Implementation of PID-Based Temperature Control System for Helmet Dryers

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Abstract – This research aims to design an automatic helmet dryer that uses PID-based temperature control to maintain a stable temperature at a setpoint of 45°C, especially in rainy season conditions that often make helmets wet and damp. A damp helmet has the potential to become a breeding ground for fungi and bacteria, as well as causing unpleasant odors and health problems. This tool controls the temperature using a PID controller with a BTS7960 driver module with temperature readings from a DHT22 sensor. The Ziegler-Nichols tuning method produces initial constant values Kp=7.64, Ki=0.1273, and Kd=114.6, but *fine tuning* is required to achieve the best constants Kp=100, Ki=1, and Kd=114.6. The test results show that the open face helmet can dry in 68 minutes with a final humidity of 38.9%, and the system response was 1,1% overshoot, 0 °C steady-state error, 246 seconds rise time, and 561 seconds settling time.

Keywords: PID (Proportional-Integral-Derivative), Helmet Dryer, Ziegler-nichols.

I. INTRODUCTION

Motorcycles are the most popular means of transportation for most Indonesians. Based on annual motorcycle sales data compiled by AISI (Indonesian Motorcycle Industry Association), in the last 5 years the number of motorcycle sales in Indonesia has increased every year, recorded in 2023 domestic motorcycle sales of 6.24 million units. This number has increased by 19.45% compared to 2022 which only sold 5.22 million units [1]. In every house in Indonesia, it is certain to have at least 1 unit, with the proliferation of motorbikes in Indonesia, the need for helmets will also increase, because helmets are mandatory equipment when driving when using a motorcycle [2].

Helmets are mandatory devices that function to protect the user's head when traveling on a motorcycle [3]. Helmets have several types on the market, namely half face, full face, modular, and so on. Helmets are usually made of hard materials such as carbon kevlar, resin, fiber, thermoplastic, and other hard materials [2]. Comfort is a factor that is highly considered when someone wants to buy a helmet [4].

Comfort is a very important factor for someone who will wear a helmet when traveling while riding a motorcycle. A comfortable helmet is one that is dry, not damp, and clean [5]. During the rainy season, helmets are often wet and damp from rainwater. This dampness has the potential to develop bacteria and fungi on the helmet, which can lead to bad odor and skin health problems. When the helmet is in this state, the first thing to do is to dry the helmet. However, the problem is the unpredictable weather, especially since Indonesians often still use manual methods when drying helmets. Helmets that are often dried in direct sunlight over time will be damaged, especially on the inside of the helmet or commonly called the inner helmet, the part will quickly deflate and fall off. In addition, the helmet paint will fade quickly due to exposure to direct sunlight [6].

Based on these problems, a PID-based temperature control system is designed on a helmet dryer, which is expected to dry helmets without considering weather conditions so that they can dry helmets at any time and can dry helmets quickly. In this dryer system, PID has the function of controlling the heater so that the temperature in the box is stable according to the set point determined by the researcher. The PID controller controls the temperature to reach the setpoint with input from the temperature reading from the DHT22 sensor.

This research aims to test the efficiency of PID-based automatic helmet dryer on various types of helmets, such as open face and half face helmets. The results of this study are expected to provide useful data related to the performance of the device in reducing helmet moisture and maintaining a stable temperature during the drying process.

II. LITERATURE

Helmet

Helmets are mandatory devices that must be worn by every motorcyclist when traveling using a motorized vehicle. Helmets have a safety function that can minimize a rider when a collision or accident occurs on the road. A motorcycle helmet has several types including half face, full face, modular, and so on. In the production process of a helmet, helmets on the market today come from materials such as metal, carbon, resin, and plastic [7], [8].

