can other abnormal behavior on the school bus [3, 4]. Some parents complain about fights on the school bus as their children exhibit signs of aggression. It is challenging for the transportation supervisor or driver to monitor the children throughout the entire trip, particularly on a crowded bus.

The third issue is that overcrowded buses where that pose significant risks to students' safety and well-being, as it can lead to discomfort, accidents, delays, and difficulties in emergency evacuations, all of which put students at risk [5]. The fourth impediment to student safety is the unruly behavior of drivers [6]. Such behavior can create a negative environment on the bus, leading to distractions, discomfort, and potentially unsafe conditions for the children. Finally, the fifth obstacle to student safety is accidents that occur when the children disembark. As they cross the road or move away from the bus, they may unknowingly position themselves in the bus's blind spots, outside of the driver's view. If the bus starts moving, there is a risk of the child being injured or killed [7, 8].

Recent technological advancements, especially within the Internet of Things (IoT), play a crucial and effective role in providing safe and effective solutions to various problems [9]. IoT refers to the network of physical objects, or "things," embedded with technologies, software, and sensors, which exchange data with other devices and systems over the internet [10]. This paper applies IoT solutions to handle the five safety issues and enhance security in school transportation. To prevent children from being forgotten on the bus, this paper suggests the use of a bracelet system, which is scanned when the student enters the bus and again when they exit. This solution tracks the boarding and disembarking times and locations, as well as the duration of the time on the bus.

The bracelets, which would be equipped with location-tracking capabilities, should transmit location data to a central system capable of receiving and processing this data. This location data could solve multiple safety issues. In addition to monitoring students who are forgotten on the bus, it could also be used to identify abnormal student behavior via a special algorithm (criteria for a fight could be included frequent position changes, the simultaneous swapping of places by multiple students, or a large gathering of students in one area); location data could also trigger automated alerts when buses surpass safe occupancy levels. In addition, the bracelet could also generate alerts for abnormal driver behavior using the location data. Finally, location data could be used to notify drivers if a student or students are in the bus's blind spot; the driver would then be restricted from moving until all students are a safe distance from the bus.

The contribution of our proposed system is to provide a comprehensive set of safety functionalities at a very minimal cost and with low computational power requirements. This makes our proposed system accessible and applicable to a wide

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*Corresponding Author.

range of users. The remaining sections of the paper are organized as follows: Section II discusses recent and updated related works. Section III describes the mathematical model used to develop this smart IoT system. Section IV contains a detailed explanation of the system's implementation. Section V presents a validation of the proposed IoT system. Finally, the discussion and conclusion are presented in Section VI.

II. RELATED WORK

This section discusses related research on IoT systems and safety. The timeframe was limited to the period from 2019 to 2024, as technology has been evolving rapidly, and any work published before this period could be considered outdated. Two factors served as inclusion criteria. Firstly, the work must address one or more of the problems outlined in the introduction (Section I). Secondly, the work should offer practical, and implementable, solutions. All theoretical works were excluded, as well as any redundant ideas.

Abbas et al., [11] addressed the issue of students being inadvertently left on school buses by introducing a system that enabled parents to monitor their children's daily commute using GPS technology. This system alerted parents before the bus reached their home, ensuring the safety of their children. In study [12], Liu and Peng, addressed safety incidents where young children were left unattended on school buses during the summer by implementing a Force Sensing Resistor (FSR) sensor array. This system detected the movement of a forgotten child based on the resistance of the FSR module. Krishnan and Vasuki, in study [13], created an intelligent system employing Global System for Mobile applications (GSM) and Radio Frequency Identification (RFID) technologies. RFID was utilized to recognize students and link them to their parent's contact information, with GSM serving as the medium to notify parents of their child's whereabouts via text message. Paul and Sasirekha, in the study [14], developed a smart system by utilizing three technologies—global positioning system (GPS), RFID and GSM—to ensure a safe school bus journey. RFID oversaw children entering and exiting the bus and sent SMS notifications to parents. If the child didn't reach school or home on time, parents could activate the registered number on the GPS tracker. The tracker then monitored the child's position, providing the latitude and longitude coordinates to the parent's mobile device.

