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Analysis of Temperature Stability and Accuracy on the Design of Thermometer Calibrator Based on Fuzzy Logic and On-Off Control Systems

Yunik Pujiastuti¹, Andjar Pudji¹, Singgih Yudha Setiawan¹, and Farid Amrinsani¹, Khongdet Phasinam²

¹ Department of Medical Electronics Technology, Poltekkes Kemenkes Surabaya, Surabaya, Indonesia

² Pibulsongkram Rajabhat University, Thailand

Corresponding author: Andjar Pudji (e-mail: andjar@poltekkesdepkes-sby.ac.id).

ABSTRACT A thermometer is a medical device used to measure body temperature. To maintain the accuracy of the thermometer measurement results, periodic calibration is required. Calibration is an activity to determine the conventional correctness of the indicator values of measuring instruments and materials by comparing them with the national and international standards for units of measure and/or international and certified reference materials. Based on the results of the identification of chronological problems that have been observed, a body thermometer that needs to be calibrated in order to maintain its accuracy. The purpose of this study was to analyze the Temperature Stability and Accuracy of the Body Thermometer Calibrator Based on on-Off Controller and Fuzzy Logic Control. This research is further expected to give contribution in the forms of tool that applied a fuzzy logic control method to produce temperature stability in the Body Thermometer Calibrator (Digital). Furthermore, the method used in this study was fuzzy control and on-off control. The results of this study from the suitability test obtained a maximum error of 0.2% in the fuzzy control and 0.6% in the On-Off control. The average rise time difference for the two controls was 13.53 Seconds, while the average settling time difference was 130.46 seconds. Based on the results of this study, it can be concluded that the Fuzzy System is better than the On/ Off system, so the Fuzzy system is more suitable for thermometer calibration media.

INDEX TERMS Calibration, Thermometer, Calibrator, Fuzzy Logic.

I. INTRODUCTION

The problem in measuring using a thermometer is accuracy. The accuracy of the thermometer will have an impact on the doctor's diagnosis. It is necessary to conduct re-calibration on the thermometer to minimize errors in determining the patient's health status. The re-measurement is meant to test and calibrate the thermometer. In this case, calibration is an activity to determine the correct value of the designation of measuring instruments and/or measuring materials [1]. Regular medical devices must be calibrated at least once a year. In this case, a body thermometer is one of the measuring instruments that must be measured, routinely checked, and calibrated before use or after use at least once a year or at certain intervals. Calibration is done by comparing the instrument used with the national and international standards and certified reference materials. A quality management system requires an effective measurement system, including formal, periodic, and documented calibration for all

measurement devices. This is intended so that the measurement results are not too far from the desired tolerance limit [2][3]. Many research projects have been done in making calibration tools with temperature parameter testing [4][5][6]. There is also a lot of research conducted aiming to easily read and save the calibration results [7][8][9][10], starting from using bluetooth as data transmission and an android system. Designing thermometer calibrator has been carried out by several researchers using several temperature regulation methods to produce an accurate calibrator [11][12]. In 2011, T. Barry et al studied Infrared Thermometer Calibration with low-temperature measurement. The study used a calibration method at low-temperature measurements for remote temperature monitoring in cold climates. The disadvantage of the research is that the response time of the IR thermometer using this technique was limited by the time it took to insert the cover into the optical path [13]. Furthermore, Ernour et al also conducted a study in 2013 PID and Fuzzy Logic in

Temperature Control Systems. This study compared Fuzzy Logic and PID controls. The advantage of this research is that FLC has a faster response to settings compared to PID and is more stable to external disturbances. Meanwhile, the drawback is that PID had a less fast response [14]. In 2018, another research project was also conducted by H. Okan et al on the calibration of infrared ear thermometers. This study used the conical plate method with various temperatures according to the depth of the plate made hollow under the EN 2003 and ASTM 1998 standards. The box on the tool was designed to be airtight so that the calibrated temperature had good stability and homogeneity. The advantage of this research was that the measurement accuracy was under the tolerance in the specified standard. In future research, the tool was smaller and portable [15]. In 2019, research on calibration was also conducted by Handayani, particularly on designing Body Temperature Thermometer Calibration Media using Arduino-Based Ds18b20 Sensor with a heater using a Dry Heater and a Ds18b20 temperature sensor at temperature setting of 35-40°C and a Thermo-One thermometer as the comparison tool. However, this study had a weakness in the form of the average temperature of 30.82°C that took a relatively long time to reach the setpoint temperature stably [16][17]. Furthermore, in 2020, research by D. Matsunaga was conducted on non-invasive thermometers for continuous monitoring of body temperature in various convective conditions. This study used the method of measuring body temperature from the skin surface in an environment that often experienced temperature changes. The advantage was that the probe can measure accurately even when there was a temperature change. Meanwhile, the weakness was that there was still an error in the estimation of readings caused by convective changes (temperature fluctuations) [18]. Based on the description of the results of the literature study that has been described, several things need to be resolved through a new study, namely finding and using an accurate and efficient system in the sense of being stable for the measurement results. Therefore, this research will design a thermometer calibrator to analyze the Temperature Stability and Accuracy of the Body Thermometer Calibrator Based on On-Off Control and Fuzzy Logic Control. This research was conducted aiming to develop the Fuzzy Logic control method to produce temperature stability and accuracy on the Body Thermometer Calibrator (Digital), conduct a comparative analysis with standard tools that have been calibrated, as well as test and calibrate the body thermometer (Digital). The use of this design is considered more effective because it has advantages in terms of accuracy and temperature stability when using the Fuzzy Logic control method for the thermometer calibrator. The purpose of this study was to analyze the Temperature Stability and Accuracy of the Body Thermometer Calibrator Based on On-Off Control and Fuzzy Logic Control. Furthermore, it is expected that the current research can give contribution in the forms of good control methods to be used

in making thermometer calibrator designs. Therefore, thermometer calibration can be done faster and more accurate.

