Optimizing Drying Efficiency Through an IoT-based Direct Solar Dryer System: Integration of Web Data Logger and SMS Notification

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***Abstract*—Various agricultural and culinary products are dried to extend their shelf lives, mostly for marine foods. In many coastal locations of the Philippines, drying fish traditionally is still practiced, although study has shown that due to weather conditions and other factors, this technique is not seen to be reliable or cost-effective. The Internet of Things (IoT)-based Direct Solar Dryer System is optimized for drying efficiency by combining a web data logger and SMS notification system using Arduino Uno and ESP-32 to address difficulties with reliability and cost effectiveness. The study focuses on the potential and system efficiency of drying Sardinella fish (Tamban) in Brgy, Calibunan, Agusan Del Norte, Philippines; as well as investigating and assessing temperature, heat index, humidity, and temperature range alert conditions using a web application portal to serve as a remote monitoring platform for dependable data visualizations. The system delivered the expected results because the direct solar drier was able to raise and maintain the requisite temperature to accelerate drying while keeping the acceptable relative humidity. Furthermore, the system's monitoring and notification capabilities, as well as effective data collecting and data display via physical and remote monitoring, are supported by SMS notifications. As a result, the effectiveness of upgrading traditional sun drying with IoT technology can help reduce the challenges and disadvantages that fish drying farmers have faced. The study, with correct drying monitoring criteria, could serve as a model for other food products that can be dried.**

***Keywords*—Arduino Uno; Internet of Thing (IoT); solar dryer system; web application portal; ESP-32; SMS notification**

I. Introduction

Filipinos consume the most fish and fishery items. 11.68% of total food intake is made up of fish and fishery products. This works out to 93.90 grams each day. This was 63.0% higher than the price of beef and meat products; more expensive than poultry by 205.86%. Filipinos consume an average of 34.27 kg of fish and fish products per year, accounting for 23.36% of overall consumption, according to the DOST-FNRI survey report for 2018-2019. This includes 23.35 kg fresh fish, 2.85 kg dried fish (as fresh fish), 4.97 kg processed fish, and 3.10 kg frozen fish, Crustaceans and mollusks (estimated fish consumption based on population) [5][9]. After a half-decade the data of total fisheries output increased by 2.2 percent to 4,339.89 thousand metric tons in 2022, from 4,248.26 thousand metric tons the previous year [14][18]. Increases in production were observed in maritime municipal fisheries and aquaculture, whereas commercial and inland municipal fisheries saw setbacks during the year [7]. In Calibunan, a coastal barangay in Cabadbaran City, Agusan del Norte in the Caraga Region in the Philippines, the drying of fish is one of the sources of living in the community. Fish dried in the open ground while others were hung on the racks with a net, or a flat board bamboo called “kaping”. The traditional drying or sun drying method is prone to inconvenience and is labor-intensive and known for its slow process that can cause product losses apart from an issue concerning the quality of the product when it comes to cleanliness. Traditional sun-drying may cause microorganism growth, insect infestation, and other potential food safety hazards that may occur in the food due to the inadequate drying process [6].

The objective of the research is to utilize emerging technologies in order to develop an IoT-based Direct Solar Dryer System with a Web Data Logger and SMS notification. The ultimate goal is to enhance the efficiency of food drying operations [10] and fill the gaps identified in related studies within the research methods. The findings of the research would help to promote knowledge on developing innovative solutions in the field of Internet of Thing (IoT) monitoring systems for food drying [15]. Furthermore, this research highlights the power of technology in enhancing the lifestyles of fish drying farmers, supporting breakthroughs in the food drying sector, and encouraging future research efforts. The paper is organized as follow: Section II presents the discussion of the three phases in research methodology, design and development of the system parameters, coding the firmware and creating a web data analysis using MATLAB based on ThingSpeak Application monitoring. Finally, Sections III and IV present the evaluation results and conclusion, respectively.

II. Research Methodology

The research is divided into three (3) phases in Fig. 1 Research Framework, each of which is dependent on its upper processes.

The Input phase was when the researchers acquired essential information on the actual activities in the drying field, the issues they encountered, and the current ideas and studies that would help accomplish the intended system output.

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The Process phase, during which the obtained data was processed and put to use. This phase saw the implementation of the system's components and functionality.

In the Output phase, the desired output such as physical monitoring, web monitoring, and SMS sending to users is produced.