Mott and Kotla, in [15], addressed the issue of children being run over after disembarking from the school bus by developing a detection system based on a LiDAR unit and a dashcam, both controlled by a Raspberry Pi computer. Kumari et al., in [16], created an IoT- and Android-based system that allowed parents and schools to monitor the comfort and safety conditions on the bus in real-time. Gadekar et al., in [17], developed a smart school bus tracking system using QR codes to monitor student boarding and disembarking. To track bus movement, they created a mobile application utilizing the Django framework and GPS integrated with the Google Maps API, enabling parents to stay informed about the real-time location of the bus. In Naik et al.'s research [18], a school bus monitoring system was developed to share details on the bus's location, speed, estimated arrival time, and the students' whereabouts. This functionality was facilitated by IoT technology. The tracking of the school bus was carried out using GPS technology. Parents are alerted through GSM. Everyone is identified by a unique ID through RFID. The bus tracking system allowed for real-time tracking on smartphones. Additionally, the researchers incorporated an algorithm to track the bus and estimate its arrival time.

Sakphrom et al., in [19], developed a smart system for monitoring children inside a school bus by utilizing Bluetooth Low Energy (BLE), which is compatible with a signal strength indicator (RSSI) algorithm. The system monitored children entering and exiting the bus and notified the driver to help them ascertain whether any child was left on-board. The system assessed the distance between devices to determine the current position of the children. To achieve this, this study employed a simplified and highly accurate machine learning approach known as the least mean square (LMS) algorithm, combined with model-based RSSI localization techniques. Malathy et al., in [20], introduced a smart module that relied on GPS to transmit data to a remote server via Wi-Fi. The data uploaded was subsequently accessible to the client through a mobile application, which retrieved the information and mapped the vehicle's location. An alert system activated the microcontroller to generate a push notification from the server script upon scanning the student's RFID tag with the RFID reader, signaling to the relevant authorities and parents that the student has boarded the bus.

Wang et al., [21], developed an abnormal behavior prediction method by integrating multiple indices of student behavior and text information within a big data environment. They utilized an optimized K-means algorithm for clustering student behavior data and combined it with long-short-term memory (LSTM) networks and neural factorization machines for predictive analysis. This study enhanced the field's ability to identify and manage potentially dangerous behaviors in educational settings. Ding et al., [22], developed an intelligent system to detect abnormal behavior in students using human skeleton analysis and deep learning. They utilized the OpenPose deep learning network to extract spatiotemporal features of the human skeleton and classified these features with a graph convolutional neural network to reduce computational complexity. The system demonstrated high accuracy, with a recognition rate exceeding 99.50%. These results underscore the system's potential for real-time monitoring of student behavior on school buses, enhancing safety measures through effective detection and classification of abnormal behavior. Murawski et al., [23], deployed an intelligent system for overseeing school bus drivers using a "stability" index, which contrasts with the 11 risky driving behaviors determined by the digital tachograph (DTG) and GPS integrated with the Google Maps API.

Etaati et al., [24], evaluated the effectiveness of promoting active transportation to school by utilizing the Safe Routes to School (SRTS) program to estimate the likelihood of students choosing to walk to school. They employed SHapley Additive exPlanations to identify significant variables that influenced active transportation behavior in their models. The findings highlighted factors such as home-to-school distance and safety concerns, including crime rates and traffic speed along the route. In this solution, however, they replaced the bus transportation system with a safe road, which may not be applicable in all locations.

