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Comparative Analysis of Water and Oil Media on Temperature Stability in PID Control-Based Digital Thermometer Calibrator

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ABSTRACT Digital thermometers are measuring instruments needed to perform temperature measurement actions and must be calibrated periodically according to standard measurement methods. The purpose of developing this tool is to add PID control to the calibration media where PID control aims to regulate the stability of the temperature setting to be achieved. This is achieved by studying and evaluating the effect of temperature stability on the heater and LM35DZ temperature sensor. This research method uses the Arduino Nanosystem for data processing and PID system control. The LM35DZ temperature sensor on the heater is regulated by a 2 Channel SSR module using a PID system then the temperature generated by the heater will be read by the LM35DZ and displayed on the LCD. The results of this study, digital thermometer calibrator measurements have been successfully carried out by comparing 3 digital thermometers with different brands, namely Omron 343F, Omron 245, and ThermoOne. The difference in error values in oil media is 3-4% and in water media 2-4% with the value of time stability in water media for 3-3.3 minutes and in oil media for 1-2 hours. With this comparison of calibration media, it is hoped that it can help in measuring temperature with better and more effective results. find methods, results, conclusions.

INDEX TERMS Thermometer, PID, Temperature, LM35DZ, Heater.

I. INTRODUCTION

In the field of medicine, a thermometer functions to measure the temperature of the human body to find out if someone has a fever or not. Measuring body temperature with a thermometer is an initial diagnosis which will then be followed up with other diagnoses. So information on a person's body temperature is very important. For this reason, the thermometer as a tool for body temperature needs to be calibrated. The calibrator used to calibrate the thermometer uses a dry block system. J. Nielsen's research by comparing international standards and dry block calibrators, this comparison involved 16 laboratories, and the results of the dry block system can be used to calibrate thermometers [1]. Currently, there are many infrared-based digital thermometer calibrators or temperature sensors that have been made by Hüseyin Okan Durmuş [2]. M. Hohmann made the Dry Block Calibrator with increased internal temperature homogeneity in the field developed for the range from room temperature to 600^{0}C 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 [3]. Yingxiang Huang conducted research using predictive models by utilizing information technology, but this method is difficult to apply to thermometer calibration [4]. Adelina Ramadhani developed her research by designing a digital thermometer calibrator using water-based PID control and on/off to help routinely check digital body thermometers according to standards before or after use at certain intervals.

The design of this calibrator consists of a series of heaters with water media and a series of LM35 temperature sensors. This study demonstrates the design of a digital thermometer calibrator using water as the medium with the smallest correction value using PID control, namely 0.1% [5].

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 [6][7][8]. O. Ongrai The main factor in thermocouple calibration is the homogeneity of the media used [9]. S. Marin makes a dry-block calibrator using indium, tin, and zinc media [10]. 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 [11]. 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[12][13]. 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 [13]. 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 [14]. 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 [15]. Avilia also made a design for a body thermometer calibrator based on PID control by evaluating the temperature stability of the calibrator media which is currently used to respond relatively long to achieve a stable temperature. This study uses the Arduino system as data processing, using the PID system as a temperature controller on the Peltier element, the DS18B20 sensor as a temperature sensor, and an LCD as a display[16][17]. The measurement according to the Calibration Working Method has a correction value of 0.07% and the thermometer can be calibrated when the temperature stabilizes after 2 minutes. It can be concluded that PID control is suitable for use as a control for temperature stability in thermometer calibrators. However, in this study, there was no other media as a comparison. PID research on temperature control has been carried out [18]. Ning Wang conducted research on temperature control with PID. From the results of the research, it was concluded that PID is very helpful in terms of energy efficiency, the error is only ± 0.35 °C [19]. Ratna Aisuwarya Ziegler-Nichols PID Adjustment Method to control temperature stability. The experimental results show that the system can keep the hot water temperature in the dispenser stable with a range from 92.31ºC to 92.62ºC, while the system without a controller is unable to maintain the stability of the hot water temperature because the hot water temperature reaches a maximum temperature of 95.62ºC exceeding the setpoint 92ºC [20]. Hsiao-Chung Chen controls the fan speed to make it more efficient, which all depends on the existing temperature. By using PID control this research ensures that the airflow can be controlled [21]. Yang Xiaoqian PID-based constant speed heating control method is suitable for medium frequency induction heating tube empty temperature control system. The application of this control method to production sites also shows the effectiveness of the method, and the results show that the temperature control meets the needs of the production process [22]. Siti Nur Hasinah Johari conducted research on the astiri oil production process, by using PID control the production process is more efficient because it reduces disturbances in the production process [23]. Cuicui Xu pointed out that the control method, whose control precision is between ±0.1ºC can improve temperature stability, reduce energy consumption, and have good robustness [24]. Anastasia Yuzhakova temperature measurements using the infrared thermography method using nano polycrystalline (PIR) fibers, the objects used are liquids, oils and dry materials [25].Making a calibrator thermometer by comparing the use of water and palm oil as a medium is important to determine the collegial nature and concentration of the solution so that digital thermometer calibration can be carried out effectively and accurately. Based on the description of the literature study above, several things need to be resolved through a study, including The use of calibrator media which will affect the time to reach the temperature setting, and PID control for temperature stability. Therefore in this study, a comparative analysis of water and oil media will be carried out in a digital thermometer calibrator based on PID control to compare calibration media, which is expected to assist in checking and obtaining better and more effective results. . The use of this design is more effective because it has advantages in terms of knowing the effect of the properties of each calibration medium on the time a stable temperature is reached according to the temperature setting and knowing the effectiveness of PID control on temperature stability. The contribution of this research can help the thermometer calibration process quickly with the appropriate media.

