RESEARCH ARTICLE OPEN ACCESS

Manuscript received January 18, 2024; revised March 10, 2024; accepted March 12, 2024; date of publication March 25, 2024

Digital Object Identifier (**DOI**): https://doi.org/10.35882/teknokes.v17i1.643

How to cite: Yohanes Cristomus Co'o, I.D.G. Hari Wisana and Abd. Kholiq, " Fuzzy Logic Temperature Control on Baby Incubator Transport Battery Efficiency", Jurnal Teknokes, vol. 17, no. 1, pp. 29–36, March. 2024.

Fuzzy Logic Temperature Control on Baby Incubator Transport Battery Efficiency

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"This work was supported in part by the Department of Electromedical Engineering, Health Polytechnic Ministry of Health Surabaya"

ABSTRACT Baby incubator transport is a life support tool used to maintain the body temperature of newborn babies during transportation from one place to another, such as from a hospital to an intensive care center with more complete facilities. The problem that often occurs in transport incubators is limitations in the power system. Baby incubator transport uses a battery as the main power source. However, the limited battery power can cause risks to the baby if there is a problem with the power system or the battery runs out. This study aims to monitor the remaining battery voltage in a transport baby incubator that uses fuzzy logic to control the temperature inside and will compare with the performance of PID control. This research uses a fuzzy logic method to control temperature and maximize battery power. In this study, researchers only looked at the efficiency of the fuzzy logic method in temperature control and the battery that will be used. The research uses a display that will display the battery voltage and current values, battery power percentage, skin temperature, chamber temperature, humidity and the selected temperature control. The module that has been made is then compared with the Digital Multimeter measuring instrument. From the results of data collection, the measurement of the remaining battery voltage between the sensor reading and the measuring instrument has a difference where at a temperature of 34 ºC it is 2.1%, at a temperature of 35 ºC it is 2% and at a temperature of 36 ºC it is 3.9%. When compared to research using PID control, fuzzy logic takes longer to reach the desired temperature and demands more battery power when compared to PID control.

INDEX TERMS: Baby Incubator Transport, Battery, Fuzzy Logic

I. INTRODUCTION

Baby incubator transport is a life support tool used to maintain the body temperature of newborn babies during transportation from one place to another, such as from a hospital to an intensive care center with more complete facilities. The ideal temperature required for room and skin temperature is 32-37°C[1][2], and the normal range for a baby's body temperature is between 36.5 to 37.5°C[3]. A baby is said to be hypothermic, namely the baby's body temperature is below 36 °C, and hyperthermia is when the baby's body temperature is above 38 °C [4][5]. To maintain a stable baby's body temperature, a transport incubator is needed that can regulate temperature, humidity and air circulation accurately and consistently. This incubator must also have sufficient safety and comfort features so that the baby remains safe and comfortable during the journey[6]. The problem that often occurs in transport incubators is limitations in the power system. Baby incubators use batteries as the main power source, but limited battery power can cause risks to the baby if there is a problem with the power system or the battery runs out. Therefore, a reliable and long-lasting power system is very important for baby incubators[7]. Accurate temperature control is very important in carrying a baby incubator to keep the baby's body temperature stable and safe. Fuzzy logic is a temperature control method that can be used to achieve this goal. Fuzzy logic combines Boolean logic and fuzzy mathematical principles, fuzzy sets enable more accurate decision-making in situations where membership is not completely certain or not clearly defined[8]. With fuzzy logic temperature control, the temperature can be adjusted automatically and quickly based on surrounding environmental conditions. The use of fuzzy logic temperature control in the baby incubator transport can ensure that the baby's body temperature remains stable, is not affected by temperature disturbances from the surrounding environment and increases battery efficiency. This way, the battery can last longer and allows the baby incubator transport to be used for a longer time. Following up on this problem, research was carried out by I. Adam, H. F. Rozi, Development of a Fuzzy-based baby Incubator. This research designed and developed a fuzzy-based control system to control the temperature and humidity of baby incubators. The research results show that temperatures in the range of 30ºC to 45ºC can be adjusted with an average error of 0.04ºC which is smaller than the target of 0.3ºC. Meanwhile, humidity can be adjusted with an average error of 0.4% for the range of 55% to 85%, lower than the maximum allowable error of 5%[9]. The research used Fuzzy logic temperature control for baby incubators which were in a room with controlled room temperature and humidity and had not researched outside air where the temperature and humidity were not controlled. Then Y.A.K Utama's research, temperature control techniques used in baby incubators to maintain the baby's body temperature at the right and stable level. This technique combines two control approaches, namely PID (Proportional-Integral-Derivative) control and Neuro Fuzzy Inverse Model. This research compares 3 controllers, namely On-Off control, PID control, and PID-DOB (PID Disturbance Observer) control in controlling temperature at 35°C. The three controllers are given interference in the form of 4 variations in outside air temperature so that they affect the environmental temperature in the incubator. The results of the research show that PID-DOB control with and resistance to disturbances in the form of outside air precisely controls the environmental temperature of the Neuro Fuzzy Inverse Model incubator which is the most effective control in temperature variations[10]. The weakness of this study was that it only took one control temperature of 35°C.