This article consists of 5 parts, part II contains the methods and developments carried out, Part III is the results obtained, Part IV is the discussion of the findings, and Part V is a conclusion.

II. MATERIALS AND METHOD

The study was conducted as experimental research. The authors proposed an analyzer of temperature stability and accuracy on the design of a thermometer calibrator based on fuzzy logic and on/off control. An explanation of the data collection, the theoretical basis, and data analysis are described in the following sections.

A. DATA COLLECTION

In this study, the researchers compared the study design and the manufacturer's temperature calibrator as a comparison device. This study used the DS18B20 temperature sensor, Peltier Element, Arduino Nano Module, TIP3055 Transistor, and LCD 2x16. The methods used for temperature control in the design were the Fuzzy System and the on/off system which were then compared and analyzed for its accuracy. Meanwhile, the data processing used was Arduino software [19][20].

At the measurement stage, the temperature was regulated at 37°C, 39°C, and 41°C. This proposed research design was measured with the manufacturer's temperature calibrator INCU II (standard INCU analyzer) to obtain the temperature value created according to the value of the calibrator. After the temperature approached the value on the calibrator, the rise time response, steady-state, and overshoot were analyzed on 3 temperature settings and 2 types of control systems with 2 PWM ranges, namely 0 – 100 and 0 -255.

FIGURE 1 shows a block diagram of the entire system. A small box represents the proposed design, that is, a temperature calibrator. The block diagram of the system used is shown in FIGURE 1. The input consists of a temperature setting in the form of a push-button and a temperature sensor using the DS18b20. In the processing block, there was an Arduino Nano microcontroller as the data processor. The output block consists of an LCD for temperature measurement results and a Peltier for the heating element. When the adapter was connected to the PLN grid, the entire circuit obtained a voltage. Furthermore, the temperature was set using the up and down buttons in a temperature range of 37 –41°C. The DS18B20 temperature sensor worked to detect the Peltier temperature that was working to reach the temperature setting, then the LCD displayed the DS18b20 temperature sensor reading.

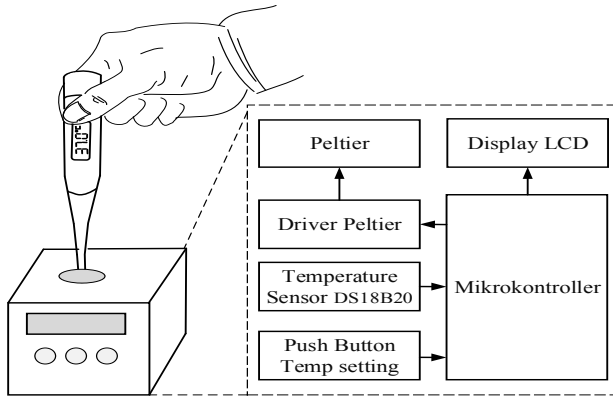


FIGURE 1 The proposed design of the calibrator thermometer using Peltier elements as heat generators. The system was controlled using Arduino modules and Fuzzy logic system control.

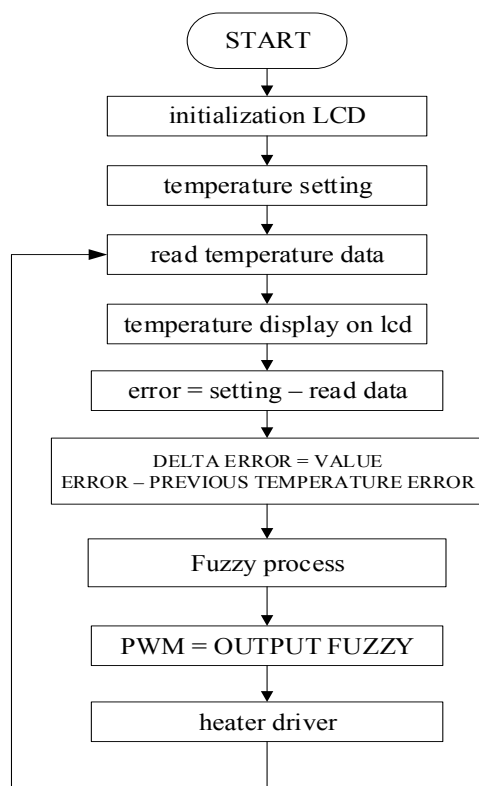


FIGURE 2 The Flowchart system detected the temperature parameters and used a fuzzy logic control system. The heater was used in this study using Peltier.

FIGURE 2 The Flowchart system detected the temperature parameters and used a fuzzy logic control system. This system started when the initialization occurs from the input-output of the microcontroller and the 2 X 16 LCD interface. After the initialization process was complete, the temperature setting and temperature reading process began. After the temperature reading was complete, then the results were displayed on the LCD. Furthermore, the next process was calculating the error (difference) between the temperature read and the desired temperature as well as the delta error (difference) between the error value with the previous temperature error value.

