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RESEARCH PAPER

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ANALYSIS OF TEMPERATURE STABILITY THERMOGUN CALIBRATOR WITH FUZZY-PID CONTROL

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ABSTRACT
Body temperature measurement is an important parameter in medical diagnosis. Thermogun, as a non-infrared technology-based temperature measuring device, requires periodic calibration to maintain its measurement accuracy. This study aims to design and develop a Thermogun calibrator based on FUZZY-PID control using air as a temperature stabilizer medium. The main contribution of this study is the incorporation of the FUZZY-PID control method which is effective in improving temperature stability and measurement accuracy compared to conventional control methods used in previous calibrators. This system is designed to maintain temperatures in the range of 32°C to 45°C. The main components used include a DS18B20 sensor for temperature measurement, an Arduino Mega 2560 microcontroller as the main controller, a heating plate for heating, and a Nextion LCD screen as a user interface. The test results show that the system is able to increase the heating rate with a low measurement error rate. From the data analysis, the temperature error against the thermometer standard is 0% at all temperature settings between 32°C and 45°C. In addition, from the test using 3 Thermoguns, Thermogun 3 showed the most accurate reading with the largest average error of 0.625%, while Thermogun 1 and 2 had errors of up to 3.15%. These measurement results indicate that FUZZY-PID control can be used effectively to maintain temperature stability in the Thermogun calibrator. The implication of this study is that the FUZZY-PID control method has the potential to be applied to other temperature calibration systems that require a high level of accuracy, especially in the medical field. This study succeeded in achieving the desired temperature with high accuracy, and the device functioned well according to the stated objectives.

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1. INTRODUCTION

Temperature is one of the physical quantities that are often measured in the medical world. Temperature measurement provides information about the energy of an object. Temperature measurement is very important for diagnosis in the medical field. From a biophysical perspective, temperature measurement determines the changes in physical quantities that occur in a thermodynamic system. This involves determining the difference between the temperature of the medium being measured and the temperature conventionally considered to be 0 on a temperature scale that provides a numerical value corresponding to a certain temperature range[1]. The most frequently used temperature scales are Celsius, Fahrenheit and Kelvin [2]. Body is a vital sign that is measured to check the health status of the patient and confirm the diagnosis. Normal body temperature ranges from 36.5°C to 37.5°C [3]. Human temperature is the result of the process of heat release released in metabolism and absorbed by the skin layer (through conduction and convection), heat released to the environment (through radiation, convection, and evaporation), and heat obtained from the environment. To determine the surface temperature of the human body, we most often use a medical thermometer. The way in which heat is transferred between the thermometer and the body is the basic criterion for the division of thermometers. Thermometers are divided into contact and non-contact thermometers [4]. Body temperature is an important sign of a patient's condition [5]. Inaccurate temperature measurement can result in a diagnosis of febrile illness. Therefore, accurate body temperature measurement is required for clinical examination [6].

The development of infrared technology in the mid-20th century brought something new to non-contact temperature checks. This technology relies on the detection of infrared radiation emitted by an object to determine its temperature. Currently applied in non-

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contact thermometers or commonly called thermometer guns or often known as Thermoguns [7]. Thermometers that are often used in the health world are mercury thermometers, digital thermometers, and thermoguns. Thermoguns are one of the measuring instruments that must be measured, checked regularly, and calibrated according to standards before use or after use at certain intervals. There are various media for calibrating thermometers, including dry blocks and water media [8], [9]. Calibration is an activity to determine the actual value of the indication of measuring instruments and measuring materials by comparing them with standard measuring instruments that can be traced to national standards and international standards [10]. According to ISO/IEC Guide 17025:2017 and Vocabulary of International Metrology (VIM), calibration is an activity that compares the value indicated by a measuring instrument or the value given by a measuring material with the value related to the quantity being measured under certain conditions. Calibration of the instrument used in the analytical stage of clinical laboratory testing has an accuracy contribution to the uncertainty of the final measurement results [11].

