

Design and Implementation of an IoT Based Chicken Egg Incubator

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Abstract- A technical design and development of an IoT-enabled smart egg incubator was carried out at Zimbabwe Open University. The aim was to develop a locally designed control system that utilises Internet of Things (IoT) capabilities. Existing incubators normally require physical presence to read off temperature and humidity values that are displayed. A 100 x 70 x 43 cm smart incubator was designed, which used an ESP32 microcontroller with onboard Wi-Fi as the main control device. This facilitated real-time monitoring and regulation of environmental parameters. The DHT22 sensor was used to monitor temperature and humidity, utilizing thermodynamic and capacitive sensing methods to provide precise environmental data. An Android app, built with Java in Android Studio, enables wireless communication with the incubator, allowing users to receive real-time notifications and remotely track conditions. This innovation removes the need for constant onsite oversight, significantly improving the efficiency and reliability of the incubation process. It also helps reduce reliance on imported equipment while encouraging local entrepreneurship and advancing innovation in agricultural technology.

Index Terms- IoT, Egg incubator, ESP32 microcontroller, Poultry.

I. INTRODUCTION

Poultry farming remains a significant contributor to food security and income generation in Zimbabwe and other developing nations (Pedersen, 2002). At the core of successful poultry production lies the incubation process, which requires precise environmental control to ensure high hatchability rates. Egg incubators, whether for small-scale family farms or large commercial operations, play a critical role in maintaining optimal conditions of temperature, humidity, and egg rotation throughout the embryonic development period. Existing incubators in Zimbabwe, typically imported, face

several technical limitations. A major challenge is the reliance on manual intervention for tasks such as egg turning and environmental monitoring, which increases labour demands and introduces the risk of human error (Alex, 2022). This not only reduces the efficiency of hatchery operations but also compromises embryonic development and chick survival rates (Adame & Ameha, 2023). To address these limitations, there is a growing need for locally developed, automated incubators that incorporate modern technologies. Such systems should feature durable housing, proper thermal insulation and intelligent environmental control systems. A promising solution involves integrating Internet of Things technologies with embedded systems to create smart incubators that offer remote control, real-time monitoring, and adaptive environmental regulation. The smart egg incubator developed at Zimbabwe Open University uses an ESP32 microcontroller as its central control unit. The ESP32 was chosen for its low power consumption, integrated Wi-Fi capabilities and suitability for real-time data acquisition and communication (Hercog et al., 2023). Coupled with DHT11 sensor, the system measures temperature and humidity based on thermodynamic and capacitive sensing principles. These parameters are essential for maintaining optimal incubation conditions, typically ranging between 36.5°C–38.5°C and 55%–65% relative humidity (Adame & Ameha, 2023). The incubator employs a control algorithm programmed into the ESP32 that dynamically adjusts heating and ventilation elements based on continuous sensor feedback. This allows for an automated, self-regulating system that minimizes human intervention while improving incubation reliability. Furthermore, an Android-based mobile application was developed to allow users to receive real-time updates and alerts, facilitating remote management of the incubation process. Additionally, the incubator features an automatic egg-turning mechanism, which is critical for proper embryo

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development(da S. Oliveira et al., 2020).

II. RELATED LITERATURE

The advancement of smart agricultural systems has been a significant area of research, particularly in automating critical

farming operations such as incubation (Abbasi et al., 2022). Numerous studies have proposed automated incubators that integrate microcontrollers and sensors to regulate the incubation environment. For instance, Cahyo Ardi Prabowo et al (Cahyo Ardi Prabowo et al., n.d.) integrated a PID control algorithm with temperature and humidity sensors in their automated egg incubator. Their design featured hyper tuned PID parameters for optimal environmental control, real-time temperature and humidity monitoring, and a voltage-based protection system all integrated with Internet of Things functionality. Although this improved system response and stability, it relied heavily on imported components and software platforms, posing challenges for scalability in local Zimbabwean contexts where cost and availability of parts are major considerations.

