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Design of ATMEGA328p-Based Digital Wet Media Thermometer Calibrator

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ABSTRACT Temperature calibration is an activity that formed the relationship between values indicated by a measuring instrument or measuring system with the temperature scale value measured under certain conditions. A clinical thermometer is a device that doctors use to measure the temperature of a patient's body. In the field of calibration, the suitability of medical device readings with the allowed standard values (tolerance values) is very necessary so that the readings are kept accurate. The purpose of this research is to make ATmega32p-based digital wet media thermometer calibrator to monitor the performance of the thermometer with a temperature setting of 35°C – 40°C in order to maintain its accuracy. The design of this calibrator consists of a wet heater circuit using a DS18B20 temperature sensor processed by ATmega328p minimum system, which then displayed on a 2x16 LCD. This device was designed to make it easier to calibrate the thermometer so that its accuracy is maintained. Thermometer calibration was done by comparing the module with a standard calibrated measuring device. The measurement of the instrument against the setting temperature has the smallest error of 0% and the largest value of 0.25%. Meanwhile, the measurement of the instrument against a standard thermometer (which has been calibrated) has the smallest error value of 0% and the largest value of -1.17%.
INDEX TERMS Wet Media, Calibrator, Thermometer, Temperature.

I. INTRODUCTION

In everyday life, temperature is a measure of how hot or cold a substance or an object is. The device used to measure temperature is called a thermometer [1]. Temperature is the main parameter that affect the refractive index of fluid substances [2]. Meanwhile, body temperature is a balance unit of heat measurement called degrees. Such temperature refers to the heat or cold of a substance [3][4]. Furthermore, body temperature is also defined as the difference between the amount of heat produced by body processes and the amount of heat lost to the external environment. Meanwhile, a thermometer is a device used to measure the temperature. There are several thermometers commonly used, such as room thermometers, laboratory thermometers, clinical thermometers, and six-bellani thermometers. Clinical thermometer is the one commonly used when someone is having a fever. Doctors use this thermometer to determine the temperature inside the patient's body. When the body has a fever, the temperature can exceed 40 degrees, while when the body is healthy, the temperature is around 30 degrees [5].

A thermometer is a device used to measure the temperature of an object [6]. When a temperature measures an element to detect the temperature, the display panel will show the measured temperature according to the temperature of the element measured [7]. In this case, the most commonly used thermometers in the medical field are mercury thermometers and digital thermometers. Body temperature thermometer is one of the measuring device that must be regularly measured, checked, and calibrated according to standards before being used or after being used at certain intervals [8]. Related to this, there are various media for calibrating a thermometer; two of them are dry block and water media. Calibration is an activity to determine the conventional truth of the value of the designation of measuring device and measuring materials. The calibration is carried out by comparing the measuring device and measuring materials to be calibrated against the measuring standards, which are traceable to national and or international standards. In this case, the purpose of calibration can be determined by the deviation of the conventional truth of the value of the designed measuring instrument [9].

Handayani, in her research in 2019, made a thermometer calibration media using the DS1820 sensor as the temperature sensor and a dry heater as the heating medium with a humidity sensor. The drawback of this study is that the media used still has an error value between the display of the device and the thermometer compared [10]. Ardelina in 2019 also calibrated a thermometer using the LM35 sensor as the temperature sensor and a dry heater as the heating medium. The drawback of this study is that the media and sensors used still have errors between the display of the device and the temperature setting [11]. Furthermore, Rifika in 2020, also designed a water media in a body's digital thermometer calibrator. The disadvantage of this device is that it used an LM35 temperature sensor and the room is too large so that the error value on the display of the device for setting is quite high [12].

