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TEMPERATURE CONTROL USING PI CONTROLLER

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Abstract
Indonesia is a large archipelago with a tropical climate consisting of dry and wet seasons. Indonesia has had high rainfall and temperature over the year because this country lies on the equator lines. Moreover, severe global warming occurs because of the depletion of the ozone which affects the inclement weather, air, and temperature over the years. Therefore, special equipment is required to obtain appropriate thermal conditions by controlling the temperature. This paper proposed the PI controller to maintain the temperature in their nominal values and its temperature stability is analyzed using pole placement. In this study, the system model is 1st order, called first order plus dead time (FOPDT). Pole placement is utilized to improve the output signal to obtain the gain of the PI controller. The gain of the PI controller obtained is K_p as of 0.36095 and K_i is as of 0.00072231. The percentages of overshoot and steady-state error are 29.98% and 1.5% for the Ziegler Nichols method while 1.28% and 0.26% for the PI Tuner, respectively. PI controller is robust for this system where the pole's position is on the left side of the real axis and has small values of overshoot and steady-state error.

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Keywords:
Temperature; PI; Pole Placement stability; Tools; Thermal Conditions.

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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 (t_s), and delay time (t_d). 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 tunning result bad. To increase the performance and make less overshoot from the system, PI tunning 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 tunning 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).

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

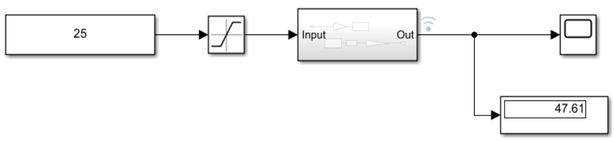

Figure 1. Block diagram of FOPDT

K is a gain value, τ 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).

$$K = \frac{T_{SS} - T_0}{\Delta u} \quad (2)$$

Meanwhile, to find τ, it is necessary to know the temperature value at T_τ which is obtained using (3).

$$T_\tau = \frac{63.2}{100}(T_{SS} - T_0) + T_0 \quad (3)$$

Thus, a temperature T_τ is obtained when temperature point is determined through curve model. Then, time at the current point T_τ can be determined. The predetermined time based on the temperature T_τ is τ 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° where it can be seen in Fig. 2.

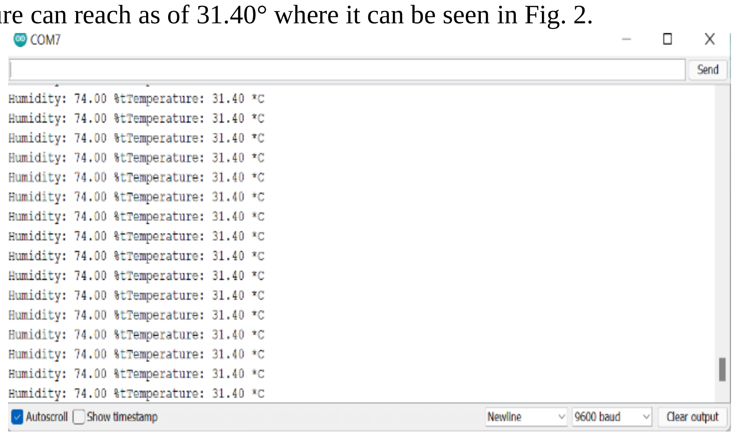

Figure 2. Temperature checking with DHT11

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.