PID Controller

The PID system is a control system that has a working principle in a closed loop, PID consists of three controls, namely proportional (P), Derivative (D), and integral (I). of the three controls have their respective weaknesses and advantages in terms of system response. The combination of the three controls has the intention of maximizing a system so that it reaches a predetermined setpoint [9]. PID is widely used because it has the advantage of being able to stabilize an existing system. When the process of stabilizing a system, PID requires an error after that converts the error into a system response until the system reaches stability The PID controller tries to reduce the error value as in equation 1 [10], [11]. The PID system block can be seen in Figure 1.

$$u(t) = P(t) = K_p.e(t) + Ki\int e(\tau)\,d\tau + K_d \frac{de(t)}{dt} \quad (1)$$

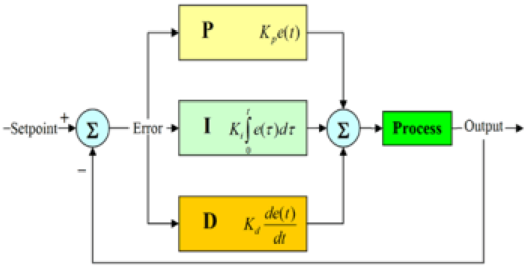

Figure 1. PID System Block

Ziegler-Nichols Curva Reaction Tuning

By examining the reaction of the open loop process to changes in the value of the output variable, the method of tuning the constants Kp, Ki, and Kd with the Ziegler Nichols Open Loop Step Response is also known as the process reaction method. Certain process response values are entered into the Ziegler Nichols equation in Table 1 once they are found. These values are added with certain multiplier constants to power the controller with P, PI, or PID actions. Time delay (L), also known as dead time, and time constant (T) are obtained from open loop testing with step input as shown in the step response graph in Figure 2 [12].

Table 1. PID parameters Ziegler Nichols Reaction Curve

Control Type	Kp	Ti	Td
P	T/L	∞	0
PI	0.9T/L	L/0.3	0
PID	1.2T/L	2L	0.5L

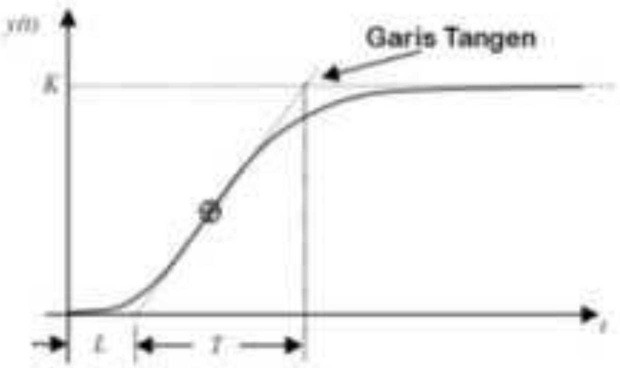

Figure 2. Step Response

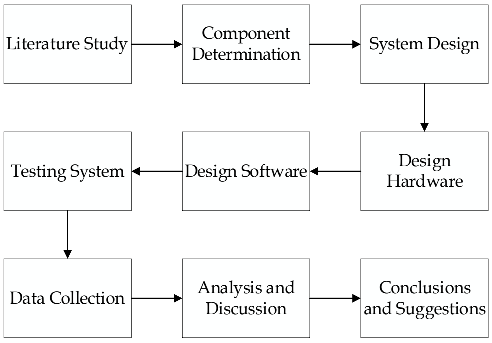

Figure 3. Research Stages

III. METHOD

Research Stages

The research stages carried out in this study can be seen in Figure 3.

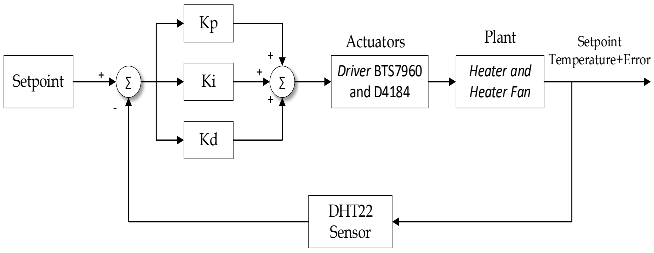

Figure 4. Design System PID

Figure 4 shows block diagram of a helmet dryer with PID control. In the block diagram above there are actuators as outputs that will be controlled by PID in the form of BTS7960 modules and D4184 MOSFET modules, then there are plants in the form of heaters and heater fans, and DHT22 sensors as feedback from PID control. At the initial stage is to determine the setpoint in the form of temperature to be achieved or stabilized by PID, the setpoint value will be read by the DHT22 sensor placed in the box containing the helmet. The setpoint value in the form of temperature will turn into a signal that will be processed by the PID which has previously been used on the Arduino Uno microcontroller. Then the value in the form of temperature data will be processed by PID with (Error = Setpoint - Process Variable) which will be issued in the form of a PWM signal as output, then the PWM value will go through a mapping process whose results are converted into power or Duty Cycle which in the end PID will issue the appropriate PWM value so that the heater spouts the heat in accordance with the setpoint that has been set.