In metrology, especially measurement tools, calibration is required. In general, calibration is an activity to compare a measuring instrument with other measuring instruments that have been traced or standardized. Calibration is the process of comparing results and the field data and making proper adjustments so that both results are recorded [13]. Calibration is also defined as a technique of enhancing the accuracy by reducing the error in the instrument's reading [14]. Another definition refers calibration as an activity to determine the conventional truth of the value of the measuring instruments and measuring materials. In addition, calibration is carried out by comparing the measuring instruments and measuring materials to be calibrated against the measuring standards that are traceable to national and or international standards. Meanwhile, the purpose of calibration can be determined by the deviation of the conventional truth of the value of a measuring instrument [15]. Calibration is carried out through a measurement after the heat transfer process has established a heat balance in the apparatus between the standard and the temperature sensor being tested [16]. In this case, instrument calibration at the stage of the analytical function of the clinical laboratory testing process has a significant contribution to the uncertainty of the final measurement results [17]. The function of calibration is to compare a measuring instrument that has been traced or has a relationship with an international standard measuring instrument with a measuring instrument that has not been traced [18]. According to ISO/IEC Guide 17025:2005 and the Vocabulary of International Metrology (VIM), calibration is a series of activities that establish a relationship between the value indicated by a measuring instrument or measurement system, or the value represented by a measuring material, with known values. related to the quantity measured under certain conditions [19].

Based on the results of the search for the problem above, the author intended to design a device called ATmega328p-based digital wet media thermometer calibrator using DS18B20 sensor with an accuracy of ± 0.5 ℃ at a temperature range of -10℃ to +85℃ [20] and a measurement range of -55℃ - 125℃ [21], which will be heated in an ideal room and controlled using PID control [22]. The purpose of this study is to design ATmega328p-based digital wet media thermometer calibrator to monitor the performance of a thermometer with a temperature range of 35 - 40 ℃ in order to maintain its accuracy. By using different sensors and with an ideal volume, it is expected that it can assist the regular checking of the body's digital thermometer according to standards before or after being used at certain intervals.

II. MATERIALS AND METHODS

A. EXPERIMENTAL SETUP

This research was conducted on a digital wet media thermometer calibrator using a DS18B20 sensor which has an accuracy of ± 0.5ºC from a temperature of -10ºC to +85ºC and a measurement range of -55-25. The heating was carried out in an ideal room and using PID control. The ATmega328p minimum system was also used for the process of displaying the temperature reading from the sensor to 2x16 LCD to display the temperature reading. The calibrated thermometer, in this case, is a body digital thermometer. Data were collected using 4 digital body thermometers by setting the room temperature at 35-4ºC. Furthermore, data were collected 3 times on each thermometer with an interval of 10 minutes at each temperature setting.

1) MATERIAL AND TOOL

This research used DS18B20 temperature sensor that further immersed in water media. The ATmega328p minimum system was also used for the process of displaying the temperature reading from the sensor to the 2x16 character LCD. Furthermore, it is necessary to compare the measurements with the standard device. The comparison device used is a calibrated digital body thermometer. In this study, the Omron brand thermometer was used.

2) EXPERIMENT

In this study, the thermometer to be tested was inserted and pressed in a place that has been designed. This design was made so that the position of the thermometer being tested is upright and a little air could enter the room. The next process is setting the temperature. In this case, the settings were made at a temperature of 34, 35, 36, 37, 38, 39, and 40ºC. The results of the temperature reading test were then compared to the standard device. In this study, the standard used is a standard thermometer calibrated by the testing and calibration agency. Based on this comparison, the errors obtained were calculated.