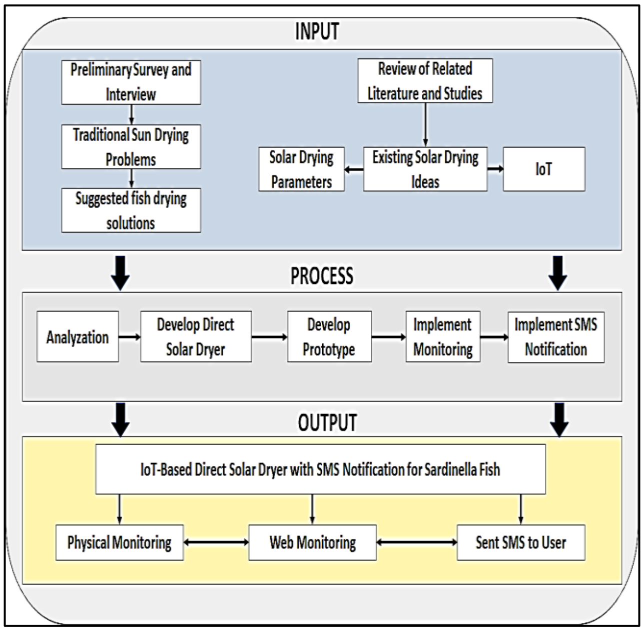

Fig. 1. Research framework.

A. *Analysis of Gathered Related Literature*

1) Prelimenary survey: The researchers conducted a preliminary survey on the Research Locale Map at Barangay Calibunan in Cabadbaran City, Agusan del Norte in the Caraga Region of the Philippines in Fig. 2, and the data gathered was appraised by the researchers as valuable in the study.

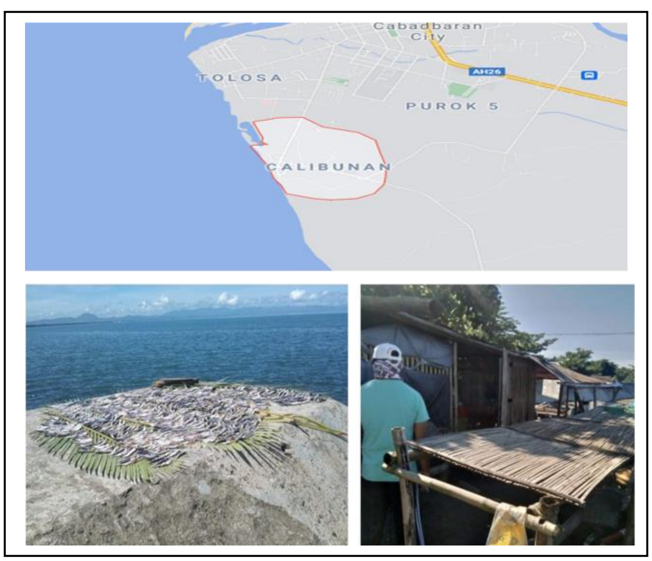

Fig. 2. Research locale map "Barangay Calibunan in Cabadbaran city, Agusan del Norte in the Caraga region in the Philippines"- google maps.

In Fig. 3. 68.4% of respondents "Strongly Agree", that there were concerns with sun drying methods such as human work, insect infestation, and the number of days required to dry the fish. With 12.63% of respondents "Agree" that a need for technology innovations may apply for fish drying, 14.21% of respondents "disagree" of changing traditional way to more efficient drying technology and 4.75% "Strongly disagree" of the use of innovative solutions. It's because of the cost of maintaining the system. Overall, according to the comments of the respondents, adding a monitoring system is a terrific innovation to improve their process.

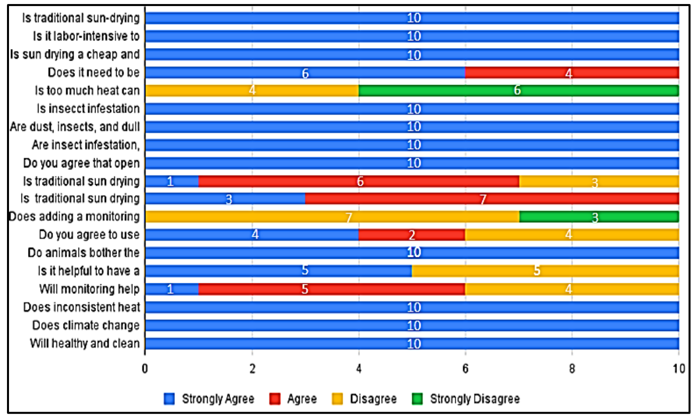

Fig. 3. Preliminary survey result traditional sun drying issues and system implementation.

2) Types of Sardinella fish found in the Philippines: In Philippines, several species of Sardinella fish waters presented in the Table I can be found namely: Bali sardinella, Goldstripe sardinella, Fringescale sardinella, White sardinella, Taiwan sardinella, Freshwater sardinella, Spotted sardinella, White sardine, Blacksaddle herring, Bluestripe herring, and Rainbow sardine [22].

