International Journal on Science and Technology (IJSAT)
E-ISSN: 2229-7677 ● Website: www.ijsat.org ● Email: editor@ijsat.org

Design and Simulation of an Indigenous IoT-Based Smart Egg Incubator for Local Farmers

Abraham Atosona[1], Dr Stephen Akobre [2], Prof. Mohammed Ibrahim Daabo[3]

[1] Systems Analyst, Technical Support Services, Directorate of ICT Services, C. K. Tedam University of Technology and Applied Sciences, Navrongo, Ghana. ()
[2]Senior Lecturer, Department of Cyber Security and Computer Engineering Technology, School of Computing and Information Sciences, C. K. Tedam University of Technology and Applied Sciences, Navrongo, Ghana ()
[3] Senior Lecturer, Department of Computer Science, School of Computing and Information Sciences, C. K. Tedam University of Technology and Applied Sciences, Navrongo, Ghana.)
[1]abratosona@gmail.com, [2]daabo2025@yahoo.com, [3]aweyass@yahoo.com

Abstract
This study addresses the challenges local farmers face in achieving optimal hatch rates due to the inability to precisely monitor and control incubation conditions. To mitigate losses and improve process efficiency, this research designed, implemented and simulated a low-cost, smart egg incubator framework leveraging Internet of Things (IoT). The system was built using ESP32 microcontroller, integrating sensors to continuously monitor critical incubation parameters including temperature and humidity within the incubation chamber. A key feature of the framework is its capability to allow farmers to remotely monitor and control these conditions in real-time via a user-friendly interface. The design prioritized the use of indigenous and locally available materials to ensure affordability and durability for local farming communities. The system's functionality and control logic were rigorously simulated to validate its effectiveness and reliability. The results demonstrate a robust and user-friendly IoT incubator framework that offers enhanced functionality and convenience. The practical implications of this research are significant, providing local farmers with a viable technological solution to minimize losses, reduce time wastage and improve the overall efficiency and success of the egg hatching process. This work contributes to the field of agricultural technology by offering a practical, sustainable and accessible solution for small-scale poultry farming.

Keywords: Smart Incubator, Internet of Things (IoT), ESP32, Environmental Control, Indigenous Design, Poultry Farming, Hatchability

1. Introduction

The integration of Internet of Things (IoT) technologies into agriculture is revolutionizing traditional farming practices, enabling enhanced monitoring, control, and automation. IoT facilitates the creation of smart environments by autonomously collecting, exchanging, and analyzing data from a network of connected devices [1]. The potential economic impact of this transformation is profound, with projections estimating a global economic impact of over $11 trillion by 2025 according to [2]. Within the agricultural sector, the smart farming market is expected to reach $6.2 billion by 2025, a growth accelerated by recent disruptions to supply chains and labor shortages [3]. These technologies empower farmers with precise control over environmental variables, leading to significant gains in efficiency and productivity.

In developing nations, poultry farming is a critical economic activity for small-scale farmers and a vital source of protein. However, a major challenge faced by these local farmers is the inefficient and labor-intensive process of hatching eggs. Traditional methods, relying on broody hens or manual incubators, are often plagued by high rates of egg spoilage, wastage of energy and time require constant attention to maintain optimal conditions [4]. This constant monitoring is particularly challenging for farmers engaged in mixed farming systems, who cannot dedicate continuous attention to their incubators.

An incubator is designed to provide a meticulously controlled environment maintaining optimal temperature, humidity and ventilation to emulate the conditions provided by a broody hen for embryonic development [5]. While modern incubators can mitigate some challenges of natural hatching, traditional automated models are often unaffordable or complex for local farmers and still lack remote capabilities [6]. This creates a need for accessible, low-cost technological solutions.

To address this gap, this study focuses on the design and implementation of an indigenous, IoT-based smart incubator framework specifically for local farmers. Leveraging the ESP32 microcontroller, the proposed system integrates sensors to continuously monitor and automatically regulate the internal environment of the incubator. A key innovation is its remote functionality, allowing farmers to monitor and control conditions in real-time via a user-friendly interface, thus relieving them from the constraints of constant physical oversight. The design prioritizes the use of locally available materials to ensure affordability, maintainability and sustainability for farming communities in regions like Northern Ghana.

2. Literature Review

2.1 The Role of IoT in Modern Agriculture

The integration of Internet of Things (IoT) technologies has become a transformative force in agriculture, enabling the development of smart farming systems that optimize resources and improve productivity. IoT facilitates the creation of intelligent environments through a network of sensors and devices that autonomously collect, exchange and analyze data for informed decision-making [2]. The economic potential of this transformation is vast, with projections indicating a global economic impact of over $11 trillion by 2025 [4]. Within the agricultural sector, the smart farming market is expected to reach $6.2 billion by 2025, a growth accelerated by disruptions to supply chains and a need for more efficient practices [7]. These technologies empower farmers with precise, real-time control over environmental variables, leading to significant gains in efficiency and sustainability.

2.2. The Critical Need for Incubators in Poultry Farming

Poultry farming is a vital source of income and protein for millions worldwide, particularly in developing nations. Incubation is a critical process in this value chain, as it determines the success rate of hatching viable chicks. Traditional hatching methods, relying on broody hens or manual incubators, are plagued by high rates of egg spoilage, energy waste, and labor intensity [6]. These methods are highly susceptible to human error and environmental fluctuations, leading to suboptimal and inconsistent hatch rates [7].

Modern incubators address these challenges by providing a meticulously controlled environment maintaining optimal temperature, humidity, and ventilation essential for embryonic development [9]. They enable farmers to hatch large quantities of eggs simultaneously, drastically improving production efficiency [10]. Furthermore, by isolating the hatching process, incubators significantly reduce the risk of disease transmission from pathogens like Salmonella and E. coli, which is a major concern in dense poultry operations [11]. For local farmers, especially those engaged in mixed farming, the reliability and consistency offered by incubators are invaluable, as natural incubation is subject to the availability of broody hens and external threats [12].