TABLE I. SUMMARY OF RELATED WORKS

No	Work	Techniques/ Algorithms	Limitation
1	Krishnan and Vasuki, in [13]	SMS and GSM	The speed and cost are affected by the use of GSM technology.
2	Abbas et al., in [11]	GPS and Mobile application	There is no monitoring system in place for the students themselves; instead, manual checks are required to ensure students board the bus.
3	Liu and Peng, in [12]	Force Sensing Resistor and android application	The accuracy could be affected by the movements of students.
4	Paul and Sasirekha, in [14]	GPS, RFID and GSM	It is very difficult to provide real-time data.
5	Mott and Kotla, in [15]	LiDAR unit a dashcam, both, and Raspberry Pi	High processing cost.
6	Kumari et al., in [16]	Dashcam, Android	High-cost devices are challenging to provide.
7	Gadekar et al., in [17]	QR Code, Google Maps API, Django	Scanning the QR code of every student when boarding and disembarking slows the system and makes it impractical.
8	Naik et al., in [18]	GPS, GSM, RFID, and Android application	High-cost devices are challenging to provide to everyone.
9	Sakphrom et al., in [19]	Bluetooth Low Energy (BLE), signal strength indication (RSSI) algorithm, and least mean square (LMS) algorithm	High processing cost.
10	Malathy et al., in [20]	GPS, Wi-Fi, RFID, and Android application	High processing cost.
11	Ding et al., in [22]	OpenPose deep learning network Graph convolutional neural network (GCN) Sliding window voting method	High processing cost.
12	Wang et al., in [21]	Optimized K-means, Long-Short-Term Memory (LSTM) networks, Neural Factorization Machines (NFM)	High processing cost.
13	Murawski et al., in [23]	DTG and GPS integrated with the Google Maps API	High-cost devices are challenging to provide to everyone.
14	Etaati et al., in [24]	random forest, logistic regression, and support vector machines	The researchers replaced the bus transportation system with a safe road, which may not be applicable in all locations.
15	LR et al., in [25]	RFID and GPS	Does not provide complete solutions.
16	Gadade et al., in [26]	ESP32 microcontroller, GPS module, RFID reader, RTC module, LCD	High-cost devices are challenging to provide to everyone.
17	Kumari et al., in [27]	Python-configured PC with a camera and OpenCV	High processing cost.

LR et al., in [25], developed a system that addressed safety standards by ensuring continuous student monitoring through RFID and GPS technologies. This system recorded the boarding and disembarking times of students passing through two checkpoints, tracked the real-time location of the bus, and monitored its speed to comply with regulations. In Gadade et al.'s research [26], a smart school bus and student tracking system based on IoT was developed utilizing an ESP32 microcontroller, GPS module, RFID reader, RTC module, LCD display, and integration with Google Sheets. The ESP32 microcontroller functioned as the central processing unit. The GPS module facilitated the tracking of the school bus's location, enabling real-time monitoring for parents, school staff, and authorities.

Furthermore, RFID technology was employed to monitor students during boarding and disembarking. For accurate timekeeping, a Real-Time Clock (RTC) module was integrated to synchronize system time and ensure precise event logging. Additionally, an LCD display served as a local interface, offering real-time updates on bus location, current time, and important announcements. Kumari et al., in [27], created a smart system utilizing a Python-configured PC with a camera and OpenCV for instant facial recognition of students during school bus boarding and exiting. Upon identifying a student, the system automatically sent an email notification to inform parents, providing reassurance to caregivers. Alongside student recognition, the system included alcohol detection features for the driver. In cases where the driver was deemed intoxicated, the bus's ignition system would lock, preventing unsafe driving.

Table I, illustrates this analysis of the related works, defining the techniques or algorithms that each utilized and detailing their limitations. The related works have been analyzed by defining the strengths and weaknesses of each work. The datasets are associated with their related work. Similar works have discussed safety in school transportation systems. The database used in the work is specific to each study, and currently, there is no general-use database available.

III. MODELING

This section presents a mathematical model that serves as the foundation for implementing this paper's five solutions. There are three assumptions, which are:

Assumption 1: Each student should wear a bracelet.

Assumption 2: The bus driver should wear a bracelet.

Assumption 3: Each bracelet has a unique integer number.

Fig. 1 displays the variables utilized in these proposed solutions, which are incorporated into the mathematical model.

1. s → student
2. b → bracelet
3. seat → bus seat
4. r1 → first reader
5. r2 → second reader
6. r3 → inside reader
7. r4 → inside reader
8. r5 → inside reader
9. bdrv → driver bracelet
10. driver_set → driver seat

Fig. 1. Variables of the proposed solutions.

In the following formulas, the mathematical model has been described in form on First Order Logic (FOL), which is suitable for describing real life problems [28].

$$\forall b: bracelet\ (b) \land integer(number) \Longrightarrow unique(b, number) \tag{1}$$

Rule 1 denotes that there is a unique integer number assigned to each bracelet, which functions as the primary key or identifier for a bracelet.

$$\exists s\ \exists b: student(si) \land bracelet\ (bj) \land wear\ (si\ , bj) \Longrightarrow assign(si, bj) \tag{2}$$

Rule 2 denotes that each student has their own unique bracelet, which means the reading of a specific bracelet number identifies the associated specific student.

$$\forall s\ \forall r1\ \forall r2\ \forall ti\ \forall b: reader(r1) \land reader(r2) \land time(t) \land bracelet\ (bj) \land assign(si, bj) \land read(r1, bi, t1) \land read(r2, bi, t2) \land (t2 > t1) \Longrightarrow si\ boarding\ the\ bus \tag{3}$$