Block Diagram System

Figure 5 shows the system block diagram. The Arduino Uno serves as the control center, with a 12 V power supply providing voltage for components that require DC current. The system is switched on and off via a switch connected to an AC power source. The DHT22 sensor is used to read the temperature and humidity, while the data is displayed on the LCD. The BTS7960 driver and MOSFET D4184 control the heater and heater fan based on the Duty Cycle PID output. In addition, MOSFET D4184 also activates the blower fan to reduce humidity and temperature until it reaches the setpoint. The system is equipped with a buzzer to indicate when the helmet is dry and the system stops working.

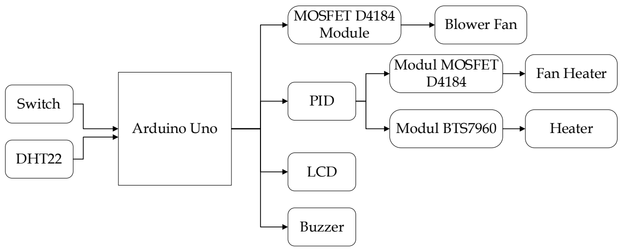

Figure 5. Block Diagram System

Hardware Design

Hardware design carried out in this study includes mechanical design in the form of a 3D design of a helmet dryer.

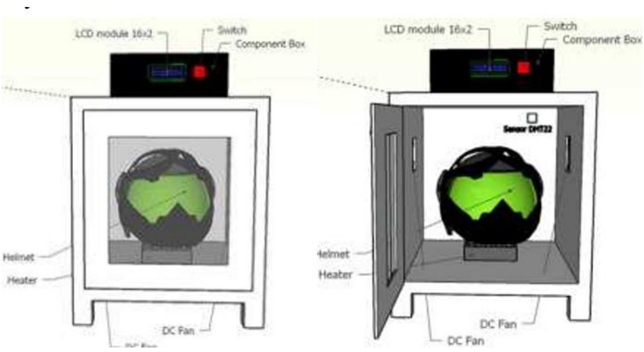

Figure 6. 3D Hardware Design

Based on Figure 6, the design of the drying box has dimensions of 47 cm long, 40 cm wide and 45 cm high. The component box is placed on top of the drying box, on the front of the component box there is a 16x2 LCD which is used to monitor the temperature and humidity.

Software Design

a. Arduino IDE Software Design Temperature Control

Figure 7 shows the flowchart of the PID control-based helmet dryer system starting with the start stage to initiate the program. Next, program initialization is performed, which includes library input on the Arduino Uno and variable declarations. The main inputs of the program are the temperature and humidity setpoints. The system then reads data from the DHT22 sensor to monitor the temperature and humidity inside the drying box. The temperature is controlled using PID, while the humidity is used as an indicator of when the system should stop.

DHT22 sensor reads the humidity to check if the helmet is dry, when the humidity is still far from the target, the DHT22 sensor will read the temperature, the temperature value is processed by PID. When the temperature is still below the predetermined setpoint, the system will activate the heater and heater fan quickly through the BTS7960 module and the D4184 MOSFET module based on the PWM PID value, while the blower fan is off. Then the DHT22 sensor will read the temperature and humidity again, when the temperature has reached or above the setpoint, the PID will stabilize the temperature by reducing the speed of the heater and heater fan based on the PWM value, while the blower fan is active so that the temperature decreases and keeps the humidity in the dryer box from getting too high. If the humidity has reached the target, the system will stop operating marked by a buzzer sounding.