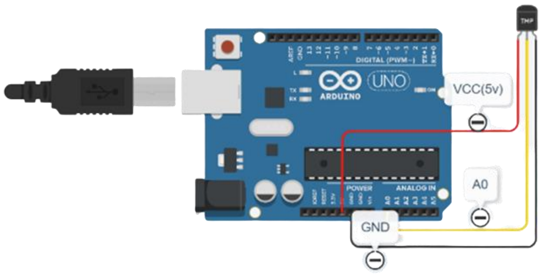

Figure 3. *Software* circuit LM35

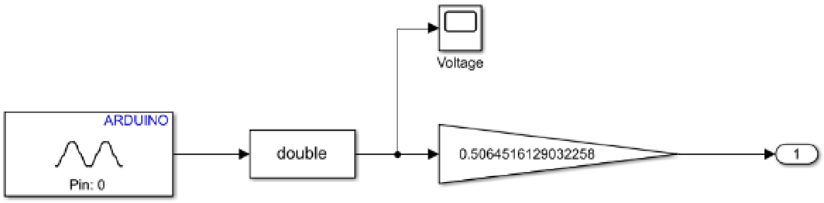

Figure 4 Block diagram of LM35

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

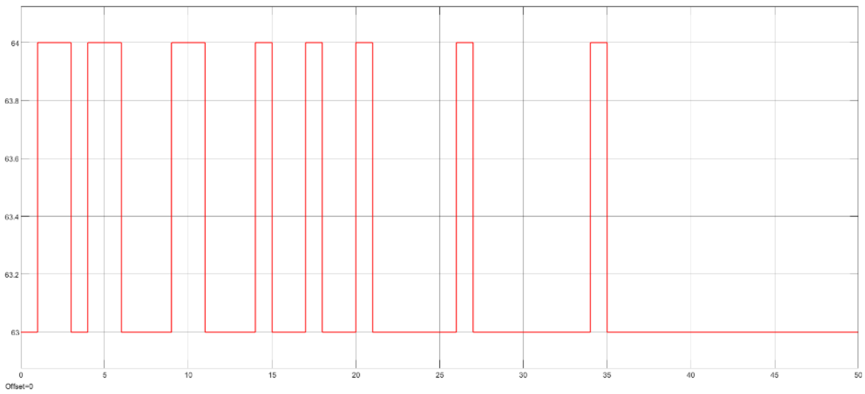

Figure 5. Output voltage of LM35

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

$$K_{LM35} = \frac{Real\ Temperature}{Calibrate\ Voltage} \tag{4}$$

$$K_{LM35} = \frac{31.40}{62mV}$$

$$K_{LM35} = 0.506\ ℃/mV$$

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.

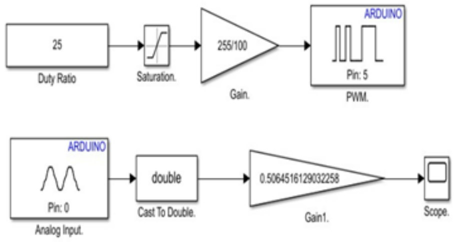

Figure 6. Block diagram using duty ratio in MATLAB/Simulink

The saturation given in the block diagram above is the highest voltage value from the power supply. In this design, the power supply has a maximum voltage of 12 V DC.

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 (τ) 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.

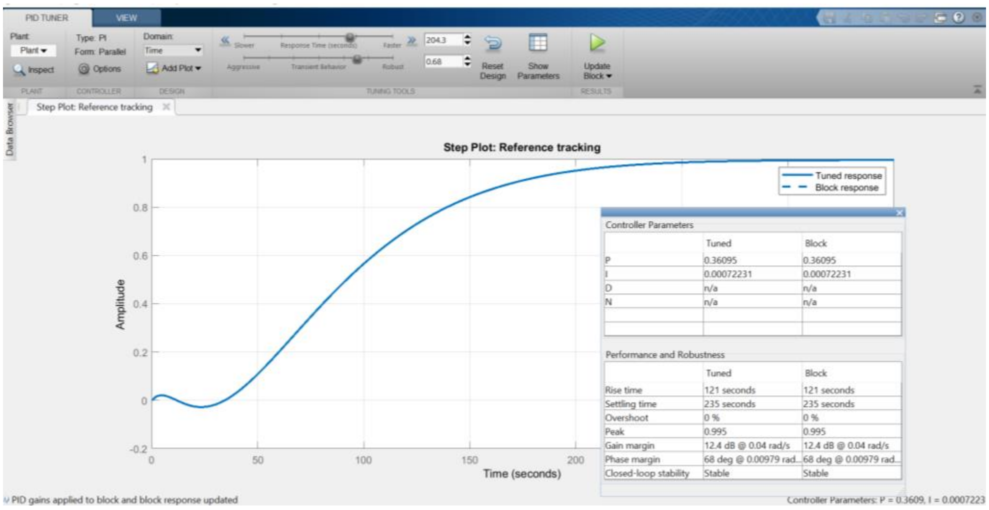

Figure 7. PI tuner gain determination

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 *Kp* and K_I that has been determined by calculation in (5).

Table 1. ZN Method Gain

Control	K_P	Ti
PI	$= 0.9\frac{T}{L}$ $= 0.9\frac{481}{40}$ $= 10.8225$	$= \frac{L}{0.3}$ $= \frac{40}{0.3}$ $= 133.33$

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

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

$$K_I = 0{,}08117$$

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.