Next, Satryo Budi Utomo conducted research on an automatic baby incubator system with a fuzzy-PID controller. The method that will be used is Fuzzy-PID control which functions to maintain temperature stability and speed up the system response to the incubator. The heater used in this study was an incandescent lamp to produce heat that is safe for babies. Research was carried out by comparing PID controls to determine the speed of system response. Apart from that, measurements to assess controller stability were also carried out by analyzing the effect of load on temperature variations. The test results show that the Fuzzy - PID system response is faster than PID control and stability at temperature set points of 32°C, 33°C, 34°C and 35°C. The time required to reach equilibrium at the highest temperature setpoint is 205 seconds with a maximum overshoot of 0.5%. With max overshoot, the incubator can still work at a temperature that is safe for babies[11].

The advantage of existing research on baby incubators with the method applied is that Fuzzy logic control has the advantage of producing a stable and precise response to changes in input, such as changes in temperature and humidity for babies in the incubator. This will help maintain appropriate and stable environmental conditions for the baby being cared for in the incubator. Fuzzy logic can help overcome uncertainty and complexity in baby incubator systems. In some cases, it is not always possible to easily control changes in temperature or humidity inside an incubator using conventional control methods such as PID. In such situations, fuzzy logic can provide more responsive and flexible input tuning. Fuzzy-PID combines the advantages of PID control and fuzzy logic. In situations where stable and accurate feedback is required, PID control can provide better performance. However, in more complex situations, fuzzy logic can help create more responsive and adaptive control[12]. Fuzzy-PID can help overcome the limitations of these two control methods, so that you can control the baby incubator more efficiently and effectively. The weakness of this research is that it has not been applied to transport incubators, the use of fuzzy PID control in transport incubators can also help reduce energy consumption and extend battery life. Based on the results of identifying problems found in existing research, the authors are willing to develop a research tool with the title "Fuzzy Logic Temperature Control on Baby Incubator Transport Battery Efficiency" to evaluate the battery efficiency in transport incubators using fuzzy logic temperature control. This is crucial in the use of transport incubators because inefficient batteries can lead to heating failures, posing a threat to the safety of babies. The contribution of this study is as follows;

a. Optimal Temperature Control
b. Transport Battery Efficiency
c. Medical Technology Innovation
d. Enhanced Infant Safety

II. METHOD

A. *FUZZY LOGIC*

Fuzzy logic is a technique or method used to manage uncertainty in problems with multiple solutions. The basic concept of fuzzy logic is multi-valued logic, capable of determining values between conventional states such as true or false, yes or no, white or black, etc. Fuzzy logic provides reason to understand system performance by evaluating system inputs and outputs based on observations. The peculiarity of this logic is the ability to draw definitive conclusions from vague, ambiguous and imprecise information. Therefore, fuzzy logic offers a more flexible way to handle uncertainty in decision making or systems analysis[13]. There are three main processes if you want to implement fuzzy logic in a device, which are fuzzification, rule evaluation, and defuzzification.

1. Fuzzification is the process of converting a sharp input into a fuzzy one, usually represented as a fuzzy set with corresponding urban functions[14]–[16]. Converting input data values to their respective membership values within the 0 to 1 interval can be accomplished by employing equations (1) and

(2)[17]–[19].