Furthermore, the fuzzy method was processed. In this case, the output of the fuzzy controller functioned to manipulate the PWM value to get results that show the size of the heating power. If the result of the comparison between the temperature read and the desired temperature obtains high error, then the program will give an order to add the temperature power driver. If the result of the comparison between the temperature read and the desired temperature is small, the program will give an order to reduce the temperature power driver, in this case, the power will continue to decrease as the value decreases.

B. FUZZY LOGIC

Fuzzy logic is a variable processing approach that allows multiple possible truth values to be processed through the same variable. Fuzzy logic tries to solve problems with an open spectrum of data and heuristics. Vague or fuzzy logic is designed to solve problems by considering all available information and making the best decisions given input. The following figures show the section as well as the architecture in fuzzy logic:

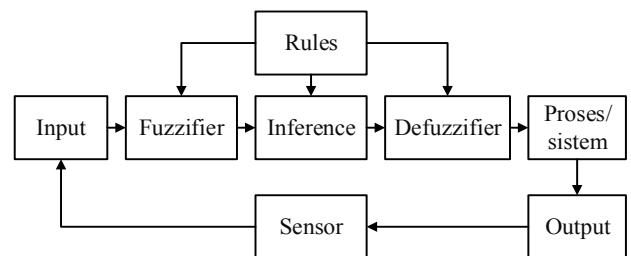


FIGURE 3 The proposed calibrator thermometer design using the Fuzzy logic system control to control the Peltier element according to the set point value.

FIGURE 3 shows a block diagram of a fuzzy logic system control. Fuzzy controllers have fuzzification, rule bus control, degasification, and output in the form of Peltier elements as heat generators in this design. The resulting temperature of the element was detected by the temperature sensor and was calculated as the error value where the error value is as input to the control system [21][22][23]. The fuzzy control has two input signal processing to the controller, namely the error signal (error, E) and the error change signal (delta error, dE). The E signal is obtained from reducing the process output to the setpoint, while the dE signal is obtained from the reduction of the E(k) error signal, with the previous error signal E(k-1). Both signals are then processed by the fuzzy controller's desired temperature until the heating power will turn off because the error value is 0.

In **FIGURE 3**, the Fuzzy Logic architecture has 4 (four) main sections as discussed below.

1. Base Rule

The first part of the fuzzy architecture is the rule base. It contains all the if-then rules and conditions offered by

experts to control the decision-making system. The latest update in fuzzy theory provides a variety of methods for the design and tuning of fuzzy controllers. This update significantly reduces the number of fuzzy rule sets.

2. Fuzzifier

The next type of fuzzy part is fuzzification. The fuzzification step helps to convert the input, as well as allows user to convert clear numbers into fuzzy sets. Sharp inputs are measured by sensors and passed to the control system for further processing. The determination of a fuzzy set is not limited by certain rules. In the case of this study, triangular membership function was used. The triangular function is defined as follows (1) [24]:

$$T(u; a, b, c) = \begin{cases} 0 & u < a \\ \frac{u-a}{b-a} & a \leq u \leq b \\ \frac{c-u}{c-b} & b \leq u \leq c \\ 0 & u > c \end{cases} \quad (1)$$

The diagrammatic form of the triangular function is shown in FIGURE 4 [24].

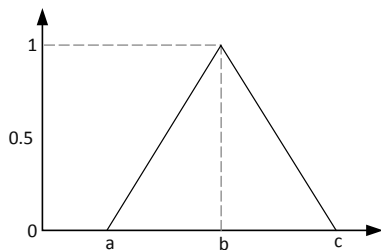


Figure 4 Diagrammatic form of the triangular function

3. Intelligence or Inference Engine

Next is the intelligence or inference machine. This part of the architecture helps to determine the degree of match between the fuzzy input and its rules. Based on the percentage rate (%) of matches, it will determine which rules need to be applied according to the given input field.

4. Defuzzifier

The last type of fuzzy architecture section is defuzzification. After going through all the previous processes, a defuzzification process is carried out to convert the fuzzy set into a crisp value.

C. DATA ANALYSIS

The measurements of each experiment are all repeated 6 times. The average value of the measurement was obtained by using the average or average by applying the equation (2):

$$\bar{x} = \frac{x_1 + x_2 + \dots + x_n}{n} \quad (2)$$

where \bar{x} indicates the mean (average) value for n-measurement, x1 indicates the first measurement, x2 shows

the second measurement, and Xn indicates the n measurement. The standard deviation is a value that indicates the level (degree) of variation in a group of data or a standard measure of deviation from its mean. The standard deviation (SD) formula can be shown in equation (3):

$$SD = \sqrt{\frac{\sum (x_i - \bar{x})^2}{(n-1)}} \quad (3)$$

The %error shows the error of the system. The lower error value is the difference between the mean of each data. The error can show the deviation between the standard and the design or model. The error formula is shown in equation (4).

$$\%ERROR = \frac{(x_n - x)}{x_n} \times 100\% \quad (4)$$

where Xn is the value measured from the calibrator machine. The x is the value measured from the design.