2.3. The Evolution towards Smart and IoT-Based Incubators

While traditional automated incubators represent an improvement, they often lack remote monitoring capabilities and can be cost-prohibitive for small-scale local farmers. This gap has led to the development of smart incubators leveraging IoT technology. IoT-based incubators integrate sensors and microcontrollers to monitor environmental conditions like temperature, humidity, and gas levels in real-time

The primary advantage of an IoT framework is the ability for farmers to remotely monitor and control the incubation process via mobile or web applications, reducing the need for constant physical oversight and thereby lowering labor costs [13]. These systems provide real-time data and insights, allowing farmers to make immediate adjustments to optimize conditions, which leads to more precise and consistent hatching rates.

2.4. Frameworks for System Implementation and Standardization

The successful implementation of a complex system like an IoT incubator benefits greatly from a well-defined framework. A framework provides a standardized structure and set of procedures, ensuring consistency, accuracy, and reliability in the incubation process [14]. It establishes specific parameters for monitoring and evaluation, helping to identify and address potential issues early, thus mitigating their impact on hatchability [15].

Furthermore, a robust framework optimizes the use of resources such as electricity and water, which is crucial for designing cost-effective and sustainable solutions, particularly for rural applications [16]. By establishing common protocols, frameworks also facilitate knowledge-sharing and collaboration, allowing for the adoption of best practices across the farming community [17].

2.5. Summary and Identification of the Research Gap

A critical review of the literature establishes the clear significance of egg incubators in enhancing poultry productivity. It further highlights the evolution from manual and basic automated systems towards smart, IoT-enabled solutions that offer remote control, real-time monitoring, and data-driven optimization.

However, a significant gap exists in the development of indigenous, low-cost IoT incubator frameworks specifically designed for local farmers in regions like Ghana. Many existing solutions are either too expensive, too complex, or not tailored to the specific needs (e.g., hatching various egg types like guinea fowl, chicken, ducks, turkeys), economic constraints, and mixed farming contexts of these users. Many studies focus on the implementation of a single device but neglect to provide a generalized, adaptable framework that can be replicated with locally available materials.

3. RESEARCH METHODOLOGY

3.1 Introduction

This research designs and implements a cost-effective, IoT-based framework for a smart egg incubator. The goal is to help local farmers successfully hatch various egg types through a system that allows for remote monitoring and control. The methodology includes a feasibility study, detailed system design, and simulation for validation.

3.2 Feasibility Study

A feasibility study was conducted to ascertain whether the design of an indigenous IoT incubator framework was technically, economically, and logically viable for local farmers. The study involved:

- **Technical Feasibility:** An assessment of the availability and cost of required components (e.g., ESP32 microcontroller, DHT22 temperature/humidity sensor, heating elements, fans) in the local market. It was confirmed that all core components are readily available and affordable, making the technical implementation feasible.
- **Economic Feasibility:** An analysis of the cost of materials versus the potential economic benefits for a farmer (reduced losses, improved hatch rates, labour savings). The is concluded that building the system with locally sourced materials presents a significantly lower-cost alternative to commercial incubators, making it an economically viable solution.
- **Operational Feasibility**: Engagement was made with local farmers to understand their pain points, technical capacity and specific needs (e.g., hatching different types of eggs like chicken, guinea fowl, etc.). This confirmed a clear need for an automated, remote-monitoring solution and that the proposed system would fit logically into their mixed-farming workflows.

3.3 Framework for Egg Incubator Implementation

The focus of this methodology is to design an IoT egg Incubator framework. The framework specifies how the hardware and software components are integrated to make the IoT egg incubator work, providing a universal incubation solution for all types of eggs, while enabling the user to monitor and control the process using a mobile device.

3.4 Tools and Methods used in Designing the IoT Incubator Framework

A comprehensive set of tools and methods are utilized to design and develop the IoT egg incubator using the ESP32 microcontroller and other components. The hardware design involved selecting and integrating sensors, relays and communication modules, while the software design encompassed programming the ESP32 firmware using Arduino Integrated Development Environment (IDE) and implementing cloud connectivity.

To simulate the system's functionality, the Arduino Cloud platform was employed, enabling virtual testing and validation of the incubator's performance.
The combined use of these tools and methods allowed for the successful implementation and evaluation of the IoT egg incubator, ensuring an efficient and reliable hatching process

3.5 Hardware and Software Connections

The hardware and software components for the IoT egg incubator are connected based on several factors, including ease of development, reliability, and compatibility.

3.5.1 Hardware components

Building an IoT egg incubator using ESP32, the following are the list of hardware components needed. Table 1.0 shows the various component of hardware of the IoT setup

Table 1. 0 Hardware components

Item	**Description**
ESP32 Development Board	This is brain of the incubator and controls the various functions.
Temperature and Humidity Sensor (DHT11)	This measures the temperature and humidity levels inside the incubator and provides data for monitoring and control.
Relay Module	Controls the power supply to the heating element and bulb, ensuring they turn on and off at the appropriate times
Power Supply (12V DC)	This provides a stable power supply for the smooth operation of the IoT egg incubator
Display	The Display module Monitoring the temperature and humidity the incubator is crucial for successful egg incubation
AC Bulb/ Heating element	provides heat inside the incubator during the incubation process. Maintaining a constant temperature in the incubator is crucial for successful egg incubation
Jumper Wires	These are cables wire that are used to connect the various electrical and data components of the incubator
Breadboard	This provides a platform for prototyping and connecting the various components of the incubator
Egg Tray	This holds the eggs during the incubation process
The fan	The fan plays a crucial role in an incubator because it helps to distribute heat and regulate temperature evenly throughout the incubator
Plywood box/ Old fridge	Used to create the enclosure for the incubator

3.5.2 Procedure for Connecting the Hardware components of the Incubator

Figure 1 shows the hardware component connectivity making up the framework implementation of the IoT egg incubator for indigenous farmers.
To establish this, the following steps are taken:

- Connect the temperature/humidity sensor to the ESP32 development board using jumper wires. The DHT11 sensor typically has four pins: VCC (Voltage common connector +), GND (ground),

International Journal on Science and Technology (IJSAT)
E-ISSN: 2229-7677 ● Website: www.ijsat.org ● Email: editor@ijsat.org

DATA, and NC (not connected). Connect VCC to 3.3V or 5Vpin on the board, connect GND to GND pin and DATA to digital pin four (4) on the board.