The research focuses on the design concept of drying Sardinella fish, also known as "Tamban" or "Tunsoy" in the native language, which is a widely available fish species in the Philippine seas. The main objective of the research is to determine the appropriate system parameters for drying Sardinella fish and establishing threshold values for optimal drying [11]. By studying the drying process of this particular fish species, the researcher aims to develop a comprehensive understanding of its drying characteristics and identify the key factors that affect the quality and efficiency of the drying process. The design concept of drying Sardinella fish serves as the foundation for adjusting the main system parameters. This concept provides valuable insights into the drying requirements specific to Sardinella fish, including temperature, humidity, air circulation, and drying time. By establishing threshold values based on these parameters, the research aims to optimize the drying process and ensure consistent quality and preservation of the fish. The findings of this study will contribute to the development of effective and efficient drying techniques for Sardinella fish, benefiting fish drying farmers and enhancing the overall fish drying sector in the Philippines.

TABLE I. TYPES OF SARDINELLA FISH FOUND IN THE PHILIPPINES

Type #	SARDINELLA FISH FOUND IN THE PHILIPPINES		
	Type Scientific name	***International Name***	***Philippine Local Name***
1	Sardinella lemuru	Bali sardinella	Tamban/Tunsoy
2	Sardinella gibbosa	Goldstripe sardinella	Tamban/Tunsoy
3	Sardinella fimbriata	Fringescale sardinella	Tamban/Tunsoy
4	Sardinella albella	White sardinella	Tamban/Tunsoy
5	Sardinella hualiensis	Taiwan sardinella	Tamban/Tunsoy
6	Sardinella tawilis	Freshwater sardinella	Tawilis
7	Amblygastersirm	Spotted sardinella	Tamban/Tunsoy
8	Escualosa thoracata	White sardine	Bolinaw
9	Herklotsichthys dispilonotus	Blacksaddle herring	Dilat
10	Herklotsichthys quadrimaculatus	Bluestripe herring	Dilat
11	Dussumieria acuta	Rainbow sardine	Tulis/Alabaybay

3) Related studies on fish drying with the use of technology: The researchers gathered information on several related studies presented in Table II, these studies were examined through their innovations in the use of technologies in the system design and scrutinized the research gaps in the common technologies being implemented that were accessible in recent years [2].

The researchers found that appropriate design of the system by creating a solar dryer/storage unit using sensing components/devices: first for weighing the fish with load cell weight sensor, second by checking the temperature, heat index, and humidity using DHT22 sensor, third using fan control system to reduce humidity and increase more heat inside the storage.

The innovative solutions are introduced in this paper by integrating an SMS notification system as well as a web application portal to serve as a remote monitoring platform using *ThingSpeak* or dependable data visualizations in temperature range alert conditions for notifications to the users' smart mobile messaging [4].

B. Architectural Design

Fig. 4 illustrates the System architecture diagram which explains how the prototype is connected and how the connection relates to each component. The power bank acts as the power supply of the system except for the fan which has its own power supply of 12V. All sensors and actuators are connected to the Arduino Uno, and from the Arduino Uno, all the data are then transmitted to ESP32-CAM and to GSM/ GPRS Module. The endpoint of all data being transmitted is in *ThingSpeak* and Web Database analysis using MATLAB, where all raw data are converted into information.

TABLE II. RELATED STUDIES ON FISH DRYING WITH THE USE OF TECHNOLOGY

No.	RELATED STUDIES FISH DRYING WITH THE USE OF TECHNOLOGY		
	Publications. Year & DOI	***Authors***	***Technology use in the system***
1	IOT Based Solar Dryer and Irrigation System (2022) DOI: 10.22214/ijraset.2022.41823	Prof. Meena Ugale, Mr. Ankur Foujdar, Mr. Sushil Nikumbh, Mr. Suyash Joshi	• Solar Dryer with Solar panel in drip irrigation [15]
2	Internet of Things-Based Crop Classification Model Using Deep Learning for Indirect Solar Drying (2022) DOI: 10.1155/2022/1455216	Brijesh Sharma, Gaurav Gupta, P. Vaidya, Shakila Basheer, F. H. Memon, R. N. Thakur	•Temperature of the solar dryer [3]
3	Design and Construction of an IoT Solar Dryer for Semi-Dried Jerky (2021) DOI:10.24940/ijird/2021/v10/i6/feb21023	V. Ngo, H. Do, T. T. Duong, M. Tran, Sylvain Nguyen, D. Tong, Thi Bich-Hue Duong	•Food Safety (Total Aerobic Organisms, Heavy Metal, Bacteria) •Temperature of Drying Process •Humidity Of Drying Process [20]
4	A review on solar dryers integrated with thermal energy storage units for drying agricultural and food products (2021) DOI: 10.1016/j.solener.2021.07.075	G. Srinivasan, D.K. Rabha, P. Muthukumar	• Thermal energy storage unit dryer types, product dried, operating parameters, sensible and latent heat storage materials [8]
5	Computational fluid dynamics and experimental analysis of direct solar dryer for fish (2019) DOI: N/A	O. I. Alonge, S. O. Obayopo	•Collector Efficiency •Temperature Elevation [12]
6	Development and Quality Analysis of a Direct Solar Dryer for Fish (2018) DOI: 10.4236/FNS.2018.95037	S. O. Obayopo, O. I. Alonge	•Moisture Content of Dried Fish •Drying Efficiency •Proximate Composition of Fish Before and After Drying [17]

