JOIV : Int. J. Inform. Visualization, 8(1) - March 2024 465-472

INTERNATIONAL JOURNAL ON INFORMATICS VISUALIZATION

journal homepage : www.joiv.org/index.php/joiv

# Development of an IoT-Based Egg Incubator with PID Control System and Mobile Application

Muhamad Cahyo Ardi Prabowo [a,*], Ilham Sayekti [a], Sri Astuti [a], Septiantar Tebe Nursaputro [a], Supriyati [a]

[a] *Department of Electrical Engineering, Politeknik Negeri Semarang, Tembalang, Semarang, 50275, Indonesia*

*Corresponding author: [*]m.cahyoardi.p@polines.ac.id*

***Abstract*— The rapid development of technology significantly impacts various aspects of life, including the field of livestock farming. The advancement of technology is expected to enhance the rate and effectiveness of production, particularly in the hatching of chicken eggs or chick breeding. The existing technology relies on manual on/off systems and manual monitoring, hindering successful egg-hatching rates and percentages. Therefore, this research aims to explain the development of an automated egg incubator using a Proportional Integral Derivative (PID) control system with hypertuning parameters, as well as temperature and humidity monitoring, along with a protection system based on voltage sensors, all integrated with the Internet of Things (IoT). The PID control is employed to regulate the temperature of the egg incubator, ensuring stability according to the predetermined set point temperature. The IoT system in this study comprises an ESP32 node as a microcontroller connected to a sensor, using Firebase and User app for monitoring the egg incubator. The study employed PID control with parameter values Kp=10, Ki=3, and Kd=8. The research yielded time-efficient egg incubation and prevention of turning delays. The DHT21 sensor achieved a 90% success rate in detecting room temperature (38°C) and humidity (77%-84%) within the incubator, while PID control effectively maintained the target temperature. The ACS712 sensor accurately detected current in the heater, power supply, and motor. The Kodular application can display sensor readings. The future implication is developing a more adaptive PID method toward changes and nonlinear dynamics.***

***Keywords*— Egg incubator; PID control; sensor; IoT; fire base.**

*Manuscript received 10 Aug. 2023; revised 16 Sep. 2023; accepted 1 Nov. 2023. Date of publication 31 Mar. 2024.*


## I. INTRODUCTION

The Internet of Things (IoT) technology has seamlessly integrated and revolutionized various industries, including livestock farming. With the advancement of technology, egg incubation has evolved from traditional methods to digital egg incubators that leverage IoT technology. This technology has significantly impacted the current industrial landscape, as almost every device can now be monitored and controlled through internet connectivity [1].

In the case of egg incubation, the egg-hatching process requires a consistently stable temperature between 37-39°C [2], [3]. If the temperature exceeds or falls below that number, it can result in suboptimal embryo development and potentially lead to developmental abnormalities in the egg. Embryos that experience insufficient development can produce chicks with defects during hatching. Additionally, the relative humidity parameter must adhere to the predetermined value based on the number of incubation days. The last parameter is that the hatching process requires the eggs to undergo periodic position changes within the specified time. Therefore, these three factors are crucial in the egg-hatching process [4].

An incubator is a device that can control temperature and humidity for the egg incubation process. By using an incubator, farmers do not need to manually hatch eggs by allowing the female chickens to brood them. Thus, an incubator can assist farmers in hatching eggs on a large scale to produce a larger population of chickens [5], [6]. This is the critical factor that serves as the primary reference point during the design process of a duck egg-based egg-hatching machine, incorporating DHT22 and PIR sensors [7].

In previous research, STEM methodology was employed to create and operate a cyber-physical system for a chicken egg incubator. It encompasses scientific exploration, technological application, and programming skills development to control ventilation, temperature, and humidity for successful egg hatching [8], [9].

The current study involves the development of an affordable incubator using a microcontroller. This incubator incorporates both the hatcher and setter functions within a single enclosure [10]. The microcontroller-based controller allows for precise regulation of temperature, humidity, ventilation, and egg-turning mechanism. Notably, the cost of this designed incubator is expected to be lower compared to commercially available alternatives [11]–[13].

In the development of research conducted by several researchers citing Szolga, Azahar, and Chitra, further advancements involve the creation of an intelligent and automated egg incubator system that integrates various features. These features include an LCD screen, a stepper motor to facilitate egg rotation, accurate temperature and humidity sensors, as well as a GSM module to notify the farmer of relevant information. It also includes power backup in case of failures to resume the process without starting from the beginning [14]–[16]. In modern times, the cost-effectiveness and efficiency of bird reproduction can be enhanced through remote monitoring and control of egg incubator parameters from a remote location [17].

A prototype egg incubator was developed by incorporating temperature control by implementing Mamdani fuzzy logic control. The DFT11 sensor plays a crucial role in providing input data for the fuzzy logic, enabling the system to adjust the fan speed (PWM) accordingly. Two lamps are used to maintain the ideal temperature in the incubator [5]. The microcontroller is programmed as a fuzzy logic control system to ensure the best conditions for different types of eggs. It controls the egg's position, incubator temperature, and humidity, resulting in optimal conditions for successful incubation [18], [19]. The main aim is to compare temperature management in an egg-hatching incubator using LabVIEW 2015 software with on/off and fuzzy logic controllers [20], [21].