Nawaz et al implemented an IoT-enabled egg incubator utilizing both the PIC16F887 microcontroller and the ESP8266 Wi-Fi module for comprehensive parameter control (Nawaz et al., 2021). The system employed dual DS18B20 temperature sensors to ensure accurate temperature regulation, and an HSM-20G humidifier was integrated for humidity control. Additionally, water level sensors and egg tilt sensors were included to monitor critical incubation conditions. One of the notable challenges addressed in their system was the noise in sensor data due to environmental interference. The researchers incorporated the Kalman filter algorithm, which effectively reduced noise and provided more accurate temperature and humidity readings (Lim et al., 2016). The Kalman filter estimates the system state at time k based on the state at time $k-1$ according to the state-space model:

$$X_k = AX_{k-1} + BU_k + W_{k-1} \quad (1)$$

where A is the state transition matrix, B is the control input matrix, U_k is the control vector and W_{k-1} represents the process noise. Their findings demonstrated that incorporating IoT technologies and advanced filtering techniques such as the Kalman filter significantly improved system stability and accuracy in maintaining optimal incubation conditions. However, the design involved a relatively complex and costly architecture due to the use of multiple microcontrollers and a wide array of electronic components. In contrast, the present study proposes a cost-effective solution by utilizing a single ESP32 microcontroller reducing both hardware complexity and overall cost while maintaining effective control of temperature and humidity. Despite these advancements, few solutions have focused on indigenous designs tailored for local manufacturing and socio-economic contexts in Sub-Saharan Africa.

III. METHODOLOGY

The control architecture of the IoT-based Smart Egg Incubator was centred around the ESP32 microcontroller,

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which served as the main processing and communication unit.



Figure 1: ESP Wroom 32 module

The microcontroller facilitated continuous monitoring and control of environmental parameters within the incubator and governed the operation of all connected actuators. A DHT22 temperature and humidity sensor was employed to measure and monitor the internal environmental conditions of the incubator. The DHT22 is a digital sensor known for its cost-effectiveness, stability and reasonable accuracy in embedded applications (Feresu et al., 2022). The data collected by the sensor was continuously read by the ESP32 and used to adjust the system's heating and humidifying mechanisms to maintain optimal incubation conditions. Two 12V DC fans were installed for forced air circulation. These fans were controlled synchronously with the temperature readings from the DHT22 sensor. When the sensed temperature exceeded predefined thresholds, the ESP32 activated the fans to redistribute air and prevent thermal hotspots.

A. Egg Turning Mechanism

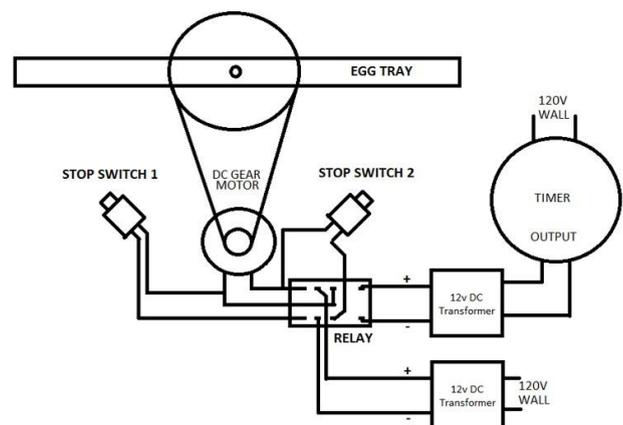


Figure 2: Egg turning mechanical system

An electric motor was integrated into the system to facilitate automated egg turning, which is critical for preventing the

embryo from sticking to the eggshell and ensuring
uniform

heat distribution(Jabbar, 2023). The motor was controlled by the ESP32 and operated at fixed intervals. Two limit switches were installed to detect and restrict the tray’s angular displacement, ensuring accurate and repeatable 45-degree rotations in each direction.