Rule 3 denotes that if the bracelet of student (i) was read by reader 1 first and then read by reader 2 later, this means that student (i) has boarded the bus.

$$\forall s\ \forall r1\ \forall r2\ \forall ti\ \forall b: reader(r1) \land reader(r2) \land time(t) \land bracelet\ (bj) \land assign(si, bj) \land read(r1, bi, t1) \land read(r2, bi, t2) \land (t1 > t2) \Longrightarrow si\ gets\ off\ the\ bus \tag{4}$$

Rule 4 denotes that if student (i)'s bracelet was read by reader 2 first and then reader 1 later, then the student (i) has gotten off the bus.

$$\forall s: true\ (rule\ 3) \land true(rule\ 4) \Longrightarrow time(si, boarding\ and\ alighting) \land location(si) \tag{5}$$

Rule 5 indicates that once rules 3 and 4 are met, the boarding and disembarking of a student have been established, along with their location during the bus ride. Rules 3, 4, and 5 present the mathematical formulation for the first solution, which confirms that no students were forgotten on the bus.

$$\forall bn\ \forall ri\ \forall seatj\ \forall sx : ((ri == reader\ 3) \land (ri == reader\ 4) \land (ri == reader\ 5)) \land student(sx) \land seat(seatj) \land set(setj, sx) \land wear\ (si\ , bn) \land read(ri, bn) \Longrightarrow assign(sx\ , seat\ j) \land location(seatj) \tag{6}$$

Rule 6 specifies that the three readers, r1, r2, and r3, are used to determine the student's seat. After the student takes a seat in a specific location, the three readers employ the triangulation method to identify the student's seat and exact location.

$$\forall ri\ \forall bx\ \forall setj\ \forall sx : ((ri == reader\ 3) \land (ri == reader\ 4) \land (ri == reader\ 5)) \land seat\ (setj) \land bracelet\ (bx) \land assign(setj, sx) \land ((distance(ri, bx) == n) \land ((distance(ri, setj) == m) \land (n \neq m) \Longrightarrow sx\ in\ incorrect\ seat \Longrightarrow send(alarm) \tag{7}$$

Rule 7 states that if the distance between a particular reader i and a specific seat j (predefined distance) assigned to student x is not equal to the distance between bracelet x assigned to student x and the particular reader i, this indicates that student x is seated in the incorrect seat; an alarm will be sent to administrators.

$$\forall ri\ \forall b\ \forall setj\ \forall s : ((ri == reader\ 3) \land (ri == reader\ 4) \land (ri == reader\ 5)) \land bracelet\ (bx) \land bracelet(by) \land (distance(ri, bx) == n) \land (distance(ri, by) == m) \land (m \land n) < safe\_distance \Longrightarrow student\_gathering \Longrightarrow send(alarm) \tag{8}$$

Rule 8 states that if the distance between two or more students is less than the predefined safe distance that should be maintained, indicating a group gathering, an alarm will be triggered and sent to the administrators as an alert. Rules 6, 7, and 8 illustrate the mathematical representation for the second solution, which seeks to prevent student fights and other erratic behavior.

$$\forall r1\ \forall r2\ \forall bi: reader(r1) \land reader(r2) \land bracelet\ (bi) \land read(r1, bi) \land \neg read(r2, bi) \land count(bi, n) \land (n > bus\_capacity) \Longrightarrow send(alarm) \tag{9}$$

Rule 9 states that if the number of students who have been scanned by the first reader but not by the second reader exceeds the bus capacity, the system will send an alert to the administrators to indicate overcrowding. Rule 9 illustrates the mathematical representation for the third solution.

$$\exists bdrv\ \exists r1\ \exists driver\_set: reader(r3) \land reader(r4) \land reader(r5) \land bracelet\_driver\ (bdrv) \land (distance(ri, driver\_set) == x) \land$$

$$distance(r1, bdrv) > x \Longrightarrow driver\ misplaced \wedge send(alarm) \quad (10)$$

Rule 10 denotes that if the distance between the driver's bracelet and the readers is greater than the distance between the first reader and the driver's seat, it indicates that the driver is not in the correct position and triggers an alarm to administrators. Rule 10 presents the mathematical formulation for the fourth solution, which seeks to prevent erratic driver behavior.

