SMART IOT-BASED EGG INCUBATOR FOR SMALL-SCALE POULTRY FARMERS

Samuel Owoeye
Department of Mechatronics
Federal University of Agriculture
Abeokuta, Nigeria
owoeyeso@funaab.edu.ng

Folasade Durodola
Department of Mechatronics
Federal University of Agriculture
Abeokuta, Nigeria
durodolafo@funaab.edu.ng

Chidinma Uche
Department of Computer science
Hallmark University, Ijebu-Itele
Ogun State, Nigeria
ocuche@hallmarkuniversity.edu.ng

Adedayo Akinade
Department of Mechatronics
Federal University of Agriculture
Abeokuta, Nigeria
akinadeadedayo1@gmail.com

Tobiloba Farinde
Department of Mechatronics
Federal University of Agriculture
Abeokuta, Nigeria
tobbyfarinzz@gmail.com

Omotolani Sulaimon
Department of Mechatronics
Federal University of Agriculture
Abeokuta, Nigeria
suaazini@gmail.com

ABSTRACT- Artificial egg hatcheries are being used to produce enough chicken products to satisfy the increased demand. Still, courtyard and poultry producers on a small scale are hampered by relying on natural incubation or industrial hatcheries to produce young birds for breeding. In this study, an incubator with an incandescent heat source for 4500 chicken eggs is developed and built. The incubator system's Arduino microcontroller, through relays, manages the heaters, air circulation fans, and tray-turning mechanism. A 16x2 LCD panel shows the incubator's current conditions, including temperature and humidity. The incubator system may be remotely monitored in real time with the help of the ESP32 CAM. The project aims to create an affordable, energy-efficient incubator that can be used in the hatchery process of eggs.

Keywords: Incubator, Hatching, Eggs, Microcontroller, IoT.

I. INTRODUCTION

Incubators have been in use for a very long period of which it has been used for numerous applications ranging from developing vaccines for deadly viruses to aiding in hatching chicken eggs. The Incubators have also been very helpful in molecular and cellular Biology experiments for medical advancements [1]. The Incubator has a chamber for regulating factors such as temperature, humidity, air renewal, egg turning, gas composition, and ventilation within that chamber [2]. The earliest incubators were used to keep chicken eggs warm and were discovered in Egypt and China.

As chicks could hatch from eggs without a hen sitting on them, the adoption of incubators changed food production and allowed chickens to produce more eggs faster [3]. Both early Egyptian and Chinese incubators were essentially large rooms heated by fires, where the operator turned the eggs at regular intervals to ensure even heat distribution. As time passed, other improvements were made to the incubator, like using wood stoves and a Reaumur thermometer to measure temperature [4]. The need for sustainable and environmentally friendly energy supply resources can never be overestimated for sustainability in poultry chick production. Such energy resource measures ought to be appealing, accessible, or replenished by nature, such as through the utilization of solar energy [5]. A special feature of solar-powered incubators is that they can harness solar energy using available materials and are adaptable to rural and urban poultry production [6]. Significant advantages of a solar-powered poultry egg incubator are that it could lead to a pollution-free environment, systems that are free from fire hazards, and the development of small, medium, to large-scale commercial incubators [7].

This work addresses the problem of the traditional incubator in that the operator is required to turn the eggs at regular time intervals and is also required to regulate the temperature of the incubator chamber. These actions require that an operator be always present to monitor the process, which might pose a problem. It seeks to construct an Automatic Egg Incubator, equipped with IoT capabilities for remote control and monitoring, thus, providing a means of checking the status of the eggs during the incubation period. In addition to improving the traditional incubator system, an alternative source of power (solar power) is provided for the system to solve the challenges of constant power supply.

II. RELATED WORKS

Around 3,000 years ago, in Egypt, humans are first known to have conceived the idea of incubating homes for the hatching of eggs. To maintain a constant temperature, they piled mud brick buildings with numerous small rooms and ovens on either side of the passages [8].