B. IOT Technology

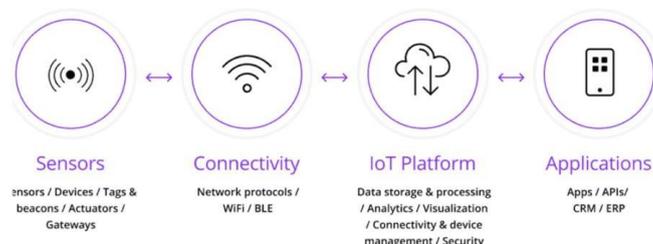


Figure 3: IoT System Architecture

The Internet of Things (IoT) is a technological paradigm that enables the interconnection of physical objects such as sensors and embedded systems through the Internet to collect, transmit and act upon data autonomously(Shaddad Abdul-Qawy et al., 2015). It leverages protocols and wireless communication technologies to enable real-time data exchange and intelligent decision-making without the need for human intervention(Abdul-Qawy et al., 2015). In this study, IoT technology was employed to facilitate wireless monitoring and control of key incubation parameters, namely temperature and humidity(Khan & Rashid, 2024). The ESP32 microcontroller, which features built-in Wi-Fi capability, transmitted sensor data from the incubator to a custom-built Android mobile application.

C. Mobile Application Development

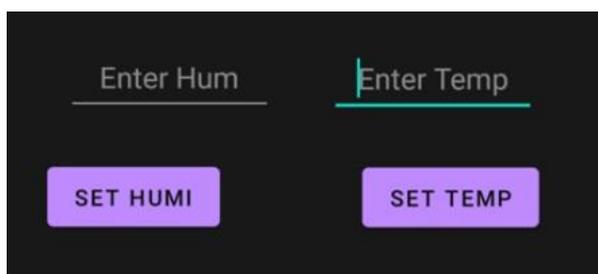


Figure 4: User Input Interface

An android-based mobile application was developed using the Java programming language within the Android Studio Integrated Development Environment to enable real-time monitoring and user interaction with the smart egg incubator. The mobile application serves as the application layer interface in the IoT architecture, providing seamless connectivity between the user and the incubator system. The app was designed to prioritize usability and responsiveness, featuring an intuitive graphical user interface (GUI) that displays real-time temperature (°C) and humidity (%) values.

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These readings are sourced from the DHT22 sensor via the ESP32 microcontroller and transmitted over Wi-Fi. The mobile application also offers a crucial feature that allows users to set their desired temperature and humidity levels directly from their smartphones as shown in the snippet above. Users can input their preferred parameters for optimal egg incubation remotely.

D. System Architecture

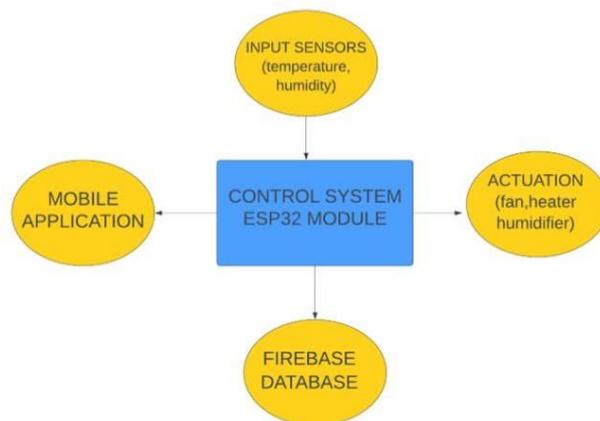


Figure 5: System Architecture

To facilitate seamless data synchronization and remote monitoring, the smart incubator system integrates with Google Firebase, a cloud-based backend platform. The Firebase Realtime Database was configured to receive and store sensor data transmitted by the ESP32 microcontroller via Wi-Fi in real time. This enables two-way communication between the incubator and the mobile application, ensuring continuous updates of environmental parameters such as temperature and humidity.

Upon system initialization, the ESP32 microcontroller assumes control of all critical components of the smart egg incubator, including the temperature and humidity sensors, actuators (lamp, fans, humidifier) and the egg-turning mechanism. The control logic is modularly divided into three functional sections to manage the incubation environment efficiently:

Temperature Regulation

Temperature monitoring and control are achieved using the DHT11 sensor, which provides real-time temperature feedback to the ESP32. If the measured temperature drops below the threshold of 36.5°C, the incandescent heating lamp is activated to increase the chamber temperature. Conversely, if the temperature exceeds 38.5°C, the heating lamp is deactivated, and the ventilation fans are triggered to facilitate

heat dissipation and restore optimal thermal conditions.

