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Design of Incubator System for Laboratory: Development, Implementation, and Performance Evaluation

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ABSTRACT

Laboratory incubators play a pivotal role in microbiology research by facilitating the incubation and propagation of microorganisms. However, conventional incubators are often limited to specific sample containers and models, necessitating the use of multiple units for different applications. In response to this challenge, this study presents the development of a multifunctional digital incubator using acrylic materials and digital temperature control. The aim was to create an incubator capable of accommodating various sample containers, including tubes and microplates, within a single unit. The designed incubator features dimensions of 40cm x 40cm x 40cm, with the capacity to hold one rack of 48 tubes (measuring 27x9.5x8cm) and four microplates. It consumes 350VA of power and utilizes a BR6 temperature control system to maintain a precise temperature of 37±1°C. Performance testing revealed temperature variations of only 0.1°C (0.21%) within the permissible range of ±1°C, while timer accuracy was demonstrated at 100%. Measurements were conducted using a thermohygrometer and stopwatch. The developed multifunctional digital incubator meets the intended objectives, offering researchers a versatile and reliable tool for various laboratory applications, including ELISA assays and clinical chemistry experiments.

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1. INTRODUCTION

The current healthcare facility is becoming more conscious of the topic after pandemic Covid 19 a few past years ago. One of the main goals is to prepare equipment so that it is useful to patients. Not only manufacturing activities that focus on maintenance, but also hospitals as healthcare facilities have begun to shift towards effectively service into patient [1] [2]. Laboratory incubators play a crucial role in microbiological and cellular research by providing controlled environments conducive to the growth and maintenance of microbial cultures or cell cultures [3]. These instruments regulate temperature, humidity, and other conditions, such as CO2 and oxygen levels, within their chambers. Incubators are essential for a wide range of experimental work in fields like biology, microbiology, and molecular biology, particularly for cultivating bacterial cells. The simplest incubators consist of insulated chambers with adjustable heaters, typically capable of reaching temperatures between 60 to 65°C and rarely exceeding 100°C. [4] The most used temperature for bacterial and cell culture incubation is around 37°C, as it optimally supports the growth of organisms. However, some organisms and cell types may require different temperature settings, underscoring the need for incubators with adjustable temperature capabilities. More advanced incubators offer additional functionalities, such as cooling to lower temperatures, humidity control, and CO2 gas regulation. These features are particularly crucial for cultivating mammalian cells, which often require high humidity levels (over 80%) to prevent evaporation and a slightly acidic pH achieved by maintaining a 5% CO2 level. Laboratory incubators come in various shapes and sizes, influenced by the types of sample containers and examination methods they accommodate. Manufacturers design and produce incubators with specialized functions to meet specific laboratory needs, resulting in a diverse array of models and forms. In this scientific paper, we focus on two distinct types of laboratory incubators as reference points: Microplate Incubators and Dry Bath Incubators. Microplate Incubators are specifically designed to accommodate and incubate microplates, also known as ELISA plates. These incubators not only heat samples to 37°C but can also be adjusted to temperatures ranging from room temperature to 70°C, with some models featuring orbital shaker functions to expedite incubation. Dry Bath Incubators, on the other hand, are utilized in molecular biology, microbiology, and biochemistry laboratories to heat samples contained in tubes. These incubators, sometimes referred to as dry block heaters, distribute heat through blocks within the chamber, accommodating multiple samples simultaneously. The features and specifications of selected models of both Microplate Incubators and Dry Bath Incubators are presented to illustrate their functionalities and capabilities effectively. Overall, laboratory incubators with specialized functions are integral tools in scientific research, contributing to the advancement of knowledge and innovation in various fields of study. Figure 1 [5] illustrates the direct heating technology employed in the laboratory incubator, facilitating the creation of a gentle convection within the chamber. This convection mechanism plays a pivotal role in regulating the temperature uniformly across the entire incubation chamber. The heating element within the incubator generates heat, which is then evenly distributed throughout the chamber via convection currents. As a result, the temperature remains consistent across all areas of the chamber, ensuring uniform conditions for the specimens or samples being incubated. This parallel operation of heating and temperature regulation within the equipment guarantees precise control over the incubation environment, thereby optimizing experimental conditions and promoting reliable results.