To make sure each egg was just perfect, Egyptian hatchers would place fertile eggs on their eyelids, which are the bodily parts that are most sensitive to temperature; they also rotate their eggs once a day to avoid the embryo sticking to a side [3]. These mud homes also contained shelves for burning charcoal, dung, and straw, which could be burned to raise the temperature in the incubator rooms. Eggs could be cooled and smoke could be released through vents in the room [8]. By covering the eggs with damp burlap in the last stages of incubation, the humidity was increased and controlled [9].

The Chinese started using a very similar incubation system in 246 BC, with brick furnaces and entire structures devoted to the hatching of hens. Chinese hatchery workers discovered that when chick embryos developed, they would start to emit heat, contrary to the Egyptians. They produced their heat by using the older, more developed eggs mixed in with young, underdeveloped embryos [4]. Modern incubators, which are spaces with temperatures always controlled to the tenth of a degree, were created by the middle of the 20th century as a result of advancements in electronics, thermostats, and other technologies as well as a rise in the number of poultry flocks. The computer rotated the massive racks once every hour, and the humidity was kept at the ideal level and varied for the best hatch rates [10]. Techniques for incubating artificial eggs have lately undergone a technological, economic, and social revolution. Amazing technological and scientific developments have made it possible to convert from manual incubation to massive incubation machines that hatch far bigger quantities of eggs with less labour and improve chick output year-round [2]. On the other hand, this incubation revolution generated costs associated with constructing more complex facilities and operating costs, such as energy and water, with maintaining the proper incubation conditions [11]. It also impacted social interactions, dividing society into producers and consumers. The fundamentals of artificial egg incubation have been known for decades. At this point, consideration had already been given to the incubation environment's temperature, humidity, and air replacement requirements, as well as the turning of the eggs [1].

III. METHODOLOGY

Temperature and Humidity Control System

The 100-watt bulb, shown in fig. 1 has an estimated efficiency of about 10 per cent, that is the lighting effect is about 10W while the remaining 90W is lost to heat generation [12]. Therefore, four 100-watt tungsten incandescent bulbs were used as the main source of heat in the project, which is well arranged to sustain the required temperature in the incubator within the pre-defined range.

Fig. 1: 100W Incandescent Bulbs

Fig. 2: 12 V DC Fan

Fig. 2 shows the extractor fans that are placed on the bulbs to extract the heat and thereafter distribute it uniformly. The inside temperature is monitored continuously by the temperature sensor (DHT11). This sensor transmits a feedback signal to the microcontroller, which activates the heater relays and regulates the ON and OFF states of the heat sources based on the information from the sensor (lamps). The controller sends out an ON signal to turn on the heat source if the detected temperature rises above 37.5 °C. However, the controller sends out an OFF signal to turn off any or all of the heat sources if the perceived temperature is higher than or equal to 37.8 °C.

Mechanical System

The incubator cabinet casing material is hardwood because it is preferable to softer wood [4]. The incubator can fill up to 12 eggs. The dimension of the incubator is 32cm x 45cm x47cm.

According to [7], the eggs' orientation and position during incubation affect how much water is lost. The eggs should be rotated at an angle of 180 degrees because this is more advantageous. The embryo must rotate to prevent adhesion to the eggshell and lower the mortality rate during incubation. The egg crate holders, or trays, are attached to rectangular frames that resemble window louvres and are mounted to the incubator cabinet at 3-cm intervals. A connecting bar connects the tray stands and a DC motor through a gear. The tray stands oscillate up and down like a seesaw when the engine rotates the gear. Specifically, the gear side is where the turning is done. Due to the circular nature of the gear, 180° of rotation implies up, and another 180°, down. Every three hours, a signal from the microcontroller triggers the DC motor, as shown in fig. 3, to rotate the trays at an angle of 15 degrees, which causes the eggs to rotate 180 degrees. The egg roller is made of an aluminium plate and an aluminium rod.

Electronic and Control System

This system provides power and control to every system for efficient operation. The components utilized include.