Metwally [22] presented a study on modern methods using Pulse Repetition Frequency (PRF) techniques to examine the effects of different pulse intensities and durations on low-level quail egg incubation. The objectives include designing an electronic circuit to control pulses generated by the PRF circuit and optimizing operational parameters for the incubation system.

In previous research, the Mamdani fuzzy inference system is preferred over the Takagi-Sugeno system for controlling temperature and humidity levels inside the egg incubator due to its efficiency. The methodology applies to various avian species, although it focuses on optimizing conditions for chicken eggs [23]. This paper discusses a solar-powered egg incubator designed for regions without electricity access but with the potential for chicken farming [24].

The research conducted by Purwanti et al. [25] successfully designed monitoring capabilities for egg incubators involving utilizing a webcam camera to oversee temperature conditions and the egg incubation process. Gutierrez explains the development of a smart chicken-egg incubation system based on Arduino, LabVIEW, Google Firebase, and MIT App Inventor. It automatically controls temperature, humidity, and egg rotation while allowing remote monitoring by the farmer [26].

In a previous study, Maharani et al. [27] developed an egg incubator device utilizing a heating lamp to maintain room temperature stability. Temperature and humidity data were collected using a DHT11 sensor and transmitted to a Blynk server through a Wemos D1 microcontroller. The temperature and humidity information can be accessed in real time through a smartphone using the Blynk IoT platform. The movement of the incubator racks is controlled by a synchronous motor and a time delay relay, which are programmed using Arduino. This study details the creation of a prototype Smart Chicken Eggs Incubator System that utilizes the Internet of Things (IoT). The system consists of three subsystems: embedded systems, web-based applications, and a Telegram bot [28]. The poster paper introduces IoT-based mobile app development using Android Things and MIT App Inventor for data collection from connected sensors [29].

This study presents a comparative analysis of recent incubator design approaches in the literature. It identifies a gap in the field, specifically the lack of remote control and monitoring using Internet of Things (IoT) technology. The study emphasizes the importance of this feature in enhancing accessibility and productivity and reducing losses caused by malfunctions [30]. The intelligent incubation system is created to integrate IoT technology with smartphones, enhancing user convenience in monitoring and operating the system [31], [32].

In another case study conducted by Supriyo, the PID control method was chosen based on a combination of the Relay Feedback and Ziegler-Nichols formulas. The performance evaluation utilizes Rise Time, Settling Time, Overshoot, and Steady State Error at temperatures of 50ºC, 60ºC, and 70ºC. The PID controller is chosen as the best one with a maximum steady state error of around 0.2ºC, responsiveness, and no overshoot [33]. They are using HO-PID controllers with low-pass filters to achieve similar goals as an alternative fractional-order PID control. Solving various new problems [34].

In this research case study, the authors designed an IoT-based egg incubator with temperature and humidity parameters. The incubator is equipped with sensors to monitor these parameters. We also implemented a power monitoring system to ensure the incubator's integrity and control of the temperature using a PID (Proportional-Integral-Derivative) control system. The designed system is integrated with Firebase and can be monitored through an Android application.

In this research case study, authors have developed an egg incubator that incorporates IoT architecture to control and monitor temperature and humidity parameters. The incubator is equipped with temperature and humidity sensors that are connected to a microcontroller or an IoT module.

Additionally, the authors have implemented a power monitoring system to ensure the reliability of the egg incubation system. This system monitors the power consumption of the incubator and provides alerts in case of abnormal power spikes or drops. This helps prevent damage to the incubator and maintains a stable incubation environment.

For precise temperature control, the authors have employed a PID (Proportional-Integral-Derivative) control system. This system automatically adjusts the heating or cooling in the incubator based on temperature differences detected by the sensors. The PID control ensures that the temperature inside the incubator is maintained optimally for proper embryo development.

All the temperature, humidity, and power data collected by the incubator are sent to the Firebase platform. Firebase provides a cloud infrastructure to store and manage this data. Furthermore, the authors have developed an Android application that connects to Firebase. This application allows users to monitor the real-time temperature, humidity, and power conditions of the incubator through their mobile devices. This integrated and user-friendly application enables farmers to oversee the egg incubation process quickly and efficiently.

## II. Materials and Methods

In the material and methods section, the egg incubator system was developed using an ESP32 microcontroller device, incorporating a PID control system for temperature regulation. The system utilized sensors such as the DHT21 temperature and humidity sensor, current sensor, PTC heater, AC motor, Omron timer, and Firebase integration, ensuring connectivity with the IoT (Internet of Things) framework.

In this section, the authors discuss several aspects related to IoT-based egg incubators. These include IoT architecture, system flowcharts, hardware model design, PID control system, mobile application, and the egg incubator frame model. All these aspects contribute to creating an efficient and reliable egg incubator, ensuring an optimal environment for egg development, and facilitating users in effectively monitoring and controlling the entire process.

### *A. Internet of Things Architecture*

*1) Device:* The ESP32 is a microcontroller that supports Wi-Fi connectivity and can send real-time data to Firebase. Its operation begins by connecting the ESP32 to an available Wi-Fi network. Once attached, the ESP32 reads data from desired sensors or other sources, such as temperature and humidity sensors. The data is then sent to Firebase using HTTP or WebSocket protocols through the Firebase API. In this context, the device is also referred to as a Node.