Humidity Regulation

Humidity control is also performed using data from the DHT11 sensor. When relative humidity falls below 55% RH, the ESP32 activates an ultrasonic humidifier to increase moisture content in the incubation chamber. If the humidity level exceeds 65% RH, the humidifier is automatically turned off. This ensures that the environment maintains consistent and optimal humidity levels, a key factor in successful embryonic development and hatching viability.

voltage regulators. The circuit design included a 12V (7812)

Electronic Circuit Design and Simulation

An electronic circuit for the smart incubator was designed and simulated using Proteus 8 Professional. The PCB layout, shown in Figure 7, represents the physical arrangement of components, tracks and holes on the circuit board. In the PCB layout, different components are placed strategically to ensure optimal functionality and efficient use of space. Tracks are the conductive pathways that connect the various components on the board, allowing the flow of electrical signals. The tracks are carefully routed to minimize interference and ensure reliable signal transmission. The PCB layout also includes holes, which serve multiple purposes such as component mounting, connection points, and mechanical stability.

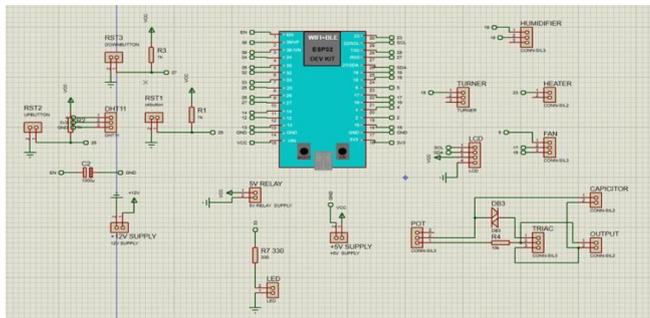


Figure 6: Proteus control circuit layout

The schematic power supply circuit, as shown in Figure 8, was designed using Proteus software. It provided two output voltage levels, 12V and 5V, which were essential for powering different components of the Smart egg incubator system. The circuit comprised an input voltage source, typically an AC voltage source, which was then fed into a transformer. The transformer converted the input voltage to a desired level suitable for the subsequent stages of the power supply circuit. After the transformer, a rectifier circuit was implemented to convert the AC voltage to DC voltage. This rectification process involved the use of diodes to rectify the alternating current, resulting in a pulsating DC waveform. Once the DC voltage was filtered, it was regulated using

regulator and a 5V (7805) regulator to generate the desired output voltages.

Figure 7: Layout of the Incubator Power Supply Circuit

E. Prototype Construction

A functional prototype of the smart egg incubator was constructed with dimensions $100 \times 70 \times 43$ cm. The design emphasized affordability, local material availability, energy efficiency and ease of use, particularly tailored for rural and resource-limited settings. The incubator frame was fabricated using metal sheets with foam insulation sandwiched between, which provided structural strength while minimizing thermal losses. The foam layer acted as a thermal barrier, maintaining internal temperature stability by reducing heat exchange with the external environment. Key components included an ESP32 microcontroller (central control unit), DHT22 sensors for temperature and humidity monitoring, a water-based heater and humidifier for humidity control, a synchronous motor with limit switches for automated egg turning, exhaust and cooling fans for air circulation, an LCD for real-time display of temperature, humidity, a relay module for switching high-current devices and a power supply unit. Inside the incubator, eggs were placed on a movable tray, while the DHT22 sensor ensured accurate readings. The humidifier was housed in a water container and air circulation was maintained by two fan blowers. The front panel featured an LCD screen for parameter display.