III. RESULT

Based on the temperature measurement that has been done, we found that the error values ranged between -0.21% and 0.08%. In this case, the detailed measurement results are shown in the following table and graphics. These measurements were done 6 times for each experiment, where INCU II (standard INCU analyzer) was used as a comparison tool. Furthermore, TABLE 1 and FIGURE 5 show the average measurement results on the standard INCU design and analyzer. We further found the difference between the calibrator and the design result when noise was measured on these two devices. The measurement error of the temperature parameter between the calibrator (INCU 2) and the design for the setpoint of the difference is shown in TABLE 1 and FIGURE 5.

A. MEASUREMENT RESULTS ON/OFF CONTROL AND FUZZY CONTROL

TABLE 1

The calculation results of the average value and standard deviation of compatibility test with the temperature calibrator when using the on-off control system and fuzzy logic

System Control	Setting Temp	Mean		Standard Deviation		Error (%)
		Device (°C)	Calibrator (°C)	Device (°C)	Calibrator (°C)	
On-Off	37°C	37.36	37.37	0.0897	0.0516	0.02
	39°C	39.35	39.37	0.0738	0.0516	0.04
	41°C	41.36	41.33	0.0492	0.0516	0.06
Fuzzy Logic	37°C	36.97	37.05	0.0467	0.0548	0.21
	39°C	38.96	39.00	0.0310	0.0632	0.10
	41°C	41.01	40.98	0.0723	0.0310	0.08

TABLE 1 above shows the Measurement Results of On/Off control and fuzzy control by combining the temperature values of the design and calibrator. In this case, the smallest error obtained was 0.02% at temperature setting of 37°C using the on-off control system, while the biggest error was

-0.21% at the temperature setting of 37°C using the fuzzy control system.

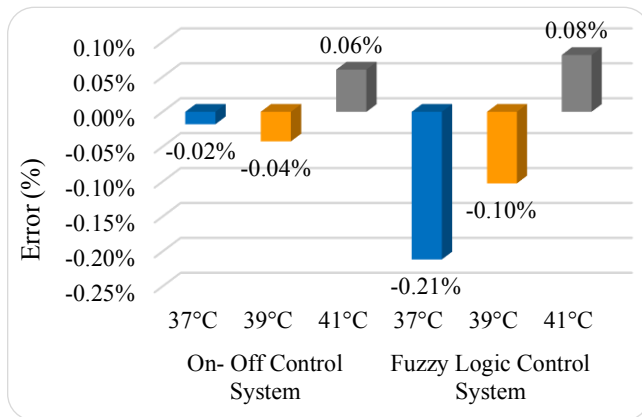


FIGURE 5 Compatibility test error calculation results with temperature calibrators using the on-off control system and fuzzy logic

B. RISE TIME MEASUREMENT RESULTS IN ON/OFF CONTROL AND FUZZY CONTROL

TABLE 2

Table II explains the differences in methods with PWM range settings to find out the rise time in each temperature setting, as well as displaying the average and standard deviations

Control System and PWM Range	Temperature Setting (°C)	Mean (second)	Standard deviation (second)
On-Off with PWM range 0-100	37°C	117.60	0.84
	39°C	141.00	1.33
	41°C	168.40	0.82
On-Off with PWM range 0-255	37°C	47.40	0.52
	39°C	51.20	0.41
	41°C	60.40	0.82
Fuzzy logic with PWM range 0-255	37°C	57.20	0.41
	39°C	67.60	0.84
	41°C	74.80	1.03

TABLE 2 presents the Rise Time Measurement in On/Off control and Fuzzy control. From the results of the calculation of the average rise time at temperature settings of 37°C, 38°C, and 41°C using the On-Off control with a PWM scale of 0-100, the minimum value obtained was 117.6 seconds, while the maximum value obtained was 168.4 seconds. Meanwhile, for the data using the On-Off control with a PWM scale of 0-255, the minimum value was 47.4 seconds, while the maximum value was 60 seconds. Meanwhile, the trial using fuzzy control with a PWM scale of 0-255 obtained a minimum value of 57.2 seconds and a maximum value of 74.8 seconds.

C. MEASUREMENT RESULTS OF RESPONSE TIME UNTIL STEADY-STATE ON ON/OFF AND FUZZY SYSTEM CONTROLS.

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TABLE 3

The calculation results of the average and standard deviation of Response Time until Steady State using the on-off and fuzzy logic control system

Control System and PWM Range	Temperature Setting (°C)	Mean (second)	Standard deviation (second)
On-Off with PWM range 0-100	37°C	199.2	1.03
	39°C	214.8	0.41
	41°C	224.4	0.84
On-Off with PWM range 0-255	37°C	224.6	0.52
	39°C	230.6	0.84
	41°C	236.8	0.41
Fuzzy logic with PWM range 0-255	37°C	90.2	0.41
	39°C	100	0.63
	41°C	110.4	0.82

TABLE 3 above shows the Response Time to Steady Measurement State using On/Off control and Fuzzy control system. Based on the results of the calculation of the average Response Time to Steady State at temperature settings of 37°C, 38°C, and 41°C using the On-Off control with a PWM scale of 0-100 obtained a minimum value of 199.2 seconds and a maximum value of 224.6 seconds. Meanwhile, for the data using the On-Off control with a PWM scale of 0-255, it obtained a minimum value of 224.6 seconds and a maximum value of 236.8 seconds. Meanwhile, the trial using fuzzy control with a PWM scale of 0-255 obtained a minimum value of 90.2 seconds and a maximum of 110.4 seconds.