*2) Connectivity:* Wi-Fi technology in IoT serves as a connectivity node that enables seamless communication between devices and the server. By utilizing Wi-Fi, IoT devices can establish a wireless connection to the server, allowing them to transmit and receive data efficiently. This technology enables real-time data streaming, remote monitoring, and control, making it a vital component in building a robust and interconnected IoT system.

*3) Cloud Platform:* On the Firebase side, the application has been configured to receive and store real-time data from the ESP32 in its database. Firebase offers a real-time database feature that enables seamless synchronization between the IoT devices and the server. The ESP32 sends data to Firebase using the Firebase API, utilizing either the HTTP or WebSocket protocol. Firebase also provides powerful listener capabilities, allowing the application to listen for and respond to data changes instantaneously. This integration with Firebase empowers the IoT system to effectively manage and process data, facilitating efficient monitoring and control of connected devices.

*4) User Apps Interface:* In the context of egg incubation in the IoT system, the user application developed using Kodular plays a crucial role. The application is designed to provide an intuitive interface for users to monitor and control the incubation process. By integrating with the IoT infrastructure, the Kodular app connects to the ESP32 microcontroller and Firebase, allowing real-time data exchange. Through the Kodular app, users can access vital information such as temperature, humidity, and incubation progress. The app is equipped with features to display the data in user-friendly formats, including charts, numerical values, and notifications. Users can also set desired temperature and humidity levels, monitor the status of the incubator, and receive alerts in case of any abnormalities. Fig. 1 below shows the Internet of Things architecture.


Fig. 1 Internet of Things Architecture – Overview

### *B. Egg Incubator System Flowcharts.*

The flowchart for the egg incubator system starts with the initial state. Upon pressing the push button to turn it on, the device powers up. The setpoint for temperature and humidity is then adjusted according to the desired conditions for the incubator space. The DHT21 sensor detects the temperature and humidity in the room. If the room temperature is less than or equal to 38°C, the heater turns on. If the room temperature exceeds 38°C, the fan turns on, and the heater works to lower the incubator room temperature. Similarly, for humidity control, if the room humidity is less than or equal to 80%, the humidifier is activated to increase the moisture. If the room humidity exceeds 80%, the humidifier turns off. The detected temperature and humidity data are displayed on the LCD screen and can be read on a smartphone. This process continues as long as the device is powered on.

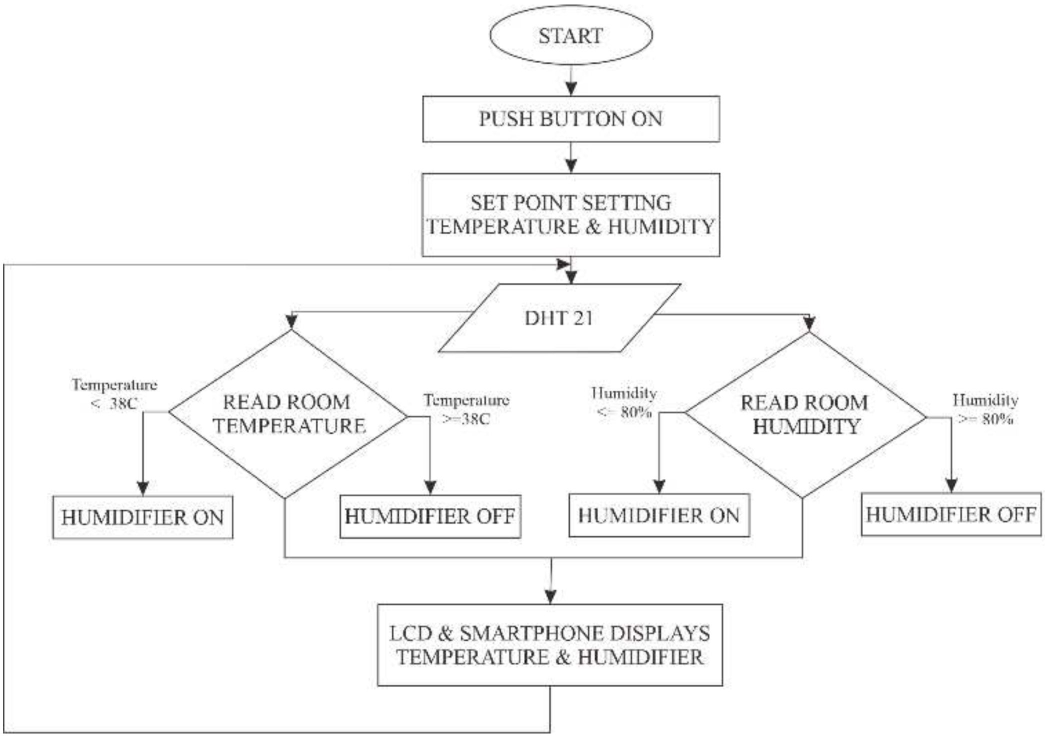


Fig. 2 Egg Incubator System Flowchart

*C. Model Designing Hardware System*

In this research, a current sensor is used to measure or detect the electric current flowing through a circuit or device. There will be three current sensors, and each sensor's pin-out will be connected to pins D12, D13, and D14 of the ESP32. Each current sensor's pin-out will include a voltage divider circuit since the ESP32 can only accept input up to 3.3V, while the output signal from the current sensor is 5V.