Several previous studies include research by Ardelina Ramadhani (2019) creating a digital body thermometer calibrator tool based on Arduino using a dry heater and LM35 temperature sensor. However, the dry heater and LM35 sensor used resulted in a high error value on the tool display against the set temperature [12]. Then in 2019, Handayani also conducted research by creating a body temperature thermometer calibrator using an Arduino-based DS18B20 sensor. However, the weakness lies in the use of a dry heater for heating, which results in a high error value on the comparison tool [13]. In 2020, Rifika Dwi Saptania made a digital body thermometer calibrator using water media. The weakness of the tool that has been made is that it uses an LM35 temperature sensor and the chamber is too large so that the error value on the tool display against the setting is quite high and has not used a control system to minimize overshoot and increase temperature stability [14]. D. Matsunaga created a tool to make a non-invasive thermometer for continuous monitoring of body temperature in various convective conditions. The drawback of the research is that there are still errors in the estimation of readings caused by convective changes (temperature fluctuations) [15]. Then in 2023 Sofyan made an analysis of the comparison of the use of water and oil as a medium for calibration. The results of the experiment showed that the use of water as a calibration medium produced calibration results with an error of less than ±2%, meeting the calibration requirements for precision. In addition, when using oil as a calibration medium, the error value was still within acceptable limits of around ±5% [16]. M. Hohmann made the Dry Block Calibrator with increased internal temperature homogeneity in the field developed for the range from room temperature to 6000C to overcome the main problem of conventional Dry Block Calibrators namely the axial temperature gradient which is divided into three parts which have heat sensor flux between the parts and The calibration results are greatly influenced by the geometry and thermal properties of the thermometer with an internal reference to control the absolute temperature value [17]. Yingxiang Huang conducted research using predictive models by utilizing information technology, but this method is difficult to apply to thermometer calibration [18]. S.Pradeep Kumar The thermometer calibration process is time-consuming so it requires short-term temperature stability over several measurements. In this paper, an automated system for thermometer calibration is presented. This system allows the entire calibration process to be driven by a computer [19], [20], [21]. O. Ongrai The main factor in thermocouple calibration is the homogeneity of the media used (a6). S. Marin makes a dry-block calibrator using indium, tin, and zinc media[22]. Michael Hohmann researched to reduce the uncertainty value on dry blocks where this uncertainty is very important in determining the level of precision of a calibrator [23]. Xia Zhao researched dry blocks focusing on stability measurement, on-site temperature calibration method, and uniformity of temperature distribution. The axial temperature distribution of dry-block furnaces is an important factor affecting their accuracy [24],[25]. research to study the relationship between calibration temperature and axial temperature distribution of dry well furnaces using experimental methods. The results found that from the bottom of the furnace to the wellhead side, the insertion depth of the temperature probe should be as close as possible to the bottom of the well, and the closer the temperature calibration is to the ambient temperature, the higher the accuracy of the temperature measurement [25]. Min Zhang designed a measuring system to reduce temperature fluctuations in the thermostat for calibration thermocouples by periodically applying the theory of heat conduction.The purpose of this research is to obtain a liquid environment and obtain a controlled constant temperature for thermocouple calibration measurements. The experimental results show that the temperature stability in this measurement system is superior to the traditional multipoint thermocouple system, which can be calibrated simultaneously and data acquisition and control is carried out automatically, the weakness of this study is that the instrument is only used for thermocouple calibration and has not been developed for thermometer calibration [26]. Leobardo Hernández González explains Thermometer calibration can be carried out by inserting the thermometer into a fixed point cell filled with highly pure material and entering the phase transition temperature [27].

PID (Proportional Integral Derivative) control has become a common control method used in various applications due to its ability to effectively regulate a system using proportional, integral, and derivative values. However, in some cases, PID control may not be flexible enough to handle non-linearity or environmental variations in the system. On the other hand, fuzzy logic offers a more flexible approach to address uncertainty and complexity in the system. Fuzzy logic allows us to describe ambiguous or uncertain variables using fuzzy sets and fuzzy rules. The combination of PID control and

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fuzzy logic results in Fuzzy-PID, where fuzzy logic is used to adjust the PID control parameters according to changing system conditions. Thus, Fuzzy-PID can improve control performance in the face of uncertainty and complex environmental variations[28],[29]. Based on the literature search conducted, there are things that need to be developed through research by making a tool entitled "Analysis of temperature stability thermogun calibrator with fuzzy-pid control" based on the development of previous tools. The tool that will be designed by the author is to design a temperature control system on the Thermogun Calibrator, the temperature will be set stable at the desired set point, which is between 32 ° C to 45 ° C.

This study uses a DS18B20 sensor with a reading accuracy of ± 0.5 ℃ In addition, using the Arduino Mega 2560 microcontroller as the controller of the tool and the heater driver as the heater controller. Then for heating it uses a heater plate. This study aims to develop a FUZZY-PID-based Thermogun calibrator using water as a temperature stabilizer. The main difference from previous studies is the use of a more intelligent and adaptive FUZZY-PID control system. This system uses a DS18B20 temperature sensor that has an accuracy of ±0.5°C and is equipped with an Arduino Mega 2560-based main controller and a Nextion LCD screen to display temperature data in real time and facilitate temperature parameter settings. By integrating FUZZY-PID, it is expected that this system will be able to maintain temperatures in the range of 32°C to 45°C with a higher level of accuracy and stability compared to conventional methods. This research is expected to provide new contributions by adopting FUZZY-PID control to overcome the shortcomings of conventional control methods. FUZZY-PID allows faster and more stable temperature settings, reduces overshoot, and accelerates the time to achieve stable temperature. With better temperature control, the Thermogun calibration process becomes faster and more accurate, meeting national and international calibration standards. The results of this study are expected to be used as a reference in the development of Thermogun calibration methods and strengthen measurement standards in medical devices. In addition, the practical implication of this study is to increase the efficiency of the calibration process in laboratories or health facilities.