D. OVERSHOOT MEASUREMENT RESULTS ON ON/OFF CONTROL

TABLE 4

The results of calculation of average and standard deviation of Response Overshoot using the on-off and fuzzy logic control system

Control System and PWM Range	Temperature Setting	Mean (°C)	Standard deviation
On-Off with PWM range 0-100	37°C	0.98	0.0408248
	39°C	0.98	0.0408248
	41°C	0.98	0.0408248
On-Off with PWM range 0-255	37°C	3.48	0.0408248
	39°C	3.66	0.0516398
	41°C	3.98	0.0408248

TABLE 4 above shows the results of overshoot of the On-Off control measurements with PWM in the range of 0-100 which obtained an equal average values of 0.98 °C. When it used PWM with a range of 0-255, the average value ranged from 3.48 – 3.98 °C

E. ANALYSIS OF TEMPERATURE TEST RESULTS USING ON/OFF CONTROL SYSTEM

To test the temperature of the On/Off system, data retrieval was taken with a temperature setting of 37°C, 39°C, and 41°C with a time setting for the stability monitoring process for 500 seconds.

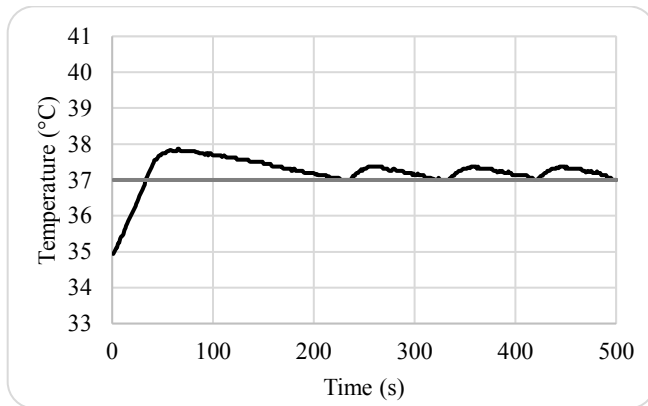


FIGURE 6 Graphic of Response using on/off control system at temperature setting of 37°C

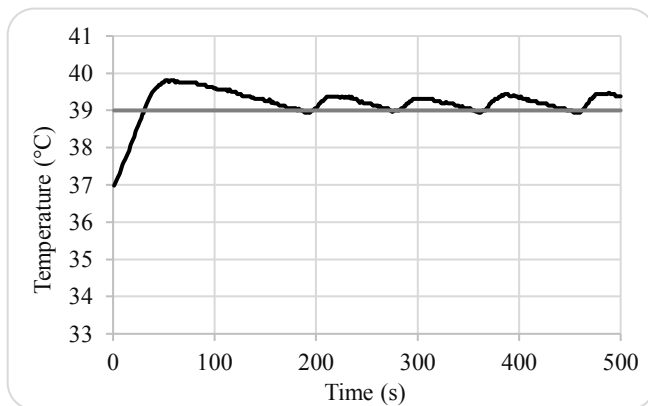


FIGURE 7 Graphic of Response using on/off control system at temperature setting of 39°C

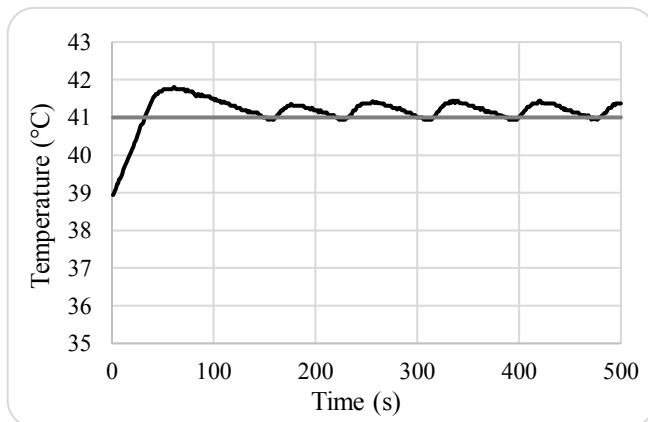


FIGURE 8 Graphic of Response using on/off control system at temperature setting of 41°C

FIGURE 6 is the result of temperature plotting using on/off system with a temperature setting of 37°C for 500 seconds. **FIGURE 7** is the result of temperature plotting using on/off system with a temperature setting of 39°C for 500 seconds. **FIGURE 8** is the result of temperature plotting using on/off system with a temperature setting of 41°C for 500 seconds.

Based on the results of the testing at 37°C, 39°C, and 41°C using on-off control systems, it shows that the On-Off system works according to its characteristics. However, the control results were still oscillatory, so the results are not very accurate. The documentation of the measurement can be seen in **FIGURE 9**.



FIGURE 9 Documentation of On/Off and Fuzzy Control System Test

F. ANALYSIS OF TEMPERATURE TEST RESULTS USING FUZZY CONTROL SYSTEM

Fuzzy system testing was done with the following system: The fuzzy control has two input signal processing to the controller, namely the error signal (error, E) and the error change signal (delta error, dE). The E signal is obtained from reducing the process output to the set point, while the dE signal is obtained from the reduction of the current error signal E(k), with the previous error signal E (k-1). Both signals are processed by a fuzzy controller.