The purpose of developing this tool is to incorporate PID control into the calibration media. PID control is implemented to enhance the stability of temperature regulation and ensure precise temperature settings are achieved. This research contributes to the development of more effective digital thermometer calibrators, selection of appropriate calibration media, improvement of temperature measurement accuracy, and a better understanding of the properties of calibration media.

II. MATERIALS AND METHOD

A. EXPERIMENTAL SETUP

This research uses three Thermometer brands Omron 343F, Omron 245, and ThermoOne. Measurements in the temperature setting range of $37^0C - 41^0C$. Data were collected 5 times repeatedly on oil and water media.

1) MATERIALS AND TOOLS

In this study, the design of the tool uses the LM35DZ sensor as a temperature sensor and uses a heater as a heater in water and oil media. Arduino Nano Microcontroller IC is used to convert analog signals to digital and control system tools.

2) TRIAL

In this study, after the design of the tool was completed, the temperature response was tested using the PID control system. Data collection was carried out at a temperature setting of $37^0C - 41^0C$ then compared the temperature measurements on 3 Omron 343F, Omron 245, and ThermoOne brand thermometers. The time for reaching the setting and stable temperature on oil and water media was measured using a stopwatch.

B. DIAGRAM BLOCK

When the power supply switch is turned on, the entire circuit will be active. Users can choose the temperature setting in the temperature range of 370C – 410C. In this system, there are two chambers for water and oil media equipped with an LM35DZ temperature sensor. The LM35DZ temperature sensor will change the voltage according to the measured temperature and will process the ADC data on the Arduino Nano. The digital data is then displayed on a 16 x 2 character LCD. When the setting temperature has not been reached, the heater driver remains on and vice versa when the temperature has been reached, the heater driver will turn off. The working system of the tool is shown in FIGURE 1.

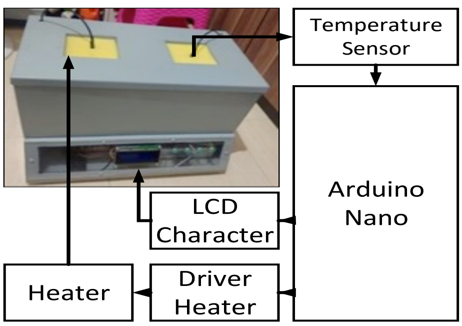

FIGURE 1. Diagram Blok System

C. THE FLOWCHART

The workings of the flow chart FIGURE 2 above when the tool is turned on the program will initialize the LCD and the PID control starts running according to the temperature setting driver. When the heater driver has reached the set temperature, the Analog voltage from the temperature sensor reading is converted into a digital voltage and processed on the Arduino ADC to be converted into binary numbers so that it can be displayed in the form of numbers on the LCD according to the measured temperature.