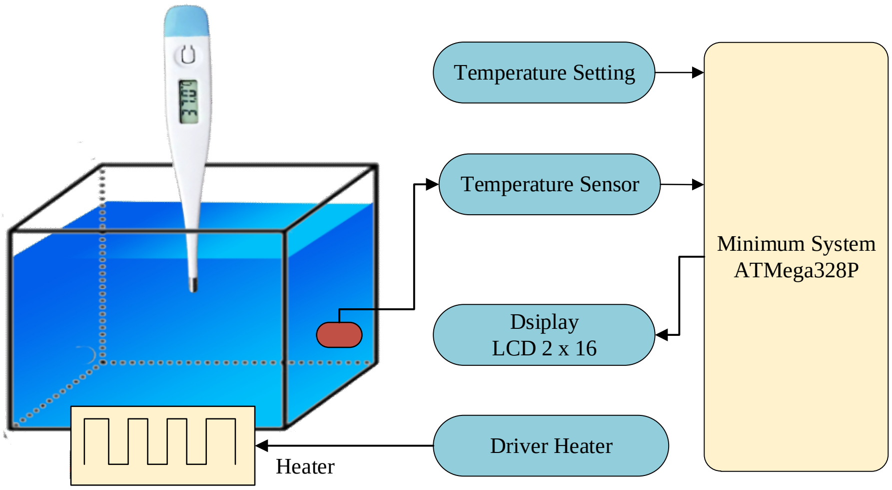

FIGURE 1 The block diagram of Digital Wet Media thermometer calibrator, input temperature sensors, is processed by a ATMega328P minimum system. Result of the temperature reading will be displayed on the 2x16 LCD to display. Heating was carried out in an ideal room and is controlled using PID control.

B. THE DIAGRAM BLOCK

In this study, the thermometer was placed in water media which has been heated at a temperature of 35-40°C. The temperature sensor used is the DS18B20 sensor. As shown in FIGURE 1, the sensor output enters the ATmega328p minimum system. The resulting temperature was further processed through ATmega328p minimum system and displayed on 16x2 LCD screen. This module is also equipped with UP & DOWN buttons to adjust the temperature setting and the start button to start the process.

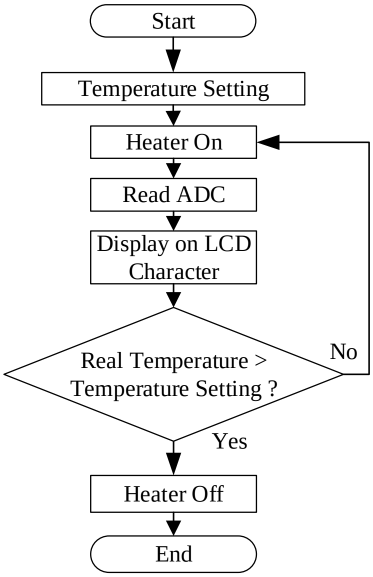

FIGURE 2. Flowchart of the design of the ATmega328p-based digital wet media thermometer calibrator

C. THE FLOWCHART

The flowrate process is based on the flow chart as shown in FIGURE 2. When the device is turned on, the LCD will perform initialization automatically. After the initialization, the temperature can be set by pressing the UP & DOWN buttons with a temperature range of 35 – 40°C. After setting the temperature, press the SET button and the heater will be ON. When the real temperature (reading) has not reached the setting temperature, the heater will remain ON. On the other hand, when the real temperature (reading) has been reached, then the heater will be OFF and the temperature reading by the temperature sensor will be displayed on the 2 x 16 LCD.

D. MINIMUM SYSTEM

The minimum system circuit of the digital data from the sensor is processed by ATmega328p via pin D2. Furthermore, a 16x2 LCD is used to display temperature data detected by the sensor. The UP & Down buttons are used to select the temperature setting. In addition, there is also START button to start the process. The output for the heater driver is on pin D3. When the program is running, the temperature reading will be displayed on the LCD.

III. RESULT

In this study, the measurements of the Thermometer Calibrator were compared with a calibrated digital thermometer (Omron). In this case, the measurement results are feasible to be used for thermometer calibration. The proposed design is shown in FIGURE 3.