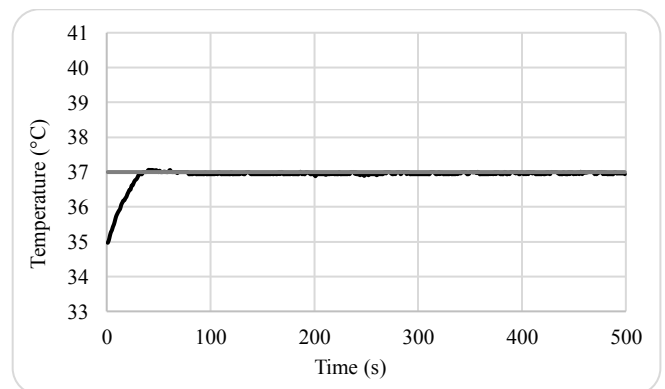


FIGURE 10 Test results of Fuzzy control system at the temperature setting of 37°C

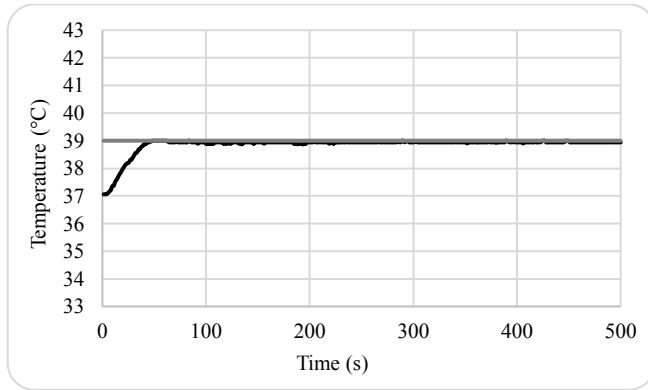


FIGURE 11 Test results of Fuzzy control system at the temperature setting of 39°C

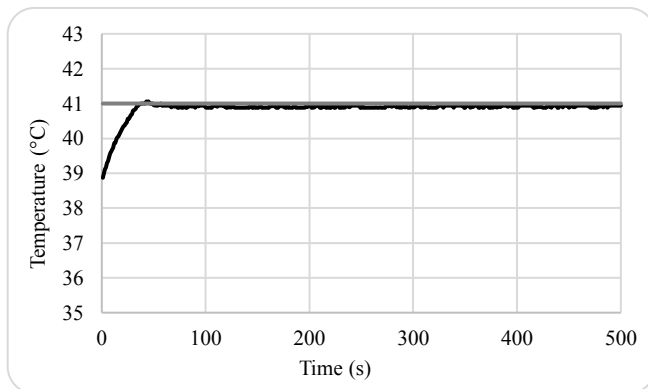


FIGURE 12 Test results Fuzzy control temperature setting 41°C

FIGURE 10 is the result of temperature plotting using a fuzzy control system with a temperature setting of 37°C for 500 seconds with room conditions of 27°C. FIGURE 11 is the result of temperature plotting using a fuzzy system with a temperature setting of 39°C for 500 seconds with room conditions of 27°C. FIGURE 12 is the result of temperature plotting using a fuzzy system with a temperature setting of 41°C for 500 seconds with room conditions of 27°C. Based on the testing results at temperature settings of 37°C, 39°C, and 41°C, it was found that the fuzzy system worked well and stably approached the temperature setting. In addition, there were no overshoot and excess oscillations either. However, it tended to be a steady below the temperature regulation.

G. TEST RESULTS IN TEMPERATURE RISE TIME ON ON/OFF CONTROL SYSTEM WITH PWM 100

FIGURE 13 is the rise time data collection on the results of temperature plotting using On-Off control system, PWM 100, and setting a temperature of 37°C that obtained a rise time of 117 seconds. FIGURE 14 is the rise time data collection on the results of temperature plotting using On-Off control, PWM 100, and setting a temperature of 39°C that obtained a rise time of 140 seconds. FIGURE 15 is a rise time data collection on the results of temperature plotting using On-Off control, PWM

100, and setting a temperature of 39°C that obtained a rise time of 168 seconds.

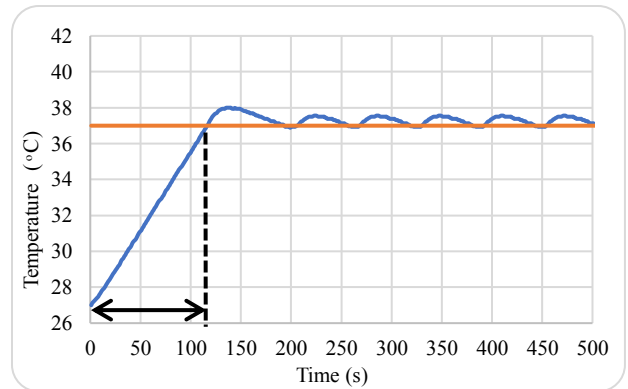


FIGURE 13 Response of on/off control system, PWM 100, and temperature setting of 37°C

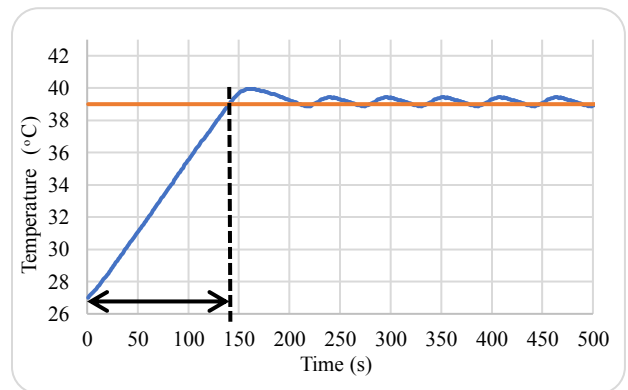


FIGURE 14 Response of on/off control system, PWM 100, and temperature setting of 39°C.