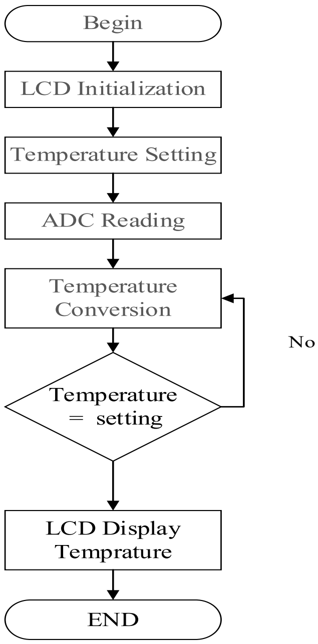

FIGURE 2. The Flowchart

III. RESULT

This device uses an Arduino Nano microcontroller for data processing, an LM35DZ Sensor module, and a Heater Driver consisting of SSR and a Heater. The LM35DZ sensor is used to display time data as an X-axis on a graph. While the Y axis shows the temperature of the sensor readings. This can be seen in FIGURE 3.

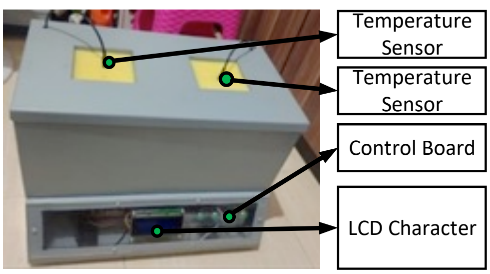

FIGURE 3. Digital Thermometer Calibrator Device Design

A. DIGITAL THERMOMETER CALIBRATOR DEVICE DESIGN

FIGURE 5 shows the components used in the module design. The analog part consists of the Heater Driver and the LM35DZ

Sensor. The digital part consists of the Arduino Nano microcontroller which is the main board of the ECG module and a LCD16x2 character.

B. RESULT DIGITAL THERMOMETER CALIBRATOR DEVICE PROGRAM

In this paper, the program is divided into two parts, namely for programming Temperature Settings and PID.

1) Listing Program Setting Suhu

Listing temperature setting program as in Listing Program 1.

Program listing 1. Temperature Setting Program

```
if (set_value_up == LOW){
    delay(200);
    setpoint_suhu += 0.5;
    }
if (set_value_down == LOW){
    delay(200);
    setpoint_suhu -= 0.5;
if (setpoint_suhu < 37){
setpoint_suhu = 41;
}
if (setpoint_suhu > 41){
setpoint_suhu = 37;
```

2) Listing Program PID

The listing program for PID functions for temperature control in water and oil media is shown in Listing Program 2.

Program listing 2. PID program

```
if (menu == 1){
    PID_eror_1 = setpoint_suhu1 - suhu_1;
    PID_eror_2 = setpoint_suhu2 - suhu_2;
if (suhu_1 <= setpoint_suhu){
    PID_P_1 = 0.01 * KP_1 * PID_eror_1;
    PID_I_1 = 0.01 * PID_I_1 + (KI_1 * PID_eror_1);
    timePrev_1 = Time_1;
    Time_1 = millis();
    elapsedTime_1 = (Time_1 - timePrev_1) / 1000;
    PID_D_1 = 0.01 * KD_1 * ((PID_eror_1 -
previous_eror_1)/elapsedTime_1);
    PID_1 = PID_P_1 + PID_I_1 + PID_D_1;
if (PID_1 < 0){
    PID_1 = 0;
    } if (PID_1 > 255) {
    PID_1 = 255; }
if (suhu_2 <= setpoint_suhu){
    PID_P_2 = 0.01 * KP_2 * PID_eror_2;
    PID_I_2 = 0.01 * PID_I_2 + (KI_2 * PID_eror_2);
    timePrev_2 = Time_2;
    Time_2 = millis();
    elapsedTime_2 = (Time_2 - timePrev_2) / 1000;
    PID_D_2 = 0.01 * KD_2 * ((PID_eror_2 -
previous_eror_2)/elapsedTime_2);
   PID_2 = PID_P_2 + PID_I_2 + PID_D_2;
   if(PID_2 < 0){
   PID_2 = 0;
   } if(PID_2 > 255){
    PID_2 = 255;
 }
```

C. RESULT MEASUREMENT

1) TEMPERATURE MEASUREMENT IN OIL AND WATER MEDIA

PID data that has been processed from Arduino can be displayed on the telemetry viewer. The data displayed is a graph of stability and the time the temperature setting is reached on oil (t_temperature 1) and water (t_temperature 2) media. FIGURE 4 shows the results of the comparison of temperature measurements at the 37^0C temperature setting on the oil medium, adjusting the temperature setting with the sampling rate to 47500, which is for 75 minutes. While the water medium is still stable according to the temperature setting of 37^0C.