- Connect the relay module to the ESP32 board. Relay modules typically have three pins: VCC, GND, and Signal. Connect the VCC pin to the 5V pin on the board, GND to GND pin and Signal to any digital pin on the board.
- Connect the AC bulb and the humidifier to the relay's AC output and connect the relay's DC input to the relay module's output pins.
- The heater line is looped to supply the fan power for even distribution of heater within the incubator.
- Place the ESP32, DHT11 sensor, and relay module on the breadboard. Connect the power supply's positive and negative terminals to the breadboard's signal traces.
- Place the egg tray in the incubator, and place the temperature/humidity sensor inside the incubator. The sensor should be close to the eggs.

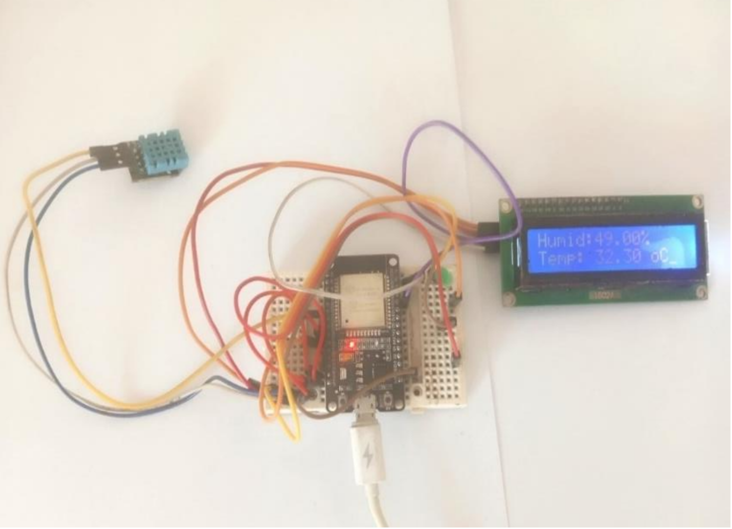

Figure 1 Physical connection of IoT egg incubator

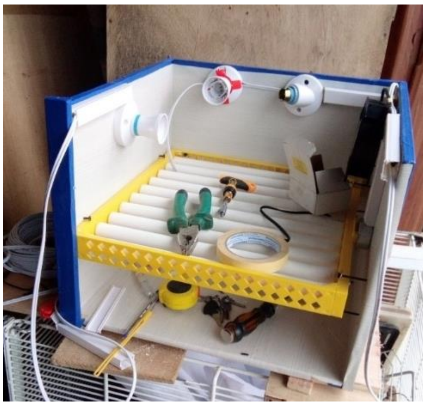

Figure 2 Physical object under construction

3.5.3 Procedure for setting up and programming the IoT egg incubator

- Initial Setup: Install the necessary software (Arduino IDE with ESP32 support) and connect the ESP32 board to your computer.
- Programming: The code sketch is written and uploaded that automates the incubator's functions, such as reading sensor data to control temperature (via a relay), humidity, the egg turner, and the fan.
- Upload Code: Select the correct board and port in the IDE and upload the finished code to the ESP32 microcontroller

3.5.4 System Workflow of the Incubator

In this workflow, the incubator starts and then the temperature and humidity are checked. If the temperature or humidity is too low or too high, the incubator adjusts accordingly by adding or removing heat or moisture. After checking the temperature and humidity, the incubator turns the eggs. This process repeats until the eggs are ready to hatch. The workflow ensures that the eggs are kept in the ideal environment for hatching, which can help increase the success rate of the incubation process.
The incubator system's successive processes for achieving its intended goal of hatching eggs are depicted in Figure 3 as the activity diagram.

3.5.5 Representation of the Incubator parameters

A represents Minimum Temperature, **B** represents Maximum Temperature, **C** represents Minimum Humidity, **D** represents Maximum Humidity, and **E** represents the Number of Egg Turns per day