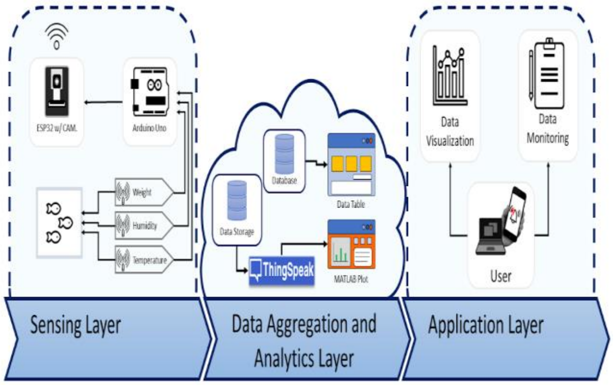

Fig. 4. System architecture.

C. Design and Setup of IoT-based Direct Solar Dryer System: Integration of Web Data Logger and SMS Notification

Integration of Web Data Logger and SMS Notification with a physical monitoring system and web application to display valuable data is shown in Fig. 5, System Diagram, which includes a.) Thermal Storage Unit System [1][13], b.) Cloud Data Storage, c.) Visualization, d.) Web Monitoring [23]. Fig 6 illustrates the hardware components connection that includes DHT22, Weighing Sensor, SIM800L GSM/GPRS Module, D. 20x4 LCD (Liquid Crystal Display), Relay Module, ESP32-CAM, LED with Rocker Switch, and SPDT.

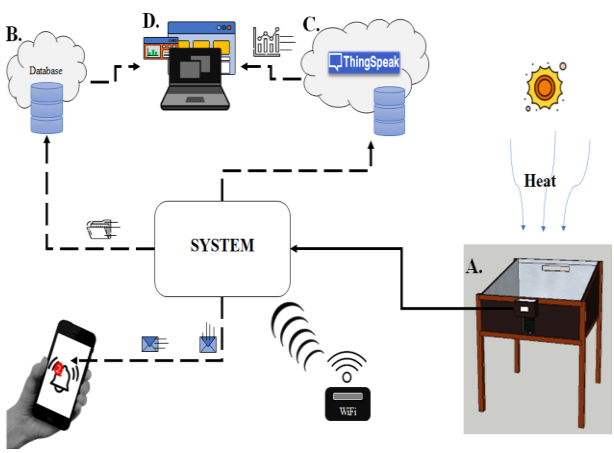

Fig. 5. System diagram - a.) thermal storage unit system, b.) cloud data storage, c.) visualization, d.) web monitoring.

D. Firmware Development

In the firmware development stage, the researchers utilized C/C++ programming language for the Arduino Uno and ESP32-CAM microcontrollers to program the sensors, actuators, and monitoring functions. The open-source Arduino IDE was used to simulate and compile the codes, while GitHub facilitated collaborative coding during the pandemic. The web application was developed using Visual Studio Code, with HTML, PHP, CSS, and JavaScript for coding. MySQL was used for local testing before deployment on web hosts, and *ThingSpeak* software platform integrated with MATLAB visualization for instant chart generation in the web application.

For integration and testing, the researchers conducted tests and debugging to ensure proper functionality of the hardware components and correct code execution. Once the solar dryer and hardware codes were finalized, the system underwent thorough testing.

E. System Performance and Evaluation Result

The evaluation was divided into two parts: analyzing the concept dryer's performance and evaluating the complete system with functional components [19]. Based on relevant investigations and data collection, a one meter squared direct sun dryer was tested to examine its performance in drying Sardinella fish under ideal weather conditions and within an experimental temperature range of 35-55°C. The whole system evaluation included testing the fish dryer's functionality and assessing its capacity to meet the targeted goals. Temperature, humidity, heat index, weight, moisture content, and presumed time were measured using an Arduino Uno, retrieved via ThingSpeak, and saved in a database. Intervals of data communication were created between the ESP32-CAM, ThingSpeak, and the web database analysis using MATLAB.