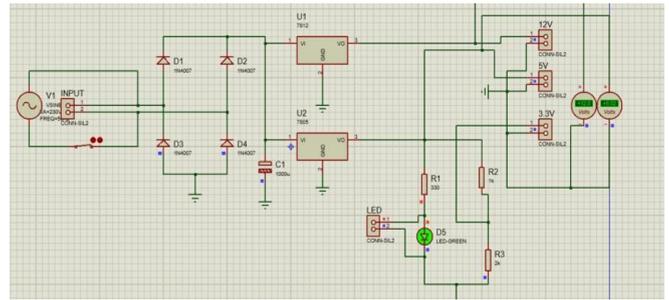




Figure 8: Incubator Prototype

IV. DISCUSSION AND RESULTS OF PROTOTYPE TESTING

TABLE I.

DHT 22 AND CLINICAL THERMOMETER TEMPERATURE READINGS

| Time (Minutes) | DHT11 Reading (°C)/ Incubator Reading | Clinical Thermometer Reading (°C)/Standard Reading |
|----------------|---------------------------------------|--|
| 5 | 27.2 | 27.1 |
| 10 | 29.8 | 30.2 |
| 15 | 35.6 | 35.5 |
| 20 | 36.9 | 37.3 |
| 25 | 34.7 | 34.6 |
| 30 | 35.4 | 35.3 |

Table I displays comparative temperature readings from the DHT22 sensor and a clinical thermometer, recorded at consistent 5-minute intervals for calibration. The calibration process was performed to align the readings of the DHT22 sensor with those of a standard clinical thermometer. This ensures accurate and reliable temperature measurements within the incubator. Both the DHT22 sensor and the clinical thermometer were placed in the same environment and temperature measurements were simultaneously taken from both devices. Any variations between the readings of the DHT22 sensor and the clinical thermometer were noted. By comparing these measurements, adjustments were made to the DHT22 sensor's readings to bring them in line with the reference thermometer. The calibration process involved determining the offset or correction factor required to compensate for any discrepancies between the DHT22 sensor and the clinical thermometer. This offset value was then applied to subsequent temperature readings from the DHT22 sensor to ensure accurate temperature measurements within the incubator. By performing the calibration process, the

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DHT22 sensor's accuracy was enhanced, allowing for reliable temperature monitoring and control within the incubator.

After Calibration the smart incubator system was successfully implemented and tested to evaluate its performance in controlling temperature and humidity, as well as its egg turning functionality. The temperature in the incubator was measured successively every 20 minutes for a duration of 200 minutes, with the set point set at 36 degrees Celsius. The initial temperature, representing the room temperature, was recorded at 27 degrees Celsius. Figure 9 summarizes the temperature readings at each 20-minute interval. At the start, the incubator temperature was lower than the set point due to the initial room temperature. However, it gradually reached and maintained the desired temperature range. Overall, the incubator successfully achieved and maintained the set temperature of 36 degrees Celsius for the majority of the 200-minute duration.

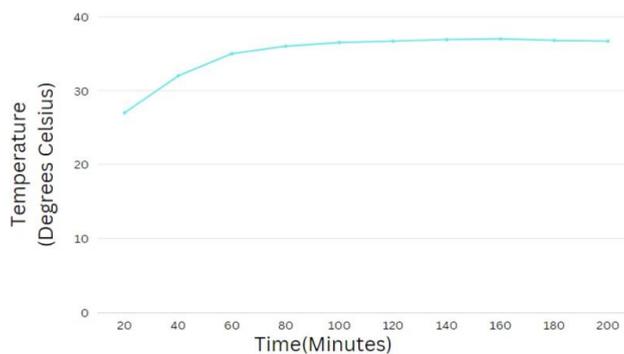


Figure 9: Final Temperature results in a graph

During testing, the smart incubator consistently maintained the temperature within the desired range. The heating lamp was turned on when the temperature fell below 36.5°C, and turned off when the temperature exceeded 38.5°C. This precise temperature control ensured optimal conditions for successful incubation. TABLE II presents the humidity control parameters and the corresponding control actions taken by the system.

TABLE II.