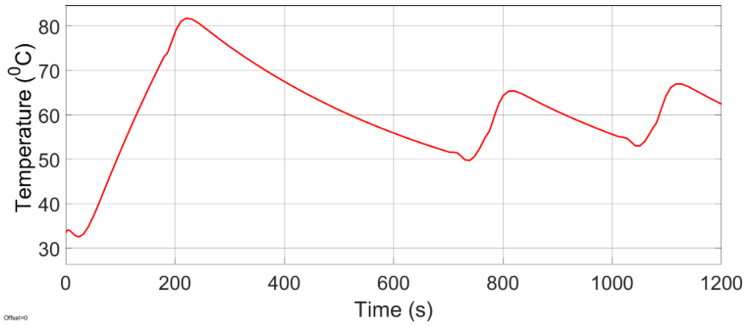

Figure 8. Temperature control using *Ziegler-Nichols* method

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.

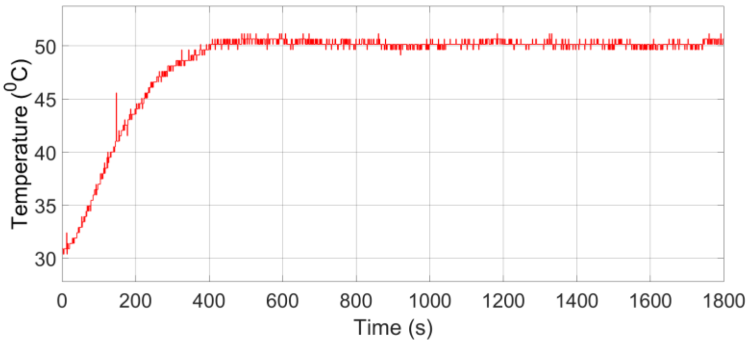

Figure 9. Temperature control

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.

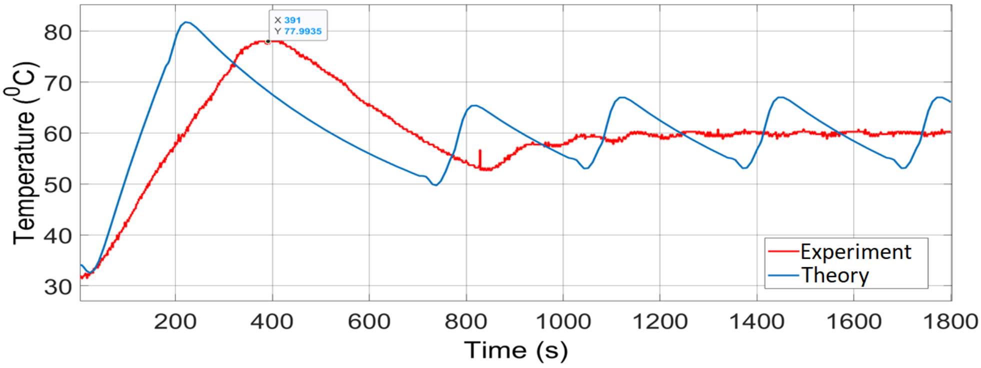

Figure 10. Comparison Graph of Experiment with Simulation

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.

$$Overshoot = \frac{Overshoot\ Temp - Reference\ Temp}{Reference\ Temp}\ x\ 100\% \qquad (6)$$

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

$$Overshoot = 29.98\ \%$$

Then the following is the calculation of the obtained SSE value

$$SSE = \frac{SSE\ Temp - Reference\ Temp}{Reference\ Temp}\ x\ 100\% \qquad (7)$$