Power Supply

The majority of the components require DC power for their functioning, but a source of power is an AC supply. As shown in fig. 4, this power supply is a 12V 10A Switching Mode Power Supply (SMPS) that does the AC-DC conversion.

The technical specifications are:

i. AC Input Voltage: 110~230 AC @50 Hz.
ii. Stable Output Voltage (V DC): 24V.
iii. Output Current (Amp): 6.25.
iv. Output Power (Watt): 150.
v. Leakage Current: <3 mA at 240V AC

Microcontroller

Fig. 5 shows the microcontroller which is the heart of the system. It would receive signals from the sensors and send appropriate signals to the output. The controller to be employed is the ATMega328P microcontroller. It is an 8-bit integrated circuit based on AVR RISC architecture having 32 pins.

ATMega328P technical data:

i. Program memory size: 32 kB
ii. CPU Speed (MIPS/DMIPS): 20
iii. SRAM: 2 Kb
iv. Data EEPROM: 1 kB
v. Temperature range: -40 °C to 85 °C
vi. Operating voltage: 1.8 to 5.5 V

I2C Liquid Crystal Display (LCD) Screen

This helps to display important parameters of the system while in operation. Parameters include temperature and humidity levels, days in operation, and voltage levels. This provides the user with statistics that could be recorded and used for future decision-making.

Fig. 3: Geared DC Motor

Figure 4: 12 V 10 A SMPS Power Supply

Figure 5: ATMega328P Microcontroller Chip

Specifications of the LCD screen (fig. 6) to be used are:

i. Screen Type: Dual colour LCD
ii. Screen Resolution: 128 x 64 Pixels
iii. Screen Active Area: 47.1 x 26.5 mm
iv. Individual Pixel Size: 0.33 x 0.33 mm
v. Communication Mode: I2C (100 Kbit/s and 400 Kbit/s)
vi. Controller: STM8S005KBT6
vii. Operating Frequency: 16 MHz
viii. Weight: 20g

DHT 11 Sensor

This helps to monitor the humidity and temperature levels in the incubator cabinet. It provides necessary signals that aid the actuation of the microcontroller for efficient incubation actions. One often used temperature and humidity sensor is the DHT11 (see fig. 7). The sensor includes a dedicated NTC for temperature measurement and an 8-bit microprocessor for serial data output of temperature and humidity information. Additionally factory calibrated, the sensor makes it simple to integrate with other microcontrollers. The sensor has an accuracy of 1°C and 1% and can measure temperature from 0°C to 50°C and humidity from 20% to 90%.

The technical specifications are:

i. Operating Voltage: 3.5V to 5.5V
ii. Operating current: 0.3mA (measuring) 60uA (standby)
iii. Output: Serial data
iv. Temperature Range: 0°C to 50°C
v. Humidity Range: 20% to 90%
vi. Resolution: Temperature and Humidity both are 16-bit
vii. Accuracy: ±1°C and ±1%

Fig. 6: 16 x 2 I2C LCD Screen

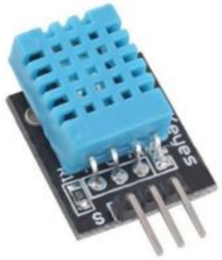

Fig. 7: DHT 11 Sensor

Relays

Relays are electromechanical switches that electrically or electromechanically open and close circuits. By opening and closing contacts in another circuit, relay s manage one electrical circuit. Based input signals from the controller, assist in controlling the heaters

Technical specifications are:

i. Trigger Voltage (Voltage across coil): 5V DC
ii. Trigger Current (Nominal current): 70mA
iii. Maximum AC load current: 10A, 250/125V AC
iv.Maximum DC load current: 10A, 30/28V DC
v. Compact 5-pin configuration with plastic molding
vi.Operating time: 10msec Release time: 5msec
vii. Maximum switching: 300 operating/minute (mechanically)

Limit Switch

Limit switches are used to automatically detect or feel the presence of an object as well as to track and signal when an object's movement restrictions have been exceeded. This switch is attached to the cabinet door and acts as a fail-safe mechanism to ensure the door is well shut. If the door is not shut correctly, the limit switch detects this and ensures the incubation process does not start to avoid heat loss to the outside environment.