LIGHT BULB SENSOR DATA

| Control Parameter | Desired Range | Control Action |
|-------------------|---------------|---|
| Humidity | 55%RH - 65%RH | Humidifier ON (if< 55%RH) Humidifier OFF (if > 65%RH) |

The smart incubator effectively regulated the humidity levels within the desired range. The heater automatically turned on when the humidity dropped below 55%RH and turned off

when the humidity exceeded 65%RH. This ensured an optimal environment for successful incubation and hatching.

throughout the incubation period promotes embryo

Egg Turning Functionality

The system rotated the eggs at regular intervals throughout the incubation period. The initial rotation raised the egg trays by 45 degrees, creating an angle that provided a gentle and uniform distribution of heat across the egg surface. Subsequently, the system reversed the trays by 45 degrees in the opposite direction, bringing the eggs back to their original position. The eggs on a tray in the incubator are shown in figure 10 below.

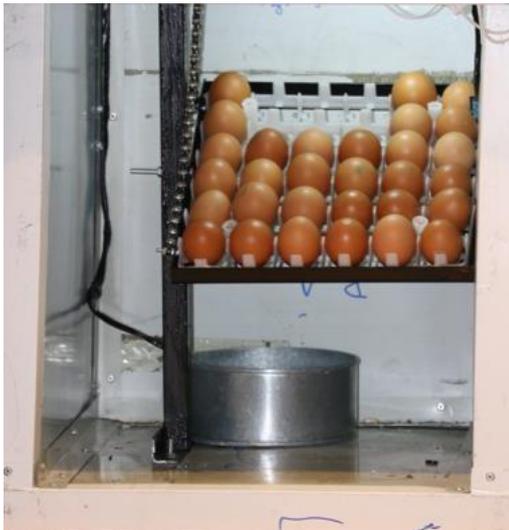
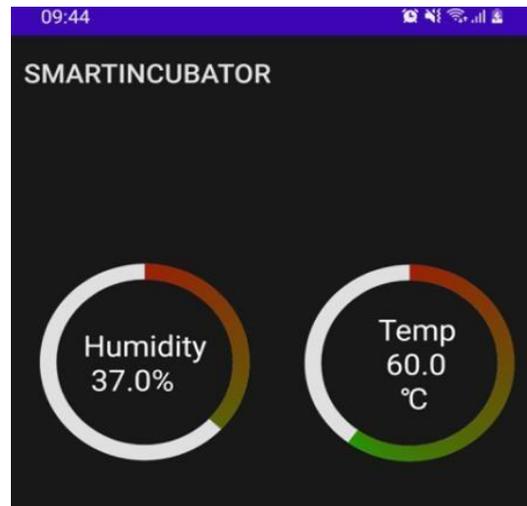


Figure 10: Eggs on a tray in incubator

The results obtained from the IOT smart incubator system demonstrated its effectiveness in controlling temperature and humidity levels, implementing an automated egg turning mechanism and creating optimal incubation conditions. The smart incubator system successfully maintained temperature levels within the desired range of 36.5°C to 38.5°C. This precise temperature control is essential for the proper development of embryos within the eggs(Boleli & Aidar De Queiroz, 2012). Fluctuations in temperature outside the optimal range can lead to compromised embryo development, reduced hatchability, and potential abnormalities in hatched chicks. By effectively regulating the temperature, the smart incubator system provides a stable and controlled environment for optimal incubation. The humidity control feature of the smart incubator system ensured that humidity levels remained within the desired range of 55%RH to 65%RH. Adequate humidity is crucial for maintaining the moisture balance within the eggs, enabling proper gas exchange and preventing excessive moisture loss(Humidity in Incubation, 2001). Maintaining optimal humidity levels

development, facilitates the movement of the embryo within the egg, and reduces the risk of dehydration. The precise humidity control achieved by the system contributes to favourable incubation conditions and supports healthy chick development (Maulana et al., 2023). Figure 11 below shows the displayed humidity and temperature values on the developed Application interface.

Figure 11: Developed Mobile Application Interface



V. CONCLUSION

Through the integration of IoT technology, the incubator system provided real-time monitoring and control of temperature and humidity levels, ensuring optimal incubation conditions. Also, the system's autonomous operation minimized human error and optimized resource utilization, resulting in potential cost savings.

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