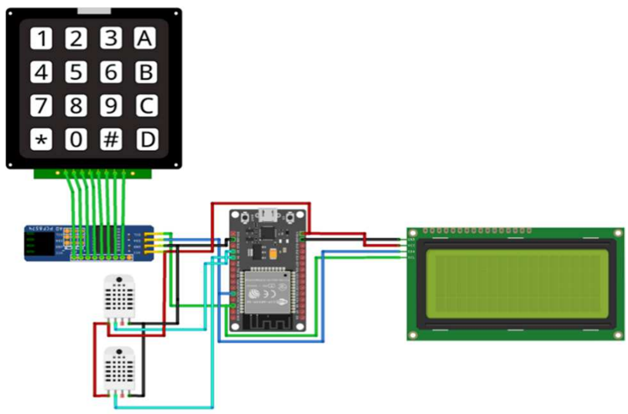

Fig. 3 (a) Temperature & Humidity sensor hardware design

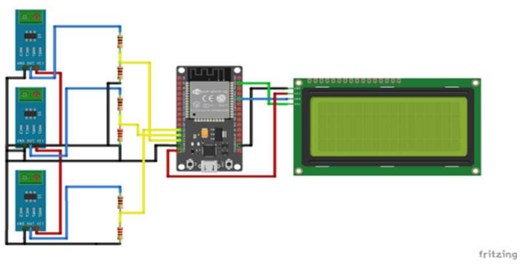

Fig. 3 (b) Current sensor hardware design

Additionally, for the connection of the DHT21 sensor with the ESP32, the first pin of the DHT21 sensor is connected to VCC, Pin 2 is attached to a digital pin (input pin), and Pin 3 is attached to the Ground on the ESP32. This device will use 2 DHT21 sensors, with each sensor connected to pins D2 and D4 of the ESP32. The keypad used for setpoint adjustment is attached to the ESP32 using the Inter-Integrated Circuit (I2C) communication protocol using the PCF8574 IC. Furthermore, the SDA pin is connected to pin D21, and the SCL pin is connected to pin D22.

*D. Proportional Integral Derivative (PID) Control System*

The Set Point (SP) system is programmed to maintain a temperature of 38°C. This desired temperature value, SP, is inputted into the ESP 32 microcontroller, which utilizes a proportional integral derivative (PID) control system to process the SP value. The PID control system computes the necessary adjustments and generates a Pulse Width Modulation (PWM) value. This PWM value is responsible for regulating the flame intensity of the heater.

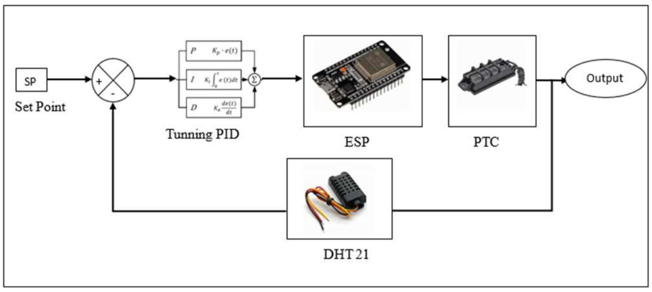


Fig. 4 Proportional Integral Derivative (PID) System

To monitor the actual temperature, DHT sensor 21 is employed to measure the heat generated by the heater. The sensor output is then compared to the SP value, and any disparity is considered an error. This error is fed back into the microcontroller and undergoes further processing through the PID control system. The PID controller calculates the appropriate corrective measures to be taken to ensure that the heater produces a stable heat.

### *E. Application System*

In this research, a Kodular mobile app is utilized to detect current using an ACS712 sensor. The application is designed with features that enable users to measure current accurately. Furthermore, if any measurement errors occur, Kodular automatically sends short notifications to the user's smartphone. With these notifications, researchers can promptly identify any issues and take immediate action to rectify or validate the collected data. This ensures the integrity and accuracy of the data used in the research journal, thereby enhancing the quality and reliability of the research outcomes.

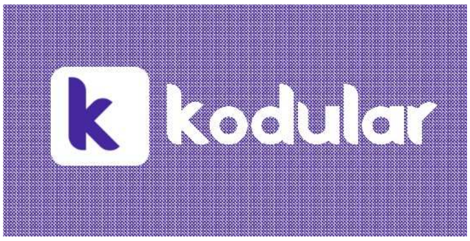

Fig. 5 Application Kodular

Furthermore, the Kodular mobile app is specifically designed to monitor temperature and humidity using the DHT21 sensor, providing users with real-time monitoring of temperature and humidity conditions through their smartphones. The application establishes a connection between the DHT21 sensor and the mobile app, periodically retrieving temperature and humidity data. This data is then displayed clearly and interactively on the application interface on the user's smartphone. By using this application, users can monitor changes in temperature and humidity within the Smart Incubator in this research.

### *F. Egg Incubator Frame Model*

The egg incubator model consists of a sturdy aluminum, multiplex, and aluminum foil framework. It features five tiered racks with a total capacity of 500 eggs. Additionally, the incubator is equipped with a reliable and efficient drive system for smooth operation.


Fig. 6 Egg Incubator Frame Model

## III. Result and Discussion

Based on the results of the experiments conducted in the research design, several performance test results of the device were obtained, which can be demonstrated in the following explanation:

### *A. Temperature and Humidity Sensor Data*

Based on Figure 7, the temperature measurements obtained from the egg incubator, it was found that the temperature remained stable at the set point of 38°C. The temperature data was recorded at 30-minute intervals, demonstrating consistent and reliable temperature control throughout the incubation process. This indicates the effectiveness of the incubator in maintaining a constant and optimal temperature for successful egg hatching.