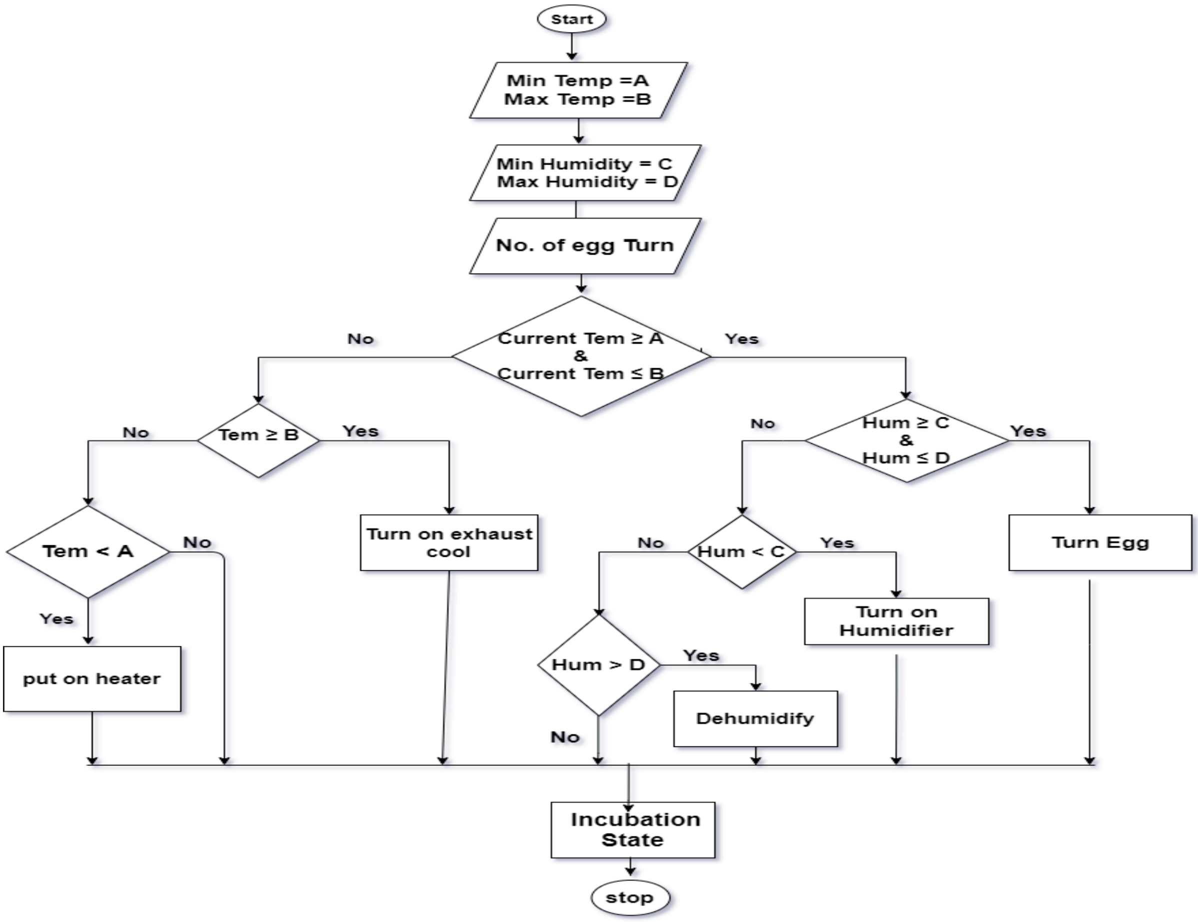

Figure 3 Activity Diagram of the incubator

3.5.6 Procedure for setting up and programming of Android mobile application to monitor and control IoT egg incubator in real-time

- Install the Android Studio: Download and install Android Studio, which is the official integrated development environment (IDE) for developing Android apps.
- Create a New Project: Open Android Studio and create a new project. Give the project a name, such as Ab IoT Incubator, and choose the minimum SDK version that you want to target.
- Design the User Interface: Design the user interface for your app using the layout editor in Android Studio. You can add buttons, text fields, and other UI components to allow the user to monitor and control the incubator.
- Connect to the ESP32 Board: In order to connect to the ESP32 board, the Wi-Fi module on the ESP32 board is used. A Wi-Fi network is created on the ESP32 board allowing the Android app to get connected.
- Write the Code: Write the code to connect to the Wi-Fi network on the ESP32 board and read the temperature and humidity data from the DHT11 sensor.

3.6 Software Design

The firmware/software for the ESP32 microcontroller is developed using the Arduino IDE. The firmware also implements a RESTful API to enable communication with the mobile application allowing the user to control the temperature and humidity.

3.6.1 Mobile application

The mobile phone application is developed using Java programming language on Android Studio IDE. The application communicates with the ESP32 microcontroller via Wi-Fi, utilizing the Arduino API implemented in the firmware. The application's developed to be user simple friendly

3.6.2 Cloud integration

Cloud integration is implemented in the IoT egg incubator framework to enable remote monitoring and control. The cloud integration is accomplished using the MQTT (Message Queuing Telemetry Transport) protocol, which is a lightweight and efficient messaging protocol designed for IoT devices. The ESP32 firmware is integrated with a cloud platform, such as Arduino IoT cloud, to send telemetry data, receive commands, and trigger notifications and control.

3.7 Simulation of the Egg Incubator Framework

3.7.1 Methodology in carrying out simulation of the framework

The objective here is to simulate a virtual incubator system that maintains a temperature range of 37.5-38.0 degrees Celsius and a humidity level of 60-65 percent.

3.7.2 Tools for Simulation of the Incubator

Arduino Cloud was leveraged upon to simulate the egg incubator system virtually. The Simulator was effectively used simulate the incubator system alongside egg turning mechanism, temperature and humidity control, allowing for thorough testing and optimization before implementing the system physically.

3.7.3 Hardware and Software Requirements

This section outlines the hardware and software components required for the simulation. It includes:

- Virtual microcontroller
- Virtual sensors for temperature and humidity measurements
- Virtual relay for controlling temperature, humidity, and egg turning
- Arduino Cloud Simulator platform (IDE)

3.7.4 System Architecture

The system architecture diagram illustrates the various components and their interactions within the IoT egg incubator simulation. It depicts the connection between the virtual sensors, relay and the Arduino board. Additionally, it explains the communication flow between the Arduino Cloud Simulator and the simulated incubator, emphasizing the integration of egg turning mechanisms.

3.7.5 Simulation Setup

The following steps setting up the simulation in the Arduino Cloud Simulator. The following steps are taken to carry out the simulation process:

Step A: Set up the Arduino Cloud Simulator
Step B: Define the required libraries
Step C: Set up the Arduino Cloud variables and functions
Step D: Set up the Arduino Cloud properties and callbacks
Step E: Set up the Arduino Cloud connection and main loop
Step F: Upload the written code to the Arduino Cloud Simulator

3.7.6 Simulation Algorithm

The algorithm for controlling the virtual incubator system is programmed, incorporating the egg turning mechanism. It outlines the logic for maintaining the temperature and humidity within the desired ranges and includes the periodic egg turning process. The algorithm takes inputs from the virtual sensors, calculates deviations from the target values, adjusts the virtual actuators for temperature and humidity control, and triggers the egg turning mechanism at the specified intervals.

3.7.7 Testing and Validation

This phase involves testing and validating the simulated incubator system to ensure its functionality and performance. Scenarios are simulated to verify the system's ability to respond and maintain the desired temperature, humidity, and egg turning intervals. Results are recorded and analyzed, allowing for necessary adjustments to the simulation parameters or algorithm.

3.7.8. Optimization

Based on the testing results, the simulation parameters and algorithm are optimized to enhance the performance of the IoT egg incubator. This includes fine-tuning the control algorithm, adjusting the thresholds for temperature, humidity and validating the system's response to different conditions. The optimization process aims to achieve optimal temperature and humidity control while ensuring proper egg turning intervals.

3.7.9 Summary of Methodology

In summary, the Arduino Cloud Simulator was used to simulate the IoT egg incubator for the temperature and humidity while incorporating egg turning. The methodology highlights the simulation techniques in validating and optimizing the system before physical implementation are carried out. The findings from the simulation serve as a foundation for future physical implementations and provide valuable insights for improving the efficiency of real-world egg incubators.

4.0 Results and Discussions

4.1 Egg Incubator Framework Results

The results of this study demonstrates the development of an IoT egg incubator framework that outlines the interconnectivity between hardware and software components to achieve a functional IoT egg incubator. The framework provides a universal solution for incubating various types of eggs, while allowing users to monitor and control the process remotely using their mobile devices. The successful implementation of this framework contributes to the design of an incubator that can simulate the conditions of a natural nest, providing an optimal environment for the development of eggs.

4.2 Block Diagram

The block diagram shows how the various parts interact with one another to carry out the incubation process. DHT11 sensor, electric motor, electric bulb, relays and electric fans are connected to the ESP32 development board (the main brain of the incubator) using the jumper cables. GPIO (General-purpose Input/output pins) are used as jumper wires for the connections within the system.