Solar Panel

The most important feature of the incubator is the uninterrupted heat supply. The inadequacies of electricity distribution companies necessitated the use of solar panels. This provides an alternate and uninterrupted power supply to the system as it converts energy from the sun into electrical energy. 20W solar panels would be deployed.

The technical specifications are:

i. Panel Size: 435 x 35 x 25 mm
ii. Weight: 2.2kg
iii. Peak Power: 20w
iv. Open Circuit Voltage: 21.4V
v. Short Circuit Current: 1.32A
vi. Power Allowance Range: 5%
vii. Max Power Voltage: 16.94V
viii. Max System Current: 1.18A
ix. Max System Voltage: 300VDC
x. Number of Cells: 36

3.3.8 Battery

This acts as a storage bank for the solar panels' energy retained from the sun. The battery to be used is a 12V 18AH Lead Acid battery.

Technical specifications are:

i. Nominal Voltage: 12 V
ii. Rated Capacity: 18 AH
iii. Approx. Weight: 5.24 kg
iv. Charge: 0 °C (32 °F) to 40 °C (104 °F)
v. Storage: -20 °C (-4 °F) to 40 °C (104 °F)
vi. Capacity: 25 °C (77 °F) 20-hour rate (0.9 A) 18AH

Solar Charge Controller

This regulates the rate at which the batteries charge. This helps to ensure there is no overcharging or inadequate charging. It regulates the voltage and current received from the solar panels which are going to the battery and prevents it from completely getting discharged, thereby increasing battery life.

The technical specifications are:

i. Operating temperature: 0 °C to 50 °C
ii. Storage temperature: -10 °C to 60 °C
iii. Charge controller type: Two-step charging algorithm
iv. Battery temperature compensation: -4 mV to -5 mV/°C/cell
v. Solar Module size (Max): 40 W

Remote Monitoring and Control

The extra capabilities of the incubator system to be developed are remote operations. This enables monitoring system parameters from a remote location and easy access to control parameters like temperature, humidity, the rate at which eggs are turned, or even stopping the whole process.

ESP32 Camera

ESP32-CAM is a not-too-expensive development board featuring a Wi-Fi camera. Its built-in PCB antenna enables video streaming at various resolutions. It allows for real-time remote viewing of the incubation processes. The camera module is shown in figure 8.

The technical specifications are:

i. Dimensions : 40.5 mm x 27 mm x 4.5 mm
ii. Weight: 20 g
iii. Package: DIP-16
iv. SPI Flash: Default 32 Mbit
v. RAM: 520 KB SRAM + 4 MB PSRAM
vi. Bluetooth: Bluetooth 4.2 BR/EDR and BLE standards
vii. Wi-Fi: 802.11 b/g/n/
viii. Support interface: UART, SPI, I2C, and PWM
ix. UART Baud rate: Default 115200 bps
x. Spectrum Range: 2412 ~2484MHz
xi. Transmit Power: 802.11b: 17±2 dBm (11Mbps); 802.11g: 14±2 dBm (54Mbps); 802.11n: 13±2 dBm (MCS7)
xii. Receiving Sensitivity: CCK, 1 Mbps: -90dBm; CCK, 11 Mbps: -85dBm; 6 Mbps (1/2 BPSK): -88dBm; 54 Mbps (3/4 64-QAM): -70dBm; MCS7 (65 Mbps, 72.2 Mbps): -67dBm
xiii. Operating Voltage: 5 V
xiv. Operating Temperature: -20 ℃ to 85 ℃