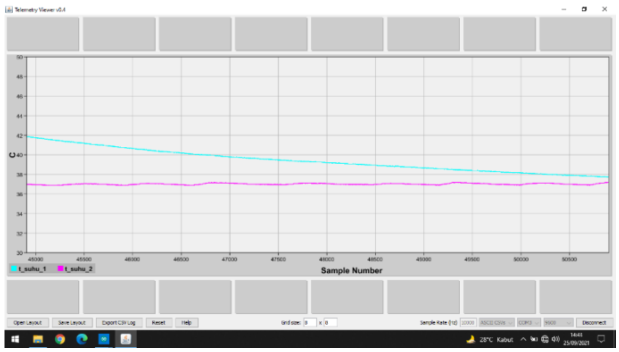

FIGURE 4. **Temperature Measurement Chart on Telemetry Viewer**

2) MEASUREMENT ERROR VALUE

The measurement data collection for the device function test was carried out 5 times and repeated up to 3 times according to the BPFK calibration standard. Tables 1, 2, and 3 show the error values for each measurement according to the temperature setting from 370C - 410C on the LCD and the Omron 343F, Omron 245, and ThermoOne calibrated thermometers. The highest error value in the measurement was 5% in the thermometer reading of the TermoOne brand with oil media shown in TABLE 3 and the lowest was 2% in the LCD, Omron 343F, Omron 245, and TermoOne brand thermometers in water and oil media shown in TABLE 1, TABLE 2, and TABLE 3.

TABLE 1.
Measurement Error Value 1

Setting Temp.	Error (%) LCD		Omron 343F		Omron 245		ThermoOne	
	T1	T2	T1	T2	T1	T2	T1	T2
37	3	4	3	4	4	4	4	4
38	3	4	3	4	4	4	3	4
39	3	4	3	4	3	4	4	4
40	4	4	4	4	4	2	4	4
41	3	4	3	4	3	4	3	4

TABLE 3.
Measurement Error Value 2

Setting	Error (%)							
Temp.	LCD		Omron 343F		Omron 245		ThermoOne	
	T1	T2	T1	T2	T1	T2	T1	T2
37	4	4	4	4	4	4	4	2
38	4	4	4	4	4	4	3	5
39	3	4	3	4	2	4	4	4
40	3	4	3	4	2	2	4	4
41	3	2	3	2	4	4	3	3

TABLE 2.
Measurement Error Value 3

Setting	Error (%)							
Temp.	LCD		Omron 343F		Omron 245		ThermoOne	
	T1	T2	T1	T2	T1	T2	T1	T2
37	2	4	2	4	4	5	4	2
38	3	4	3	4	4	4	3	5
39	3	4	3	4	2	4	4	4
40	4	4	4	4	4	2	4	4
41	3	2	3	2	2	4	3	3

3) MEASUREMENT OF TEMPERATURE STABILITY

The length of time for achieving a stable temperature at a temperature setting of 37^0C - 41^0C was measured using a stopwatch and is shown in TABLE 4. Table 4 shows the variation in the length of time for achieving a stable temperature measured on oil (T1) medium of about 1 - 1.3 hours and water (T2) with a length of time 3 - 3.3 minutes. The time to achieve a stable temperature in oil media is longer than in water media.

TABLE 4
Stable Temperature Reach Time

Setting	Time	
Temp.	T1 (hours)	T2 (minute)
37	1.2	3.3
38	2	3
39	1.2	3.3
40	1	3
41	1.3	3.3

IV. DISCUSSION

Temperature measurement and calibration are critical aspects in various scientific, industrial, and medical applications. Accurate temperature readings are vital for ensuring the reliability and safety of processes and products. In this study, the author's module was developed and tested according to the BPFK calibration measurement procedure. The module's performance was compared against three calibrated digital thermometers, namely the Omron 343f, Omron 245, and Thermo One brands, with temperature measurements conducted on both water and oil media. This discussion section presents a comprehensive analysis of the experimental results, highlighting the error values, the effect of media properties, the influence of the heating process, and the benefits of employing PID control and Peltier elements as media heaters. Moreover, comparisons with existing thermometer calibrators are provided to demonstrate the advancements made in this research.