When the system is turned on by pushing the power button, the 12/5 volts AC/DC converter regulates the electricity from the source to stop the microcontroller from receiving an excessive amount of power. When the system is powered on, the LED turns on, Temperature, humidity, and the number of egg turns per day get activated.

The DHT11 sensor measures the temperature and humidity inside the incubator and sends this data to the ESP32 board for processing.

Logical processes are performed by the microprocessor to control the relays that regulates the electric motor, fans, and light bulbs based on the data received from the DHT11 sensor probe.

When the temperature inside the incubator falls below the ideal temperature for the specific egg being incubated, the heating element/bulb is turned on. When the temperature exceeds the ideal temperature, the electric bulb turns off. The electric motor rotates the eggs in the incubator periodically at intervals of one hour. The electric fan maintains even air distribution and relative humidity within the incubator. With the wireless capabilities of the ESP32 microcontroller, it transmits the real- time data to the user's mobile application through the server for remote monitoring and control. Figure 4.3 illustrates the block diagram.

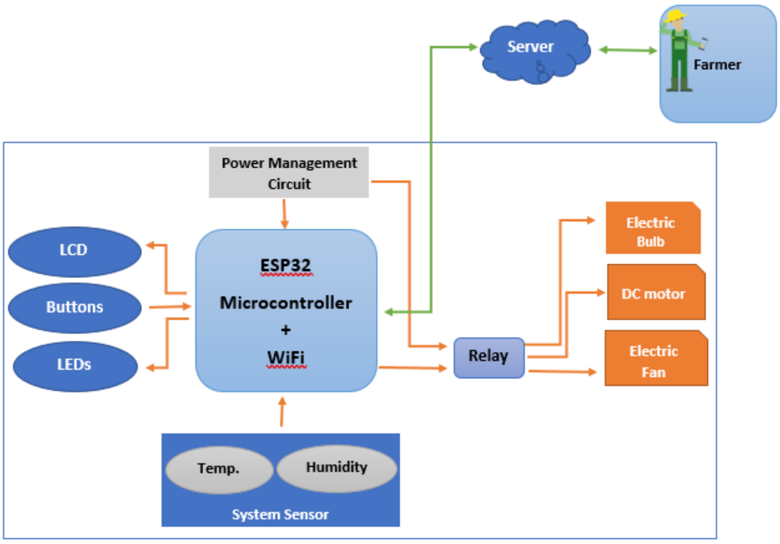

Figure 4 System block diagram for the Smart Incubator


Figure 5 Physical object (incubator)

Figure 5 shows the physical implemented system of the incubator.

4.3 Simulation Results

4.3.1 A circuitry Diagram of a Smart Incubator

Figure 6 shows the circuit diagram of how the components are connected to the circuit board as described in the methodology. The ESP32 is the main microcontroller that controls the egg incubator. DHT11 sensor to read the temperature and humidity data. The temperature range is set to between 37.5°C and 38.0°C ideal for incubating eggs and the egg turning interval is set to every hour.
Two relays are used, one for heating and one for egg turning. The heating relay is turned on or off based on the temperature range. The egg turning relay is turned on every hour for a brief period to turn the eggs and then turned off. The LEDs were used as indicator lights and capacitors were introduced to store excess currents. Farmers are able to monitor their incubators remotely from anywhere.
Overall, this framework provides a simple and effective solution for controlling an egg incubator using ESP32 and integrating it with a mobile application for remote control and monitoring.

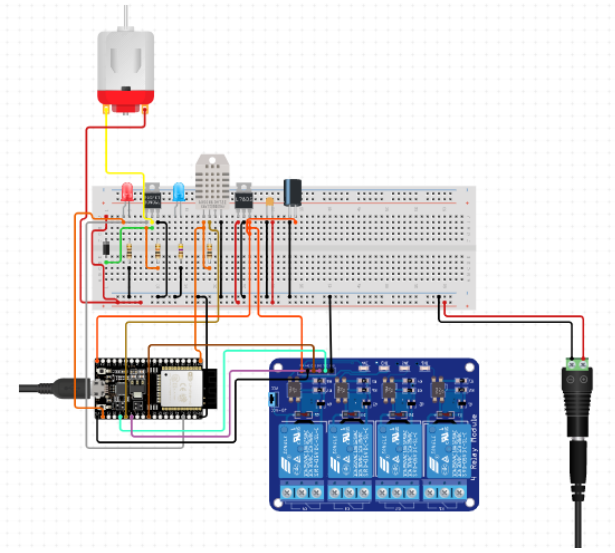

Figure 6 Implementation of incubator framework

4.3.2 Test of the Incubator

To test the incubator, place the temperature and humidity sensor inside the incubator. The sensor should be close to the eggs. Turn on the main switch of the incubator. The heating bulb is turned on using the relay module and controlled by the ESP32. The bulb should heat up the incubator and maintain the desired temperature and humidity levels.

4.3.3 Interpretation of the IoT Egg Incubation Simulation Results

Arduino cloud simulator was used to simulate the virtual egg incubator. In this simulator, the serial plotter is used to graphically display the temperature and humidity received from the sensor.
The results here present the interpretation of the simulation results obtained from the IoT egg incubation system. It focuses on the monitoring of temperature and humidity levels over time virtually. The simulation is aimed to replicate the conditions required for successful egg incubation, specifically maintaining a temperature range of 37.5-38.0 degrees Celsius and a humidity range of 60-65% ideal for all types of poultry eggs. The simulation takes an average time of one (1) hour.

4.3.4 Simulation of Humidity and Temperature Using DHT11 and ESP32 Microcontroller

The results from figure 7 shows the simulation temperature and humidity values. The source code and the output data collected by the DHT11 sensor are shown here. The data is displayed on a Serial Monitor. The data is automatically updates itself every ten seconds (10s) which can be seen on the right upper corner of the screen. The humidity data is expressed in percentage whiles that of the temperature is measures using degree Celsius. The temperature and humidity values during the simulation are displayed in the simulator.
The following analysis provides insights into the observed temperature and humidity patterns throughout the simulation.