Figure 1. Heating chamber on Incubator Laboratory [5]

Previous research has delved into various aspects of incubator laboratory development, addressing both cost-effective solutions and effective management strategies. One line of inquiry explored the creation of low-cost incubators equipped with mobile systems for enhanced portability, enabling their usage in diverse settings [4]. Concurrently, studies have focused on optimizing incubator performance, emphasizing efficient management practices to ensure optimal functionality [3]. Additionally, there has been investigation into the application of incubator laboratory technology in embryo culture analysis, highlighting its versatility in biomedical research [6]. The evolving landscape of medical and laboratory equipment has spurred continuous advancements in incubator design and variation, with projects leveraging technologies like Arduino for enhanced functionality [7]. Moreover, research endeavors have explored innovative approaches such as harnessing natural irradiance through photocell coupling to develop environmentally sustainable incubators [8]. This progression extends to specialized designs tailored for bacteriological applications, reflecting a nuanced understanding of diverse laboratory needs. Recently research that we do in our lab focuses on development of many prototypes in electro-medical equipment [10] [11]. Thus, the primary objective of this research is to design a laboratory incubator using a simple system while monitoring the performance generated, contributing to the ongoing evolution of incubator technology with many options on the parts because nowadays in manufacturing process, they need to be more understanding about sensor performance for testing and also how to trial the prototype latter.

2. METHOD

2.1. Experimental Setup

The experimental setup involves the evaluation of laboratory incubators with specialized functions to determine their efficacy and suitability for various laboratory applications. The evaluation will focus on assessing key parameters such as material and tool, temperature control, uniformity, ease of operation, and versatility and the process of experiment [14].

2.1.1. Material and Tool

In the development of multifunctional digital laboratory incubators necessitate a diverse array of materials and tools to construct the apparatus efficiently. Key materials include acrylic sheets of 5mm and 3mm thickness, serving as the primary building blocks for the enclosure or housing of the incubator. The temperature control is facilitated by the BR6 microcontroller, regulating the heating element within the chamber. Solid State Relay (SSR) acts as a crucial component in controlling the flow of current to the heating element. To ensure proper heat dissipation throughout the chamber, an 8cm AC fan is incorporated. The 3-in-1 AC switch functions as an essential control mechanism, serving as an on/off switch, a safety feature, and a power input for the incubator. A timer is utilized to precisely time the incubation process and signal its completion. Power cables and color-coded cables are employed to connect various components as per the wiring diagram. Soldering materials, including a soldering iron, solder wire, and flux, are used for soldering electrical connections. Screws and bolts securely fasten components and the enclosure of the incubator. Power glue provides adhesive strength for assembling acrylic pieces, while cable ties help organize and secure cables neatly within the incubator. Hinges, insulation materials, electrical drills, electric grinders, sandpaper, and acrylic drawer handle round out the necessary tools and materials, ensuring the successful construction of the multifunctional digital laboratory incubator with precise environmental control capabilities for diverse laboratory applications.

2.1.2. Experiment

The experiment focuses on validating the performance of the developed multifunctional digital laboratory incubator. It involves several steps: first, testing the temperature control system's ability to maintain stability within the desired range; and second, testing the incubator's compatibility with different sample containers. Through these experiments, the effectiveness and basic reliability of the multifunctional incubator will be determined, contributing to advancements in laboratory practices for microbiological and cell culture research.

2.2 The Diagram of Block

The block diagram outlines the essential components and their functions within the multifunctional digital laboratory incubator. The AC 220V block serves as the power source, connecting to the 3-in-1 switch. The Temperature Control block regulates heating and activates the Timer when the desired temperature is reached. The SSR controls current flow to the heating element, while the Temperature Sensor detects heat levels. The Heating Element converts electrical energy into heat for temperature maintenance [11]. These components are integrated within a single unit denoted by "Inside." The Timer Display, equipped with a keypad and buzzer, functions as a countdown timer. Lastly, the AC Fan disperses heat throughout the chamber. This diagram offers a clear overview of the system's functionality and interconnections.