The results of the experiment revealed varying error values when measuring temperature on different media. For water media, the error value was less than ±2%, indicating a high level of accuracy in the readings. Conversely, when measuring on oil media, the error value was ±5%, showing a relatively larger discrepancy between the actual temperature and the measured value. This discrepancy can be attributed to several factors, with one significant factor being the differences in the properties of substances in oil and water media. Oil and water possess distinct thermal properties due to variations in their specific heat capacities and thermal conductivities. These differences affect the heat propagation process from the heater to the media, impacting the time required to achieve a stable temperature according to the temperature setting. The longer time needed to stabilize the temperature in oil media (1.3 hours) compared to water media (3.2 minutes) is a clear indication of the dissimilar heat transfer characteristics of these two substances.

To ensure fairness in the calibration process, the mechanical design of the module incorporated a heater with consistent power to heat both water and oil media. This design choice aimed to minimize any bias that could arise from unequal heating rates and thus contributed to the reliable comparison of temperature measurements between the two media. Additionally, the size of the chamber (container) used for both water and oil media was kept uniform, further enhancing the reliability of the results. In this study, LM35DZ sensors were employed to measure the temperature in both water and oil media. The utilization of these sensors offers numerous advantages, including high accuracy, ease of integration, and a wide operating temperature range, making them suitable for various applications. Moreover, each sensor was controlled using a PID system, which is renowned for its efficiency in maintaining temperature stability.

The performance of the developed module was compared with that of a digital thermometer calibrator using ATmega32p-based wet media, which aimed to monitor thermometer performance within the temperature range of 35°C to 40°C for accuracy maintenance [26]. The results of this comparison demonstrated the superior performance of the author's module in maintaining accuracy during temperature measurements. Furthermore, previous research conducted by Bintari in 2020 utilized Peltier elements as heating media and temperature sensors controlled by a PID system, demonstrating the feasibility of employing PID control as a calibration medium [18]. This finding aligns with the results of the current study, further validating the effectiveness of PID control for temperature stability in thermometer calibration.

While the discussed research provides valuable insights into temperature measurement and calibration using the developed module, it is essential to acknowledge some limitations and weaknesses that may impact the study's findings and conclusions. The research only compared the developed module against three calibrated digital thermometers. A larger sample size and broader range of thermometer models from different manufacturers could provide a more comprehensive evaluation of the module's performance and enhance the generalizability of the results. The study focused on a specific temperature range, and the effectiveness of the developed module might vary at extreme temperatures or in environments with temperature fluctuations beyond the tested range. Expanding the temperature range could provide a more comprehensive understanding of the module's capabilities and limitations. While using both oil and water as calibration media is an advantage, it is worth considering that different types of oils or water can have varying thermal properties. The research does not address potential differences in the thermal behavior of different types of oil or water, which may influence the module's accuracy. The research assumes a linear error for the developed module when measuring temperature. However, in reality, the error behavior might be nonlinear, especially at extreme temperatures or in specific applications. Accounting for potential nonlinear errors would improve the accuracy of the findings. The study does not consider potential environmental factors, such as ambient temperature, humidity, or air circulation, which can affect temperature measurements. Incorporating these environmental factors in the experiments would provide a more realistic assessment of the module's performance in real-world conditions. While the error values are presented, there is no discussion of the uncertainty associated with these measurements. Including a comprehensive uncertainty analysis would provide a clearer understanding of the reliability and precision of the developed module. The research primarily focuses on comparing the developed module against specific thermometer calibrators using different methods. A broader comparison with various calibration methods and techniques would offer a more well-rounded assessment of the module's performance in the context of existing calibration practices. The PID control system used in the research is mentioned briefly, but there is no in-depth explanation of the tuning process or the specific parameters chosen. A more detailed description of the PID tuning process would enhance the understanding of the module's temperature stability control. The study does not provide information on the long-term stability and performance of the developed module. Evaluating the module's accuracy and reliability over an extended period would demonstrate its suitability for continuous and long-term calibration applications. While the research identifies differences in error values between water and oil media, it does not explore the specific sources of errors in detail. A comprehensive analysis of the contributing factors to measurement errors would enable targeted improvements in the module's design and calibration process. Addressing these limitations and weaknesses would strengthen the research's findings and contribute to the development of a more robust and reliable temperature measurement and calibration module. Additionally, researchers can consider these points for future studies to further advance the field of temperature calibration and instrumentation.