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

$$SSE = 1.5\ \%$$

B.2. PI Tuner

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

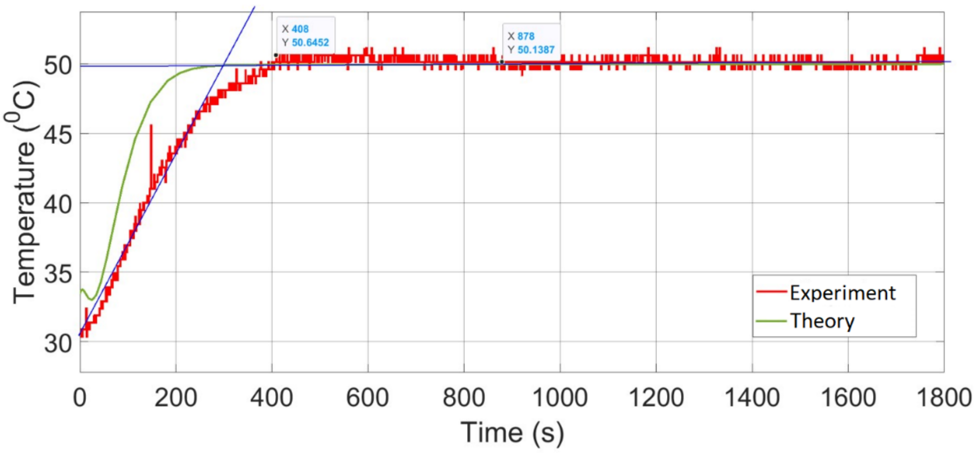

Figure 11. Comparison graph of experiment and Simulation

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.

$$Overshoot = \frac{Overshoot\ Temp - Reference\ Temp}{Reference\ Temp}\ x\ 100\%$$

$$Overshoot = \frac{50.64 - 50}{50}\ x\ 100\%$$

$$Overshoot = 1.28\ \%$$

Then the following is the calculation of the obtained SSE value

$$SSE = \frac{SSE\ Temp - Reference\ Temp}{Reference\ Temp}\ x\ 100\%$$

$$SSE = \frac{50.13 - 50}{50}\ x\ 100\%$$

$$SSE = 0.26\ \%$$

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.

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

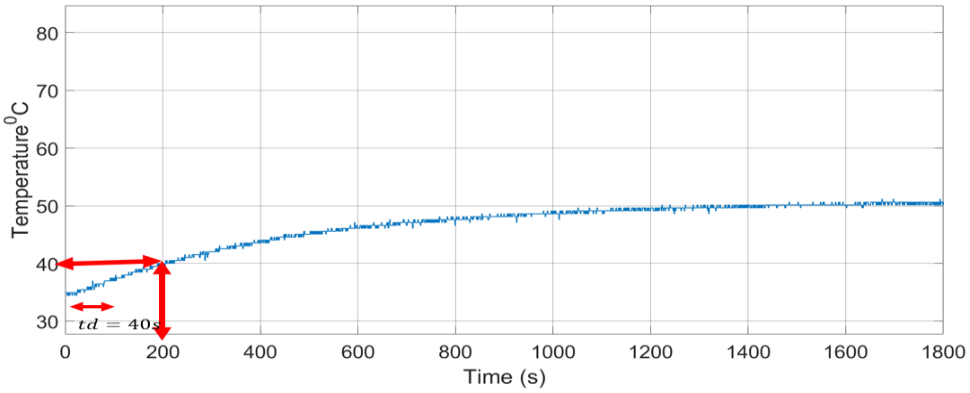

Figure 12. Calculation FOPDT

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.

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

so,

- Poles

$$481s + 1 = 0$$

$$481s = -1$$

$$s = -\frac{1}{481}$$

$$s = -0.00207$$

- Zeros

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

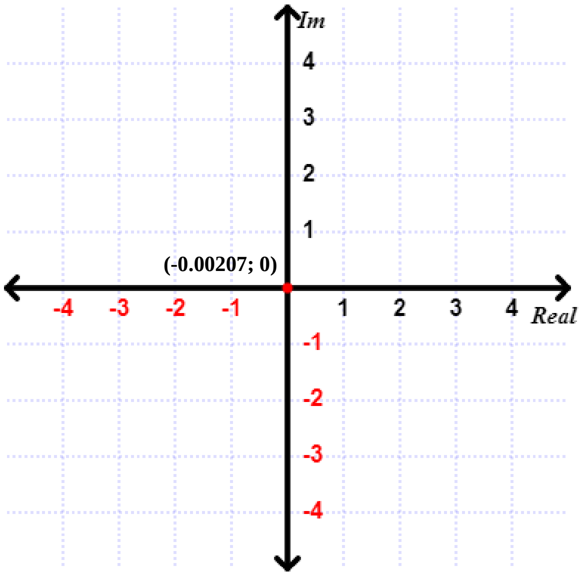

Figure 13. Cartesian Poles and Zeros Diagram

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.

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