IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 13, Issue 12, December 2023, ||Series -I|| PP 57-66

Design of Power Efficient Low-Cost Egg Incubator For Small Scale Industry

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Received 12 December 2023; Accepted 26 December2023

Abstract
Egg incubation is a critical process in the poultry industry. It plays a vital role in the production of chicks for business including meat and egg production. Egg incubation has come a long way from the conventional approach of suing broody hens to the use of modern scientific approach of artificial egg incubation. Egg incubators are those devices which are designed to simulate the natural process of egg hatching by controlling the incubation parameters such as temperature, humidity etc. These machines can be used in industries as well as by hobbyists. In this paper, a power efficient low-cost chicken egg incubator was designed using a 100 W filament lamp, an ESP 32 microcontroller, DHT 11 temperature sensor and humidifier. IOT cloud integration was done to enable the monitoring of the incubation parameters through mobile devices such as temperature and humidity. Automatic egg tilting system throughout the incubation period was integrated to enhance the success rate of fertilization of eggs. A dead band control system was implemented to obtain optimum power and energy efficiency. The recommended temperature of 36–37-degree Celsius and humidity between 60-70 % was maintained during the incubation period. The 100 chicken eggs that were tested during the entire incubation period provided a hatching rate of 98%. 6 eggs out of 100 eggs were not fertilized properly and we were able to obtain 92 chickens out of 94 eggs from the purely fertilized eggs.

I. Introduction

An egg incubator is a system that creates the perfect condition for an egg to incubate and hatch successfully. The ideal environment for an egg to successfully incubate and hatch is produced by an egg incubator. It's intended to maintain the optimal amounts of incubation humidity and temperature. The system discusses the design of an egg incubator that combines both the setting and hatching phase. The system makes use of Wi-Fi technology combined with a mobile application to control all the necessary parameters inside the incubator. The incubator explained here serves the technicalities of adding the egg tilting/rotation, maintaining humidity, temperature, and provision of good ventilation inside the incubator.

The delicacy of artificial incubation is quite challenging since the slight variation in incubation parameters of temperature, humidity, and tilting timings may result in unsuccessful hatching. So, to have a successful hatching rate, these parameters should be well maintained. An incubation period of 21 days is required to hatch the eggs into a chicken. The egg incubator combines both the setting and hatching phases. For the first 18 days of the egg incubation period, eggs must be placed in the setter where the eggs are turned every hour. After the setting period eggs are physically moved to the hatcher where eggs lay still for the last 3 days. During this period there should be a suitable condition for the embryo development, therefore, it is necessary to constantly monitor and control the natural environment for the best yield. This can be achieved by employing technology incorporated with a microcontroller to activate the heat sources or cooler, maintain the humidity level, tilt the eggs regularly, and regulate the good airflow. Here, a closed-loop control system powered by an ESP32 microcontroller integrated with IOT is discussed. The desired temperature of 36-37°C, and humidity level of around 54-60% for the first 18 days, and temperature need to drop to 36°C, and humidity level increase to around 80% until the embryo matures and emerges is maintained. So, all adjustments can be achieved through the means of filament lamp, cooling fan, 2 humidifier, and temperature sensors. If the heat source increases beyond the threshold i.e., 37, automatically the heat source is turned off and the exhaust is turned on and when the temperature decreases below 36, the heat source is turned on to maintain the optimum temperature. Similarly, the humidity level is also maintained by a similar approach. Any change in the humidity is sensed by the humidity sensor and the sensor sends this signal to the microcontroller which then, according to the instruction fed will act to maintain the humidity level inside the incubator.

II. Material and Methods

The process of designing the egg incubator system began with the creation of a prototype using wooden frames and testing it with a single egg, which proved to be successful in hatching. The final system was constructed using Aluminum Composite panels and tested with 100 eggs. The incubator system was equipped with various components, including an ESP 32 microcontroller, DHT11 sensors, humidifiers, exhaust fans, ventilation, and an egg tilting mechanism. Temperature sensors were strategically placed to monitor the optimal temperature within the incubator. The egg tilting mechanism was achieved by integrating NIMA motor, gears, and chains.

