1. Introduction

The increase in global temperature makes people need additional tools to get suitable thermal conditions [1]. With the increase of global temperature, the controlling temperature is needed which aims to design a system and control the temperature according to the desired temperature using a 1st order system which has been widely used in system settings [2]. This is due to the temperature control having transient response characteristics of 1st order, these characteristics consist of time constant (τ), rise time (τr), settling time (ts), and delay time (td). The difference between 1st order and 2nd order is that the response of 2nd order doesn’t have a time constant [3].

In addition, a PI controller with pole placement stability analysis is employed to stabilize the system model. PI controller has characteristics such as reducing rise time, increasing overshoot, descending time, and eliminating steady-state error. If the system already gives a good response to increase or reach the desired signal using only the PI controller, there is no need to add a derivative (D) controller. So, the PI controller is simpler and only has $K_p$ gain and $K_i$ gain values. The steady state error can’t be eliminated if the $K_p$ gain is greater than the $K_i$ gain [4]. The use of pole placement analysis on temperature control is to observe the stability of the output response system [5].

Ziegler-Nichols method is one example of a traditional method to determine gain for the system. However, the result of this method was made the overshoot high and made the tuning result bad. To increase the performance and make less overshoot from the system, PI tuning using PI-Tuner can help to determine the gain with auto computing and this method will help to get the optimum result.

The output for this paper is comparing the resulting temperature controlling using PI between tuning gain with the Ziegler-Nichols method and PI-Tuner. The result was expected to see the effectiveness and stability from the system with these two methods.
2. Modelling

A. Temperature Modeling using First Order Plus Dead Time (FOPDT)

This experiment utilized a first-order system to determine the transfer function of system model. The mathematical model of system in this study is represented by (1).

\[
\frac{T(s)}{U(s)} = \frac{K}{\tau s + 1} e^{-tds}
\]  

(1)

\[\text{Figure 1. Block diagram of FOPDT}\]

\(K\) is a gain value, \(\tau\) is time delay, and \(td\) is time constant [4]. The block diagram for determining the parameter of the transfer function can be seen in Fig. 1. The method for finding the gain \(K\) can be obtained by (2).

\[
K = \frac{T_{SS} - T_0}{\Delta u}
\]

(2)

Meanwhile, to find \(\tau\), it is necessary to know the temperature value at \(T_\tau\) which is obtained using (3).

\[
T_\tau = \frac{63.2}{100} (T_{SS} - T_0) + T_0
\]

(3)

Thus, a temperature \(T_\tau\) is obtained when temperature point is determined through curve model. Then, time at the current point \(T_\tau\) can be determined. The predetermined time based on the temperature \(T_\tau\) is \(\tau\) value.

3. Method

MATLAB/Simulink is used as the main supporting software in modeling this temperature in regulation system. There are several methods used to adjust the temperature namely duty ratio and determining the gain. Then, this model is implemented directly using hardware in Arduino and used to develop a temperature control tool.

A. Temperature Checking

The adjustment of the modeling temperature is conducted by checking the real temperature surrounds, one example is the real temperature in the room. The real temperature is checked using DHT11 on Arduino UNO. So, the ambient temperature can reach as of 31.40\(^\circ\)C where it can be seen in Fig. 2.

\[\text{Figure 2. Temperature checking with DHT11}\]

B. LM35 Calibration

In this temperature modeling, the sensor for temperature control is LM35. The real room temperature obtained previously is used to obtain the gain value which will be used for temperature conversion. The software circuit and the Simulink block diagram circuit of the LM35 calibration are shown in Fig. 3.
Figure 3. *Software* circuit LM35

From Fig. 4, the voltage obtained when calibrating LM35 is 62mV as shown in Fig. 5

So, based on Fig. 5, the results of gain calibration are obtained by (4).

\[ K_{LM35} = \frac{\text{Real Temperature}}{\text{Calibrate Voltage}} \]  
\[ K_{LM35} = \frac{31.40}{62mV} \]  
\[ K_{LM35} = 0.506 \, ^\circ C/mV \]

C. *Duty Ratio*

The use of duty ratio is carried out as a measure of the maximum temperature released by the power resistor as measured by the LM35 sensor. The temperature measurement is done by designing a block diagram on Simulink as shown Fig. 6.
D. Gain Determination

D.1. Ziegler-Nichols

Ziegler-Nichols method is the conventional method to get the gain. The $K_P$ and the $K_I$ will get from the calculation which needs some information. The time constant ($\tau$) and delay time ($td$) was needed to get the calculation of $K_P$ and $K_I$. The $K_I$ value can get from the calculation between $K_P$ and $T_I$.