2.3 The Flowchart

The operational sequence of the multifunctional digital laboratory incubator is delineated through a straightforward flowchart. Initiated by the connection of AC 220V power to the circuit, the activation of key components, including the Temperature Control, SSR, and fan, occurs upon switching ON. After this activation, the Temperature Sensor engages, capturing temperature readings and relaying them to the Temperature Control unit. Should the detected temperature fall below the preset value by 0.2°C, the SSR triggers the heating element until the desired temperature of 37.4°C is attained, following which both SSR and heating element are deactivated by the Temperature Control.

Notably, when the temperature reaches 36.5°C, the Timer display signals readiness for incubation, offering versatility with clock, count-up, or countdown modes for time management. Furthermore, users can adjust alarm settings for precise monitoring. This succinct flowchart serves to elucidate the sequential functionality of the incubator, facilitating a comprehensive understanding of its operational intricacies

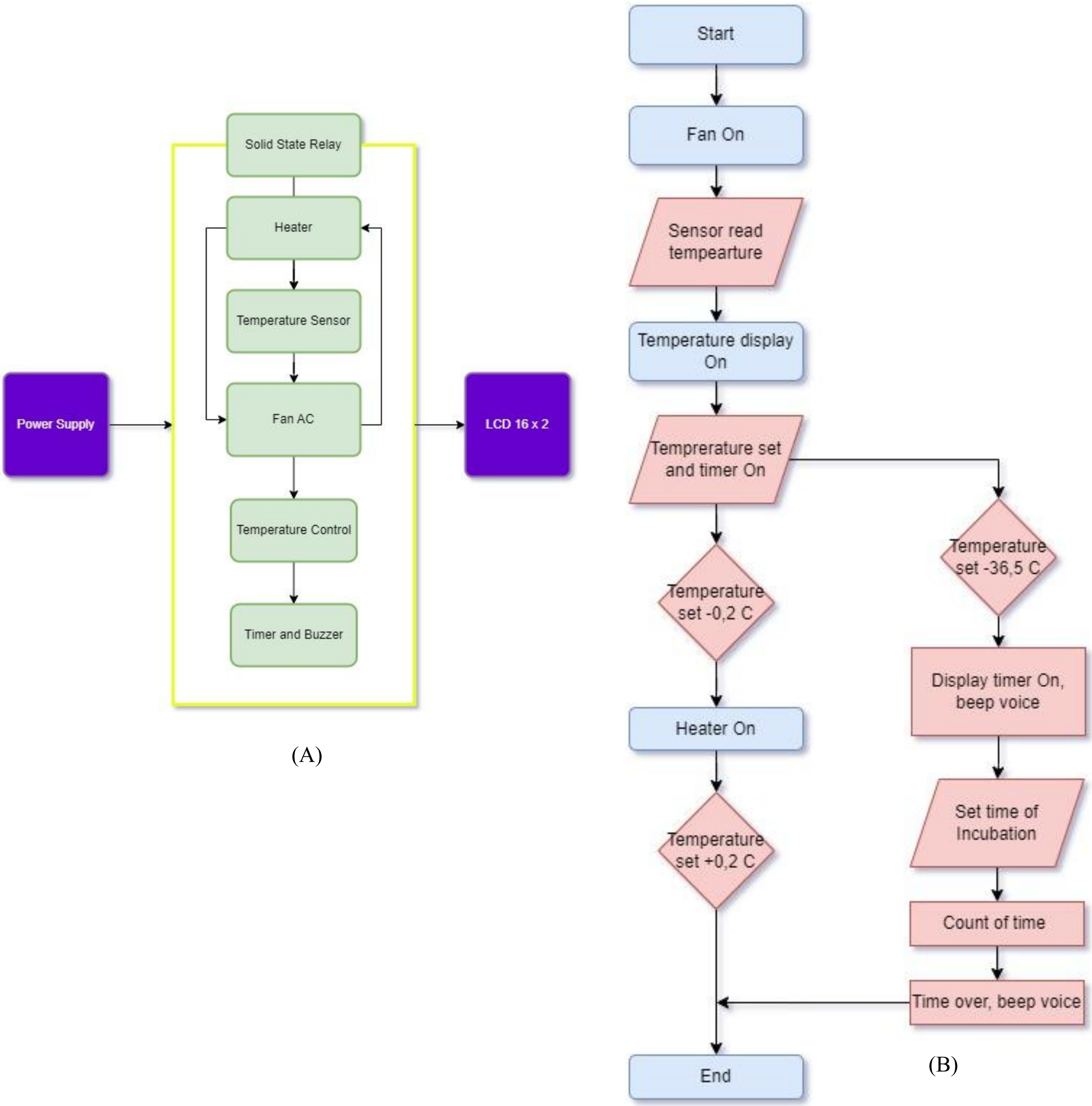

Figure 2. Diagram of block (A) and flow chart Incubator Laboratory (B)