Study Design: Design and hardware fabrication of egg incubator

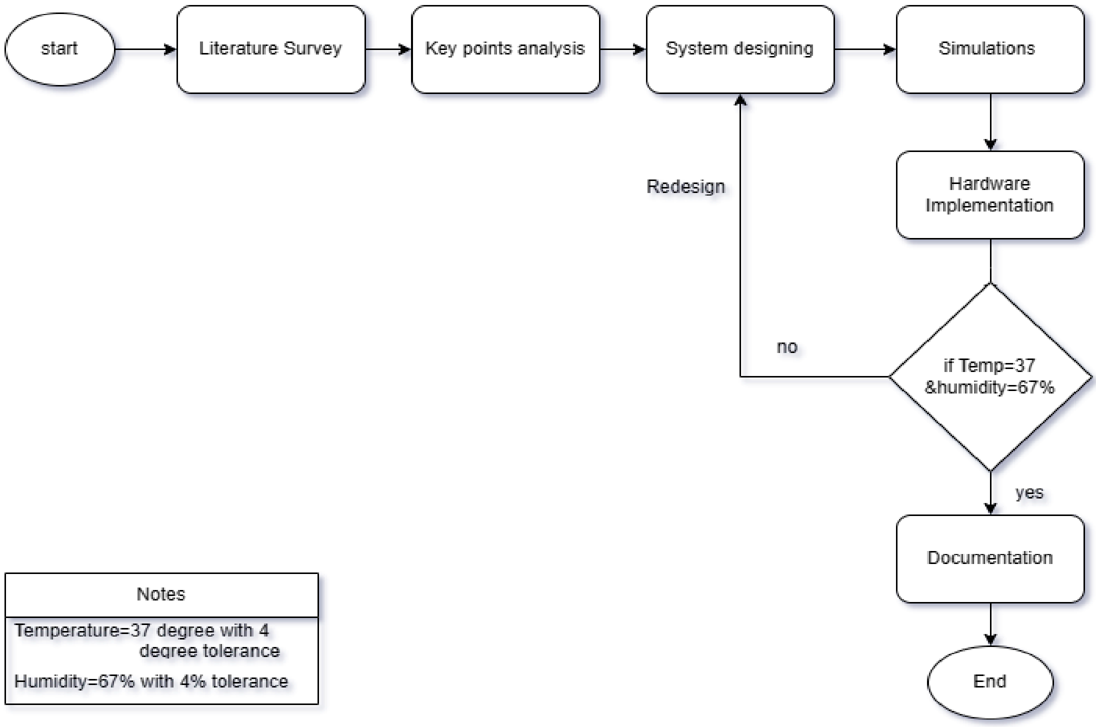
Study Location: Electronics lab at Departments of Electrical and electronics Kathmandu University with the supervision of assistance professor Kamal Chapagain, PhD.

Study Duration: January 2023 to July 2023.

Procedure and methodology

The microcontroller is a critical component in the coordination and regulation of all devices and sensors within the incubator, enabling the precise and timely delivery of optimal incubation conditions for poultry eggs. It effectively controls the filament lamp within the heating chamber, which is responsible for generating and regulating the heat required for incubation. Additionally, the microcontroller maintains a consistently controlled environment within the incubator chamber, carefully managing both relative humidity levels and temperature parameters throughout the entire incubation process for poultry eggs. The following figure explains the methodology applied:

Figure 1:Workflow Diagram



1.Setup, Incubation System Configuration and Hardware Fabrication

The model of the egg incubator is equipped with the ESP-32 microcontroller, which serves as the central control unit for the overall incubation system. Operating within a targeted temperature range of 37°C to 38°C and maintaining humidity levels between 65% and 75%, the microcontroller ensures precise regulation of these crucial parameters, creating an ideal environment for egg incubation. To accurately monitor temperature and humidity, the incubator employs DHT11 capacitive sensors. These sensors are strategically positioned at different locations within the incubator to capture comprehensive data on temperature and humidity levels. By utilizing two sensors placed at distinct positions, their readings are averaged to provide an overall insight into the incubation environment, ensuring accurate monitoring and control.

In addition to temperature and humidity regulation, the incubator design incorporates an exhaust fan and a motorized egg rotation mechanism. The exhaust fan serves a dual purpose: facilitating cooling and promoting proper ventilation within the incubator. This helps prevent heat buildup and ensures a consistent supply of fresh air, creating a conducive environment for egg development. The egg rotation mechanism plays a vital role in ensuring successful incubation. By periodically rotating the eggs, the mechanism prevents the embryos from adhering to the inner walls of the eggshells. This rotation minimizes the risk of improper development and even promotes distribution of the embryos, facilitating optimal gas exchange and nutrient diffusion. The microcontroller controls the rotation mechanism based on predetermined time intervals, ensuring regular repositioning of the eggs throughout the incubation process.