The researchers established a minimum temperature of 35°C and a maximum temperature of 55°C to ensure the desired temperature range for effective drying.

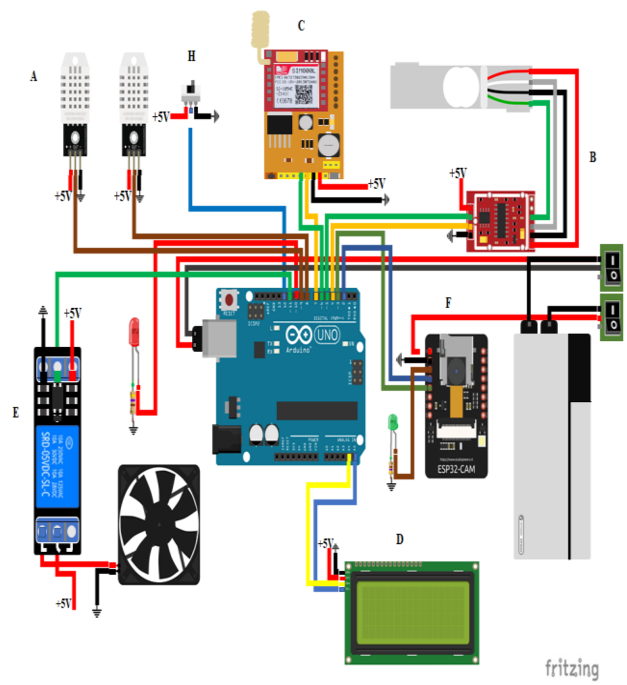

Fig. 6. Hardware componets connection (a) DHT22, (b) weighing sensor, (c) SIM800L GSM/GPRS module, (d) 20x4 LCD, (e) relay module, (f) ESP32-CAM, (g) LED with rocker switch, (h) SPDT.

III. Results and Evaluation

In this section, the study's results are presented, providing detailed information about the methods and processes employed. The discussion accompanying the results analyzes and interprets the findings, providing insights into their significance and implications. Additionally, the section addresses the observed limitations and constraints that impact the functionalities and capabilities of the system. These limitations are crucial to understanding the boundaries within which the system operates and the factors that may affect its performance. By presenting the results, discussing their implications, and acknowledging the system's limitations, this section provides a comprehensive understanding of the study's outcomes and contributes to the broader knowledge in the field.