2.4 The Analog Circuit

The operational mechanism of the multifunctional digital laboratory incubator is further detailed through a comprehensive wiring diagram, illustrating the interconnection of its components and the flow of electrical signals. Initiated by the connection of the AC 220V power source to the circuit, power flows through the wiring, passing through components such as the power cable, socket, fuse, and switch. Upon toggling the switch to the ON position, power is distributed to essential components including the Temperature Control, SSR, and fan. Subsequently, the Temperature Sensor detects ambient temperature, transmitting analog data to the Temperature Control unit. If the detected temperature falls below the preset value, the SSR activates, allowing current to flow to the heating element until the desired temperature is achieved. Notably, when the chamber temperature reaches the designated threshold, the Timer display is activated, signaling readiness for incubation. The Timer offers flexible functionality, including clock, count-up, and countdown modes, facilitating precise time management. Additionally, users can customize alarm settings for enhanced monitoring capabilities. This comprehensive wiring provides a detailed overview of the intricate electrical connections and operational sequences within the incubator, offering a comprehensive insight into its functioning.

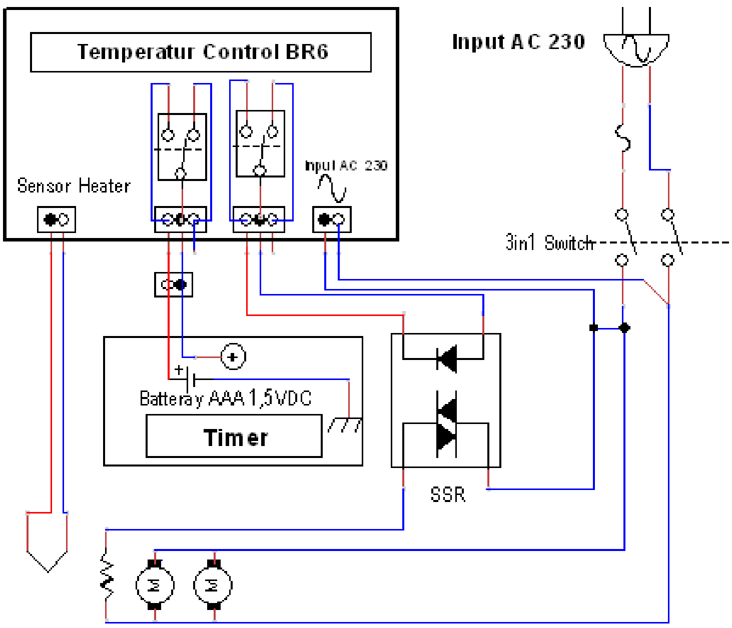

Figure 3. Wiring of Circuit Scheme

3. RESULTS AND DISCUSSION

3.1. Development of incubator laboratory prototype

This is a versatile laboratory incubator designed to cater to various sample types and examination methods commonly employed in laboratory settings. Equipped with a BR6 temperature control system, this incubator boasts two doors, facilitating convenient access to its interior. It features a spacious rack capable of accommodating up to 40 reaction tubes, each with dimensions of 23x10x7cm, allowing for extensive sample processing. Additionally, the incubator includes four slots specifically designed for microplates, catering to assays requiring this format. Operating within a voltage range of 200-240 VAC, the incubator consumes 350 VA of power, ensuring efficient performance. With a temperature setting up to 60°C, it provides flexibility for a wide range of experimental conditions. The LED 7-Segment Red display offers precise temperature monitoring, with an accuracy of 0.1°C, enhancing experimental control and reproducibility. Furthermore, the incubator features an LCD 5-digit multi-display timer powered by AAA 1.5VDC batteries, facilitating precise timing for incubation protocols. Designed to accommodate both sample tubes and microplates, this incubator integrates seamlessly into laboratory workflows. Boasting a heating power of 300 Watts, it ensures rapid and uniform heating throughout its 40cm x 40cm x 40cm dimensions. Overall, the Inkubator Laboratorium Digital Multi Fungsi represents a comprehensive solution for laboratory incubation needs, combining versatility, precision, and efficiency in a compact and user-friendly design. In this below will show all of design construction has developed for Incubator Laboratory.