2. MATERIALS AND METHOD

A. Dataset

This research was conducted at the Polytechnic of the Ministry of Health Surabaya under the auspices of the Department of Electromedical Technology. A Thermogun was used as a calibrator in this study. The research design applied in module development is a pre-experimental design with the type of after only design. In this design, researchers observed the results of the treatment by firing a thermogun at modul, while the comparison group used a standard thermometer. The main focus of this design is to perform analysis on the control fuzzy-pid. This module consists of several important components, namely the adapter, Arduino Mega 2560, and the DS18B20 sensor module. The control circuit in this module is implemented well. In addition, In the heater circuit section, there are components such as heater, heater driver and DS18B20 sensor. All these components are interconnected to produce the desired function.

In addition to the main components, this module is also equipped with a 3.2-inch Nextion LCD display, which is used to display the real temperature and setting temperature . There is also an on/off switch that allows users to turn the device on and off. In addition, a standard thermogun is also part of this module, ensuring calibration accuracy and reliability. In addition, this study used water with a capacity of 1.8liters as a medium for calibration on a thermogun calibrator with FUZZY-PID control. According to the guidelines of OIML (Organization Internationale de Metrologie Legale), the minimum water used must reach 1 liter. In this study, the requirements for water use have been met, so it can be used for the calibration process[30]. this is very large because it guarantees accuracy and reliability when using a thermogun calibrator with FUZZY-PID control, in accordance with the provisions set out in the applicable standard.

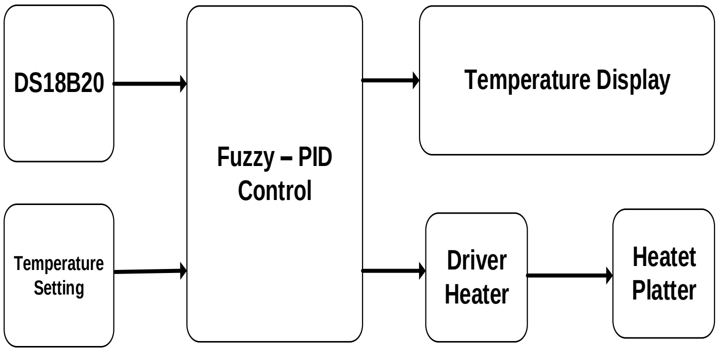

Fig. 1. System Block Diagram on research thermogun Calibrator with Fuzzy-PID Control

Fig. 1 ilustrated is a system block The voltage from PLN of 220 V is the voltage source utilized to supply the control supply . At that point the control supply will give supply voltage to the driver heater. At that point the connector will supply to all control circuits . At that point set the temperature esteem by means of the Nextion screen with a temperature extend between 32 - 45 ° C. After the temperature setting is entered, press the enter and begin buttons and after that the Arduino Mega 2560 microcontroller forms the temperature setting information with FUZZY-PID control, at that point the heater driver will control the heater plate , at that point the framework will work and the temperature sensor will read the temperature that's as of now running within the holder until the Setpoint temperature matches the set temperature . Then the Nextion LCD here shows the temperature from

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the setting in conjunction with the perusing from the temperature sensor.

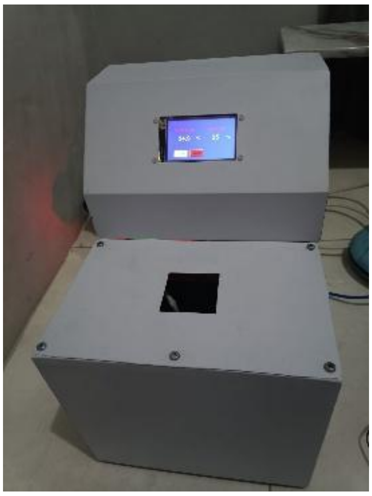

Fig. 2. Thermogun Calibrator with Fuzzy-PID Control

This research has been conducted by applying quantitative experimental methods. The focus of this study is on the measurement results obtained from the gun thermometer module that uses FUZZY-PID control. The results collected show that the measured data from the gun thermometer calibrator device, which is equipped with FUZZY-PID control, is able to reach and maintain the desired temperature with a very high degree of accuracy. One of the advantages of using FUZZY-PID control is its ability to provide a fast response to temperature changes towards the desired setpoint. In this process, FUZZY-PID control also succeeded in reducing the phenomenon of overshoot, which can disrupt the stability of the measurement, as well as maintain high temperature stability during the measurement process. Thus, the use of FUZZY-PID control has proven to be a very important element in improving efficiency and accuracy in temperature measurement in Thermogun which is explained Fig. 2.

The decision-making process with fuzzy control has different stages, one of which is the formation of membership which will later be interfered with in the rule base formation stage and the defuzzification process. In this study, fuzzy logic was built using 2 input variables and 3 output variables with each input and output containing 7 membership functions. input variables come from the read error value and also the change value of the error. While the 3 outputs of this fuzzy logic produce values that will become adaptive controls for the values of Kp, Ki, and Kd by adding them. Fig. 3. is a plot image of the membership function of the input value of the error variable which has 7 levels. Where the value -1.5 is Negative Large (NB), -1 is Negative Medium (NM), -0.5 is Negative Small (NS), 0.5 is zero (ZO), 1 is Positive Small (PS), 1.5 is Positive Medium (PM), and more than 1.5 is Positive Large (PB). This is based on the Trial error conducted.