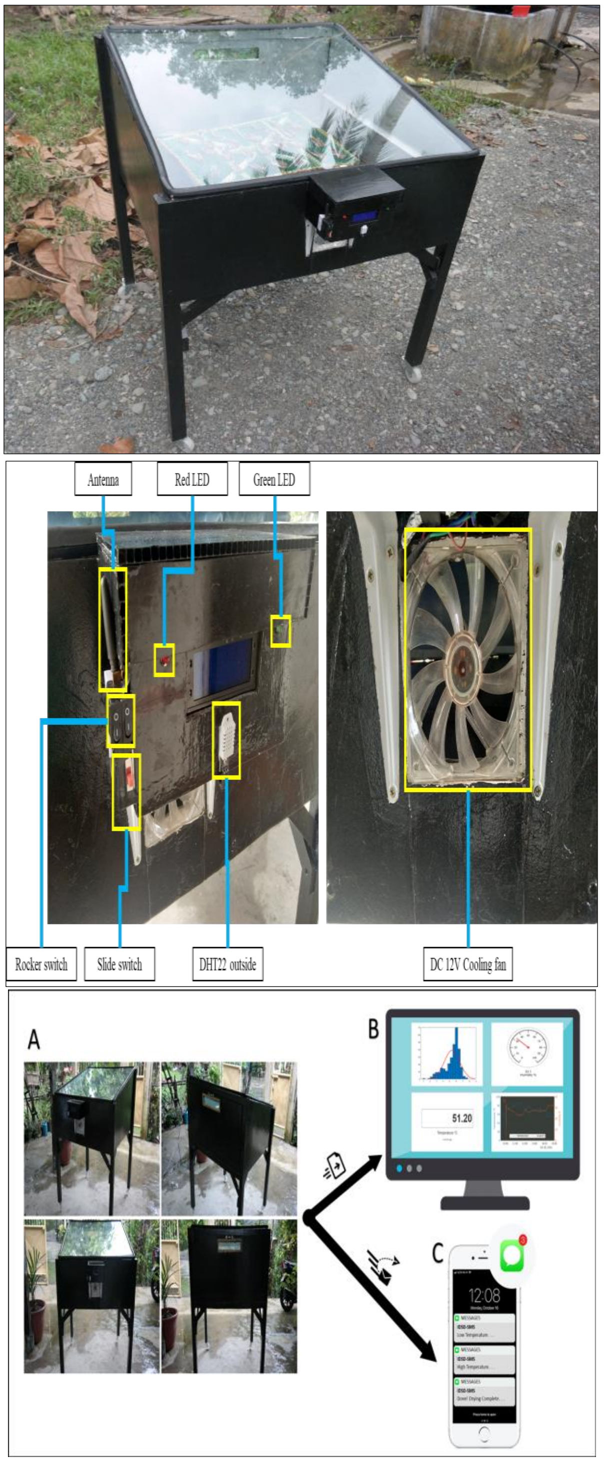

Fig. 7. Actual image of the dryer during testing.

A. Actual IDSD-SMS System

The actual testing of the system was conducted from 11:00 AM, due to its good and enough sunlight, and lasted until 3:09 PM. During the testing, one (1kg) kilogram of Sardinella fish was prepared, and approximately 410 grams was achieved after the preparation performed. In Fig. 7 the actual image of the dryer during testing is shown. All the data needed for visualizations and data interpretations were collected and stored in the web application database. Fig. 8 illustrates the current and target weights, presumed time, moisture content. Fig. 9 presents the actual LCD system display setting up display, initializing setup, reset and done drying.

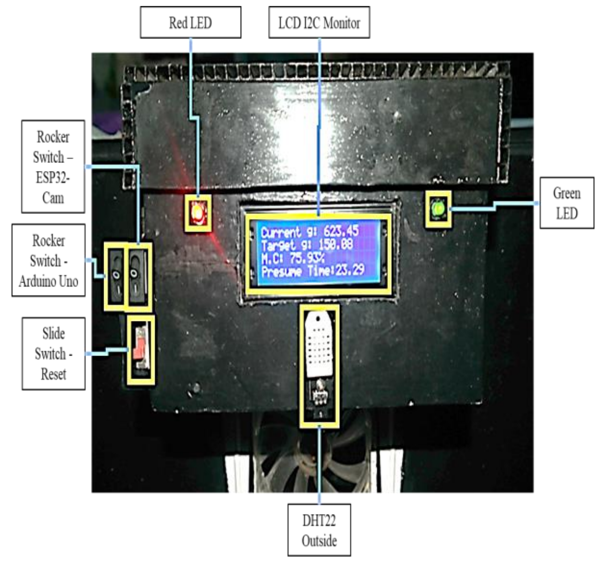

Fig. 8. Current and target weights, presumed time, moisture content.

Fig. 9. LCD system display setting up display, initializing setup, reset and done drying.

B. Web Application Portal

The web application, created by the researchers, acts as a remote monitoring platform that displays reliable data visualizations such as spline charts, gauge, numeric, and comparison charts (see Fig. 10). The web application also has a database to store raw data. The web application is accessible through the World Wide Web using the browser to log in and have access. When the system is on, and connected to the WiFi, a user can monitor the current drying session instantly anywhere in the globe [21].

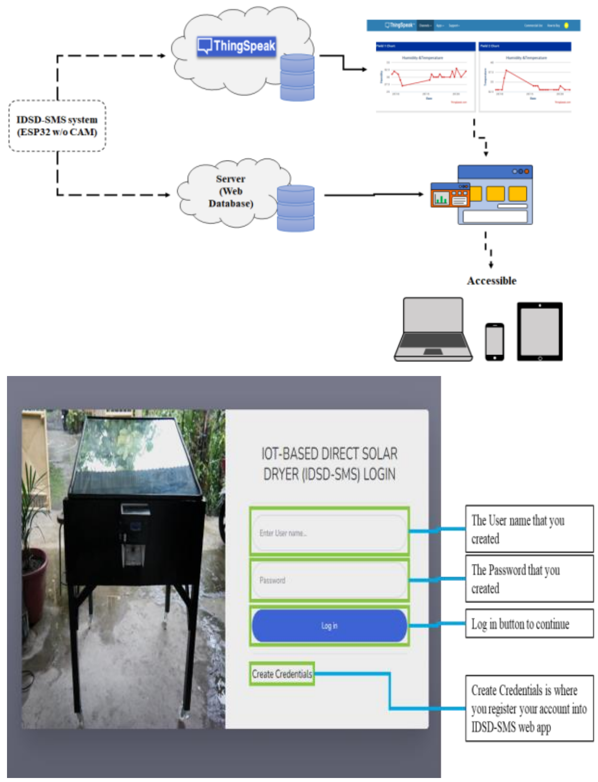

Fig. 10. Web application (login interface).