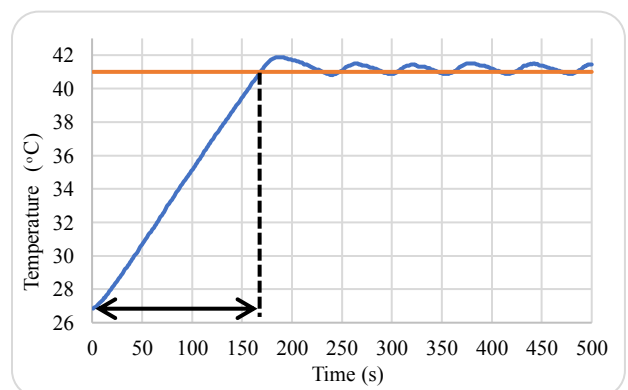


FIGURE 15 Response of on/off control system, PWM 100, and temperature setting of 41°C.

H. TEST RESULTS IN TEMPERATURE RISE TIME USING ON/OFF CONTROL SYSTEM WITH PWM 255

FIGURE 16 is a rise time data collection on the results of temperature plotting using the On-Off control system, PWM 255, and temperature setting of 37°C that obtained a rise time

of 47 seconds. **FIGURE 17** is a rise time data collection on the results of temperature plotting using On-Off control, PWM 255, and a temperature setting of 39°C that obtained a rise time of 51 seconds. **FIGURE 18** is a rise time data collection on the results of temperature plotting using On-Off control, PWM 255, and a temperature setting of 39°C that obtained a rise time of 60 seconds.

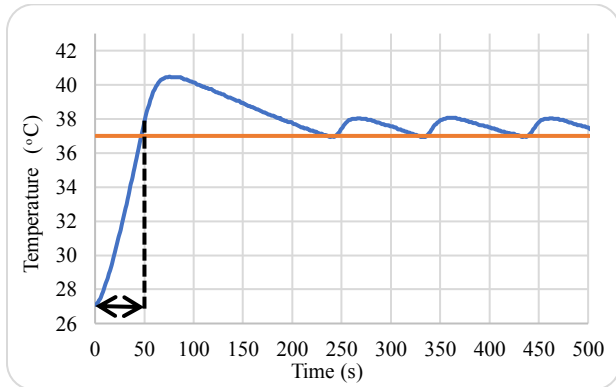


FIGURE 16 Rise time using on/off control system at temperature setting of 37°C

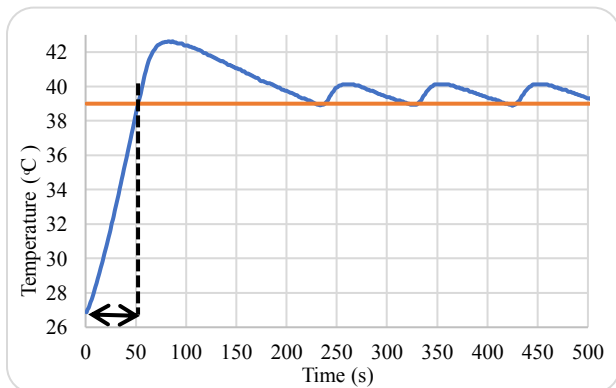


FIGURE 17 Rise time using on/off control system at temperature setting of 39°C

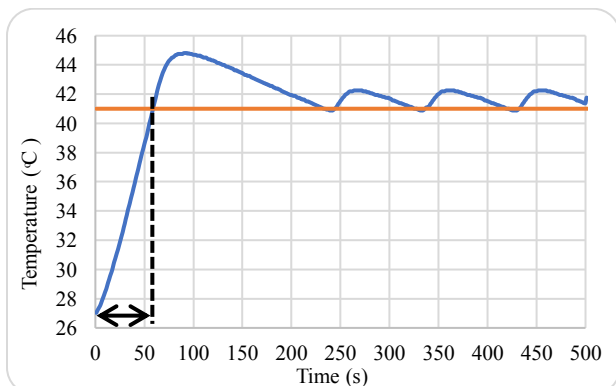


FIGURE 18 Rise time using on/off control system at temperature setting of 41°C

I. TEST RESULTS OF TEMPERATURE RISE TIME USING FUZZY CONTROL

FIGURE 19 is the rise time data collection on the results of temperature plotting using fuzzy control, PWM up to 255, and temperature setting of 37°C, where the rise time obtained was 57 seconds. **FIGURE 20** is the rise time data collection on the results of temperature plotting using the On-Off control, PWM up to 255, and temperature setting of 39°C, where the rise time obtained was 67 seconds. **FIGURE 21** is the rise time data collection on the results of temperature plotting using the On-Off control, PWM up to 255, and temperature setting of 39°C, where the rise time obtained was 74 seconds.