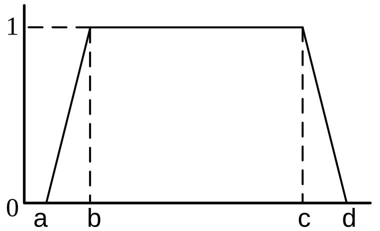

FIGURE 1. Illustrating a linear representation in ascending order

$$\mu(x) = \begin{cases} 0 & ; x \leq a \\ \frac{x-a}{b-a} & ; a \leq x \leq b \\ 1 & ; b \leq x \leq c \\ \frac{d-x}{d-c} & c \leq x \leq d \\ 0 & ; d \leq x \end{cases} \quad (1)$$

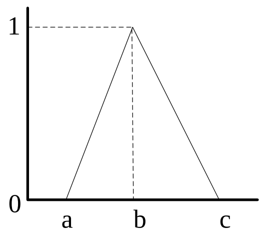

FIGURE 2. Depicting a linear trapezoidal representation

$$\mu(x) = \begin{cases} 0 & ; x < a \\ \frac{x-a}{b-a} & ; a \leq x \leq b \\ \frac{c-x}{c-b} & ; b \leq x \leq c \\ 0 & ; c < x \end{cases} \quad (2)$$

2. Inference System "Rule Evaluation" is a reference to explain the relationship between input and output variables where the processed and generated variables are blurred. To explain the relationship between input and output, "IF-THEN" is often used[20]–[22].
3. Defuzzification is the process of converting these fuzzy variables into precise data that can be sent to a control device[23]–[25]. When using the Sugeno method for rule composition, the defuzzification process involves determining the centered average value, written in equation (3).

$$z = \frac{\sum x_i \times \mu(x_i)}{\sum \mu(x_i)} \quad (3)$$

Here, z represents the crisp output, x_i denotes the crisp value corresponding to the input i, and $\mu(x_i)$ signifies the degree of membership for each xi[26]–[28].

The use of Fuzzy Logic control in this study integrated into the Arduino mega 2560 microcontroller aims to speed up the time required for the system to reach parameters and reduce signal errors[29]. To regulate the temperature inside the incubator, the amount of heat generated by the heater is controlled by the heater controller to reduce or increase the heat. The temperature sensor then senses the heat and gives it as input to the Fuzzy Logic controller to compare with the preset point[30]. For more details can be seen in FIGURE 3 which shows the design of the fuzzy logic control system.

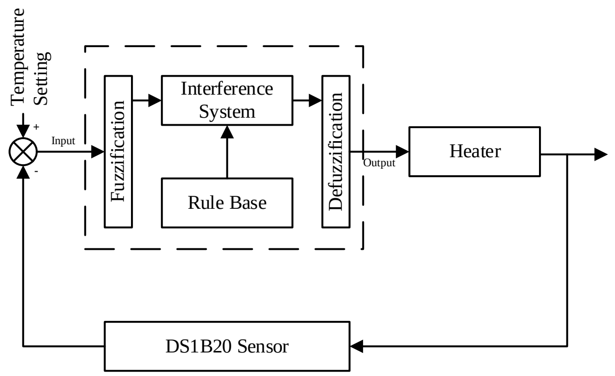

FIGURE 3. Fuzzy logic system diagram for testing battery efficiency. The data will be processed by Arduino Mega256 to test the fuzzy logic system.

B. DATA COLLECTION

The author will test the module with a digital multimeter with the aim of finding out the capabilities of the module that has been designed. In testing the module with a Digital Multimeter, data is collected five times at each measurement point in accordance with conformity test standards. The voltage sensor data readings will be displayed on the Personal Computer.

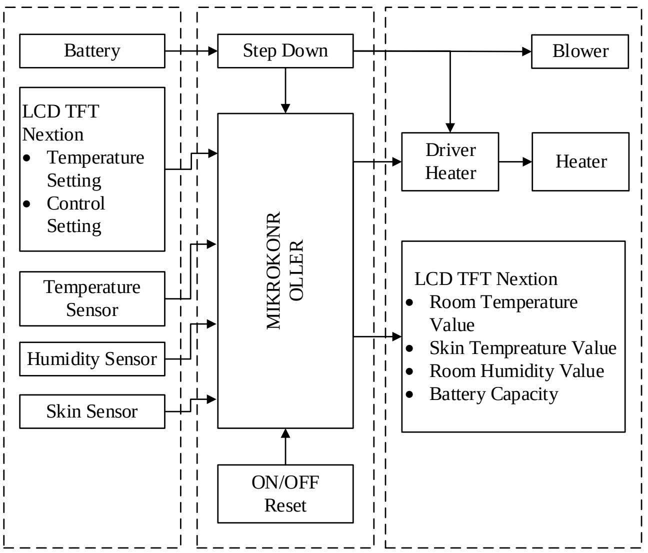

FIGURE 4. Design the incubator transport equipment. The system is controlled using the Arduino Mega256 module.