$$\forall ri\ \forall b\ \forall s:\ ((ri == reader\ 1) \wedge (ri == reader\ 2) \wedge (ri == reader\ 3) \wedge (ri == reader\ 4) \wedge (ri == reader\ 5)) \wedge bracelet\ (bx) \wedge assign(sx, bx) \wedge out\_range(ri, bx) \Longrightarrow bus\ save\ to\ move \quad (11)$$

Rule 11 mandates that the bus will only move when all students are out of the reader's range, ensuring that the bus does not depart while students are still within proximity. This rule introduces the mathematical formulation for the fifth solution, which addresses student safety after they've disembarked from the bus. Table II, displays the rules and their corresponding solutions.

TABLE II. THE RULES AND THEIR CORRESPONDING SOLUTIONS

Rule	Solution
3, 4, and 5	First solution, which prevents students being forgotten on the bus: track the boarding and disembarking times, locations, and the duration of the student's time inside the bus.
6, 7, and 8	Second solution, which prevents erratic student behavior: set thresholds for the frequency of place changes, the number of students swapping places simultaneously, and instances of groups of students gathering in one place.
9	Third solution, which prevents bus overcrowding: trigger automated alerts for administrators when buses surpass safe occupancy levels.
10	Fourth solution, which prevents erratic driver behavior: track driver movement and generate alerts for abnormal driving behavior, such as frequent changes in location
11	Fifth solution, which prevents students from being injured or killed when in the bus's blind spot: prevent the bus from moving if students are still in the bus area. The driver is restricted from moving until all students are safely outside the bus area.

IV. IMPLEMENTATION

This section explains the implementation of the aforementioned rules in order to achieve increased bus safety. The implementation system has been developed based on different components. The main concept of the developed smart IoT system for enhancing safety in school bus transportation is presented in Fig. 2.

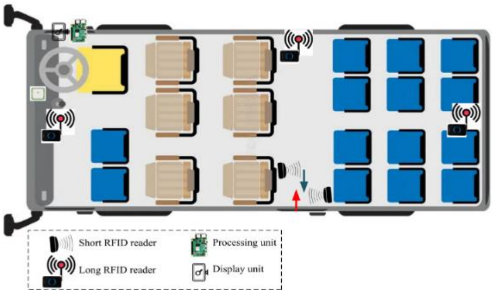

Fig. 2. The main components of the developed smart IoT system.

The entrance of the bus employs two short-range RFID readers, as presented in Fig. 2. There are two main reasons for utilizing these readers: the first is to identify students as they enter or leave the bus, and the second is to determine the direction of the student (entering or leaving). For instance, if reader A detects the RFID signal of the student before reader B does, then the student is entering the bus; whereas if reader B detects the RFID signal of the student first, then the student is leaving the bus. Algorithm 1 presents the method for determining the student's direction (entering or exiting the bus). This ensures that students are not forgotten on the bus.

Algorithm 1: Determine the status of the student (enter / exit the bus)

```
let $sb_i$ is the student's bracelet of student $i$
let $rf_e$ is the first short-range RFID reader
let $rf_x$ is the second short-range RFID reader
let status is the current status of the student (1: enter and 2: exit)
if $rf_e$ detects $sb_i$ then
    if $rf_x$ detects $sb_i$ then
        return 1
else if $rf_x$ detects $sb_i$ then
    if $rf_e$ detects $sb_i$ then
        return 2
```

One of the main benefits offered by the developed IoT system is its continuous monitoring of children's positioning on the bus. Three long-range RFID readers are employed to triangulate the children's locations. When a child enters the bus, the system records the location for each child and stores these locations in a local database. Subsequently, the system continuously estimates the location of each child to keep track of their initial location. The code used to estimate the continuous locations of the students and check for changes in position is shown in Algorithm 2.

Algorithm 2: Check for students change-position in the bus

```
let $sb_i$ is the student's bracelet of student $i$
let student[] is the array of students in the bus
let init_pos[] is the array of 2D positions for students in the bus
let new_pos[] is the array of the new estimated 2D positions for students in the bus
let change-position = False
while (every 20 seconds):
    for each student in new_pos[]:
        if dist(init_pos[], new_pos[]) >= 100 cm then
            change-position = True
            show alarm in driver display
            send alarm to administrators
End
```

When one or more students have changed their initial locations (seats), the driver will be informed by displaying an alarm on the screen, and an alarm will also be sent to the administrators. Furthermore, the developed IoT system can detect crowds, such as more than two students in the same position on the bus. In such cases, the driver will be informed by displaying an alarm on the screen, and an alert will be sent to the administrators. Algorithm 3 is utilized to check for any gatherings (crowds) inside the bus. Algorithms 2 and 3 are utilized to implement the second solution, which involves detecting abnormal behavior inside the bus.