ESP8266 Wi-Fi Module

A Wi-Fi module called the ESP8266 is used to manage devices online (fig. 8). It can be programmed to operate independently or in conjunction with a microcontroller like Arduino. The Module is a self-contained SOC that can connect any microcontroller to a Wi-Fi network thanks to its inbuilt TCP/IP protocol stack. The ESP8266 has two options: it can run applications directly or can delegate all Wi-Fi networking tasks to another application processor. The technical specifications are:

i. 802.11 b/g/n
ii. Wi-Fi Direct (P2P), soft-AP
iii. Integrated TCP/IP protocol stack
iv. Integrated TR switch, balun, LNA, power amplifier, and matching network
v. Integrated PLLs, regulators, DCXO, and power management units
vi. +19.5dBm output power in 802.11b mode
vii. Power down leakage current of <10uA
viii. 4MB Flash Memory
ix. An integrated low-power 32-bit CPU could be used as an application processor
x. SDIO 1.1 / 2.0, SPI, UART
xi. STBC, 1×1 MIMO, 2×1 MIMO
xii. A-MPDU & A-MSDU aggregation & 0.4ms guard interval
xiii. Wake up and transmit packets in < 2ms
xiv. Standby power consumption of < 1.0mW (DTIM3)

The circuit diagram of the smart incubator is shown in fig. 9.

Fig. 8: ESP32 Camera Module

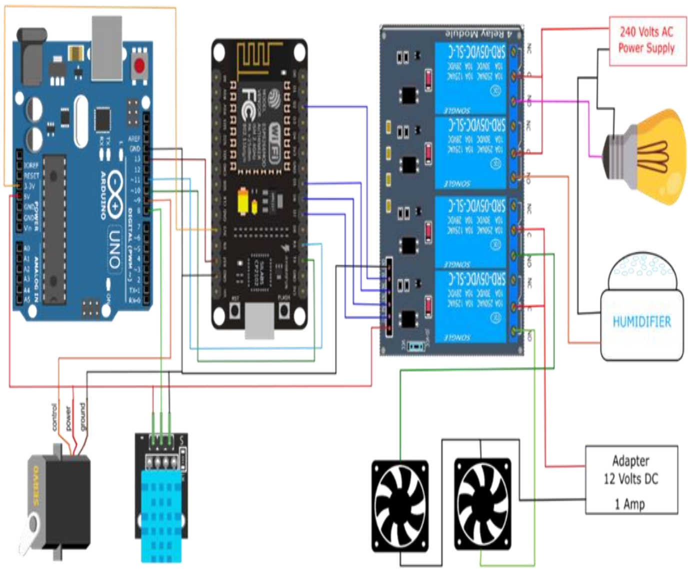

Fig. 9: Circuit Diagram of the Incubator System

IV RESULTS AND TESTING

Results

The incubator designed in this work (Plate 1) was utilized in hatching 30 eggs, and a hatchability rate of 93.3% was recorded. This hatchability rate signifies an improved efficiency over the works of [13] and [11] who reported hatchability rates of 82.6% and 33%, respectively.

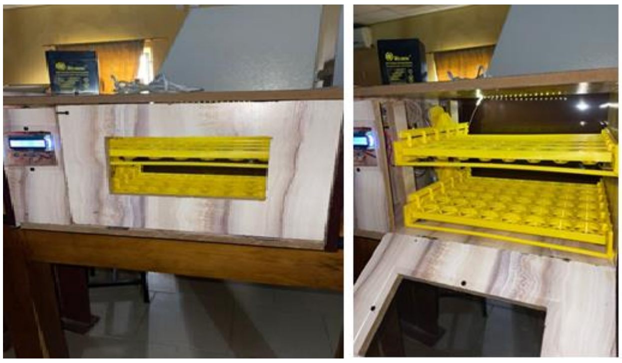

Plate 1: Constructed Incubator

Plate 2: Solar Power as an Alternate Power Source

The incubator was put to a functionality test, and the following result was obtained in one run: 30 fertile Eggs, 28 hatched eggs, and 90.33% hatchability. Also, during the incubation period, the time response of the thermocouple was observed and recorded. This represents the time elapsed during the time the sensor took to respond to a change in temperature of 39°C (either increment or decrement) while maintaining a constant temperature of 39°C. This time response was 17 to 20 seconds.