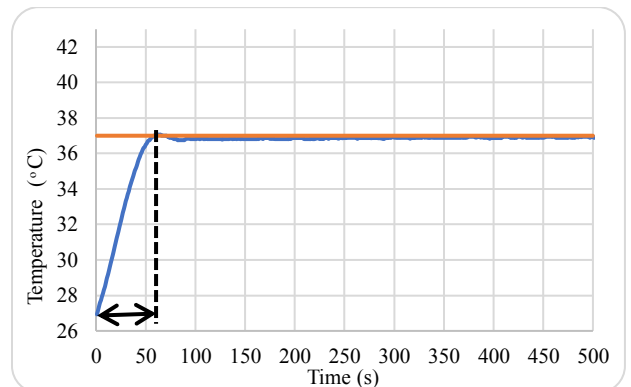


FIGURE 19 Rise time using Fuzzy control system at temperature setting of 37°C

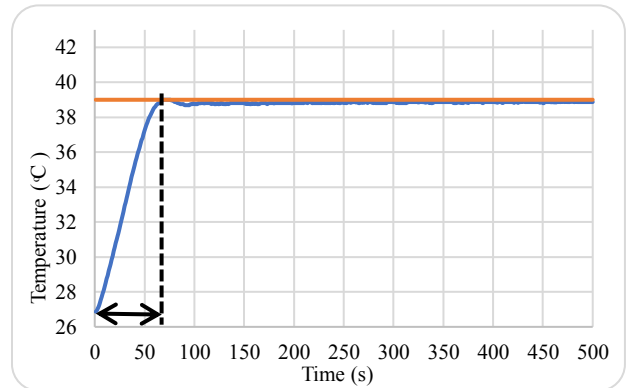


FIGURE 20 Rise time using Fuzzy control system at temperature setting of 39°C

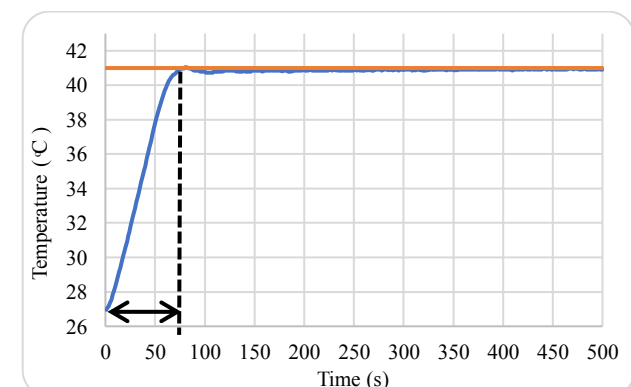


FIGURE 21 Rise time using Fuzzy control system at temperature setting of 41°C

IV. DISCUSSION

In terms of the design, this device is more efficient because it is made portable, allowing this tool to be moved easily. Based on the results of the study, it was found that the tool using a fuzzy system can control temperature stability as in previous studies. The operation of the tool was also easier, even though there are still shortcomings in the forms of the small media. Therefore, only one measurement was used for one thermometer.

The results showed that the proposed design could be used to calibrate the thermometer. This module consists of DS18B22 to measure the temperature and thermoelectric (Peltier) as the heat generator. The temperature parameter is displayed on the LCD. The temperature variables measured in real-time are displayed in the upper column and the temperature settings are in the lower column on the LCD.

In this study, the programming was carried out using On-Off control and fuzzy control systems, where these two types of control were analyzed. Furthermore, for the acquisition of data for various responses of the built control system, the proposed design was compared.

First, the INCU II calibrator unit was used to validate the measured parameters of the proposed model. The smallest error resulting from the temperature was -0.02% at 37°C using the on-off control system, while the biggest error was 0.21% at 37°C using the fuzzy control system. Meanwhile, the rise time with the fastest travel time was 47.4 seconds on the on-off control system and 57.2 seconds on the fuzzy control system. The settling time with the fastest travel time was 92 seconds on the fuzzy control system and 224.6 seconds on the on-off control system. The overshoot of the results of the On-Off control measurements obtained results with PWM with a range of 0-100 equal average values of 0.98°C. When using PWM with a range of 0-255, the average value ranged from 3.48 – 3.98°C.

The limitation of this study was to produce a temperature with a steady-state that is still below the temperature setting value when using fuzzy control. Therefore, there was still an error for a calibrator tool design of 0.21%. In this case, fuzzy control system had less exploratory control parts.

V. CONCLUSION

The purpose of this study is to analyze the stability and accuracy of temperature in the design of a body thermometer calibrator based on On-Off and Fuzzy Logic control systems. This research has found that in the results of temperature plotting using an on/off system with a temperature setting of 37°C, 39°C, and 41°C, there is an overshoot, while Fuzzy Logic control system does not have. Therefore, the Fuzzy System is better than the On/Off system so the Fuzzy system is more suitable for thermometer calibration media because it can control the temperature to be more stable. The rise time of On/Off control with PWM 255 is faster than the rise time of Fuzzy control with PWM 0 to 255. The response time to steady-state using Fuzzy control is faster than On/off control with PWM 255 and PWM 100. The device using Fuzzy control is feasible to use because it has a correction value

below 0.1 according to the calibration standard. Experimental investigations require the exploration of fuzzy logic control systems to further reduce the errors generated by the current design. It is assumed that the combination of these controls might make better results. In addition, a thermoelectric (Peltier) can also be added or the design can also be changes, so that more thermometers measured can be calibrated simultaneously.

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