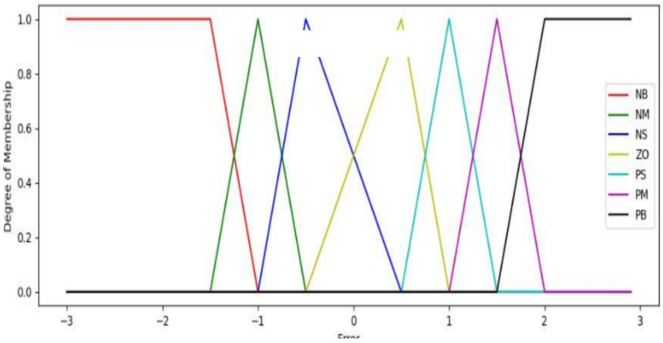

Fig. 3. Function membership error

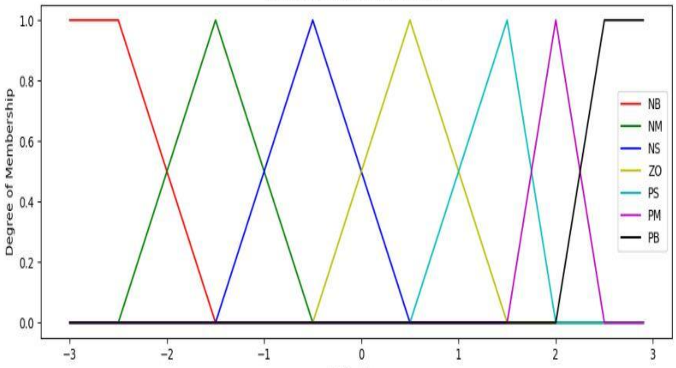

Fig. 4. Function membership delta error

Fig. 4. is a plot of membership function of input value of delta error variable which has 7 levels. Where value -2.5 is Negative Large (NB), -1.5 is Negative Medium (NM), -0.5 is Negative Small (NS), 0.5 is zero (ZO), 1.5 is Positive Small (PS), 2.5 is Positive Medium (PM), and more than 2.5 is Positive Large (PB). This is based on Trial error conducted. The fuzzy logic rule created is used to process the premise and consequence of an error value and delta error so that a fuzzy decision or fuzzy decision comes out with a constant value result. From this fuzzy rule, the output Kp, Ki, and Kd will be determined according to the error value and delta error value that have gone through the fuzzification stage first. The creation of this rule is based on observations on the graph produced by the PID control. The output variables Kp, Ki, and Kd have different rules which are shown in the following Table 1, Table 2, and Table 3.

Table 1. Rulebase Output Kpf

ERROR/ DELTA ERROR	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NM	NS	ZO	PS	PM	PB
NM	NB	NM	NS	ZO	PS	PM	PB
NS	NB	NM	NS	ZO	PS	PM	PB
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NB	NM	NS	ZO	PS	PM	PB
PM	NB	NM	NS	ZO	PS	PM	PB
PB	NB	NM	NS	ZO	PS	PM	PB

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Table 2. Rulebase Output Kif

ERROR/DELTA ERROR	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NM	NS	ZO	PS	PM	PB
NM	NB	NM	NS	ZO	PS	PM	PB
NS	NB	NM	NS	ZO	PS	PM	PB
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NB	NM	NS	ZO	PS	PM	PB
PM	NB	NM	NS	ZO	PS	PM	PB
PB	NB	NM	NS	ZO	PS	PM	PB

Table 3. Rulebase Output Kdf

ERROR/DELTA ERROR	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NM	NS	ZO	PS	PM	PB
NM	NB	NM	NS	ZO	PS	PM	PB
NS	NB	NM	NS	ZO	PS	PM	PB
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NB	NM	NS	ZO	PS	PM	PB
PM	NB	NM	NS	ZO	PS	PM	PB
PB	NB	NM	NS	ZO	PS	PM	PB

After adjusting to the rules that have been created, the output value will then go through the defuzzification stage and will produce the Kpf, Kif, and Kdf values. This figure appears to be a bar chart showing a type of fuzzy membership function, likely used in fuzzy logic control systems. Each label corresponds to a range of values:

NB = -3, NM = -2, NS = -1, ZO = 0, PS = 1, PM = 2, PB = 3

Y-Axis: Membership Degree, The y-axis shows the degree of membership, ranging from 0 to 1. In this chart, every bar has a value of 1, meaning that the elements shown have full membership in their respective fuzzy sets. This chart could be showing: A rule base visualization in a fuzzy system where each linguistic variable is fully active (membership = 1), perhaps for simplification or as a test input. The universe of discourse divided into fuzzy sets, each set represented by a bar with maximum membership which is explained Fig. 5.