FIGURE 4 shows the block diagram of the entire battery system used, namely a 12 Volt 28 Ah dry battery to supply voltage[31]. Selecting a battery suitable for a standard baby incubator transport device. The battery is stepped down to 5 Volts to supply voltage to the microcontroller which will activate the skin sensor, temperature sensor (DS18B20)[32], humidity sensor, TFT screen, driver to the heater, and blower. The 12 Volt voltage is only to supply the DC heater. The screen here uses TFT Nextion which will display temperature setting options and control settings. The microcontroller will process the temperature read by the temperature sensor and control the temperature according to the control that has been selected by turning on the heater and blower. Then the results of the work percentage of the heater will appear on the Nextion TFT screen along with the room temperature values, skin sensor, humidity and battery capacity.

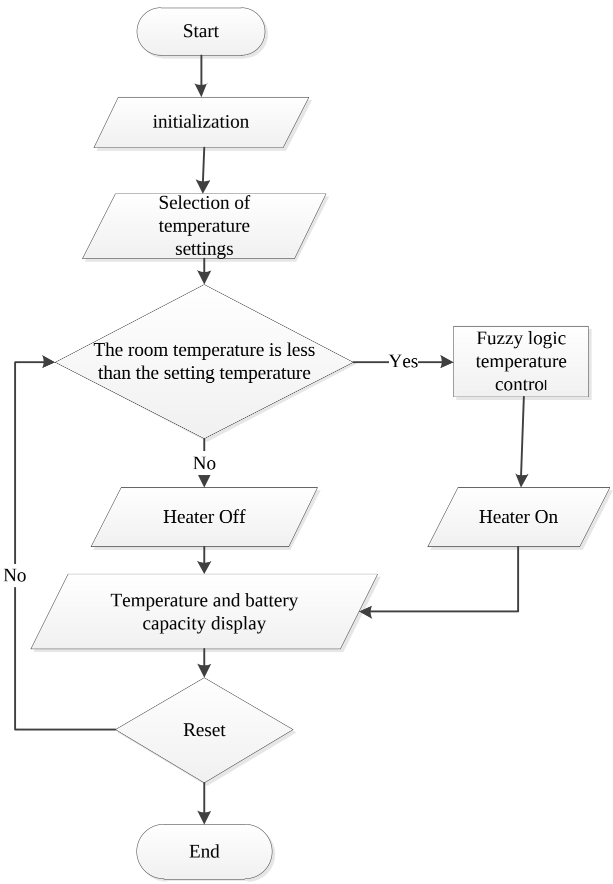

FIGURE 5. System flow diagram for testing battery efficiency. The data will be processed by the Arduino Mega256 and displayed on the personal computer.

The flow diagram shown in FIGURE 5 shows how it works. When the device is turned on, an initialization process occurs for the temperature sensor and sending data from the microcontroller (Arduino Mega) with the Nextion TFT. Then the Nextion TFT will display the temperature setting options to control the work of the heater. The temperature in the baby incubator will also be displayed on the Nextion TFT along with a graph. The heater will turn off when the temperature is on the baby incubator approaches or fits the predetermined temperature and will start turning on again when the temperature in the baby incubator room falls below the temperature that has been determined using Fuzzy logic control[33].

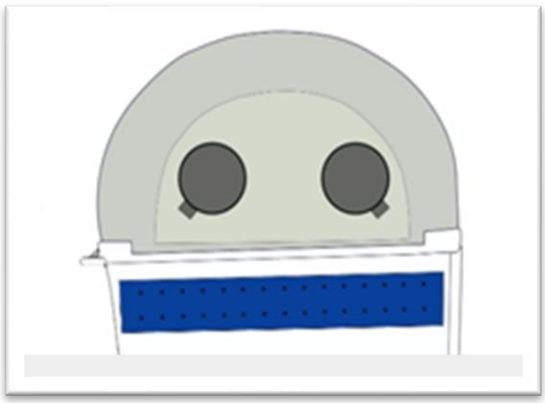

FIGURE 6. Baby Incubator Transport Chamber Mechanical Diagram side view.