Table 1: CAD model of the EGG Incubator

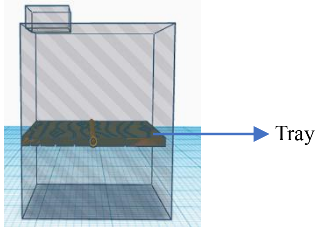
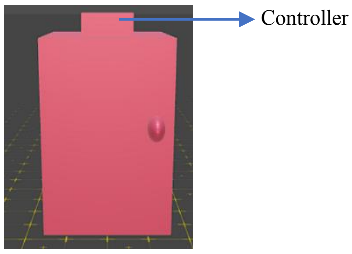
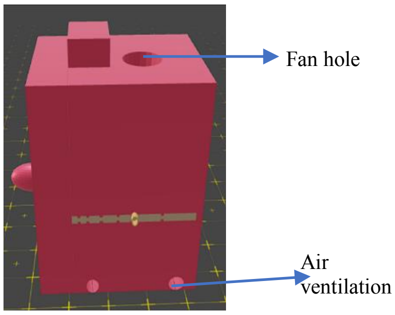
Module	Design	Description
Tray Support		The tray support consists of a vertical frame, tray holders, connecting knobs, and a movable bar.
Door Panel		The incubator's door panel is the access point for opening and closing.
Side panel		The side panel of the incubator displays one exhaust hole and two ventilation holes, providing proper air circulation and temperature control.