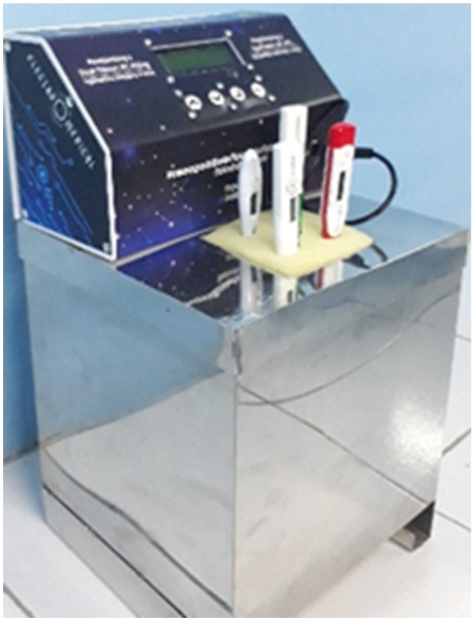

Figure 3. **Research results module. The module was designed to make it easier to place the thermometer to be tested. The display of the measurement results can be seen on the LCD**

1) THERMOMETER CALIBRATOR

The component part of the device consists of a minimum system circuit equipped with a power supply 5 VDC and SSR as a control system driver. The minimum system circuit consists of ATmega328p as a processor of all systems in the device module.

2) COMPARISON READING AND SETPOINT

The measurement of actual temperature readings on the LCD display against the set point. This measurement was carried out to determine the results of the module measurement to the set point. The measurement results are shown in TABLE 1.

TABLE I

The actual temperature readings displayed on the LCD screen were compared with the temperature at the setting. Furthermore, the uncertainty and error values were calculated

No.	Display LCD (^{0}C)	SD.	UA	Error (%)
1.	34.98	0.05	0.01	0.07
2.	35.95	0.05	0.02	0.14
3.	36.95	0.07	0.02	0.14
4.	37.99	0.05	0.01	0.02
5.	38.97	0.12	0.03	0.09
6.	39.95	0.09	0.05	0.12

Based on TABLE 1, at the temperature setting of 35°C, the mean value of the module is 34.98°C, while the standard deviation of the module is 0.05°C. Therefore, the module UA value is ± 0.01°C. Meanwhile, the error value in the module is 0.02°C with a module error presentation of 0.06%. Furthermore, when the temperature setting is 36°C, the mean value for the module is 35.95°C and the module standard deviation is 0.05°C. Thus, the module UA value is ± 0.01°C. Meanwhile, the error value in the module is 0.05 °C with a module error presentation of 0.14 %. In addition, at the temperature setting of 37°C, the mean value for the module is 36.95 °C and the module standard deviation is 0.07 °C. Hence, the module UA value is ± 0.02 °C. Meanwhile, the error value in the module is 0.05 °C with a module error presentation of 0.14 %. At the temperature setting of 38 °C, the mean value of the module is 37.99 °C and the standard deviation of the module is 0.05 °C, so the module UA value is ± 0.01 °C. Meanwhile, the error value in the module is 0.01 °C with a module error presentation of 0.02%.

Furthermore, at a temperature setting of 39 °C, the mean value for the module is 38.97 °C and the module standard deviation is 0.12 °C, so the module UA value is ± 0.03°C. In this case, the error value in the module is 0.03°C with a module error presentation of 0.08%. Meanwhile, at a temperature setting of 40°C, the mean value for the module is 39.95 °C and the module standard deviation is 0.09 °C, so the module UA value is ± 0.05 °C. In this temperature setting, the error value in the module is 0.05 °C with a module error presentation of 0.12%.

3) COMPARISON OF TEMPERATURE READING

The results of the comparison between the calibrated thermometer temperature and the actual temperature displayed on the display module can be seen in TABLE 2.

TABLE 2.

Comparison of Calibrated Thermometer Temperature standard and Design Thermometer Temperature

Temperature Setting (°C)	Mean		Error	
	Standard	Design	Error (°C)	Error %
35	34.80	34.93	0.13	0.38
36	35.93	35.93	0.00	0.00
37	36.50	36.93	0.43	1.17
38	38.03	37.93	0.10	0.26
39	38.97	39.00	0.03	0.09
40	39.87	39.93	0.06	0.15

Based on TABLE 2, at the temperature setting of 35°C, the mean value on the Omron thermometer is 34.80°C, the mean value on the display of the device is 34.93°C, the module reading error value against the standard thermometer is 0.13°C, and the module reading error value against the thermometer standard is -0.38%. Furthermore, in the case of the temperature setting of 36°C, the mean value on the Omron thermometer is 35.93°C, the mean value on the display of the device is 35.93°C, the module reading error value against the standard thermometer is 0°C, and the module reading error value against the standard thermometer is 0%.