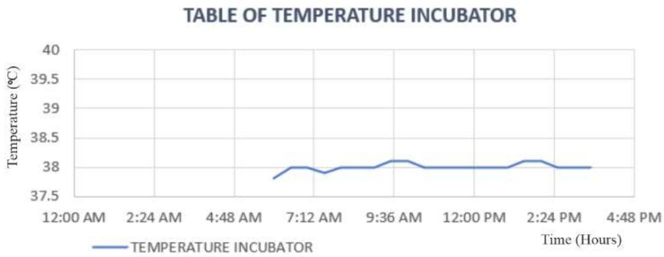

Fig. 7 Table of Temperature Incubator

Based on Figure 8, which depicts the measured humidity levels in the egg incubator, it was observed that the humidity remained stable within the desired range of 80%. The humidity data was recorded at 30-minute intervals, indicating consistent and reliable humidity control throughout the incubation process. This signifies the effectiveness of the incubator in maintaining an optimal humidity level for successful egg incubation.

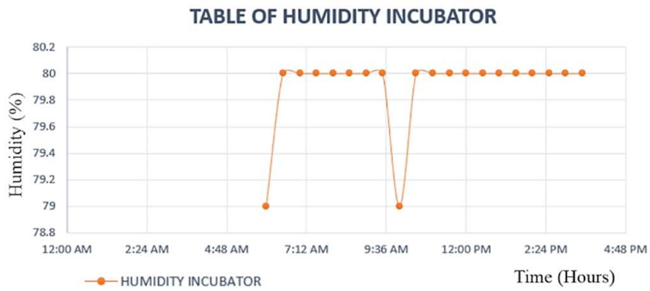

Fig. 8 Table of Humidity Incubator

Based on Figure 9, the egg incubator maintained a stable temperature at the set point of 38°C while the measured humidity remained consistently within the desired range of 80%. The data was collected at 30-minute intervals, indicating reliable control of both temperature and humidity throughout the incubation process. This highlights the incubator's effectiveness in providing optimal conditions for successful egg incubation.

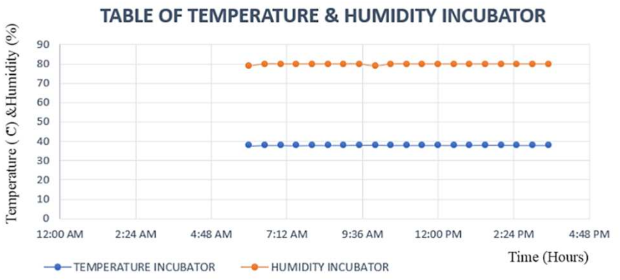


Fig. 9 Table of Temperature & Humidity Incubator

### *B. PID Control System Data*

Based on Figure 10, the data table of the PID control system for the PTC heater shows that the heater's response was directed towards the set point and made efforts to maintain stability at the desired temperature of 38°C. This indicates the adequate performance of the PID control in regulating the PTC heater to achieve and sustain the target temperature during the incubation process.

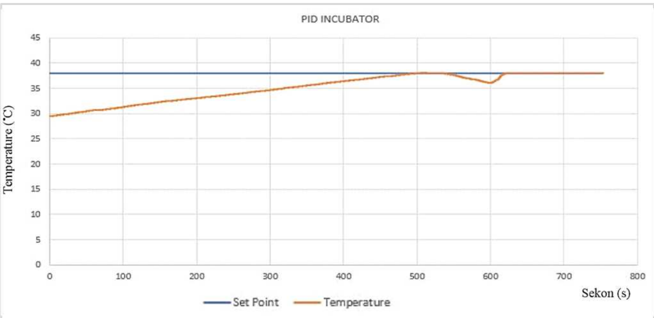


Fig. 10 Table Data of PID System

### *C. Actuator Motor Testing Results Data*

Based on Table I, the table presents the measurements of the motor's performance in moving the incubator racks at intervals of every 3 hours. The motor successfully operated according to the programmed instructions, enabling the desired movement of the egg incubation racks.

TABLE I
MOTOR TESTING

| Time Testing | Motor Condition | Running Motor (Second) | Test Result |
|---|---|---|---|
| 6:00:00 AM | ON | 40 | ON |
| 9:00:00 AM | ON | 40 | ON |
| 12:00:00 PM | ON | 40 | ON |
| 3:00:00 PM | ON | 40 | ON |
| 6:00:00 PM | ON | 40 | ON |

### *D. Current Sensor Data in the Egg Incubator*

Based on Table II, the measurements show that the average current for the PTC heater was 8 A, the power supply consumed 0.6 A, and the motor required 0.09 A in the egg incubator. These readings indicate the electrical currents drawn by each component during operation.