FIGURE 7. Front view of the control panel.

In FIGURE 6 is the side part of the Incubator Transport module mechanism diagram. The size of the transport incubator chamber studied: Length: 87 cm, height: 47 cm, width: 47 cm.

And in FIGURE 7 is the front view of the tool and the TFT display of the Incubator transport module mechanism diagram which contains the start button, battery usage, temperature parameters, humidity, baby skin temperature, control method settings to be used, temperature graph, battery graph and stop button.

C. *DATA ANALYSIS*

The measurements were repeated five times for each temperature setting. The average measurement value is obtained using the equation (4):

$$x = \frac{x_1 + x_2 + \cdots + x_n}{n} \qquad (4)$$

The equation above shows that "n" is the amount of data obtained, "x1" indicates the first measurement and "xn" indicates the nth measurement. System errors are displayed as %error. The smaller amount of difference between the means of each piece of data is Error. Error indicates the possibility that the module is not appropriate or does not meet the standards it should be. Equation (5) displays the error formula:

$$ERROR = \frac{(x_n - x)}{x_n} \times 100\% \quad (5)$$

where "xn" above represents the calibrator measuring value. Meanwhile, the value determined by the module is the symbol "x".

III. RESULT

In FIGURE 8 it is a whole series. The circuit consists of an Arduino Mega 2560 working with a voltage of 5 volts with a 5 Ampere supply. Uses a 28 AH battery as the main source connected to a switch[10]. It is also connected to the VDC input from the Arduino which has gone through a step-down output, so the Arduino gets the input voltage and is in the ON condition. Provides 5VDC and Ground to DS18B20-1, DS16B20-2 and DHT22 sensors. The Nextion LCD circuit will get input from the Arduino Mega directly. After selecting the available temperature settings (34ºC, 35ºC, and 36ºC), the Arduino will become a voltage source from the SSR switch which will then control the ON/OFF of the DC heater according to the running Fuzzy Logic program. The circuit consists of: DS18B20-1, DS18B20-2 and DHT22 circuit, DHT22 circuit, Nextion LCD circuit, SSR driver circuit, DC fan circuit, DC 28AH battery circuit and DC heater circuit.

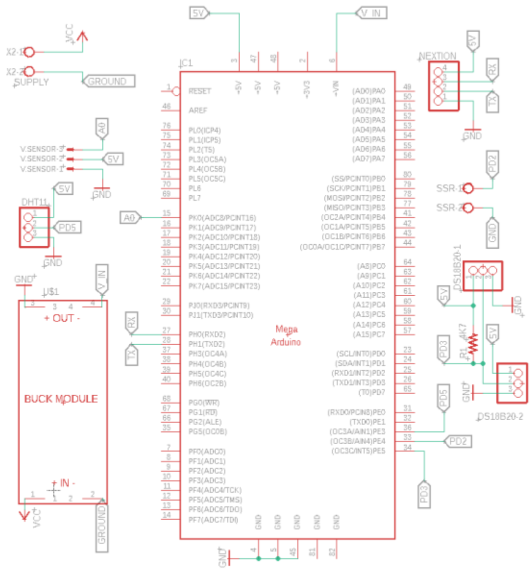

FIGURE 8. **Overall Module Circuit**

Module measurements will be compared with the Digital Multimeter as a reference and comparison in determining the truth value of battery efficiency measurements on the baby incubator transport module using the fuzzy logic method. Measurement data on the battery module is collected manually and compared with the sensor readings on the module. FIGURE 9 shows the display on the TFT screen of the device in the form of system control data, temperature data and battery capacity. In FIGURE 10 is a graphic image of the temperature reading of the incubator temperature displayed on the PC. When data was collected using fuzzy logic control for one hour, the temperature set point was 35°C, rise time, reaching the set point took 26 minutes, steady state error was 0.4%.

Meanwhile, FIGURE 11 is a graphic image of the battery voltage reading displayed on the PC, when collecting data with fuzzy logic control for 1 hour, from the voltage graph it can be seen that when there is no load the battery voltage is at 14.5 volts and when there is a load the voltage drops to 12.3 volts 30 minutes of temperature running time past the setpoint. Fuzzy logic control works following microcontroller commands. The following is the power calculation before overshoot with a sample at 1800 seconds. Battery power usage can be calculated using equation (3).

$$Wh = V \times I \times h \quad (3)$$

Wh is a unit of total battery capacity. V represents the output voltage of the battery in use. I denotes the current value of the entire circuit of the baby transport incubator. h stands for the duration of battery use in hours.