D.2. PI Tuner

In determining the PI gain values, the method used is PI tuner. This method simplifies modeling with $K_P$ and $K_I$ values that have been automatically calculated by the computer. This PI tuner is also used to refine the results obtained in real-time testing. The following is an adjustment of the gain settings using the PI tuner to obtain a fast rise time but less overshoot.

4. Results

MATLAB/SIMULINK is the environment to support this experiment and the system is using first order plus dead time (FOPDT) for temperature control. A modification was made to the system by using the PI controller in Fig 7.

A. Gain Determination

A.1. Ziegler-Nichols

In this section, a sample is taken that implements the gain from setting from Ziegler-Nichols method to temperature control to 60°C. The following is a graph of the results of temperature control for 60°C while the time constant was known using the $K_P$ and $K_I$ that has been determined by calculation in (5).
Table 1. ZN Method Gain

| Control | $K_P$ | $T_i$ |
|---------|-------|-------|
| PI      | $L \frac{0.9}{L}$ | $\frac{L}{0.3}$ |
|         | $0.9 \frac{481}{40}$ | $\frac{40}{0.3}$ |
|         | $10.8225$ | $133.33$ |

Then the $K_I$ can get from the calculation between $K_P$ and $T_i$.

$$K_I = \frac{K_P}{T_i} \tag{5}$$

$$K_I = 0.08117$$

The following is a graph of the results of temperature control for 60°C using the $K_I$ and $K_P$ that has been determined is shown in Fig. 8.

![Figure 8. Temperature control using Ziegler-Nichols method](image)

Based on the graph on the implementation, the peak value and the temperature value are not steady with overshoot is 81.73°C.

A.2. PI tuner

The use of the PI controller was assisted by computing automatically on SIMULINK while there is a PI tuner feature to improve the output signal and reduce the overshoot obtained from the experiment. The results of tuning using the PI tuner, the $K_I$ value is 0.00072231 and the $K_P$ is 0.36095. In this section, a sample is taken that implements the gain from setting via the PI tuner to reach 50°C. The following is a graph of the results of temperature control for 50°C using the $K_I$ and $K_P$ that has been determined.

![Figure 9. Temperature control](image)

Based on the graph on the implementation, the peak value and the temperature value are not steady with overshoot is 50.64°C.
B. Comparison of Experiment and Simulation

B.1. Zigler-Nichols

The following chart is a comparison of the between simulation and experiment for temperature control of 60° Celsius.

![Figure 10. Comparison Graph of Experiment with Simulation](image)

Based on the results obtained for controlling the temperature of 60° C, it is possible to find the amount of overshoot and the steady state error as follows.

$$Overshoot = \frac{Overshoot\ Temp - Reference\ Temp}{Reference\ Temp} \times 100\%$$  \hspace{1cm} (6)

$$Overshoot = \frac{77.99 - 60}{60} \times 100\%$$

$$Overshoot = 29.98\%$$

Then the following is the calculation of the obtained SSE value

$$SSE = \frac{SSE\ Temp - Reference\ Temp}{Reference\ Temp} \times 100\%$$  \hspace{1cm} (7)

$$SSE = \frac{60.9 - 60}{60} \times 100\%$$

$$SSE = 1.5\%$$

B.2. PI Tuner

The following chart is a comparison of the between simulation and experiment for temperature control of 50° Celsius.

![Figure 11. Comparison graph of experiment and Simulation](image)

Based on the results obtained for controlling the temperature of 50° C, it is possible to find the amount of overshoot and also the steady state error as follows.
\[ \text{Overshoot} = \frac{\text{Overshoot Temp} - \text{Reference Temp}}{\text{Reference Temp}} \times 100\% \]
\[ \text{Overshoot} = \frac{50.64 - 50}{50} \times 100\% \]
\[ \text{Overshoot} = 1.28\% \]

Then the following is the calculation of the obtained SSE value
\[ \text{SSE} = \frac{\text{SSE Temp} - \text{Reference Temp}}{\text{Reference Temp}} \times 100\% \]
\[ \text{SSE} = \frac{50.13 - 50}{50} \times 100\% \]
\[ \text{SSE} = 0.26\% \]

C. Determine The Effective Method

The determining the effective method can be easily with those calculation and experiment before. The aim for this experiment is to see the less overshoot and SSE between Ziegler-Nichols method and PI tuner to determine the more effective method. If we look at the calculation and the experiment before, PI tuner more effective with less overshoot and less Steady State Error.