C. Web Application Monitoring

Fig. 11 presents the save raw data collected from the system monitoring this shows a data log of 15 seconds interval from the time stamp, temperature, humidity, heat index, weight, moisture content and the remaining time of the presumed drying time. Data can now be inputted in the MATLAB analysis algorithm to output the data visualizations.

D. Comparison of the Temperature Inside and Outside the Dryers

Fig. 12 using MATLAB visualization data analysis shows the comparison between the inside and outside temperature during the conduct of the study. Based on the chart, the temperature inside was always greater than the temperature outside, as expected ranging from 45.37 - 56.9 °C which is organoleptically excellent quality according to Reza (2002)[16]. The system recorded the inside highest temperature of 56.9 °C and 46 °C on the outside, while the lowest temperature was observed at 45.37 °C on the inside and 26.33 °C outside.

#	Date	Time	Temperature	Humidity	Heat index	Weight	Moisture Content	Remaining Time
1	2021-12-26	11:11:06	46 °C	37.2 %	145.97 F	407.62 g	76.46 %	23.98 H
2	2021-12-26	11:11:20	46 °C	38.5 %	148.32 F	407.32 g	76.44 %	23.96 H
3	2021-12-26	11:12:55	47.7 °C	42.4 %	167.2 F	409.22 g	76.55 %	24.11 H
4	2021-12-26	11:13:10	48 °C	42.9 %	170.47 F	408.98 g	76.54 %	24.09 H
5	2021-12-26	11:13:26	48.4 °C	42.7 %	172.87 F	408.98 g	76.54 %	24.09 H
6	2021-12-26	11:13:42	48.7 °C	43.2 %	176.28 F	408.98 g	76.54 %	24.09 H
7	2021-12-26	11:13:57	48.9 °C	41.3 %	173.08 F	408.98 g	76.54 %	24.09 H
8	2021-12-26	11:14:13	49.1 °C	41.9 %	175.99 F	388.59 g	75.31 %	22.52 H
9	2021-12-26	11:14:30	49.3 °C	42 %	177.71 F	388.86 g	75.32 %	22.54 H
10	2021-12-26	11:14:45	49.4 °C	41.9 %	178.19 F	389.74 g	75.38 %	22.61 H

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Fig. 11. Sample raw data collected.

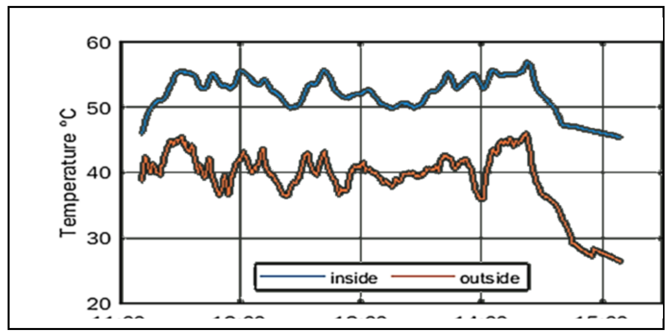

Fig. 12. Inside and outside temperature comparison (chart retrieved from web application visualization).

E. Weight and Moisture Content Relationship

The weight and moisture content are the most critical aspects in terms of drying foods. Throughout the drying session, the weight and moisture content were monitored. As Fig. 13 illustrates using MATLAB, the weight was proportional to the moisture content which means that for every loss of weight, there was also a loss in the moisture content. The researchers started drying with a total weight of 407.83 grams and its target weight of 95.96 grams which was considered safe and dry as it reached a moisture content of 15%. The desired weight was achieved after 4 hours of drying due to the high and constant temperature the fish receives. The temperature slowly goes down from 2:40 PM onwards.

Throughout the drying session, the web application collected and displayed data. The interval of receiving data from the system to the web application took about every 15 to 16 seconds depending on the network speed or/and latency. The researchers use three different kinds of devices such as the laptop, tablet, and mobile phone in monitoring the web application.

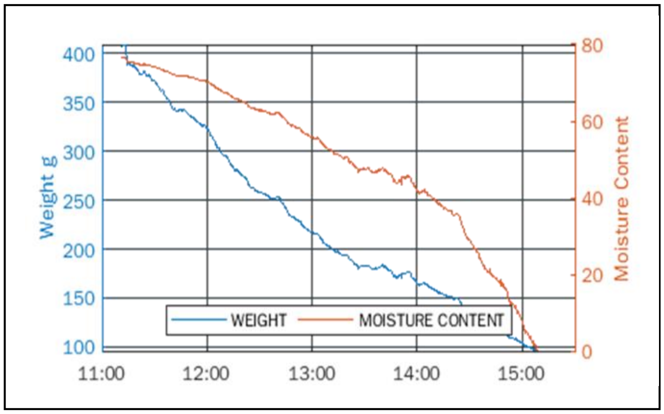

Fig. 13. Weight and moisture content relationship (chart retrieved from web application visualization).