(a) (b) (c)

Figure 4. (a) Display Temperature and Timer, (b) Chamber room in Incubator Laboratory, (c) Heater for Incubator

3.2. Functional Test

The functional testing of the Inkubator Laboratorium Digital Multi Fungsi involves a comprehensive assessment of its operational capabilities. Upon pressing the power button, the observation indicates that the switch lamp illuminates, signifying the activation of the device, while the fan begins rotating, ensuring adequate ventilation within the incubator. Subsequently, the heating element activates, and the temperature rises in accordance with the set parameters, demonstrating the effective functioning of the heating system. As the temperature displayed on the screen reaches 36.5°C, the Timer activates, accompanied by an audible beep, indicating readiness for incubation. Ensuring stability, the incubator maintains a temperature of 37 ± 1°C, meeting the required specifications. Additionally, all buttons on both the temperature control and timer exhibit proper functionality, allowing for precise adjustment and timing. The LCD screen on the timer panel illuminates as expected, providing clear visibility of timing parameters. Furthermore, thorough testing confirms the seamless operation of both doors, with Pintu 1 and Pintu 2 closing securely. The rack for reaction tubes and slots for microplates is successfully accommodated within the incubator, ensuring compatibility with various sample formats. Overall, the functional testing validates the robust performance and reliability of the Inkubator Laboratorium Digital Multi Fungsi, meeting the necessary criteria for laboratory incubation processes.

3.3. Parameter test for Incubator Laboratory

The research parameters undergo testing to verify accuracy through data calculation and analysis. This involves assessing average deviation and percentage accuracy to determine the device's precision mathematically. Using formulas such as mean value calculation, deviation value determination, percentage deviation, and accuracy level, the author evaluates data to ascertain the device's accuracy. These calculations provide insights into the device's performance based on collected data. The mathematical model for evaluating the measurement performance of the developed device is based on the comparison between the measured value (Xi) and the reference value (Ri). The mean measurement is first calculated to represent the central tendency of the collected data. The deviation between the measured and reference values is then determined for each observation. Subsequently, the percentage deviation is calculated to quantify the relative measurement error. Finally, the measurement accuracy is obtained by subtracting the average percentage deviation from 100%. This mathematical framework provides a quantitative assessment of the device's measurement performance and enables objective evaluation of its accuracy against the reference instrument. The measurement performance evaluation can be mathematically represented as

$$\{X_i,R_i\} \rightarrow D_i \rightarrow PD_i \rightarrow \overline{PD} \rightarrow \overline{Accuracy} \text{………..(1)}$$

Where:

- X_i = measured value obtained from the developed device
- R_i= reference value obtained from the standard instrument
- D_i = measurement deviation
- PD_i = percentage deviation
- $\overline{PD}$ = average percentage deviation
- $\overline{Accuracy}$ = average measurement accuracy

3.3.1 Temperature Test

The table presents temperature measurements obtained from the incubator using a thermohygrometer, alongside the desired temperature of 37.4°C. The comparison reveals slight variations between the set temperature and the actual measured values, with deviations ranging from -0.10°C to 0.4°C across multiple trials. On average, the measured temperature slightly deviates from the set value by approximately 0.16°C. While some readings exhibit a negligible difference, others indicate a slightly higher or lower temperature compared to the setpoint. These findings suggest a minor variation in temperature control within the incubator, with most measurements closely aligning with the desired temperature.