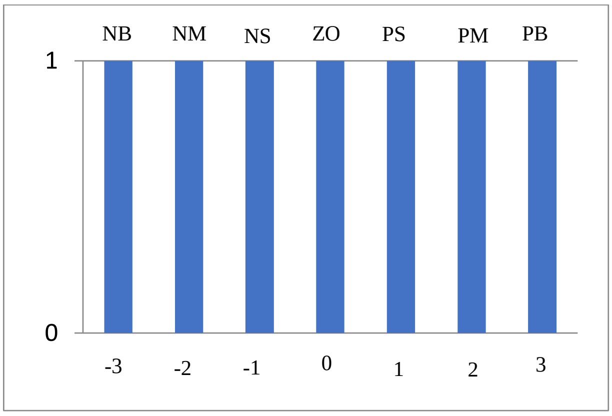

Fig. 5. Plot membership function Output Variable Kpf

This chart gives a fine-resolution look at a fuzzy system's input/output variable definitions, where each fuzzy term corresponds to a small, distinct numeric range. It's more precise than the previous figure, indicating the system might be modeling or controlling something requiring high accuracy which is explained Fig. 6, and Fig.7.

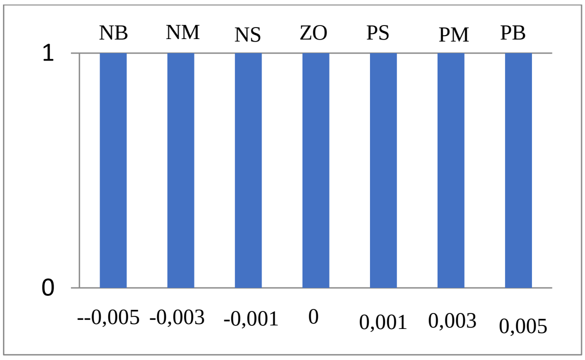

Fig. 6. Plot membership function Output Variabel Kif

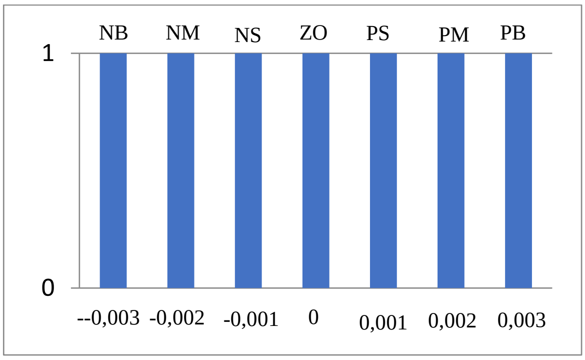

Fig. 7. Plot membership function Output Variabel Kdf

The PID system control that already has Kp, Ki, and Kd values based on the tuning results that have been made will be changed by fuzzy logic based on the output results of fuzzy logic. The constant values of the PID tuning results will be considered as initial constants (Kpa, Kia, and Kda) then the constant values of the fuzzy output are considered as fuzzy constants (Kpf, Kif, and Kdf) here function as the sum of the initial constant values so that their values can change. The calculation formula is written as follows (Eq. (1), (2), (3)):

$$K_p = K_p a + K_p f \quad (1)$$

$$K_i = K_i a + K_i f \quad (2)$$

$$K_d = K_d a + K_d f \quad (3)$$

Where Kp is result control proportional from Kpa (Proportional adjust) adding Kpf(proportional from fuzzy). Ki is result control integral from Kia (integral adjust) adding Kif(integral from fuzzy). Kd is result control derivative from Kda (derivative adjust) adding Kpf(derivative from fuzzy).

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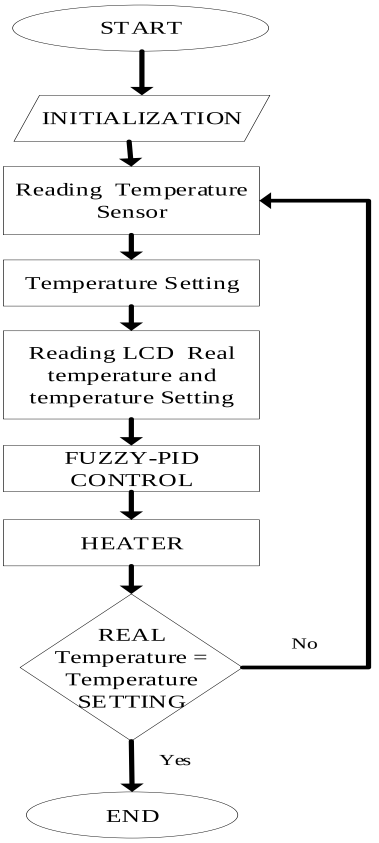

Fig. 8. Thermogun Calibrator Tool Module Flow Diagram with Fuzzy-PID Control

When the device is turned on, the LCD will automatically initialize. After initialization, the temperature sensor will read the real temperature in the room, after the real temperature is read. Next, the temperature setting can be done by entering the desired value via the Nextion screen with a temperature range of 32 ° C to 45 ° C. Next, the Nextion LCD will display the real temperature and the set temperature (Setpoint). After setting the temperature with the real temperature display and the setting temperature (Setpoint) on the LCD, the next step is to press the enter and start buttons . Then the FUZZY-PID system will process and set the heating circuit to ON and OFF. Next, the system will process the reading results by the temperature sensor, then the Nextion LCD will display the setting temperature along with the reading temperature which is explained Fig. 8.