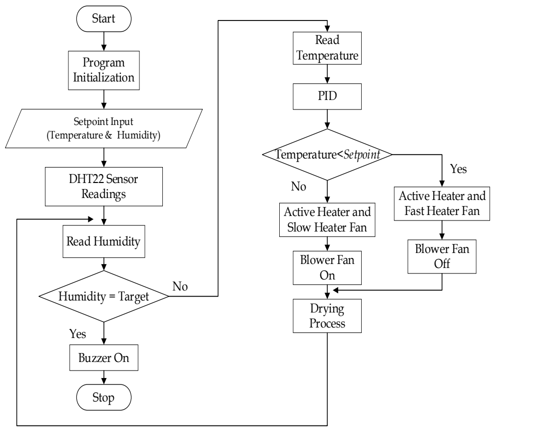

Figure 7. Arduino IDE Software Design Temperature Control

b. MATLAB Tuning Design

At this stage is the tuning stage to get the parameter values Kp, Ki, and Kd using the Ziegler Nichols method carried out with MATLAB software. The tuning process begins with creating a program to display the system response step graph. The next step is to find the value of L (time delay) and T (constant time) by drawing a tangent line. Both values can be used to find the parameters Kp, Ki, and Kd based on the calculation of the PID tuning method Ziegler-Nichols 1 in Table 1.

IV. RESULT AND DISCUSSION

Hardware Design Results

The construction of the helmet drying chamber is made with iron and iron plate as a cover for the drying box. This dryer has dimensions of 47 cm long, 40 cm wide, and 45 cm high. On the right and left of the box there is a blower fan while the heater is placed under the drying box to exhale hot air, the DHT22 sensor is placed inside the drying box precisely at the top. The component box and power supply are placed on top of the dryer box. The results of the hardware design can be seen in Figure 8.

Figure 8. Hardware Design Results

DHT22 Sensor Testing

DHT22 reads the temperature and humidity of the room during the drying process. To determine the accuracy of the DHT22 sensor, testing was carried out by comparing the temperature value of the DHT22 sensor and a digital thermometer. The test results can be seen in Table 2.

Table 2. DHT22 Sensor Testing

Minutes	DHT22 (°C)	Thermometer (°C)	Difference (°C)	Error (%)
0	32,1	32,4	0,3	0,93
1	40,2	40,7	0,5	1,23
2	47	46,6	0,4	0,86
3	50,9	51,2	0,3	0,59
4	51,8	51,8	0	0
5	52,4	52,2	0,2	0,38
6	53	53,1	0,1	0,19
7	54	54	0	0
8	54,3	54,2	0,1	0,19
9	54,7	55	0,3	0,54
10	55,3	55,3	0	0
Average			0,2	0,45

Based on Table 2, it is found that the average difference and error results from the temperature readings of the DHT22 sensor and thermometer are 0.2 and 0.45%.

PID Control Tuning Mechanism

PID controller tuning has the aim of obtaining PID control parameters, namely Kp, Kd, and Ki so that they can be applied to the system In this study, the PID tuning used is the Ziegler-Nichols method based on the reaction curve, therefore, open loop response data is needed to obtain the L and T values.

a. Open Loop Testing

The initial stage in determining the value of PID parameters in the Ziegler-Nichols method is to collect system Open Loop data by activating the heater with full PWM until it is in a stable state. The system Open Loop graph can be seen in Figure 9.

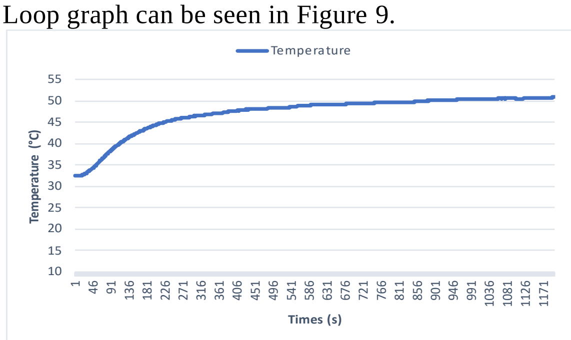

Figure 9. Open Loop Graph

Based on Figure 9 above, the system can reach a stable temperature at 50.9°C with an initial temperature of 32.4°C. After getting the two temperature values, the next step is to determine the mathematical model of the system. The mathematical form of the first-order system consists of gain and constant time (T), after calculations, it is found that the system gain and system constant time are 0.072 and 191 seconds.

b. Tuning Testing on MATLAB

After knowing the system gain and system constant time, the next step is to do tuning through MATLAB software by entering in the program Open Loop system response graph will appear. The system response can be seen in Figure 10.