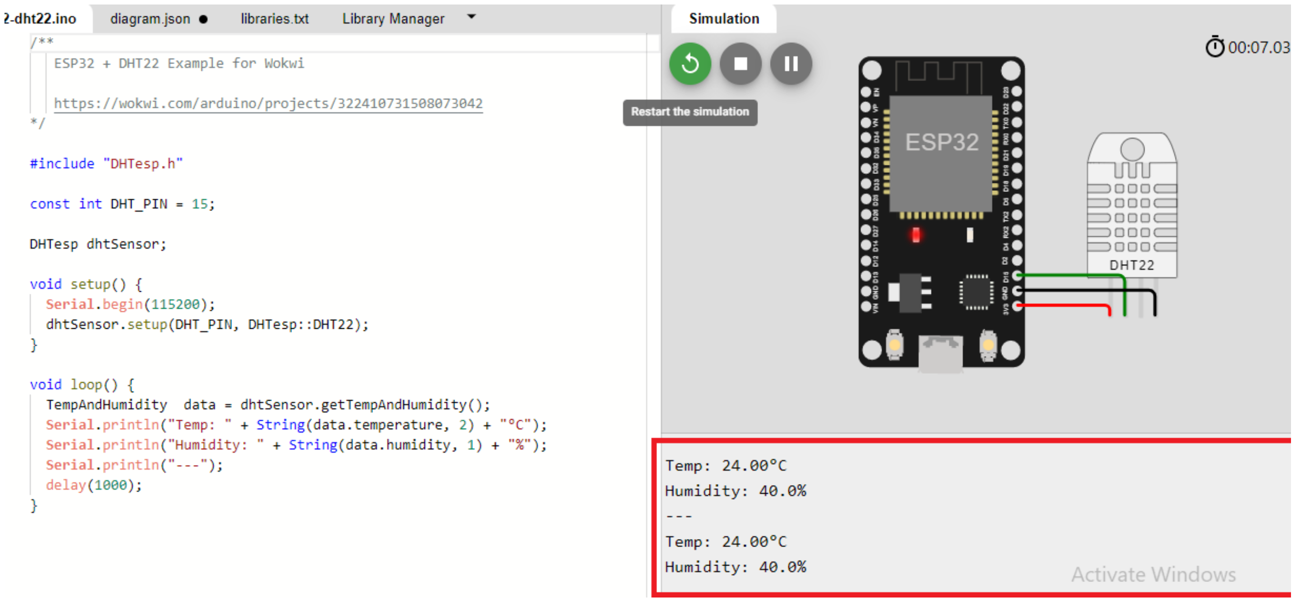

Figure 7 Simulation temperature and humidity output display

4.3.5 Simulation Using Serial Plotter

A serial plotter is a user interface in the Arduino simulator that can be used to displace sensors reading in an analogue format. As can be seen on the figure 8, the Serial Plotter, the base of the graph records Humidity readings whiles the upper portion of the graph records the temperature readings. In between the temperature and the humidity readings is an imaginary zero (0) line. Temperature and humidity readings are inversely proportional. This means if temperature increases, humidity decreases and the vice versa.

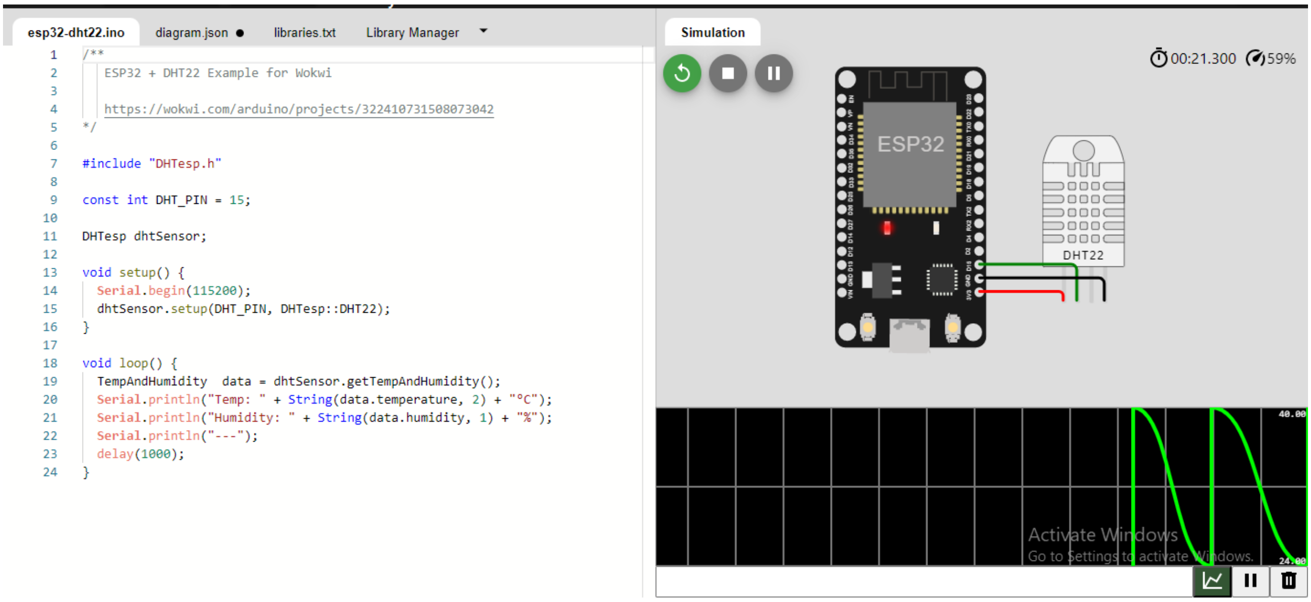

Figure 8 Serial Plotter

4.3.6 Setting of the Temperature and Humidity Readings

Figure 9 shows the results of Temperature Humidity settings. Double clicking the virtual DHT11 sensors enables you to set the temperature and humidity range of values one wishes to simulate. When you set the values, your simulated readings can never go above the set values. From the Figure 4.8, the researcher set the simulated values of temperature and humidity between 38.9°C and 26.5% respectively because the researcher is interested in studying temperature values ranging from 37.5°C and 38°C. Understanding temperature values of between 37.5°C and 38°C and the resultant consequences it poses will enable the researcher to supply the needed temperature and humidity to the incubation egg. The last part of the graph indicates a stable temperature and humidity in the serial plotter.