B. Data Analysis

This research was conducted by measuring the calibrator thermogun module using FUZZY-PID control, compared to standard thermometers. Testing of the thermogun calibrator module using PID control compared to standard thermometers was carried out repeatedly for 10 times. After completing the test, an analysis of the results obtained is carried out. From the results of the module data analysis against the standard thermometer, an error was obtained. temperature use standard thermometer t is 0% on all settings between temperatures 32 °C - 45 °C. The results of data analysis from the module on 3 Thermoguns using FUZZY-PID control In the experiment conducted, it was found that thermogun 3 had a good average reading of all temperatures that had been measured on the module with an error between the largest 0.625% at various temperature settings. Then on thermogun 1 & 2 had a fairly large error of up to 3.15%.

To get the accuracy value on the thermometer gun calibrator module that uses FUZZZY-PID control compared to standard thermometers, measurements are made 10 times. From 10 repeated measurements, it is necessary to calculate the average. Eq. (4) is used to determine the average value of the measurement :

$$(\bar{X}) = \frac{\Sigma Xi}{n} \quad (4)$$

Using the arithmetic mean, which is the number resulting from dividing the total value of the data by the amount of data in the set, we can produce the average value. Average is the result of dividing the measured amount of data by the total existing data, where x represents the average value, xi is all existing data, and n represents the amount of data present. Standard deviation, on the other hand, is a number that indicates how much variation in a set of data or standard deviation from the mean. Eq. (5) can be used to display the standard deviation formula (SD) :

$$X = \sqrt{\frac{\Sigma(Xi - X)^2}{n - 1}} \quad (5)$$

where xi is the percentage of the value in question, x represents the average of the measurement results, and n represents the total number of measurements. Uncertainty (UA) refers to doubts that may arise on any measurement result. Eq. (6) is used to display the uncertainty formula:

$$UA = \frac{SD}{\sqrt{n}} \quad (6)$$

where UA indicates the overall uncertainty level of the measurement, SD describes the standard deviation of the measurement, and n represents the total number of measurements. System errors are represented by the percentage of errors. The smaller difference between the averages of each data set is the errors that occur. The error can indicate how far the model or design is from the established standard. Eq. (7) shows the formula for calculating the error :

$$ERROR = \frac{(Xn - X)}{Xn} \, x \, 100\% \quad (7)$$

where Xn represents the value measured by the calibrator, while the predefined value of the design is x. Error is the difference between the average value and each data. This study shows that the accuracy value is still within the established tolerance limit.

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3. RESULTS

After finishing designing the thermometer gun calibrator tool module using FUZZY-PID control, the next step is to collect data. The purpose of this study was to collect data through measurements that were repeated 10 times in the module using a standard thermometer. During the data retrieval process, measurement recording is carried out in Microsoft Excel.

Fig. 9. Range of Components Used

Fig. 9 displays the electronic circuit of the thermometer gun calibrator module that uses PID control, utilizing several components. In the design of the thermometer gun calibrator module with PID control, this study uses AC voltage 220V from PLN as the main source of electricity to supply voltage to the power supply of 12V / 10 A. This module consists of several important components, including adapters, Arduino Mega 2560, and DS18B20 sensor modules. All these components are interconnected to create the desired function. Apart from these main components, this module is also equipped with various additional features. One of them is the 3.2-inch Nextion LCD display, which serves to display the actual temperature and the set temperature. The module is also equipped with an on/off switch that allows the user to turn the appliance on and off. Not only that, standard thermometers are also part of this module, ensuring calibration accuracy and reliability.

Table 4. Measurement Results Using a Standard Thermometer

Setting Temperature (℃)	Mean (℃)	Error (%)	STDV	UA (℃)
32	32	0	0	0
33	33	0	0	0
34	34	0	0	0
35	35	0	0	0
36	36	0	0	0
37	37	0	0	0
38	38	0	0	0
39	39	0	0	0
40	40	0	0	0
41	41	0	0	0
42	42	0	0	0
43	43	0	0	0
44	44	0	0	0
45	45	0	0	0

Table 4 above are the measurement results using a standard thermometer which here is a mercury thermometer. The values obtained show the values on the tool according to the readings of the standard thermometer used. From the experiments carried out, the error value, standard deviation and uncertainty are 0. It can be concluded from the Module that is made according to the standard thermometer used, so that the accuracy of the measurement can work well.