Table 1. Temperature performance test

No	Setup Unit °C	Temperature °C		Error
		Modul Incubator	Thermohygrometer	
1.	37,4	37,2	37,2	0
2.	37,4	37,6	37,6	0
3.	37,4	37,6	37,5	0,1%
4.	37,4	37,1	37,4	0,3%
5.	37,4	37,0	37,4	0,4%
	Mean	37,30	37,42	0,16%
	Deviation	-0,10	0,02	

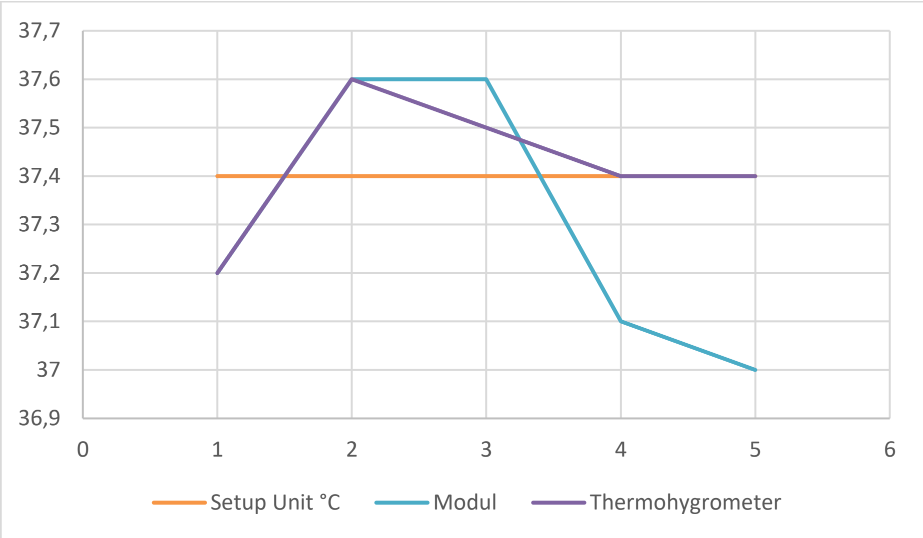

Figure 7. Heater for Incubator

3.3.2 Timer measurement

The table displays the comparison between the set timing parameters on the module of the incubator and the actual measured time using a stopwatch, presenting the deviation in seconds. Across multiple trials, including various time settings such as 60 seconds, 5 minutes, 10 minutes, and 15 minutes, the measured time closely matches the set timing parameters, with no observable deviation. Each trial indicates a consistent alignment between the set duration and the stopwatch measurements, reflecting precise timing accuracy within the incubator module. These results suggest reliable performance in maintaining and accurately measuring time intervals as programmed.

Table 2. Timer testing

No	Setup Timer	Setting Timer		Difference
		Incubator Set	Stopwatch	
		00:60	00:60	
		00:60	00:60	
1	00:60	00:60	00:60	0
		00:60	00:60	
		00:60	00:60	
		05:00	05:00	
		05:00	05:00	
2	05:00	05:00	05:00	0
		05:00	05:00	
		05:00	05:00	

3	10:00	10:00 10:00 10:00 10:00 10:00	10:00 10:00 10:00 10:00 10:00	0
4	15:00	15:00	15:00	0

4. CONCLUSION

This study successfully designed and evaluated a laboratory incubator capable of providing accurate temperature regulation and programmable timing control for laboratory applications. Experimental results demonstrated that the developed system maintained the target temperature of 37.4°C with only minor deviations ranging from −0.10°C to 0.40°C, indicating stable thermal performance. Furthermore, the timing module achieved high accuracy across various preset intervals (60 s, 5 min, 10 min, and 15 min), with negligible deviations. These findings confirm that the proposed incubator is reliable for applications requiring consistent temperature and precise timing control. The main contribution of this research is the development of a cost-effective laboratory incubator that integrates accurate temperature control and programmable timing functions using readily available electronic components. The proposed system provides an affordable alternative for laboratory environments while maintaining satisfactory measurement accuracy and operational stability. Despite these promising results, the study has several limitations. The performance evaluation was conducted under controlled laboratory conditions using a limited range of temperature setpoints and timing intervals. In addition, the incubator was validated only for temperature and timer performance, without evaluating long-term operational stability, temperature uniformity throughout the chamber, energy consumption, or biological sample incubation. Future work will focus on improving the incubator by implementing advanced control algorithms, such as Proportional–Integral–Derivative (PID) control, to further enhance temperature stability. Additional environmental sensors, including humidity and CO_2 sensors, can be integrated to enable comprehensive environmental monitoring. Other potential developments include remote monitoring through Internet of Things (IoT) technology, optimization of energy efficiency, long-term reliability testing, validation using various biological samples, and investigation of alternative heating technologies. These improvements are expected to increase the versatility, efficiency, and reliability of the incubator for broader scientific, biomedical, and educational laboratory applications.