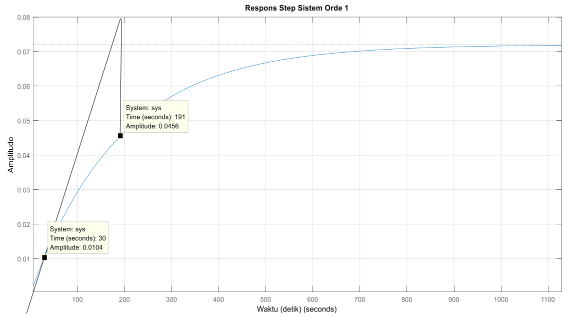

Figure 10. Tuning Testing on MATLAB

Based on Figure 10, the value of T (Time Constant) = 191 seconds while the value of L (Delay Time) = 30. After getting these two values, the next step is to tune the PID parameters by referring to Table 1.

Based on the calculations in Table 1, the proportional constant Kp = 7.64, the integral constant Ki = 0.1273, and the derivative constant Kd = 114.6 are obtained. These values will be tested by entering them into the Arduino program as PID control parameters.

c. PID Initial Parameter Testing

This test is a test conducted to see the temperature response of the dryer in an empty state without a helmet using the initial parameters of the Ziegler-Nichols tuning results. The test results of the initial PID tuning parameters can be seen in Figure 11.

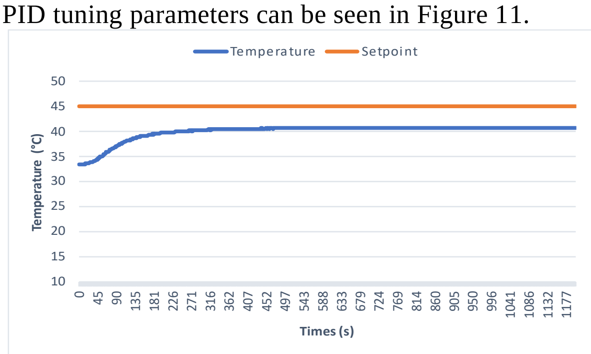

Figure 11. Initial Parameter Testing

Based on the initial tuning test results in Figure 11 with the Ziegler-Nichols PID method, it can be concluded that the temperature control system has shown stability in steady state without oscillation. However, the system is still not optimal because there is a steady state error of 4.2°C, which causes the temperature to not reach the desired setpoint. Therefore, further adjustments to the PID parameters are needed to reduce the steady state error and improve the accuracy of the system in achieving the target temperature.

d. Fine Tuning Testing

1. Variation of Kp Value

Parameter value Kp that will be done testing amounted to 3 values of 75,100, and 125. For the value of Ki = 0,1273 and Kd = 114,6 based on previous testing. The results of the system response graph can be seen in Figures 12.

Figure 12. Fine Tuning Kp Value

Based on Figure 12, the system with a proportional value of 75 exhibits a 0% overshoot, a steady-state error of 1.5°C, and a rise time of 125 seconds. Increasing the proportional value to 100 reduces the steady-state error to 1.1°C and shortens the rise time to 112 seconds, while maintaining a 0% overshoot. Further increasing the proportional value to 125 decreases the steady-state error to 0.9°C and the rise time to 107 seconds, still with 0% overshoot.

Based on the three Figures 12, it can be concluded that the system with Kp=100 value is the best proportional parameter value. It can be seen that when the value of Kp = 100 the system has a rise time of 107 seconds, faster than when the proportional values are 75 and 125. The system also looks more stable because it does not oscillate excessively compared to when the value of Kp = 125, although the steady state error is higher at 1.1°C.

2. Variation of Ki Value

In testing the Ki value this time, there are 3 Ki values that will be tested, namely 0.5, 0.75, and 1. For the value of Kp = 100 and Kd = 114,6 based on previous testing. The system response results can be seen in Figures 13.

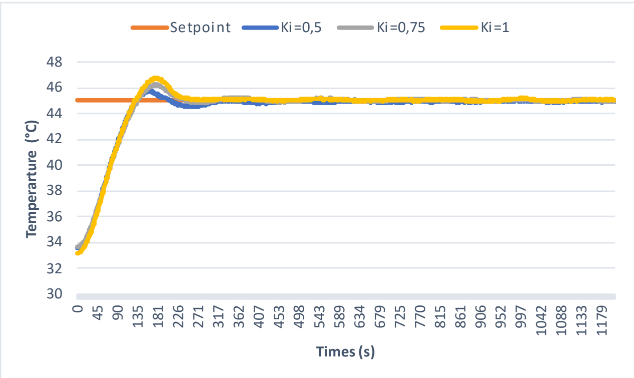

Figure 13. Fine Tuning Ki Value

Based on Figure 13, the system with an integral value of 0.5 exhibits an overshoot of 1.7%, an undershoot of 1.1%, a steady-state error of 0.1°C, and a rise time of 89 seconds. Increasing the integral value to 0.75 results in a higher overshoot of 2.8%, a reduced undershoot of 0.4%, a steady-state error of 0°C, and a slightly longer rise time of 92 seconds. Further increasing the integral value to 1 leads to an overshoot of 3.7%, undershoot 0%, a steady-state error of 0°C, and a rise time of 88 seconds.