F. Screenshots of the Received SMS

Fig. 14 shows the screenshots of the received SMS *"High Temperature 55.10°C"* or above during the actual testing first trial from 11:28am to 1:42pm and second trial triggered at 2:04pm to 2:22pm. This shows that the SMS alert notifications were repeated if triggered throughout the drying session. The user received in every 5-10 seconds delay interval depending on the providers signal strength on the user's area receptions.

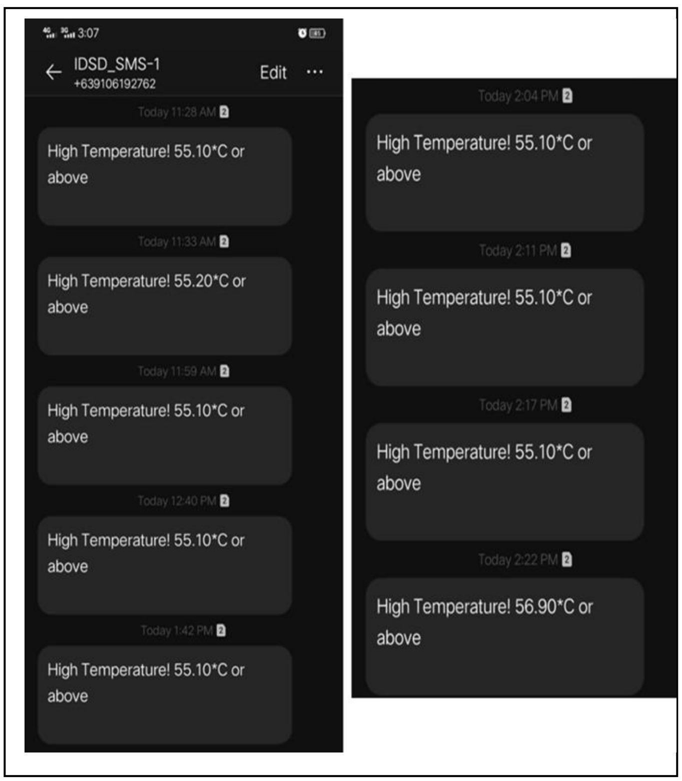

Fig. 14. Session 1 messages received during the actual testing.

G. Comparison of Two Drying Sessions

Table III shows the different drying sessions with different total and Achieved weights, the date and time the drying session started and ended as well as the hours and minutes it took to dry. The table shows that both drying sessions were successful and achieved the target weight. The Drying session 2 lasted longer compared to drying session 1. The duration of drying will always depend on the condition of the weather; and, the more fish is being dry, the longer it takes.

In comparing traditional sun drying to solar drying, it was found that solar drying dried faster than traditional drying as it only took 4-5 hours to dry a small fish at normal weather conditions compared to traditional outdoor sunlight at temperatures up to 37°C, the fish drying will take about 3 days.

TABLE III. TYPES OF SARDINELLA FISH FOUND IN THE PHILIPPINES

Drying Session No.	**COMPARISON OF TWO DRYING SESSION**				
	Total Weight	**Achieved Weight**	**Date and Time started**	**Date and Time started**	**Duration of Drying**
Drying Session 1	407.82 grams	95.96 grams	12-26-22 11:00 AM	12-26-22 3:09 PM	4 Hours & 9 mins
Drying Session 2	482.82 grams	110.53 grams	01-06-23 9:45 AM	01-06-23 2:31 PM	4 Hours & 46 mins

IV. CONCLUSION

The system IoT-based Direct Solar Dryer System: Integration of Web Data Logger and SMS Notification was able to achieve the desired results based on the conducted testing conditions in Optimizing Drying Efficiency. The direct solar dryer was able to increase the temperature up to 23% and maintain the temperature which can speed up the drying time while achieving the recommended relative humidity ranging from 24.9% up to 58.71%. The physical and remote monitoring was successful in gathering and displaying the needed information for the drying process. Moreover, the system was able to send SMS notifications to the user and the fan worked well according to its intended task. Therefore, the efficacy of improving the traditional sun drying with the use of technology can help alleviate the difficulties and disadvantages of the fish drying farmers.

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