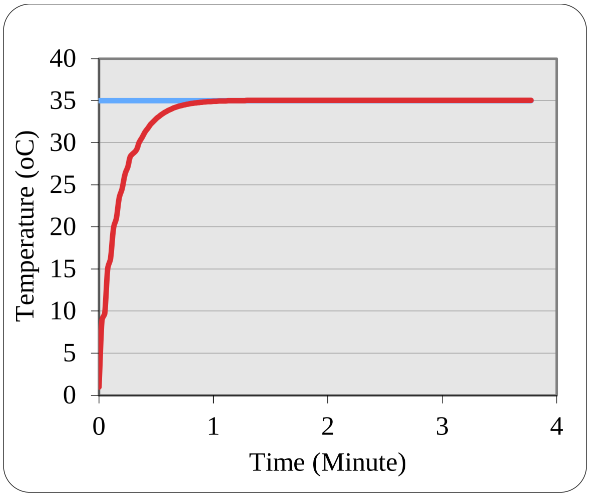

FIGURE 4 The radar graph shows the comparison between the measurement results from the Design and the standard device.

At the temperature setting of 37°C, the mean value on the thermometer is 36.50°C, the mean value on the display of the device is 36.93 °C, the error value of the module reading against the standard thermometer is 0.43°C, and the error value of the module reading against the standard thermometer is 1.17%. At a temperature setting of 38°C, the mean value on the omron thermometer is 38.03°C, the mean value on the display of the device is 37.93°C, the module reading error value against the standard thermometer is 0.10°C, and the module reading error value against the thermometer standard is 0.26%. In the case of temperature setting of 39°C, the mean value on the omron thermometer is 38.97°C, the mean value on the display of the device is 39.00 °C, the module reading error value against the standard thermometer is 0.03 °C, and the module reading error value against the thermometer standard is 0.09%.

At a temperature setting of 40°C, the mean value on the Omron thermometer is 39.87 °C, the mean value on the display of the device is 39.93 °C, the module reading error value against the standard thermometer is 0.06°C, and the module reading error value against the thermometer standard is 0.15%. Furthermore, based on FIGURE 4, the radar graph shows that almost all the graphs of the measurement points coincide, indicating that almost all the measurement points have a very small error value, which is only at 37°C. FIGURE 4 is the statistical data from the module measurement to the setting temperature. At the temperature setting of 35°C, the module reading error value against the standard thermometer is -0.38%. At the temperature setting of 36°C, the module reading error value against the standard thermometer is 0%. At a temperature setting of 37°C, the module reading error value against the standard thermometer is 1.17%. At a temperature setting of 38°C, the module reading error value against the standard thermometer is 0.26%. At a temperature setting of 39°C, the module reading error value against the standard thermometer is 0.09%. Furthermore, at a temperature setting of 40°C, the module reading error value against a standard thermometer is 0.15%.

4) PID RESPONSE

In this module, the method used to stabilize the temperature is PID. **FIGURE 5** shows the PID graph used in the module. In order to obtain the graph as shown in **Fig. 6**, the values of Kp, Ki, and Kd are needed. The values used are Kp = 37; Ki = 0.8; and Kd = 6.6.