Based on the Figures 13, it can be concluded that the best Ki value is Ki = 1, the Ki value produces a stable system response with a steady state error of 0 ° C, which means that the system is already in a stable state with a faster rise time than the results of testing Ki values with values of 0.5 and 0.75. The Ki = 1 value can be used as a reference for further testing, although overshoot can be fairly high at 3.7% with a better undershoot of 0%.

3. Variation of Kd Value

In testing the Kd value this time, there are 3 Kd values that will be tested, namely 50, 75, and 114.6. For the value of Kp = 100 and Ki = 1 based on previous testing. The system response results can be seen in Figures 14.

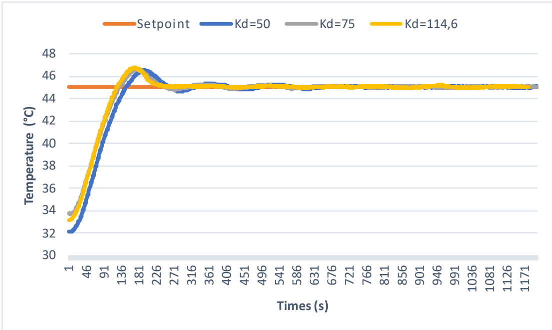

Figure 14. Fine Tuning Kd Value

Based on Figure 14, the system with a derivative value of 50 exhibits an overshoot of 3.5%, an undershoot of 0.8%, a steady-state error of 0°C, a rise time of 102 seconds, and a settling time of 427 seconds. Increasing the derivative value to 75 results in a slightly higher overshoot of 3.7%, a reduced undershoot of 0.6%, a steady-state error of 0°C, a shorter rise time of 90 seconds, and a settling time of 320 seconds. Further increasing the derivative value to 114.6 maintains the overshoot at 3.7% and eliminates undershoot, with a steady-state error of 0°C, a rise time of 88 seconds, and a settling time of 254 seconds.

Based on the Figures 14, it can be concluded that the best Kd value is the Kd = 114.6 value, the Kd value produces a stable system response with a steady state error of 0 ° C, which means that the system is already in a stable state with a faster rise time than the results of testing the Kd value with a value of 50 and 75, and the system stabilizes at setpoint (Settling Time) in 254 seconds faster than the 2 Kd values that have been tested. The value of Kd = 114.6 can be used as a reference for further testing, although overshoot can be fairly high at 3.7% with 0% undershoot.

Based on the fine tuning test, it is found that the best value for each parameter is Kp=100, Ki=1, and Kd=114.6. These values can be used as parameter values for further testing by entering these values in the Arduino program to control the helmet dryer system with PID temperature control.

Helmet Drying Testing

This test is a system test to dry a helmet that is wet to see how the system responds with PID control. The target humidity achieved is between 35%-40%, where when the humidity of a helmet ranges at that number the helmet is declared dry. The set*point* is 45°C.

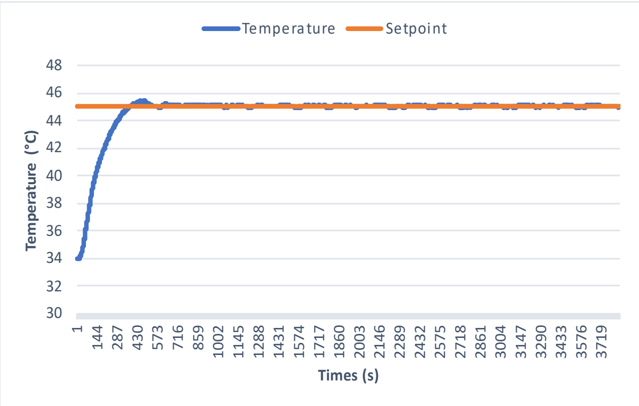

Figure 15. Temperature Response

Based on figure 15, the drying of the helmet starts with an initial temperature of 34°C and lasts for 68 minutes until the temperature reaches stability at the setpoint of 45°C. At the end of the process, the helmet's humidity level is 38.9%, indicating that the helmet has reached a dry state. System showed stable and accurate performance with good response parameters. Overshoot was recorded at 1.1%, the steady state error was recorded at 0°C, the rise time was 246 seconds, and the settling time, reached at 561 seconds.