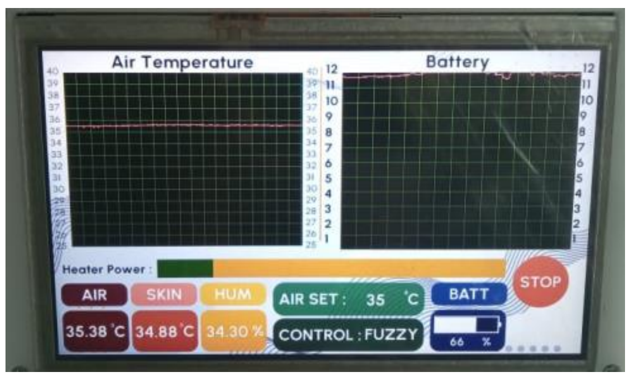

FIGURE 9. **TFT screen display on Baby incubator transport.**

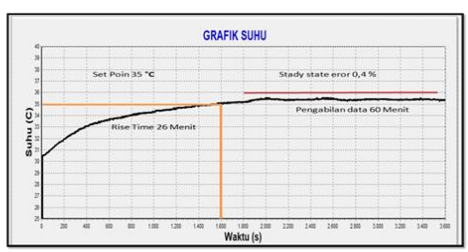

FIGURE 10. **Temperature graph display on PC with fuzzy logic control.**

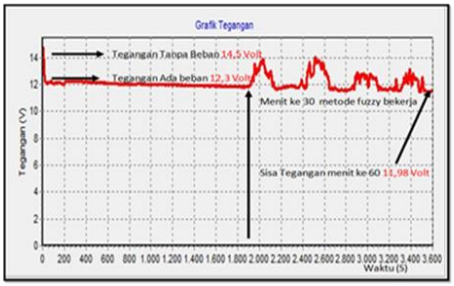

FIGURE 11. Voltage graph display on PC with fuzzy logic control.

Data collection in FIGURE 12 was carried out at a temperature setting of 35°C. Measurements were carried out 5 times, taking residual voltage data from voltage sensor readings and manual multimeter readings. FIGURE 13 is a graph of battery voltage observations for 1 hour operated using the fuzzy method at a setting temperature of 35°C. FIGURE 14 is a graph plotting the temperature achieved during 1 hour of operation of the baby incubator.

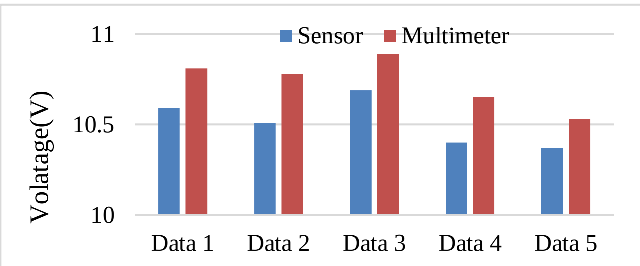

FIGURE 12. Residual Voltage Measurement Results at a temperature setting of 35 °C.

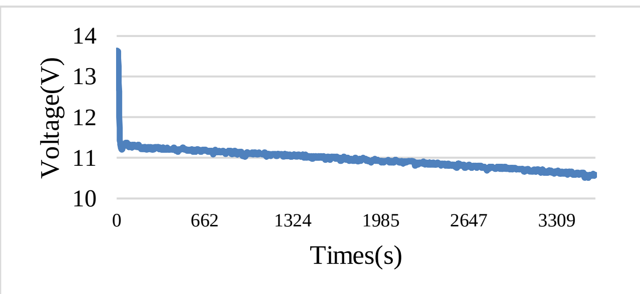

FIGURE 13. Battery Voltage Measurement Graph at set point 35 °C

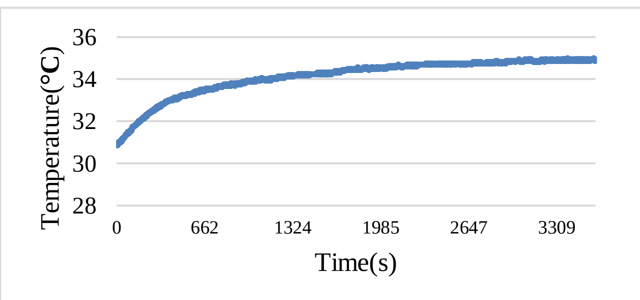

FIGURE 14. Temperature measurement graph 35 °C.