Figure 2: EGG incubator Prototype

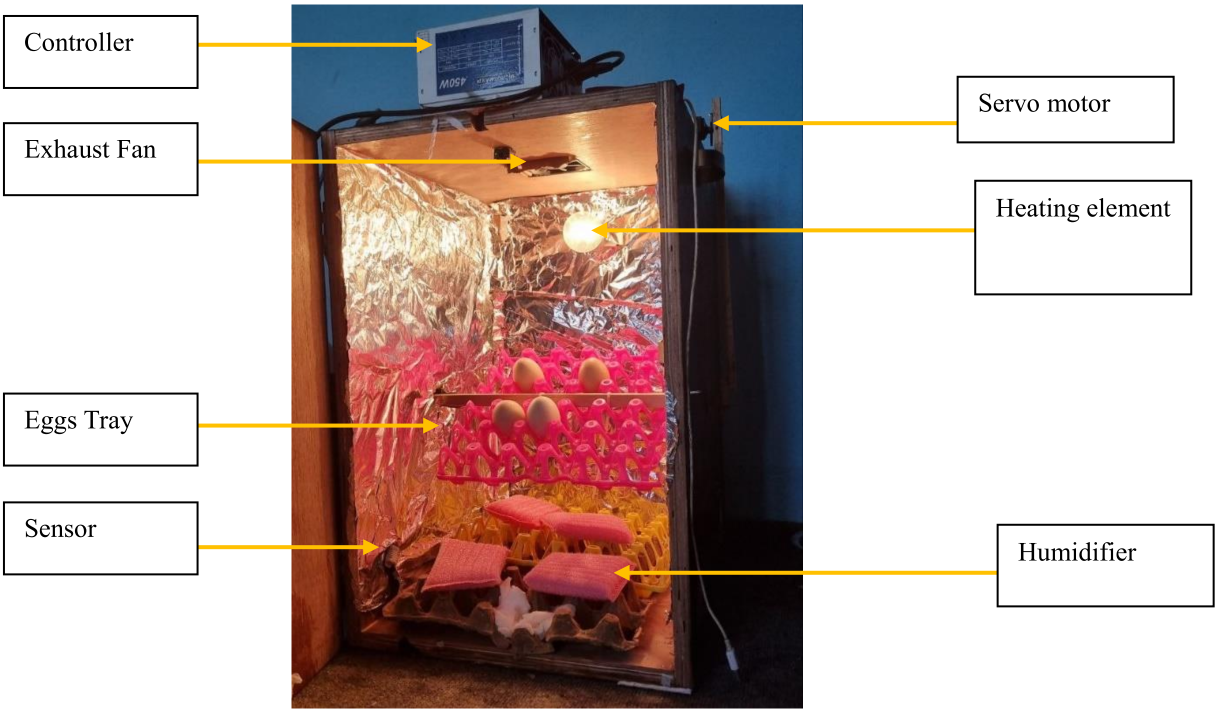


Figure 3:Final Design of EGG Incubator

By integrating the ESP-32 microcontroller, DHT11 capacitive sensors, an exhaust fan for ventilation and cooling, and an egg rotation mechanism, the egg incubator design achieves precise temperature and humidity control, effective ventilation, and prevents embryo adhesion.

2. Circuit Design and Control System Configuration

The circuit design incorporated a microcontroller as the central control unit, overseeing the regulation and operation of all components. The control system was specifically tailored to maintain optimum temperature and relative humidity levels within the enclosure. An electrically powered incubation system, powered by an AC source, was employed to enable seamless operation throughout the experiment.

The ESP32 microcontroller was selected as the primary control unit, efficiently distributing control signals to individual sensors and motors. The temperature sensor detected the internal temperature within the enclosure and relayed the data to the microcontroller. The microcontroller, in turn, interfaced with heat sources, such as bulbs, and a humidifier.

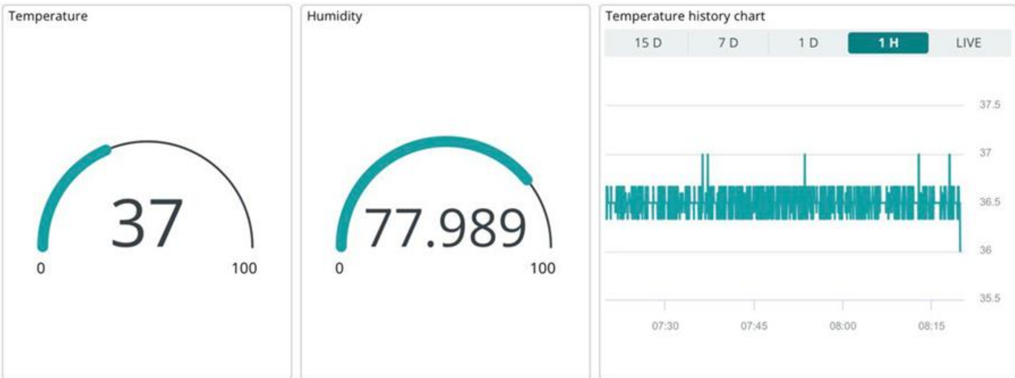
To provide power to the microcontroller and motor driver, a 240V AC source was converted to a stable 5V DC output using an adapter. The microcontroller was connected to the humidity sensor, fan, and swirl mechanism, facilitating comprehensive control over these components. In cases where the temperature exceeded the maximum threshold of 38°C, the microcontroller automatically shuts down the bulbs. Conversely, the bulbs were activated when the temperature dropped below the lower limit of 37°C.

The microcontroller efficiently managed the swirl mechanism, ensuring controlled and periodic swirling motion. An RTC module was utilized to synchronize the microcontroller and enable regular intervals of one hour for the swirl mechanism operation. This systematic approach maintained consistent and optimized functionality of the incubator system throughout the incubation process.

Remote Monitoring Through IoT Cloud Integration

Following the incubator's setup, an IoT cloud platform was implemented to facilitate remote access and display of internal parameters within the incubator. Through this cloud-based solution, users gained the ability to remotely monitor crucial information regarding temperature and humidity levels. These real-time data points were readily available for analysis and further examination.

Figure 4:Temperature and Humidity Observation through IoT Cloud



III. OBSERVATION AND RESULTS

Data Collection and Remote Monitoring

Temperature and humidity readings were systematically recorded at regular 30-minute intervals over a 24-hour period to obtain a comprehensive dataset of the incubator's internal environment throughout the entire incubation process. These data are accessed from the IoT cloud.