The choice of calibration media plays a vital role in achieving accurate and effective temperature measurements. In this study, both water and oil were used as calibration media. Water, being a common and readily available medium, allows for rapid stabilization of temperature, making it suitable for certain applications. On the other hand, oil, while taking longer to reach a stable temperature, offers more stability once stabilized, making it advantageous for extended calibration processes. Additionally, utilizing Peltier elements as media heaters provides a versatile and precise means of temperature control. Peltier elements offer advantages such as fast response times, high controllability, and accurate temperature regulation, making them an excellent choice for calibration applications.

In conclusion, the experimental results obtained in this study demonstrate the effectiveness of the developed module for temperature measurement and calibration. The module exhibited high accuracy in water media, with an error value of less than ±2%, and satisfactory performance in oil media, with an error value of ±5%. The differences in error values were attributed to the distinct thermal properties of water and oil, influencing the heat propagation process and the time required for temperature stabilization.

The mechanical design, which ensured uniform heating and container size for both media, played a crucial role in producing reliable and unbiased results. The use of LM35DZ sensors controlled by PID systems further contributed to the accuracy and stability of temperature measurements. Comparisons with existing thermometer calibrators validated the module's superior performance in maintaining accuracy. Moreover, the feasibility of PID control for temperature stability was reaffirmed by previous research findings. Ultimately, the choice of calibration media, whether water or oil, and the implementation of Peltier elements as media heaters offer valuable options for temperature measurement and calibration, allowing for more precise and efficient results in various applications. This study serves as a significant contribution to the advancement of temperature calibration techniques, paving the way for improved temperature measurement practices and ensuring the reliability and accuracy of temperature readings in diverse fields.

V. CONCLUSION

In conclusion, this research successfully achieved its objective of analyzing the temperature stability comparison between water and oil media in a digital thermometer calibrator employing PID control. The developed Digital Thermometer Calibrator, equipped with PID control, demonstrated its capability to deliver real-time temperature measurement results through telemetry media and a 16 x 2 character LCD, enhancing the accuracy and reliability of temperature calibration. The results of the experimentation indicate that using water as a calibration medium yields excellent calibration results with an error of less than ±2%, meeting the calibration requirements for precision. On the other hand, when employing oil as the calibration medium, the error value remains within acceptable limits but is slightly higher at less than ±5%. This difference in error values can be attributed to the inherent thermal properties of the substances used as calibration media. Despite the successful implementation of PID control and satisfactory performance in both media, the developed module does have certain limitations that warrant further attention. One critical area for improvement involves the selection of appropriate calibration media to increase the effectiveness of calibration activities and facilitate efficient heat transfer in digital thermometer calibrators. Conducting further research to identify the optimal calibration media based on various factors, such as specific heat capacity, thermal conductivity, and stability, could lead to enhanced accuracy and consistency in temperature measurements. Additionally, addressing the shortcomings related to heat transfer within the digital thermometer calibrator would contribute to the overall efficiency of the calibration process. Innovative design modifications, such as optimized chamber structures or better-insulated components, could potentially improve the module's performance and stability further. Future development efforts should also consider a comprehensive analysis of the sources of errors in the calibration process. Identifying and mitigating potential sources of errors, whether related to the sensor, PID control parameters, or other system components, would elevate the module's reliability and precision. In summary, this research provides valuable insights into temperature stability comparison and calibration using the developed Digital Thermometer Calibrator with PID control. The promising results in water and oil media calibration underscore the potential of this technology for practical applications. Addressing the highlighted limitations and continuing the refinement of the developed module will undoubtedly advance the field of temperature calibration and benefit various industries, ensuring accurate and consistent temperature measurements in diverse applications.

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