Algorithm 3: Check for students gathering inside the bus

```
let $sb_i$ is the student's bracelet of student $i$
let student[] is the array of students in the bus
let init_pos[] is the array of 2D positions for students in the bus
let new_pos[] is the array of the new estimated 2D positions for students in the bus
let gathering = False
while (every 20 seconds):
    for each position in new_pos[]:
        if any dist(position, position+1, position+2) <= 50 cm then
            gathering = True
            show alarm in driver display
            send alarm to administrators
End
```

The long-range RFID readers are utilized to perform a significant localization task. For example, when the system detects a person leaving the bus, the long-range RFID readers begin tracking the location of that student. If the RFID readers no longer receive signals from the student's bracelet, the driver is alerted to safely depart from the drop-off point. However, if the student remains within range of one or more long-range RFID readers, the driver is instructed to wait until the student moves away from the bus. Algorithm 4 outlines the method used to estimate the distance between the child and the bus, to ensure that children standing in the bus's blind spot are not injured or killed.

Algorithm 4: Check for student's distance to bus

```
let $sb_i$ is the student's bracelet of student $i$
let $lRF_1$ is the first long-range RFID reader
let $lRF_2$ is the second long-range RFID reader
let $lRF_3$ is the third long-range RFID reader
let must_stop = True
if status == 2: (Algorithm 1)
    if $sb_i$ in the range of ($lRF_1$ or $lRF_2$ or $lRF_3$) then
        must_stop = True
        display alarm
    else if $sb_i$ not in the range of ($lRF_1$ or $lRF_2$ or $lRF_3$) then
        must_stop = False
End
```

Moreover, the developed system can monitor the driver's behavior by continuously tracking the driver's position. Each driver possesses a unique bracelet for identification purposes. Consequently, when the driver relocates from their initial position, the coordinator is promptly notified to prevent accidents and increase safety. Algorithm 5 demonstrates this method.

Algorithm 5: Determine the location of the driver

```
let $db_i$ is the student's bracelet of student $j$
let $init\_loc_{dj}$ is the initial location of the driver $j$
let $lRF_1$ is the first long-range RFID reader
let $lRF_2$ is the second long-range RFID reader
let $lRF_3$ is the third long-range RFID reader
estimate_driver_loc($lRF_1$, $lRF_2$, $lRF_3$)
let $cur\_ loc_{dj}$ is the current location of the driver $j$
while (True):
    if ($init\_loc_{dj}$ != $cur\_ loc_{dj}$) then
        emergency_call()
        send alarm
    else: $cur\_ loc_{dj}$ = estimate_driver_loc($lRF_1$, $lRF_2$, $lRF_3$)
End
```

Furthermore, the system has the capability to calculate the total students aboard the bus to prevent overcrowding issues. This count is determined by the short-range RFID readers located at the bus entrance. If the number of students onboard exceeds the bus capacity, the coordinator is promptly alerted. Algorithm 6 demonstrates this, below.

Algorithm 6: Count the total number of students inside a bus

```
let $sb_i$ is the student's bracelet of student $i$
let $rf_e$ is the first short-range RFID reader
let $rf_x$ is the second short-range RFID reader
let $cap_k$ is the capacity of the bus $k$
let $count_k$ is the total number of students inside the bus $k$
if ($count_k$< $cap_k$) then
    emergency_call()
    send alarm
End
```

The developed system was implemented using different components (processing, RFID readers, and communication), as follows:

1) Processing unit: Raspberry Pi 4 processes the data received from short- and long-range RFID readers, and takes suitable action accordingly.

2) Long-range RFID readers: These are required to obtain the precise position of the student on the bus. Three long-range RFID readers were deployed in the bus area in order to obtain accurate localization information from each child.

3) Short-range RFID readers: Two short-range RFID readers were employed at the bus door to identify the direction of the student (entering or leaving the bus).