Table 2: Temperature/Humidity Data

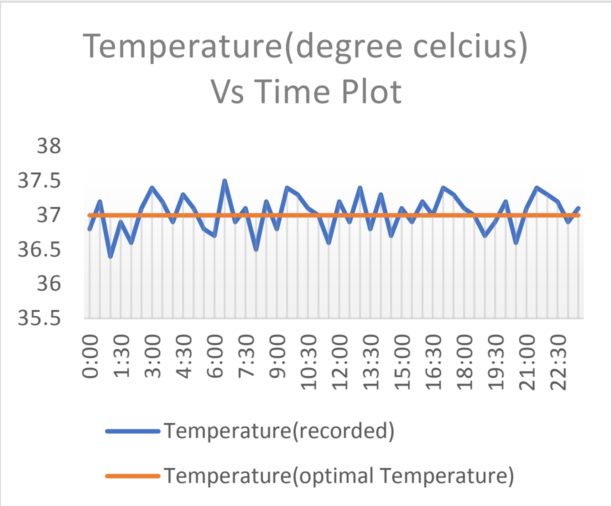
Time(hr:min)	Temperattture(degree C)	Humidity (%)
0:00	36.2	68
0:30	36.5	70
1:00	36.7	69
1:30	36.8	71
2:00	36.5	72
2:30	36.4	73
3:00	36.3	75
3:30	36.2	76
4:00	36.4	77
4:30	36.6	76
5:00	36.7	75
5:30	36.8	74
6:00	36.9	72
6:30	37	71
7:00	36.9	70
7:30	36.8	69
8:00	36.7	68
8:30	36.6	67
9:00	36.4	66
9:30	36.2	67
10:00	36.1	68
10:30	36.3	69
11:00	36.4	70
11:30	36.5	71
12:00	36.7	72
12:30	36.9	73

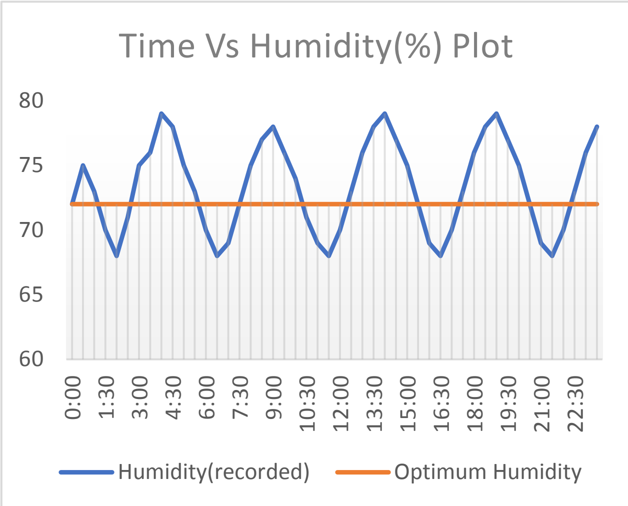
Performance Evaluation and Phase I testing

In the performance evaluation, the collected data from the incubator was compared to the optimum temperature range. Graphs of time versus temperature and humidity were created using the 24-hour data at 30-minute intervals. The analysis focused on identifying variations and deviations from the desired conditions. This evaluation provided valuable insights to optimize the incubator's design and operation for improved performance in egg incubation.

The following is the graph of Phase-I testing day 2.

Figure 5 : *24 Hour Time vs Temperature/Humidity Plot*



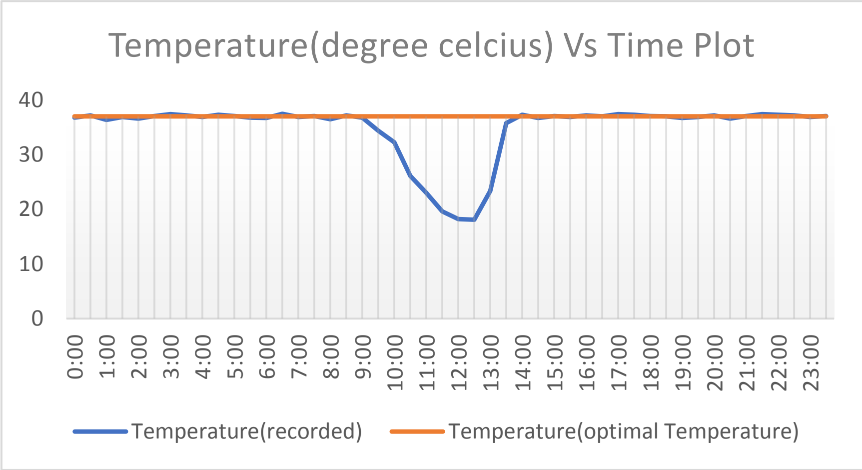


Upon analyzing the data collected over a 24-hour period, it is evident that the temperature and humidity levels were consistently maintained around the optimum values. The recorded readings indicate that the incubator effectively regulated the internal environment, ensuring that it remained within the desired range.