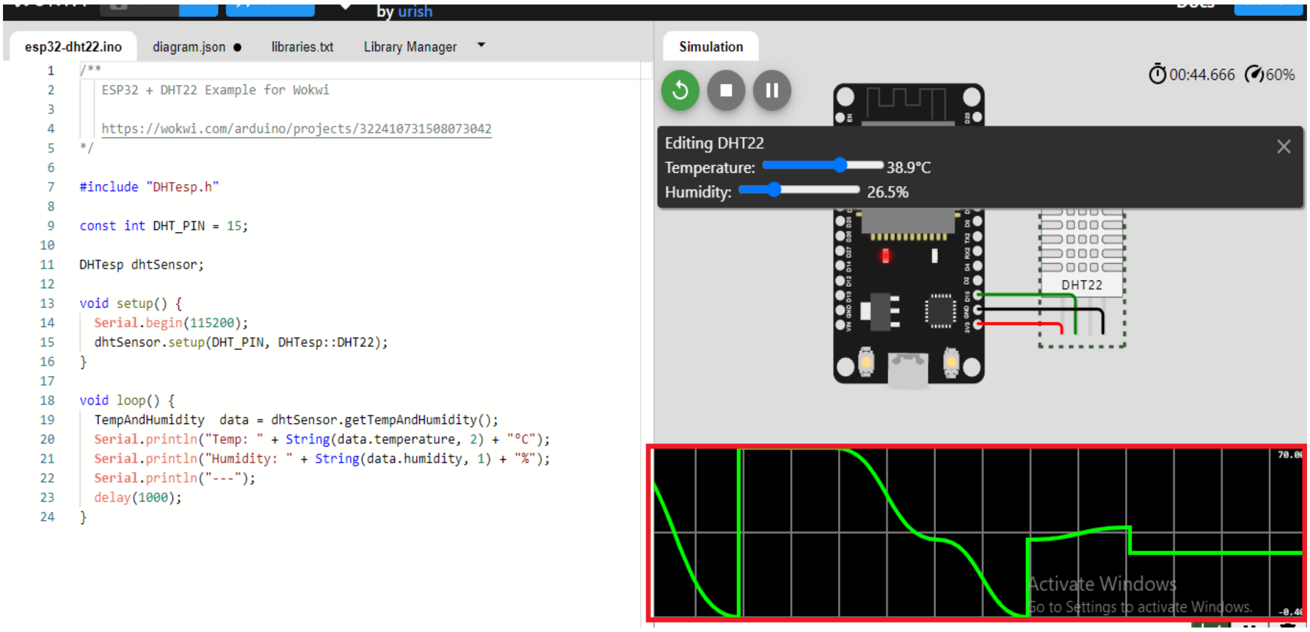

Figure 9 Graph of temperature and Humidity

4.4. Temperature Analysis

The temperature graph illustrates the variations in temperature inside the IoT egg incubator over time. The interpretation of the temperature data from the simulation is as follows:

- Incubation Warm-Up Phase: Initially, during the warm-up phase, the temperature inside the IoT egg incubator gradually increased to reach the desired incubation temperature range of 37.5-38.0 degrees Celsius. This warm-up period is essential to create an optimal environment for egg incubation, ensuring the proper development of the embryos. The warm-up stage takes an average of 5 minutes
- Optimal Incubation Temperature: After the warm-up phase, the simulation successfully demonstrated the ability of the IoT egg incubator to maintain a stable temperature within the desired range of 37.5-38.0 degrees Celsius. This temperature range is critical for successful egg incubation, as it promotes embryonic growth and development. The IoT egg incubator effectively regulated the temperature to provide a consistent environment for incubation.
- Temperature Fluctuations: Throughout the incubation period, minor temperature fluctuations within a narrow range were observed as shown in Table 4.1. These fluctuations may occur due to external factors such as ambient temperature changes or temporary disturbances in the heating mechanism. However, the IoT egg incubator demonstrated its capability to quickly adjust and restore the temperature back to the desired range, ensuring stable incubation conditions.

Table 2 Temperature Stability

Incubation Stage	Current temperature (degree Celsius)	Target temperature (degree Celsius)
Incubation Warm-Up Phase	27.8	37.5-38.0
Incubation Warm-Up Phase	30.0	37.5-38.0
Incubation Warm-Up Phase	37.3	37.5-38.0
Optimal Incubation Temperature	37.5	37.5-38.0
Optimal Incubation Temperature	37.5	37.5-38.0
Optimal Incubation Temperature	37.8	37.5-38.0
Optimal Incubation Temperature	37.8	37.5-38.0
Optimal Incubation Temperature	38.0	37.5-38.0

4.5 Humidity Analysis

The humidity graph represents the changes in humidity levels inside the IoT egg incubator throughout the simulation. The interpretation of the humidity data is as follows:

- Initial Humidity Adjustment: At the start of the simulation, the humidity levels inside the IoT egg incubator underwent an adjustment phase to achieve the desired humidity range of 60-65%. This adjustment period involved balancing the moisture content within the incubator to create an optimal environment for egg incubation. The simulation effectively replicated this phase.
- Optimal Incubation Humidity: Once the humidity adjustment phase concluded, the simulation showed that the humidity remained within the desired range of 60-65% throughout the incubation process. This humidity range is crucial for preventing excessive moisture loss from the eggs and maintaining the necessary moisture level for proper embryonic development. The IoT egg incubator successfully maintained a consistent and suitable humidity level.
- Humidity Fluctuations: Minor fluctuations in humidity were observed during the simulation, which is normal in real-world incubation scenarios. These fluctuations could be attributed to factors such as external humidity changes, ventilation adjustments, or temporary disturbances in the humidity control mechanism. However, the IoT egg incubator demonstrated its ability to regulate and stabilize humidity levels within the desired range, ensuring optimal conditions for incubation

4.6. Performance of the proposed system relative to existing Local designs and models.

The proposed system of implementing IoT incubator and predicting egg hatch rate can provide several benefits over existing systems. Some of these benefits include:

- **Improved Hatch Rate:** The ability to predict egg hatch rate using the developed model can help improve the hatch rate of eggs, resulting in increased productivity and efficiency in the hatchery.