From the results of the data collection, it can be concluded that the Fuzzy logic method has a longer rise time to reach the setting temperature, whereas, in the same research, the PID method has a faster rise time to reach the setting temperature. However, the PID method requires more battery power compared to the Fuzzy logic method. In TABLE 1, the results of measuring the remaining battery voltage between the sensor readings and the measuring instrument have a difference, where at a temperature of 34 °C it is 2.1%, at a temperature of 35 °C it is 2% and at a temperature of 36 °C it is 3.9%. The biggest error is found in voltage measurements at a temperature of 36 °C.

TABLE 1
Mean and Error Measurement Results

Setpoint Temperature	Module	Digital Multimeter	Error
	volt	volt	(%)
34°C	10,52	10,75	2,1
35°C	10,79	11,23	2
36°C	9,51	9,73	3,9

IV. DISCUSSION

The module in this study certainly still has limitations that can later be used as a reference for development. In this module, the temperature of the external environment greatly affects the temperature in the chamber and battery power consumption. If the external ambient temperature is below 28 °C, the battery power consumption is higher and it takes a long time to reach the temperature set point. In this study using a 12 Volt 28 Ah Dry Battery, the battery was only used at 70% of its power for 60 minutes, because battery performance will be affected if the battery power used is more than 70% [30]. The reading of the remaining battery voltage value for 60 minutes was measured on the module where at a temperature of 34°C the remaining battery voltage is 10.52 volts, at a temperature of 35 °C the remaining battery voltage is 10.79 volts, and at a temperature of 36 °C, the remaining battery voltage is 9.51 volts. Based on these results it can be concluded that to achieve a higher temperature setting value, the greater the power consumed.

When compared to the results of the influence of the performance of PID control that affects the performance of the battery for 60 minutes with the reading of the remaining battery voltage value measured on the module where at a temperature of 34°C the remaining battery voltage is 11.25 volts, at a temperature of 35 °C the remaining battery voltage is 10.79 volts, and at a temperature of 36 °C the remaining battery voltage is 9.51 volts. These results show that PID control can provide higher, consistent battery residual voltage values that are less affected by temperature variations than fuzzy logic. This may be due to the weakness of fuzzy logic which is less responsive to changes in temperature or system conditions that occur.

This research highlights the huge impact that external ambient temperature has on in-room temperature and battery power consumption. When the ambient temperature is below 28 ºC, battery power consumption increases, and reaching a certain temperature point takes longer. This suggests that the module may be less effective in low ambient temperature conditions. There is a difference between the residual battery voltage measurement results on the module and the measurement results on the measuring device. This error indicates that the battery voltage measurement is less accurate or may be affected by other factors. The results provide an understanding of the advantages and disadvantages of the baby incubator transport module using the fuzzy logic method. The implications include the need for further development to improve efficiency, responsiveness, and battery health. Future research can focus on developing fuzzy logic algorithms for faster response to changes in temperature and environmental conditions. Further evaluation of factors that affect battery health can also be the focus of future research.

V. CONCLUSION

This study aims to monitor the remaining battery voltage in a transport baby incubator that uses fuzzy logic to control the temperature inside and will be compared with the performance of PID control. The objective of this research is to investigate the baby incubator transportation device, analyzing its functionality during emergency evacuations by utilizing battery power. The findings, quantified through rigorous quantitative analysis, reveal insights into the strengths and weaknesses of the control methodology. Specifically, fuzzy logic is employed for automatic temperature adjustment based on environmental conditions. However, the integration of fuzzy logic optimizes battery usage while exhibiting vulnerability to ambient temperature fluctuations. Additionally, it is noted that fuzzy logic requires more time to reach the desired temperature and demands higher battery power compared to PID control. In light of these results, future works should focus on advancing the efficiency, responsiveness, and battery longevity of the module. Subsequent research efforts may concentrate on refining fuzzy logic algorithms to ensure a swifter response to temperature changes and evaluating factors impacting battery health.

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