System Analysis and Troubleshooting

During Phase-I testing, the incubator system demonstrated satisfactory performance until day 10. However, an unexpected power outage occurred, lasting for over 3 hours. Therefore, the internal temperature of the incubator dropped below 21 degrees Celsius for a duration exceeding two hours. This drastic temperature fluctuation had an adverse impact on the embryos, resulting in their mortality.

Figure 6 : Temperature vs Time plot during power failure

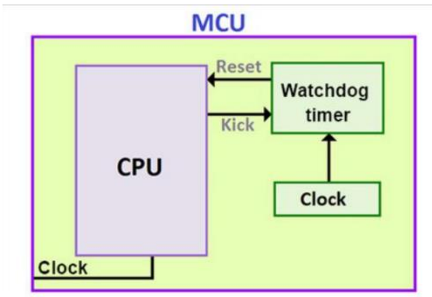


Based on the findings of the literature survey, it was established that prolonged exposure of the incubator's internal temperature below 21 degrees Celsius for more than one hour would result in embryo mortality. During a power outage lasting three hours, an internal examination of the eggs was conducted to assess their viability.

Figure 7 : Chicken Death Due to Power Failure

Watchdog implementation

An additional observation made during testing was the absence of a watchdog in the microcontroller program. The absence of a watchdog in the microcontroller program had significant consequences for the project. Without a watchdog, unexpected program crashes could occur due to software bugs or external factors, leading to system disruptions and potential data corruption. To address this issue, a watchdog mechanism was implemented in the microcontroller. The watchdog continuously monitored the program's execution and triggered a system reset if the timer expired before being reset by the program. This ensured system stability and reliability by preventing the microcontroller from getting stuck in an unrecoverable state. The watchdog also facilitated the detection and isolation of software bugs, enabling timely resolution and improving overall system performance. With the deployment of the watchdog, the project achieved enhanced resilience, fault tolerance, and data integrity.



Phase II Testing

In Phase II of testing, efforts were made to address the issues encountered in the previous phase, including the implementation of a watchdog system, and mitigating the jerking of the servo motor during the reset process. These problem-solving measures aimed to enhance the stability, reliability, and overall performance of the incubator system.

Embryo Development and Viability Assessment through Egg Candling

Egg candling was performed to assess embryo development and viability. Clear vascular patterns were observed, indicating healthy blood vessel formation and nutrient exchange within the developing embryos. No abnormalities were detected, confirming a favorable incubation environment for optimal embryo growth and viability. The results from egg candling affirm successful embryo development during the incubation process.