D. Pole Placement Stability Analysis

Based on the modelling of the design results on temperature modelling using first order plus dead time (FOPDT), the results obtained on FOPDT are as follows.

\[ \frac{T(s)}{U(s)} = \frac{1.57}{481s + 1} e^{-40s} \]

Figure 12. Calculation FOPDT

So based on the value above, it is possible to find the positions of the poles and zeros in this system. The following are the positions of the poles and zeros in this system which can be found using the following equation.

\[ \frac{T(s)}{U(s)} = \frac{\text{Zeros}}{\text{Poles}} e^{-tds} \quad (10) \]

so,

- Poles
  \[ 481s + 1 = 0 \]
  \[ 481s = -1 \]
  \[ s = -\frac{1}{481} \]
  \[ s = -0.00207 \]

- Zeros
  
  \[ \text{None} \]
Thus obtained the position of the poles on the real axis at the point -0.00207 and zeros that do not exist, this is due to the absence of $s$ in the zero’s equation. Therefore, the system can be said to be stable. This is based on the absence of the poles on the right side of the Cartesian diagram, and the poles on the left side of the real and imaginary axes. So there are no poles on the right side.

![Figure 13. Cartesian Poles and Zeros Diagram](image)

5. Conclusions

This paper focuses on the implementation of temperature control modeling using the PI controller with stability analysis by pole placement. Based on the results of the experimental and simulation figures obtained, it can be concluded that there is a difference between the experiment and the simulation. Where the difference is shown in the rise time, steady-state error, and overshoot. In the simulation the results look ideal, this is because the simulation does not care about external interference, while in the real experiment many external disturbances cause noise to appear in the resulting signal. Determining gain with PI tuner is more effective than determining gain with Ziegler Nichols method with more less overshoot and steady state error. The resulting overshoot from Ziegler-Nichols is 29.98% and the Steady State Error is 1.5 % while overshoot from PI tuner is 1.28% and the steady-state error is 0.26%. Control using a PI controller is proven stable. This can be seen from the poles position which is to the left of the real axis on the cartesian diagram and the small overshoot and steady state error value.

References

[1] D. T. W. S. M. Muhammad Nuruzzaman Alkautsar, "The Effect of Air Temperature and Room Humidity with Air Conditioning on Subjective Response and Thermal Comfort In Men," 2015. [Online]. Available: [http://etd.repository.ugm.ac.id/penelitian/detail/82236](http://etd.repository.ugm.ac.id/penelitian/detail/82236). [Accessed 05 Juli 2022].

[2] F. F. Ardiansyah, "First-order system is a system in which the denominator of the transfer function has the highest rank equal to one," [Online]. Available: [https://id.scribd.com/doc/312900076/Sistem-Orde-Satu-Adalah-Sistem-Dimana-Penyebut-Fungsi-Alihnya-Memiliki-Pangkat-Tertinggi-Sama-Dengan-Satu#:~:text=Sistem%20orde%20satu%20adalah%20sistem%20dimana%20penyebut,fungsi%20alihnya%20memiliki%20pangkat%20terti](https://id.scribd.com/doc/312900076/Sistem-Orde-Satu-Adalah-Sistem-Dimana-Penyebut-Fungsi-Alihnya-Memiliki-Pangkat-Tertinggi-Sama-Dengan-Satu#:~:text=Sistem%20orde%20satu%20adalah%20sistem%20dimana%20penyebut,fungsi%20alihnya%20memiliki%20pangkat%20terti). [Accessed 05 Juli 2022].

[3] F. Arifin, "Time Response and Frequency Response," Faculty of Engineering, Yogyakarta State University, Yogyakarta, 2015.

[4] I. Z. T. Dewi, "PID Controller (Proportional Integral Derivative Controller)," 23 February 2020. [Online]. Available: [https://imeldaazahraa.medium.com/kontrol-pid-proportional-integral-derivative-controller-c173086724af](https://imeldaazahraa.medium.com/kontrol-pid-proportional-integral-derivative-controller-c173086724af). [Accessed 3 Juli 2022].

[5] M. Dr. Fatchul Arifin, "System Stability Analysis," Faculty of Engineering, Yogyakarta State University, Yogyakarta, 2014.
[6] M. P. R.G. Kanojiya, “Tuning of PID controller using Ziegler-Nichols method for speed control of DC motor,” IEEE-International Conference on Advances in Engineering, Science and Management, ICAESM-2012. 117-122, 2012

[7] Yucelen . T, “Self-Tuning PID Controller using Ziegler-Nichols Method for Programmable Logic Controllers”. IFAC Proceedings Volumes. 39. 11-16. 10.3182/20060830-2-SF-4903.00003, 2006

[8] K. H. A. G. C. y. C. Yun Li, "PID Control System Analysis and Design." IEEE control systems, 2006.

[9] Patra. Ashis, “Application of Ziegler-Nichols Method For Tuning the PID Controller”. 2018

[10] M. a. C. S. a. B. P. a. V. D. Huba, "Making the PI and PID Controller Tuning Inspired by Ziegler and Nichols Precise and Reliable," Sensors, vol. 21, no. 10.3390/s21186157, p. 6157, 2021.

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