Table 5. Results of Thermogun Measurements on the Module

Setting Temperature(℃)		Mean (℃)	Error (%)	STDV	UA (℃)
32	Thermogun1	31.65	1.094	0.053	0.017
	Thermogun2	31.67	1.031	0.048	0.015
	Thermogun3	31.94	0.188	0.052	0.016
33	Thermogun1	32.75	0.758	0.053	0.017
	Thermogun2	32.68	0.970	0.042	0.013
	Thermogun3	33.15	0.455	0.053	0.017
34	Thermogun1	33.64	1.059	0.052	0.016
	Thermogun2	33.58	1.235	0.042	0.013
	Thermogun3	34.14	0.412	0.052	0.016
35	Thermogun1	34.86	0.400	0.052	0.016
	Thermogun2	34.83	0.486	0.067	0.021
	Thermogun3	35.12	0.343	0.042	0.013
36	Thermogun1	35.36	1.778	0.052	0.016
	Thermogun2	35.33	1.861	0.067	0.021
	Thermogun3	36.06	0.167	0.052	0.016
37	Thermogun1	36.68	0.865	0.092	0.029
	Thermogun2	36.90	0.270	0,000	0,000
	Thermogun3	37.33	0.892	0.048	0.015
38	Thermogun1	37.06	2.474	0.052	0.016
	Thermogun2	37.08	2.421	0.063	0.020
	Thermogun3	37.86	0.368	0.084	0.027
39	Thermogun1	38.56	1.128	0.052	0.016
	Thermogun2	38.57	1.103	0.048	0.015

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	Thermogun3	39.18	0.462	0.079	0.025
40	Thermogun1	38.74	3.150	0.052	0.016
	Thermogun2	38.74	3.150	0.070	0.022
	Thermogun3	39.75	0.625	0.053	0.017
41	Thermogun1	39.80	2.927	0.082	0.026
	Thermogun2	39.64	3.317	0.070	0.022
	Thermogun3	40.81	0.463	0.088	0.028
42	Thermogun1	41.08	2.190	0.132	0.042
	Thermogun2	41.04	2.286	0.052	0.016
	Thermogun3	42.04	0.095	0.052	0.016
43	Thermogun1	42.16	1.953	0.097	0.031
	Thermogun2	41.99	2.349	0.088	0.028
	Thermogun3	43.17	0.395	0.067	0.021
44	Thermogun1	43.08	2.091	0.042	0.013
	Thermogun2	42.70	2.955	0.067	0.021
	Thermogun3	44.16	0.364	0.070	0.022
45	Thermogun1	44.24	1.689	0.052	0.016
	Thermogun2	43.94	2.356	0.052	0.016
	Thermogun3	45.14	0.311	0.126	0.040

From the data in Table 5 it can be seen that the value of each thermogun is different. In the experiment conducted, it was found that thermogun 3 had a good average reading of all temperatures that had been measured on the module with the largest error of 0.625% at various temperature settings. Then thermogun 1 & 2 had a fairly large error of up to 3.15% . Temporary that , value standard the biggest deviation on Thermogun on the module uses Fuzzy-PID control, namely on thermogun 1 is 0.132 happen on temperature 42 °C, while mark standard lowest deviation there is on thermogun 2 is 0 occurs on temperature 3 7 °C. Then the largest uncertainty value obtained in thermogun 1 is 0.042 °C .

From the data it can be concluded that when the thermogun is compared with the module, various errors occur for each temperature setting that is carried out. From the measurements on 3 Thermoguns, it was found that Thermogun 3 had the lowest error value between -0.892% to 0.368%. In addition, it can also be concluded that the readings from the thermogun vary on the modules that have been made because different thermoguns are used to conduct the test. Thus, the use of the module that is made can only be used properly on certain thermoguns.

Table 6. Results of Thermogun Measurements on the Module

Temperature Setting	Overs hoot (°C)	Rise Time (minutes)	Response time to steady state (minutes)
32°	0.6	6 minutes 9 s	16 minutes 4 s
33°	0.6	7 minutes 36 s	15 minutes 27 s
34°	0.6	8 minutes 42 s	9 minutes 39 s
35°	0.6	10 minutes 4 s	9 minutes 4 s
36°	0.6	11 minutes 15 s	8 minutes 52 s
37°	0.6	12 minutes 7 s	8 minutes 45 s
38°	0.5	14 minutes 58 s	6 minutes 49 s
39°	0.5	16 minutes 33 s	6 minutes 4 s
40°	0.4	15 minutes 45 s	5 minutes 39 s
41°	0.4	17 minutes 12 s	5 minutes 27 s
42°	0.3	18 minutes 33 s	5 minutes 19 s
43°	0.3	20 minutes	5 minutes 18 s
44°	0.3	21 minutes 30 s	2 minutes 22 s
45°	0.3	23 minutes 9 s	2 minutes 10 s

From Table 6 results that have been carried out, it was found that the FUZZY-PID system works according to the characteristics of achieving the set point temperature . From the results of the system tests carried out, it was found that the FUZZY-PID system works well. The smallest overshoot at a temperature of 42 ° C - 45 ° C was 0.3 and the largest overshoot at a temperature of 32C - 37 ° C was 0.6. In addition, the rise time or the method of accomplishing the least setting temperature takes 370 s at a setting of 32 ° C, the most noteworthy takes 1389 s at a setting of 45 ° C. So, it can be concluded that at moo temperature settings the overshoot that happens will be tall and when the temperature increments the overshoot will diminish. And the reaction time to consistent state will diminish as the temperature increments.