Figure 8: EGG candling of 3rd Day Egg

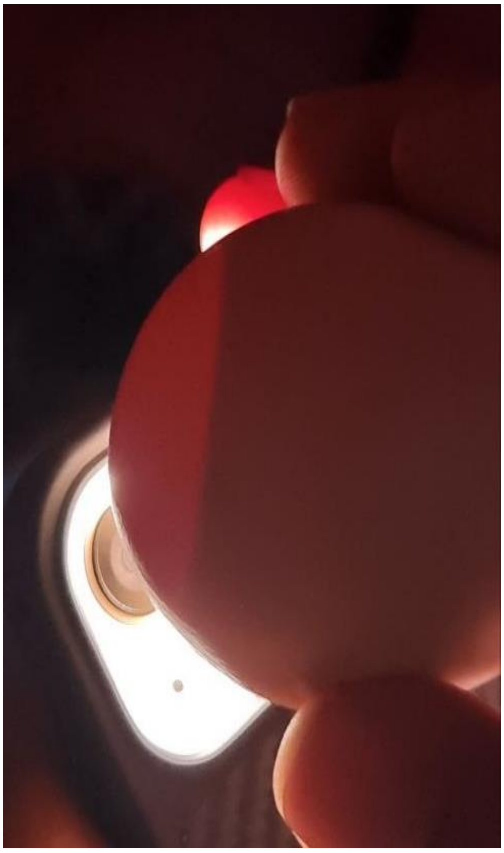
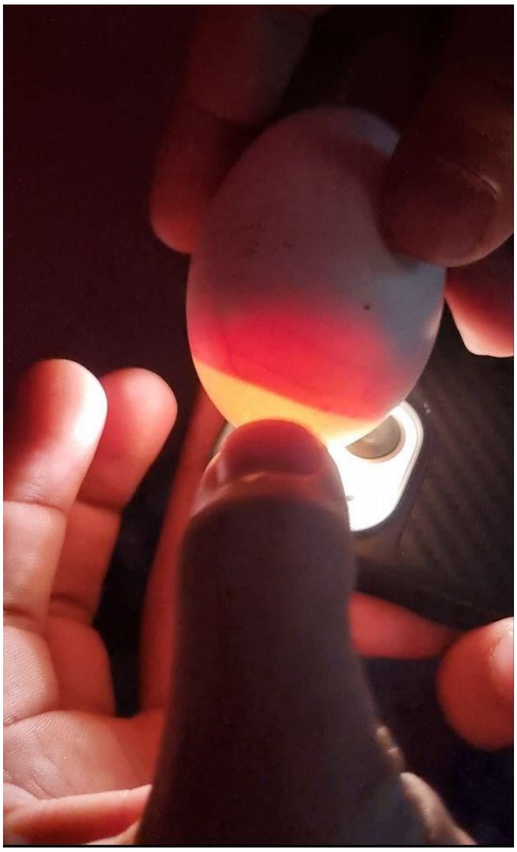


Figure 9: EGG candling of 9th Day Egg



Efficiency Testing

The second phase testing was completed after the 21 incubation days where 100 eggs were tested. From the 100 eggs 6 eggs were not fertilized properly. Out of the remaining 94 eggs 92 eggs were able to hatch good quality chickens.

Efficiency in percentage = $\frac{94}{96} \times 100\%$ = 97.91 %

97.91 % efficiency was obtained from the egg incubator after the 21 days of incubation.

Figure 10: Chicken Hatched after 21 Days of Incubation

IV. Discussion

The development and research carried out at Kathmandu University in the field of integrating agriculture and technology has yielded a low-cost, high-efficiency smart egg incubator. The project's foundation lies in the utilization of locally available resources, ensuring cost-effectiveness and accessibility for farmers in the region.

The use of 2 60 W filament lamp makes the egg incubator really power efficient and helps in increasing the efficiency of chicken hatching rate. The filament lamp slightly shows the behavior of sunlight which simulates the natural broody process in the incubation chamber. The dead band control system increases the reliability and sustainability of the system. The strategic placement of temperature sensors inside the egg incubators gives us the realistic temperature inside the egg incubator. Since the average temperature can be made around 36-37 degree Celsius inside the egg incubators, 500 eggs can be adjusted inside the final design of the egg incubator. The egg tilting mechanism has increased the hatching efficiency rather than having to tilting mechanism at all.

Despite being power efficient, it has been seen that the power outlet just for one hour can be fatal for the eggs inside the incubator. Therefore, a backup system is important for the proper functioning of the system. The Nepalese market offers egg incubators with double the price compared to what we can offer for the same egg capacity, and these incubators also have higher power ratings. In the research and design of this egg incubators, the integrations of fundamental electronics component and engineering technique such as ESP32, Filament Lamp, Dead Band Control System, Egg Tilting Mechanism has made us possible to achieve an extremely high efficiency of 97 % for the egg incubator with a very low power rating.

V. Conclusion

This introduces a design of egg incubator that enhances the efficiency of the conventional incubator system. The incubator consists of an incubating chamber equipped with advanced monitoring capabilities, including real-time tracking and display of various crucial parameters on the internet. Incubation parameters such as temperature and humidity are maintained. This system is integrated with a motor mechanism capable of continuously rotating the eggs at regular intervals, further optimizing the incubation process. The motor mechanism plays a pivotal role in the system's enhanced functionality. It is specifically designed to facilitate the continuous rotation of the eggs at regular intervals. This rotation mechanism helps to simulate the natural nesting behavior and ensures uniform heat distribution, enhancing embryo development and increasing the likelihood of successful hatching. These advancements aim to improve the overall performance and effectiveness of the incubation system, facilitating successful egg development and hatching.

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