Plate 3: Eggs Placed in Incubator for Hatching

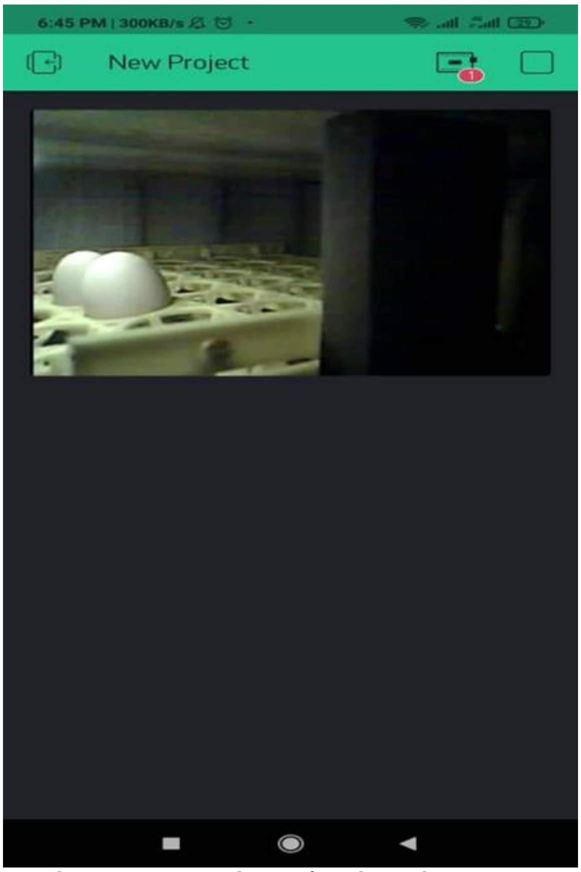

Plate 4: Remote Visual Image from the Incubator System

Testing of the Incubator

To obtain a higher level of accuracy, the incubator was isolated from weather changes during testing by placing it indoors. The humidity and temperature levels were set to 55% and between 37°C - 39°C, respectively. Also, the ambient temperature and humidity values were recorded to be 33°C and 42%.

Plate 5: Incubator Display showing Temperature and Humidity

To ascertain the functionality of the incubator, 30 fertile, healthy, and mature eggs were collected from a breeder farm in Ogun state, Nigeria. The temperature and humidity levels were controlled and continuously monitored (hourly) through the LCD for an incubation period of 21 days. At every interval of one hour, and four minutes, all the eggs underwent a turning process at an angle of 40°. This turning process was stopped on the 18th day of incubation. During the incubation process, the eggs were regularly candled to estimate the size of air space and have an overview of the rate of weight loss of the egg content. This process was also carried out to observe the embryo development closely and to ensure the safe removal of the infertile or dead embryo from the incubator.

As expected, the hatching of the eggs occurred on the 21st day. Lose observation was made during the hatching process, and some of the chicks were assisted in hatching. These chicks were observed unable to break their shells after a 12-hour duration. According to 14, this assistance was rendered by breaking the larger ends of the eggs and creating two holes.

The hatchability of the incubator was determined by equation 1 [15]:

$$Hatchability = \frac{\text{Number of Hatched eggs}}{\text{Number of eggs}} \times 100 \quad (1)$$

The system was checked hourly throughout the testing period, recording the humidity and temperature readings on the LCD panel in the incubator. This made it possible to calculate the pace at which heat rose from the incubator's starting temperature to its steady state temperature of 37.5°C. Additionally, the relationship between the incubator's humidity and temperature was to be ascertained.

Finally, we were able to estimate the incubator's power usage by determining the heaters' duty cycle. Figures 10 and 11 illustrate the link between the incubator's temperature and ambient temperature, respectively, and the incubator's humidity level and ambient humidity, respectively.

First, it was possible to see from the temperature graph that the incubator's temperature rose from 30.5°C to 37.8°C in the first two hours. Following this, the incubating temperature did not significantly deviate from the set point temperature (37.5°C). The interior incubator temperature stayed rather steady after the first two hours, oscillating between 37.1°C and 37.8°C, despite the ambient temperature fluctuating over the 24 hours between a minimum of 24°C and a maximum of 34°C. This shows that the incubator's walls barely lose any heat through conduction.