4) Communication unit: For reliable communication between the above units, processed data, and short- and long-range RFID readers, this paper utilized WiFi (IEEE 802.11) network. Fig. 3 presents the communication process between the above components; it also shows the proposed IoT system architecture. Fig. 4 shows the communication process between the main components.

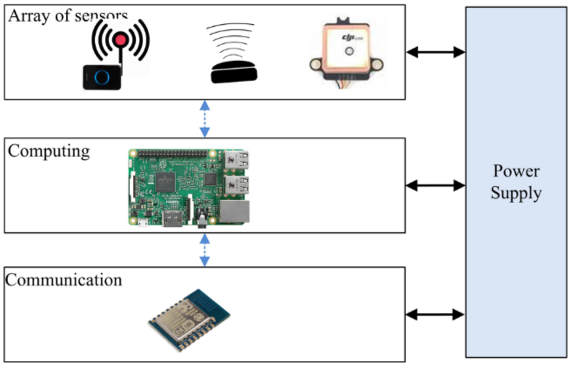

Fig. 3. The proposed IoT system architecture.

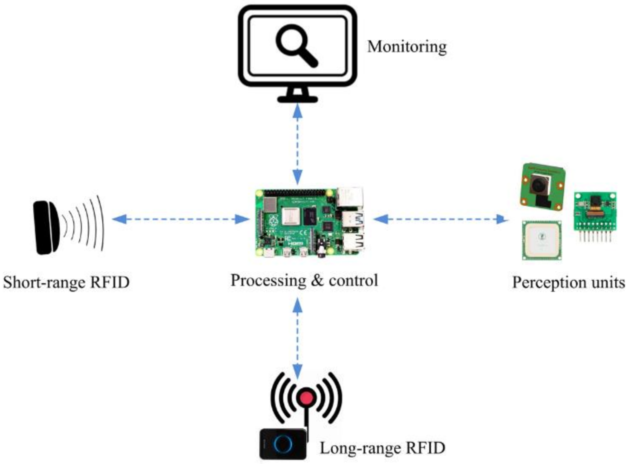

Fig. 4. The communication process between the main components.

V. VALIDATION

This paper's solutions were tested using simulation software designed by implementing the aforementioned algorithms to replicate various threats to students' safety. In an IoT environment, it is an acceptable practice to use simulated scenarios to test and demonstrate the accuracy and scalability of the proposed solutions [29, 30].

A. First Scenario

A bus with 30 seats (s1, s2, …, s30) has 30 students (st1, st2, …, st30) entering the bus and sitting randomly in the seats. The bus has been simulated as an array, and the students are represented as variables occupying the array positions. Additionally, the researchers entered an excess number of students to exceed the bus capacity in order to test rule 9.

To verify the accuracy of the IoT system, this paper compared the data from the readers' database with the array content, achieving a consistent 100% accuracy. The experiment was replicated with buses having 45 seats and 45 students, 60 seats and 60 students, 75 seats and 75 students, and 90 seats and 90 students. Assuming a one-hour bus journey, readings were recorded every 30 seconds, totaling 120 intervals. Accuracy remained at 100% throughout.

B. Second Scenario

In the same simulation environment as before, a bus with 31 seats (s1, s2, …, s30) and 30 students (st1, st2, …, st30) was considered, with the first seat reserved for the driver. Therefore, the first position of the array is occupied by a special variable 'd' representing the driver. Randomly, the driver variable 'd' changed position five times during a 30-minute period. Additionally, four random students changed their seats after five minutes and again after 10 minutes. Subsequently, three contents were compared—the readers' database, array content, and alarms file. The proposed system achieved an accuracy of 100%.

C. Third Scenario

In this scenario, a different simulation environment was implemented. The school bus safety domain model was represented as a box with four points (x,y), (x1,y1), (x2,y2), (x3,y3), as shown in Fig. 5.

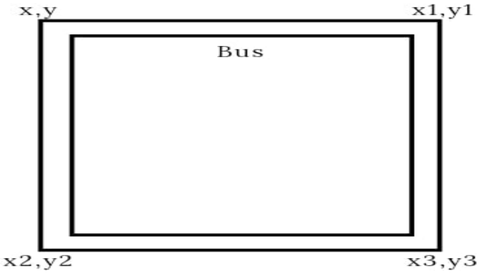

Fig. 5. Bus safety domain as simulated environment.