4. DISCUSSION

After conducting research to obtain the accuracy of the module calibration results compared to standard thermometers, researchers have designed a thermogun calibrator with FUZZY-PID control. The working system in this study, both in the circuit and software, runs well. The circuit consists of a 12V/10A power supply which is used to provide input voltage to the heater circuit. After that, an adapter is used to supply voltage to the Arduino Mega2560. Furthermore, in this circuit there are 4 DS18B20 sensor inputs connected to the Arduino Mega2560. In this module, the author uses 6 heater plates as heaters with a voltage of 12V. As well as 2 heater controls, namely the VNH2SP30 driver on the left and right sides. A driver controls 3 heaters. In addition, in this module, there is a 3.2 inch Nextion LCD. This LCD

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functions to display the results of the current temperature reading and the set temperature.

The system that has been created shows performance improvements compared to previous studies. In a study by Ramadhani in 2019, a PID-based digital thermometer calibrator with an LM35 sensor had a higher error due to the use of dry heating media[12]. Likewise, a study by Handayani and Titisari using a PID-based DS18B20 sensor without a fuzzy controller resulted in a higher error[13]. Comparison with Saptania's study (2020): The use of water media in Saptania's study resulted in an error of up to ±2[14]. Compared to Sofyan et al. (2023), which compared water and oil as calibration media, this study shows that FUZZY-PID control can maintain a lower error than oil media, which has an error of up to ±5%[16].

Meanwhile, in the research that has been done using the DS18B20 sensor and efficient heater, as well as an optimal test room, the system created has advantages. This system is able to provide good temperature accuracy and stability. Through FUZZY-PID control, the error value generated by the thermogun calibrator module using PID control varies. The largest error was recorded in thermogun 1 & 2 with an average value of 3.15%., while the smallest error occurred in thermogun 3 with an average of 0.625%. This error occurs due to differences in the specifications of the thermogun used [14],[16].

The use of 4 DS18B20 sensors placed at 4 points in the chamber significantly increases the accuracy of temperature readings. In addition, the use of a heater plate as a heating circuit helps accelerate the heating of the water media used for calibration. This study has significant implications. The system designed to improve the thermometer calibrator by utilizing water media and PID control has a positive impact. First, the use of water as a calibration medium provides better thermal stability than air, which results in more accurate and consistent temperature measurements. The integration of FUZZY-PID control allows for very precise temperature settings, improving the precise and accurate calibration process. Overall, the design of the thermogun calibrator system with Fuzzy-PID control has positive implications in improving the accuracy of temperature measurements, calibration efficiency, and producing more precise and accurate calibrations.

The limitations from this research is needed active cooling system so that the time to steady state is shorter. Also, testing is needed on the distance of the thermogun to the calibrator to ensure the ideal distance for testing. In addition, it is necessary to re-evaluate the fuzzy rule base that has been created to ensure that the calibrator with FUZZY-PID control can work even better. For the implication on this research is expected to provide new contributions to the development of technology, especially in the health sector. However, some suggestions emerged from the author. For further research, the system for making thermogun calibrators with Fuzzy-PID control has certain weaknesses. One of them is that the time required to reach steady state is still quite long so that a cooling system needs to be added to this tool to accelerate the achievement of steady state. In addition, further research is needed regarding the distance of thermogun measurements to the calibrator to ensure the suitability of the calibrator with the thermogun. With the presence of a thermometer calibrator module with Fuzzy-PID control provides flexibility and efficiency in calibrating thermometers. Its use allows simple measurements and helps users to calibrate more easily.

5. CONCLUSION

From this developed research, it will greatly assist health workers in calibrating thermometer devices flexibly and efficiently. The thermometer calibrator module using water media with Fuzzy-PID control can make a major contribution in this regard. The results of data analysis from the module on 3 Thermoguns using FUZZY-PID control In the experiments conducted, it was found that thermogun 3 had a good average reading of all temperatures that had been measured on the module with an error between the largest 0.625% at various temperature settings. Then on thermogun 1 & 2 had a fairly large error of up to 3.15%. To overcome these limitations, future research is recommended to develop an active cooling system so that the time to steady state is shorter. Also, testing is needed on the distance of the thermogun to the calibrator to ensure the ideal distance for testing. In addition, it is necessary to re-evaluate the fuzzy rule base that has been created to ensure that the calibrator with FUZZY-PID control can work even better.

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