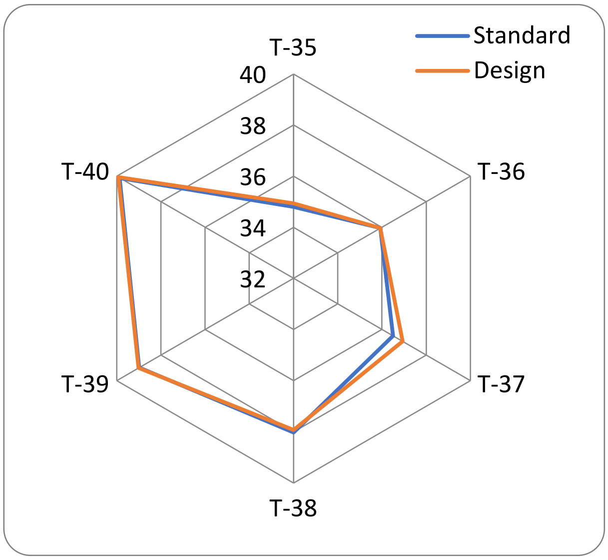

FIGURE 5. Graph of PID using Kp, Ki, and Kd values. The values used are Kp = 37; Ki = 0.8; and Kd = 6.6

FIGURE 5 is the data of the best PID that was tested by the author and used in the device module. In order to get the graph, the values of Kp, Ki, and Kd are needed. Hence, the values used are for Kp = 37; Ki = 0.8; Kd = 6.6. This value was obtained through the PID tuner and experiments that were carried out on the module to get the right value.
Based on the graph, the output obtained from the control is relatively stable and has a steady error value of close to 0%. Therefore, by using these values, the device module can reach a stable temperature according to the temperature setting within ± 6 minutes.

IV. DISCUSSION

Based on the temperature measurements with a temperature sensor on a digital thermometer calibrator, it produced an output with 6 data collection sets. The sets are 35, 36, 37, 38, 39, 40 in units of Celsius. The thermometer used is 4 thermometers with 3 data collection processes. The standard thermometer has been calibrated and was used to be compared to the device module. The smallest error value for display readings against the standard thermometer is 0%, while the largest error value is 1.17%. The smallest error value for display readings on the temperature setting is 0.02%, while the largest error is 0.14%.

The results of the temperature sensor produced a linear output for every increase of 0.1℃. The results of the calibrator were also compared with digital thermometers that have been calibrated with the Omron MC-246 brand. Error values obtained from measurements between the module and the comparison thermometer are 0.38% (35), 0.00% (36), 1.19% (37), 0.26% (38), 0.09% (39), and 0.17% (40). The error values obtained by the measurement between the module and the temperature setting are 0.07% (35), 0.14% (36), 0.14% (37), 0.02% (38), 0.09% (39), and 0.12% (40).

Based on the previous research [23], it was found that the highest error was 0.4% at the setting temperature of 40℃ and the smallest error was 0.04% at the setting temperature of 37℃. Meanwhile, another research project [11] found that the highest error was 0.20% and the smallest error was 0.10%. Furthermore, another study [24] discovered that the highest error was 1.5% at the setting temperature of 36 ℃ and the smallest error was 0.3% at the setting temperature of 40 ℃. Therefore, based on the error values data obtained by previous researchers and the results of the research from the current author [25], it can be concluded that the improper placement of sensors and thermometers can affect the temperature readings in the room.

The benefit of this research is that a digital thermometer can be calibrated using this calibrator with maximum results because the comparison was conducted using with a standard thermometer.

V. CONCLUSION

The purpose of this study is to make ATmega328p-based digital wet media thermometer calibrator in order to monitor the thermometer performance at a temperature setting of 35-40℃ in order to maintain its accuracy. This study has obtained the smallest error results in the measurement of the setting temperature of 38 ℃ with an error value of 0.02% while the largest error value was obtained from in the measurement of the temperature setting of 36℃ and 37℃ of 0.14%. Furthermore, for the comparison with a calibrated thermometer, the smallest error was obtained at the setting temperature of 36 ℃ with an error of 0.00%, while the largest error results were obtained from the measurement of the temperature setting of 37 ℃ with an error of 1.19%. Based on the measurements that have been made, it can be concluded that the placement of the sensor can affect the difference in the error obtained. In addition, grounding the device is also needed because poor grounding affects random readings, speeds up time to stabilize the temperature to be efficient, and maintain the accuracy of the device. Meanwhile, the weakness of this module is the time it takes to reach a stable temperature which is still too long. Therefore, it is expected that the time of temperature stabilization will be faster in future research.

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