The student is considered inside the bus if their location (n, m) satisfies this following equation:

$$a = b\ \forall x \forall y \forall n \forall m: (x < n) \wedge (x2 < n) \wedge (x1 > n) \wedge (x3 > n) \wedge (y < m) \wedge (y2 < m) \wedge (y1 > m) \wedge (y3 > m) \Longrightarrow student\ inside\ the\ bus\ safety\ domain \Longrightarrow \neg\, move\ (bus) \tag{12}$$

The above rule indicates that if the student is in the bus safety domain, then the student is too close to the bus, and the bus cannot move. The following rules indicate that there are no students in the bus safety domain; hence, the bus can move.

$$\forall x \forall y \forall n \forall m: (x < n) \wedge (x2 < n) \wedge (x1 > n) \wedge (x3 > n) \wedge (y < m) \wedge (y2 < m) \wedge (y1 > m) \wedge (y3 > m) \Longrightarrow false \Longrightarrow move\ (bus) \tag{13}$$

Using a full school bus, the researchers randomly redistributed students to test the model's ability to identify students within and outside the bus safety domain. This scenario also tested for the system's detection of student gatherings. A safety space of 24 cm was defined between student locations; thus, any distance less than 24 cm between two or more students indicated a gathering. Student locations were randomly distributed to test the gathering detection rules in our IoT smart system. The experiments were repeated five times with an accuracy of 100%.

First scenario proved the scalability and accuracy of rule 3 to rule 9. The second scenario proved the scalability and accuracy of rules 10. Finally, the third scenario proved the scalability and accuracy of rules 8 and 11.

VI. DISCUSSION AND CONCLUSION

In this paper, a smart IoT system for enhancing safety in school bus transportation was introduced. The main aim of this smart IoT system was to address five issues in school bus transportation that are well-documented in the literature and frequently reported in the news. These problems include: 1) forgetting children on the bus; 2) students' abnormal behavior; 3) overcrowding; 4) unruly driver behavior; and 5) the risk of a school bus running over children after they have disembarked from the bus.

TABLE III. COMPARISON BETWEEN THE PROPOSED SMART IOT SYSTEM AND RELATED WORKS

Work	P1	P2	P3	P4	P5
Krishnan and Vasuki, in [13]	√	X	X	X	X
Abbas et al., in [11]	√	X	X	X	X
Liu and Peng, in [12]	√	X	X	X	X
Mott and Kotla, in [15]	X	X	X	X	√
Kumari et al., in [16]	X	√	√	X	X
Gadekar et al., in [17]	√	X	√	X	X
Sakphrom et al., in [19]	√	X	√	X	X
Malathy et al., in [20]	√	X	√	X	X
Ding et al., in [22]	X	√	X	X	X
Wang et al., in [21]	X	√	X	X	X
Etaati et al., in [24]	X	X	√	√	X
LR et al., in [25]	√	X	X	X	X
Gadade et al., in [26]	√	X	√	X	X
Kumari et al., in [27]	√	√	√	√	X
The proposed smart IoT system	√	√	√	√	√

This paper's aim was to provide easy and accessible solutions for everyone, making them applicable across all segments of society by leveraging available technology at an affordable cost. To achieve this, this paper used a rule-based system to avoid the complexity and cost of deep learning solutions. The authors in study [31], conducted a comprehensive survey on deep learning-based anomaly detection in video surveillance. They examined various techniques, including Autoencoders, Generative Adversarial Networks (GANs), and Long Short-Term Memory (LSTM) networks, to identify effective methods for detecting abnormal behaviors. Their survey highlighted the strengths and limitations of these approaches and discussed common challenges such as occlusion, complex backgrounds, and low illumination. Additionally, the authors provided insights into future research directions, emphasizing the need for improved accuracy and robustness in anomaly detection systems. Their results proved the difficulties of using video surveillance in school bus transportation. These results motivate these researchers to provide alternative solutions for detecting students' abnormal behavior in school bus transportation. The proposed IoT system proves a complete solution in terms of providing solutions for all the mentioned problems. Table III, shows a comparison between the proposed smart IoT system and related works, Future work in this domain should include the addition of a GPS device for monitoring bus location and speed, further enhancing the safety of school bus transportation. In addition to GPS, we are planning to extend our model to provide additional safety functionality within school classrooms and facilities.

VII. DATA AND METHOD

The scenario code available at https://drive.google.com/file/d/1xv94YNfcG5b5L-bHVbHYfSGbVdpNjsWg/view?usp=share_link (TBA)

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