- **Reduced Labour Costs:** The implementation of IoT in the incubation process can reduce the need for manual monitoring, thereby reducing labour costs and increasing efficiency.
- **Increased Accuracy:** The use of IoT devices and predictive modelling can increase the accuracy of data collection and analysis, resulting in more precise and informed decision-making.
- **Real-time Monitoring:** our system can provide real-time monitoring of the incubation process, allowing for immediate action to be taken in case of any issues or abnormalities.
- **Remote Management:** The ability to remotely monitor and manage the incubation process through IoT devices can reduce the need for physical presence at the hatchery, providing greater flexibility and convenience for hatchery managers and staff.

The proposed system result in improved hatchery productivity and increased efficiency. Comparing our system to other systems based on literature reviews and performance, it can be drawn that the combination of a hatch predictive system and the IoT egg incubator gives farmers higher productivity.

5. Conclusion

The simulation results of the IoT egg incubation using the Arduino Cloud Simulator provided valuable insights into the behaviour of temperature and humidity over time. The analysis showcased the successful replication of the incubation process, including the warm-up phase, maintenance of optimal temperature (37.5-38.0 degrees Celsius), and humidity (60-65%) ranges. These findings from the incubator simulation validate the incubator framework as an effective model in providing a controlled environment for successful incubation. This experimental result shows robustness to optimize the incubation process, improve hatch rates and enhance overall efficiency. The real-time monitoring and control provided by the Android mobile application make the IoT egg incubator user-friendly and accessible to farmers with varying levels of technical expertise. This user-centric approach is crucial for the successful adoption of technology in local communities.

Overall, this study demonstrates the potential of IoT technology to address the challenges faced by farmers in local communities. The IoT egg incubator framework presented in this paper is an innovative solution that can significantly improve egg hatching rates, ultimately contributing to the growth and development of rural areas.

References

1. A. Avotins, P. Apse-Apsitis, J. Bicāns, and J. Gruduls, “Development and testing results of IoT based air temperature and humidity measurement system for industrial greenhouse,” Agronomy Research, vol. 16, no. Special Issue 1, pp. 943–951, 2018, doi: 10.15159/AR.18.141.
2. M. Stočes, J. Vaněk, J. Masner, and J. Pavlík, “Internet of Things (IoT) in Agriculture - Selected Aspects Agris on-line Papers in Economics and Informatics Internet of Things (IoT) in Agriculture - Selected Aspects,” no. October, 2017, doi: 10.7160/aol.2016.080108.
3. A. S, “Research on Smart Environment Monitoring Systems based on Secure Internet of Things (IoT),” International Journal on Future Revolution in Computer Science & Communication Engineering, vol. 8, no. 1, pp. 48–55, Mar. 2022, doi: 10.17762/IJFRCSCE.V8I1.2090.
4. K. Rose, S. Eldridge, and L. Chapin, “OCTOBER 2015 THE INTERNET OF THINGS: AN OVERVIEW Understanding the Issues and Challenges of a More Connected World,” 2015.
5. Y. A. Attia et al., “Poultry Production and Sustainability in Developing Countries under the COVID-19 Crisis: Lessons Learned,” Animals (Basel), vol. 12, no. 5, Mar. 2022, doi: 10.3390/ANI12050644.

6. W. S. M. Sanjaya et al., "The development of quail eggs smart incubator for hatching system based on microcontroller and Internet of Things (IoT)," 2018 International Conference on Information and Communications Technology, ICOIACT 2018, vol. 2018-January, pp. 407–411, Apr. 2018, doi: 10.1109/ICOIACT.2018.8350682.
7. A. Chalimov, "IoT in Agriculture: 5 Technology Use Cases for Smart Farming (and 4 Challenges to Consider)." Accessed: Nov. 17, 2021. [Online]. Available: https://easternpeak.com/blog/iot-in-agriculture-technology-use-cases-for-smart-farming-and-challenges-to-consider/
8. I. C. Boleli, V. S. Morita, J. B. Matos, M. Thimotheo, and V. R. Almeida, "Poultry Egg Incubation: Integrating and Optimizing Production Efficiency," Brazilian Journal of Poultry Science, vol. 18, no. Special Issue 2, pp. 1–16, 2016, doi: 10.1590/1806-9061-2016-0292.
9. K. Radhakrishnan, N. Jose, S. S. G, T. Cherian, and V. K. R, "Design and Implementation of a Fully Automated Egg Incubator," International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (An ISO, vol. 3297, no. 2, 2007, Accessed: Nov. 02, 2021. [Online]. Available: www.ijareeie.com
10. A. L. Cartwright, "Incubating and Hatching Eggs," 2019.
11. Martin David Rose and Thierry Guérin, "Scientific Opinion on the public health hazards to be covered by inspection of meat (poultry)," EFSA Journal, vol. 10, no. 6, Jun. 2012, doi: 10.2903/J.EFSA.2012.2741.
12. Calvin and Cindy Roberts, Incubation Hand book. 2017. Accessed: Mar. 09, 2023. [Online]. Available: https://robertsfarm.us/pdf/Incubation_Handbook.pdf
13. K. Baiduri binti Azahar, E. Ensimau Anak Sekudan, and A. Mirza Bin Azhar, "Intelligent Egg Incubator ," International Journal of Recent Technology and Applied Science, vol. 2020, no. 2, pp. 91–102, 2020, doi: 10.36079/lamintang.ijortas-0202.129.
14. Idoko E, Ogbeh G O, and Ikule F T, "DESIGN AND IMPLEMENTATION OF AUTOMATIC FIXED FACTORS EGG INCUBATOR," Peer-Reviewed, Refereed, Indexed Journal with IC, no. 5, pp. 2455–0620, 2019.
15. C. Okinda et al., "A machine vision system for early detection and prediction of sick birds: a 1 broiler chicken model 2," 2019.
16. I. C. S. Araújo et al., "Effect of vitamin E in ovo feeding to broiler embryos on hatchability, chick quality, oxidative state, and performance," Poult Sci, vol. 98, no. 9, pp. 3652–3661, Sep. 2019, doi: 10.3382/PS/PEY439.
17. P. Tiam Kapen, M. Youssoufa, M. Foutse, H. Manfouo, and F. O. Njotchui Mbakop, "Design and prototyping of a low-cost, energy efficient eggs incubator in developing countries: A case study of Cameroon," Sci Afr, vol. 10, p. e00618, Nov. 2020, doi: 10.1016/J.SCIAF.2020.E00618.