TABLE II
CURRENT SENSOR

| Heater Current (A) | Power Supply Current (A) | Motor Current (A) |
|---|---|---|
| 0 | 0 | 0 |
| 8.33 | 0.64 | 0.0909 |
| 8.33 | 0.64 | 0.0909 |
| 8.33 | 0.64 | 0.0909 |
| 8.33 | 0.64 | 0.0909 |
| 8.33 | 0.64 | 0.0909 |
| 8.33 | 0.64 | 0.0909 |
| 8.33 | 0.64 | 0.0909 |
| 8.33 | 0.63 | 0.0909 |
| 8.33 | 0.63 | 0.0909 |
| 8.33 | 0.63 | 0.0909 |
| 8.33 | 0.63 | 0.0909 |
| 8.33 | 0.53 | 0.0909 |
| 8.33 | 0.53 | 0.0909 |
| 8.33 | 0.53 | 0.0909 |
| 8.33 | 0.53 | 0.0909 |
| 8.33 | 0.53 | 0.0909 |
| 8.33 | 0.53 | 0.0909 |
| 8.33 | 0.53 | 0.0909 |
| 0 | 0 | 0 |

### *E. Node Delivery Data to Firebase*

Table III provides information on data delivery from nodes to Firebase. It presents the recorded outcomes of the data transfer process, displaying the efficiency and reliability of communication between the nodes and the Firebase platform.

TABLE III
SENDING DATA FROM NODE TO CLOUD

| Data (n) | Time Differences (ms) | Data (n) | Time Differences (ms) |
|---|---|---|---|
| Data 1 | 20 | Data 21 | 21 |
| Data 2 | 70 | Data 22 | 12 |
| Data 3 | 35 | Data 23 | 24 |
| Data 4 | 19 | Data 24 | 38 |
| Data 5 | 30 | Data 25 | 35 |
| Data 6 | 42 | Data 26 | 25 |
| Data 7 | 19 | Data 27 | 19 |
| Data 8 | 38 | Data 28 | 13 |
| Data 9 | 26 | Data 29 | 16 |
| Data 10 | 29 | Data 30 | 22 |
| Data 11 | 13 | Data 31 | 31 |
| Data 12 | 22 | Data 32 | 45 |
| Data 13 | 60 | Data 33 | 32 |
| Data 14 | 88 | Data 34 | 13 |
| Data 15 | 29 | Data 35 | 44 |
| Data 16 | 19 | Data 36 | 73 |
| Data 17 | 25 | Data 37 | 28 |
| Data 18 | 16 | Data 38 | 22 |
| Data 19 | 22 | Data 39 | 47 |
| Data 20 | 19 | Data 40 | 41 |
| **Average Time Differences: 31.3 ms** | | | |

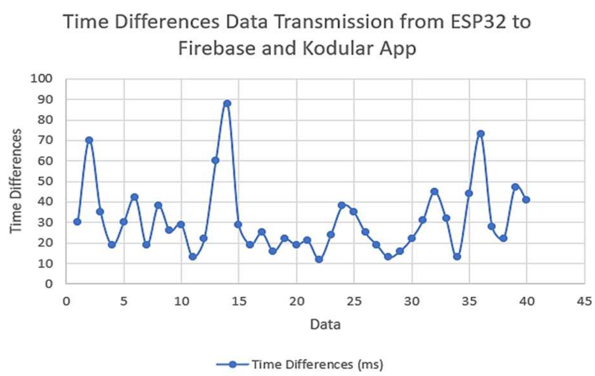


Fig. 13 Graph of sending data by time

Based on Figure 13, the average data transmission time from the node to Firebase was determined to be 31 ms. These figures provide insights into the efficiency and speed of data transfer between the node and the Firebase platform.

### *F. Egg Incubator System*

Figure 14 is an actual photograph of the egg incubation system device or prototype product with dimensions of 64 cm x 94 cm and a height of 115 cm. The total egg capacity within the egg incubator box is 500 eggs, with each of the five shelves having a capacity of 100 eggs.

Fig. 14 Monitoring mobile application display

### *G. Data System Application*

Figure 15 depicts the mobile application's user interface for monitoring the egg incubator system. The interface provides a comprehensive display of various parameters, including temperature, humidity, and other relevant information. Users can easily access and monitor the real-time status of the incubator, enabling effective oversight and control of the incubation process. The intuitive design and clear visualizations enhance the user experience and facilitate efficient management of the egg incubation system. Researchers develop mobile app systems instead of mobile applications due to Portability and Easy Access, Direct Notifications, Responsive User Interface, and Security.


Fig. 15 Monitoring mobile application display

## IV. CONCLUSION

The findings indicated that an Internet of Things (IoT)-enabled egg incubator with a PID control system achieves stability in maintaining the desired temperature and humidity levels. The recorded temperature remains steady at the set point of 38°C, while the measured humidity hovers around 80%. The motor's capability to rotate the incubator rack ensures even heat distribution and creates ideal conditions for egg development. The motor controls the rack in the egg incubator every three hours. The microcontroller's capability to transmit data to Firebase through a Wi-Fi-based IoT architecture enables real-time monitoring and remote access to crucial information. The visualization of data in the application enhances user convenience and facilitates informed decision-making in managing the incubation process. The research demonstrates the effectiveness and potential of integrating IoT, PID control, and data visualization in optimizing egg incubation processes.

Future work in egg incubation systems involves the use of AI and machine learning to develop more innovative and adaptive PID algorithms. Gathering and analyzing more extensive data sets to enhance our understanding of egg incubation behavior and aid in better decision-making. Developing more innovative and adaptive control systems utilizing technologies like fuzzy logic or neural networks.