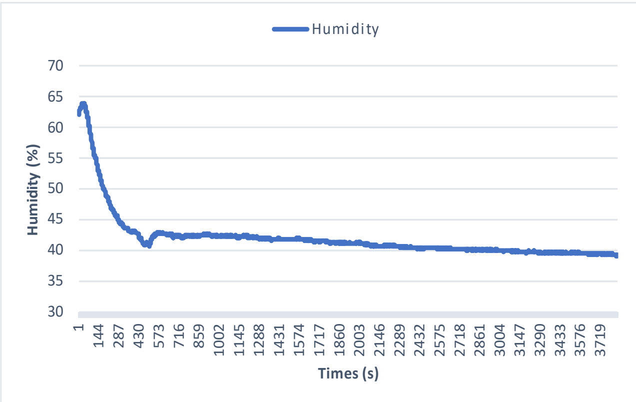

Figure 16. Humidity Response

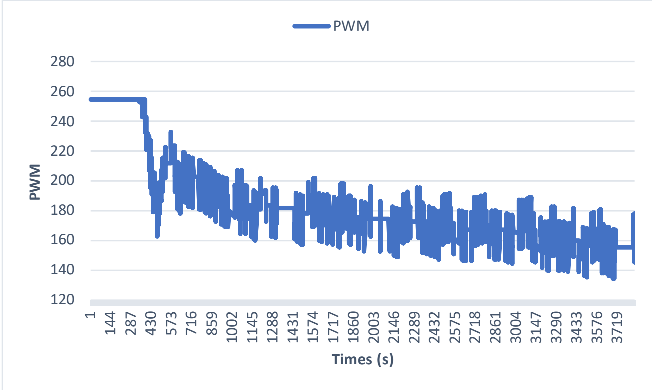

Figure 17. PWM Response

Based on Figure 16, the initial humidity of the helmet when the drying process began was 62.1%. As the drying process progressed, the system managed to reduce the humidity to 38.9%. This figure is already within the humidity range of a helmet in a dry condition.

Based on Figure 17, the graph shows the change in PWM value during the drying process. At the beginning of the process, the PID controller provides a maximum output of 255 until the temperature reaches the desired setpoint of 45°C. After the temperature approaches the setpoint, the PWM value slowly decreases, controlled by the PID controller to keep the temperature stable. During the drying process, the PWM value tends to stabilize within the range of 155 to 178, aiming to maintain the temperature at the setpoint.

V. CONCLUSION

Based on the research that has been conducted, it can be concluded that:

a. The design and manufacture of a PID-based temperature control system on a helmet dryer is made in a dryer box with dimensions of 47 cm long, 40 cm wide, and 45 cm high. the box where the components are placed on top of the dryer box. The components used include Arduino Uno, DHT22 sensor, LM2596 module, heating element, blower fan, D4184 MOSFET module, BTS7960 module, and other supporting components. The placement of the heating element is under the drying box so that hot air can spread, while the blower fan is placed on the right and left of the drying box. This tool works automatically to dry a helmet with PID-based temperature control so that the temperature can stabilize at the setpoint.

b. Testing the PID-based temperature control system on the helmet dryer is done by tuning the parameters using the Ziegler-Nichols method. The initial tuning results resulted in Kp = 7.64, Ki = 0.1273, and Kd = 114.6, but the system still has a steady state error of 4.2°C. After fine tuning, the best parameters Kp=100, Ki=1, and Kd=114.6 were obtained, which provided better performance with 3.7% overshoot, 0°C steady state error, 88 seconds rise time, and 254 seconds settling time. Drying helmet takes 68 minutes with a final humidity of 38.9%, and the system response was overshoot of 1.1%, steady state error of 0°C, rise time of 246 seconds, and settling time of 561 seconds.

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