Second, the internal humidity of the incubator varied between 53% and 68%, while the environmental humidity varied between 40% and 73% for the testing period, showing that the designed incubator can maintain the average relative humidity needed for effective hatching.

Additionally, the heater's duty cycle for the period under observation was 0.25 (25%). That is, just 25% of the observation period saw the heaters in the ON state, demonstrating the incubator's exceptional thermal capacity and energy efficiency.

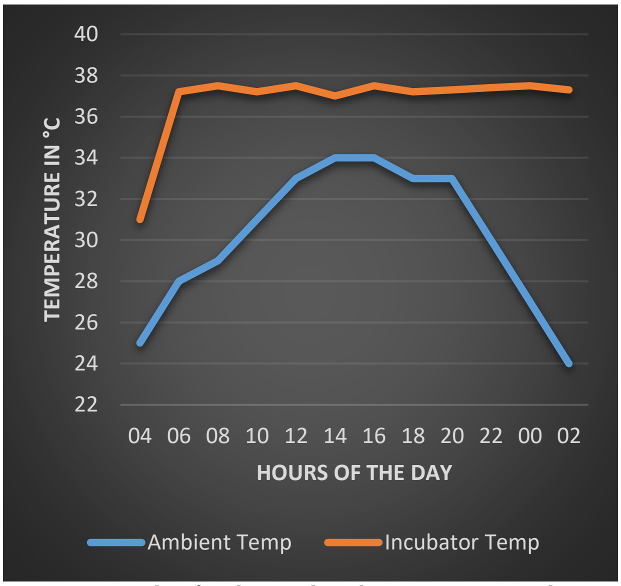

Fig. 10: Plot of Ambient and Incubator Temperature Values

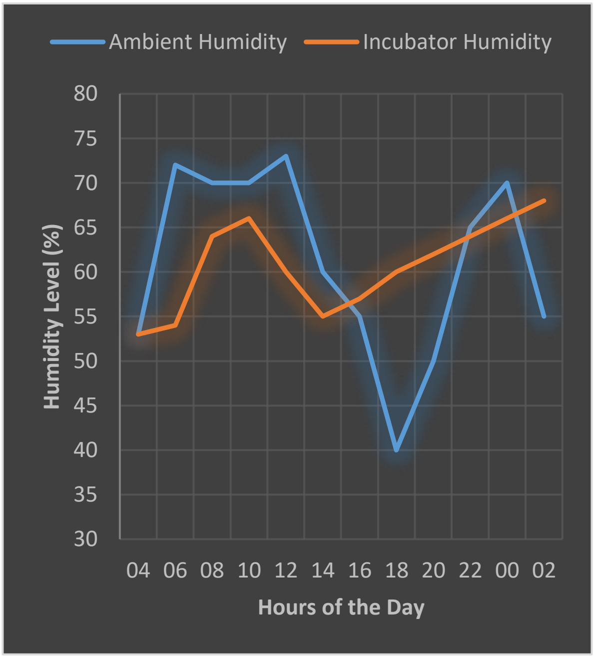

Figure 11: Plot of Ambient and Incubator Humidity Levels

V. CONCLUSION

In the construction of an automatic incubator, the heat transfer properties of an incubator cabinet were investigated. The materials, size, and other equipment were chosen after researching the incubator's reference characteristics. Using a mercury thermometer and the reference value Testo 625, the accuracy of the measuring devices was evaluated [9]. Both the temperature sensor error and the humidity sensor error were less than 1.1% and 5.3%, respectively. This demonstrates the accuracy of the sensors utilized as reliable instruments and the effectiveness of the measurement strategy used in the incubator's development. This study uses less energy and does not necessitate the constant presence of the operator. It was centred on the design, building, and performance evaluation of an autonomous turning egg incubator. If the device is successful, it will promote chicken farming nationwide and abroad.

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