## ACKNOWLEDGMENT

We express our utmost gratitude to the technical team of D3 Electronics Engineering students, namely Khaerul Umam, Rafif Naufal Nugroho, Sonia Audira, and Yohan Wahyu Pradana, for their valuable contributions to this project. Their expertise and dedication were vital to the successful implementation of the egg incubator system. Additionally, we express our gratitude to P3M Politeknik Negeri Semarang for funding this research project through the Department's Excellent Program (PTUP). Their financial support was essential in the completion of this study.

## REFERENCES

[1] M. C. A. Prabowo, S. S. Hidayat, and F. Luthfi, “Low Cost Wireless Sensor Network for Smart Gas Metering using Antares IoT Platform,” 2020 International Conference on Applied Science and Technology

(iCAST), Oct. 2020, doi: 10.1109/icast51016.2020.9557692.
[2] O. Eze Aru, "Development of a Computerized Engineering Technique to Improve Incubation System in Poultry Farms," *J. Sci. Eng. Res. 2017, 4(6)109-119 Res.*, vol. 4, no. 6, pp. 109–119, 2017.
[3] I. Boleli, V. Morita, J. Matos Jr, M. Thimotheo, and V. Almeida, "Poultry Egg Incubation: Integrating and Optimizing Production Efficiency," Revista Brasileira de Ciência Avícola, vol. 18, no. spe2, pp. 1–16, Dec. 2016, doi: 10.1590/1806-9061-2016-0292.
[4] 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), Mar. 2018, doi:10.1109/icoiact.2018.8350682.
[5] I. N. Lestari, E. Mulyana, and R. Mardi, "The Implementation of Mamdani's Fuzzy Model for Controlling the Temperature of Chicken Egg Incubator," 2020 6th International Conference on Wireless and Telematics (ICWT), Sep. 2020, doi:10.1109/icwt50448.2020.9243647.
[6] Md. Amdadul Bari, M. Julhas Hossain, and M. Monirujjaman Khan, "Development of Smart Egg Incubator," 2021 IEEE 12th Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON), Dec. 2021, doi:10.1109/uemcon53757.2021.9666653.
[7] A. Faroqi, M. R. Efendi, D. T. Ismail, and W. Darmalaksana, "Design of Arduino Uno Based Duck Egg Hatching Machine With Sensor DHT22 and PIR Sensor," 2020 6th International Conference on Wireless and Telematics (ICWT), Sep. 2020, doi:10.1109/icwt50448.2020.9243640.
[8] P. Tangsuknirundorn and P. Sooraksa, "Design of a Cyber-Physical System using STEM: Chicken Egg Incubator," 2019 5th International Conference on Engineering, Applied Sciences and Technology (ICEAST), Jul. 2019, doi: 10.1109/iceast.2019.8802564.
[9] R. Jaichandran, R. Shobana, K. Mohamed Tharick, L. Raja, H. Anandaram, and K. Vijaipriya, "Automatic Hatching System by designing IoT-based Egg Incubator," 2022 3rd International Conference on Smart Electronics and Communication (ICOSEC), Oct. 2022, doi: 10.1109/icosec54921.2022.9952082.
[10] D. A. Thomas, C. Reji, J. Joys, and S. Jose, "Automated Poultry Farm with Microcontroller based Parameter Monitoring System and Conveyor Mechanism," 2020 4th International Conference on Intelligent Computing and Control Systems (ICICCS), May 2020, doi:10.1109/iciccs48265.2020.9120982.
[11] M. A. Kabir and M. A. Abedin, "Design and Implementation of a Microcontroller Based Forced Air Egg Incubator," 2018 International Conference on Advancement in Electrical and Electronic Engineering (ICAEEE), Nov. 2018, doi: 10.1109/icaeee.2018.8642976.
[12] N. Islam, M. N. Uddin, A. M. Arfi, S. U. Alam, and Md. M. Uddin, "Design and Implementation of IoT Based Perspicacious Egg Incubator System," 2019 9th Annual Information Technology, Electromechanical Engineering and Microelectronics Conference (IEMECON), Mar. 2019, doi: 10.1109/iemeconx.2019.8877043.
[13] G. V. Kutsira, N. I. Nwulu, and E. M. Dogo, "Development of a Small Scaled Microcontroller-Based Poultry Egg Incubation System," 2019 International Artificial Intelligence and Data Processing Symposium (IDAP), Sep. 2019, doi: 10.1109/idap.2019.8875897.
[14] L. A. Szolga and A. Bondric, "Smart System for Incubating Eggs," 2020 IEEE 26th International Symposium for Design and Technology in Electronic Packaging (SIITME), Oct. 2020, doi:10.1109/siitme50350.2020.9292305.
[15] K. B. Azahar, E. E. Sekudan, and A. M. Azhar, "Intelligent Egg Incubator," International Journal of Recent Technology and Applied Science, vol. 2, no. 2, pp. 91–102, Sep. 2020, doi:10.36079/lamintang.ijortas-0202.129.
[16] K. Chitra, T. Kalpana, M. Hemalatha, S. Hari Vishnu, K. Kishore, and S. Manoj, "Automatic Egg Incubator Using IoT," 2023 International Conference on Computer Communication and Informatics (ICCCI), Jan. 2023, doi: 10.1109/iccci56745.2023.10128323.