REFERENCES

[1] A. Firdaus, "Analisa Alat Angiography Menggunakan Failure Mode and Effects Analysis (FMEA) Berbasis Fuzzy Logic," Universitas Mercu Buana, Jakarta, 2022.

[2] A. Firdaus, A. Adriansyah, N. Ferdana, R. Suhartina, R. F. Surakusumah, J. Haekal, Z. and A. U. Shamsudin, "Fuzzy logic assessment of X-ray tube risks in robotic C-arm angiography: a failure mode and effect analysis study," *IAES International Journal of Robotics and Automation (IJRA),* vol. 13, no. Desember, 2024, pp. 506-514, 2024.

[3] D. W. B. W. R. B. H. Lee Higdon, "Incubator management in an assisted reproductive technology laboratory," vol. 89, no. 3, pp. 703 - 710, 2008.

[4] A. Schertenleib, J. Sigrist and M. N. D. Friedrich, "Construction of a Low-cost Mobile Incubator for Field and Laboratory Use," *Journal of Visualized Experiments,* pp. 1-17, 2019.

[5] I. Hartmann and J. Wagener, "CO2 Incubators - Making the Best Choice for Your Lab," *White Paper Eppendorf,* 2018.

[6] J. E. Swain, "Decisions for the IVF laboratory: comparative analysis of embryo culture incubators," *SYMPOSIUM: QUALITY MANAGEMENT IN ASSISTED REPRODUCTIVE TECHNOLOGY,* 2014.

[7] T. A. Al-Kibash and S. Dana, Design and Implementation of a Bacteriological Incubator, Hebron: Palestine Polytechnic University, 2022.

[8] L. Alatse and M. E. M. Baumann, "A Laboratory Incubator Equipped with Facilities to Automatically Simulate Natural Irradiance," *Bolm Inst. Oceanogr,* 1991.

[9] A. Firdaus, N. Ferdana, R. Suhartina and Y. Borhanudin, "An Arduino-Driven Approach for Weight and Height Measurement Monitoring," *Jurnal Teknik Elektro dan Komputer,* vol. 12, no. 02, pp. 121-126, 2023.

[10] A. Firdaus , N. Ferdana , Y. Helmy and A. Ismanuri, "Innovative Approaches in Electromedical Education: Designing Low Cost X-ray Stationary Simulations Using Camera from Concept to Implementation," *Journal of Electronics, Electromedical Engineering, and Medical Informatics (ELECTROMEDIC) ,* vol. 1, pp. 14 - 18, 2024.

[11] A. Firdaus, N. Ferdana, S. Mujakar, H. Satrio and Z. , "Design and Development of Syringe Needle Destroyer Using Melting Method," *Emitor: Jurnal Teknik Elektro,* pp. 281 - 286, 2024.

[12] A. Firdaus, "Study the Application of Medical Imaging Technology in Queueing Techniques for PACS (Picture Archiving and Communication System)," *Jurnal Ilmu Teknik dan Komputer,* 2021.

[13] D. I. Z. R. S. A. P. M. Nanda Ferdana, "UVC Sterilization Robot with Remote Wireless Mode and Autonomous," *Sanitas,* vol. 13, pp. 68 - 80, 2022.

[14] A. Firdaus, Zulhamidi, W. Kristianti, S. I. Putri and S. Restuasih, "A Comprehensive Examination of 1.5 Tesla Magnetic Resonance Imaging (MRI) Through Overall Equipment Effectiveness Analysis : A Study Case On The Hospital Sector," *SANITAS: JURNAL TEKNOLOGI DAN SENI KESEHATAN ,* pp. 9 - 22, 2025.

[15] Shellab, Instalation and Operation Manual Incubator Laboratory, Oregon: Shellab, 2016.

[16] S. D. Tasneem Abo Al-Kibash, Design and Implementation of a Bacteriological Incubator, Hebron: Palestine Polytechnic University, 2022.

[17] A. Firdaus, N. Ferdana, Y. Helmy and A. Ismanuri, "Innovative Approaches in Electromedical Education: Designing Low-Cost X-ray Stationary Simulations Using Camera from Concept to Implementation," *Journal of Medical Electronics,* vol. 1, no. No.1, pp. 14-18, 2024.