[17] F. Peprah, S. Gyamfi, M. Amo-Boateng, E. Buadi, and M. Obeng, "Design and construction of smart solar powered egg incubator based on GSM/IoT," Scientific African, vol. 17, p. e01326, Sep. 2022, doi:10.1016/j.sciaf.2022.e01326.
[18] A. A. Aldair, A. T. Rashid, and M. Mokayef, "Design and Implementation of Intelligent Control System for Egg Incubator Based on IoT Technology," 2018 4th International Conference on Electrical, Electronics and System Engineering (ICEESE), Nov. 2018, doi:10.1109/iceese.2018.8703539.
[19] D. Lourençoni, D. C. T. C. de Brito, P. T. L. de Oliveira, S. H. N. Turco, and J. da S. Cunha, "Fuzzy Controller Applied to Temperature Adjustment in Incubation of Free-Range Eggs," Engenharia Agrícola, vol. 42, no. 4, 2022, doi: 10.1590/1809-4430-eng.agric.v42n4e20220050/2022.
[20] N. Khera and S. Kohli, "Comparison of Fuzzy and On/Off Controller for Winter Season Egg Hatching Incubator System," 2018 International Conference on Sustainable Energy, Electronics, and Computing Systems (SEEMS), Oct. 2018, doi:10.1109/seems.2018.8687365.
[21] R. Rakhmawati, Irianto, F. D. Murdianto, A. Luthfi, and A. Y. Rahman, "Thermal Optimization on Incubator using Fuzzy Inference System based IoT," 2019 International Conference of Artificial Intelligence and Information Technology (ICAIIT), Mar. 2019, doi:10.1109/icaiit.2019.8834530.
[22] A. Metwally, "Improving Performance of the Poultry Eggs Incubator using the Pulse Repetition Frequency," Journal of Soil Sciences and Agricultural Engineering, vol. 11, no. 5, pp. 151–156, May 2020, doi:10.21608/jssae.2020.103591.
[23] P. Dutta and N. Anjum, "Optimization of Temperature and Relative Humidity in an Automatic Egg Incubator Using Mamdani Fuzzy Inference System," 2021 2nd International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST), Jan. 2021, doi: 10.1109/icrest51555.2021.9331155.
[24] Kelebaone Tsamaase, "Construction and Operation of Solar Powered Egg Incubator," International Journal of Engineering Research and, vol. V8, no. 12, Jan. 2020, doi: 10.17577/ijertv8is120232.
[25] S. Purwanti, A. Febriani, M. Mardeni, and Y. Irawan, "Temperature Monitoring System for Egg Incubators Using Raspberry Pi3 Based on Internet of Things (IoT)," Journal of Robotics and Control (JRC), vol. 2, no. 5, 2021, doi: 10.18196/jrc.25105.
[26] S. Gutierrez, G. Contreras, H. Ponce, M. Cardona, H. Amadi, and J. Enriquez-Zarate, "Development of Hen Eggs Smart Incubator for Hatching System Based on Internet of Things," 2019 IEEE 39th Central America and Panama Convention (CONCAPAN XXXIX), Nov. 2019, doi: 10.1109/concapanxxxix47272.2019.8976987.
[27] M. Anang Sucipto and S. Bagus Prakoso, "Rancang Bangun Alat Penetas Telur Otomatis berbasi Arduino," Jurnal FORTECH, vol. 3, no. 1, pp. 43–50, Mar. 2022, doi: 10.56795/fortech.v3i1.106.
[28] S. B. Santoso, S. Adhy, N. Bahtiar, and I. Waspada, "Development of The Smart Chicken Eggs Incubator Based on Internet of Things Using The Object Oriented Analysis and Design Method," 2020 4th International Conference on Informatics and Computational Sciences (ICICoS), Nov. 2020, doi: 10.1109/icicos51170.2020.9299000.
[29] T. Munasinghe, E. W. Patton, and O. Seneviratne, "IoT Application Development Using MIT App Inventor to Collect and Analyze Sensor Data," 2019 IEEE International Conference on Big Data (Big Data), Dec. 2019, doi: 10.1109/bigdata47090.2019.9006203.
[30] G. Youcif Izadeen and I. Sarhan Hussein Kocher, "Smart Egg Incubator Based on Microcontroller: A Review," Academic Journal of Nawroz University, vol. 11, no. 4, pp. 139–146, Nov. 2022, doi:10.25007/ajnu.v11n4a1401.
[31] S. A. Nawaz, S. Satheeskumaran, C. Venkatesan, A. R. Suhas, and L. Niranjan, "Design and implementation of chicken egg incubator for hatching using IoT," International Journal of Computational Science and Engineering, vol. 24, no. 4, p. 363, 2021, doi:10.1504/ijcse.2021.10039967.
[32] E. Petkov, T. Kalushkov, G. Shipkovenski, R. Radoeva, and D. Valcheva, "Fault Tolerance Smart Incubator With IoT Control and Alerts," 2022 International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT), Oct. 2022, doi:10.1109/ismsit56059.2022.9932792.
[33] B. Supriyo, Dadi, S. Warjono, A. Wisaksono, S. Astuti, and K. Utomo, "PID Based Air Heater Controller Implemented With Matlab/Simulink and Arduino Uno," 2018 5th International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), Sep. 2018, doi: 10.1109/icitacee.2018.8576955.
[34] M. Huba, D. Vrancic, and P. Bistak, "PID Control With Higher Order Derivative Degrees for IPDT Plant Models," IEEE Access, vol. 9, pp. 2478–2495, 2021, doi: 10.1109/access.2020.3047351.