Design of PID Disturbance Observer for Temperature Control on Room Heating System

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***Abstract*— Heat is one of an energy form that can move from a high temperature to a low temperature. This will strongly make the temperature outside of the room affect the temperature in the room. Therefore, the temperature in the room becomes unstable. That is a problem for room heating system which requires a stable indoor temperature output. Because of that reason, so the system needs temperature control method that can reject disturbance that derived from the outdoor temperature. This research will propose a solution that is the use of PID Disturbance Observer (PID-DOB) method for resolving that problem. The tests that we carried out is comparing the PID controller and PID-DOB by simulation with four variation temperature and calculating the performance index by using integral time absolute error (ITAE) criteria. The result showed that the ITAE average for PID is 10.51 and PID-DOB are 1.78. This result showed that PID-DOB controller can be used as temperature control which resists to the varied temperature outside the room.**

Keywords*— *PID, PID Disturbance Observer, Room Heating System, Temperature Control

I. INTRODUCTION

The temperature in the room will tend to be affected by outside temperature. If the temperature outside is colder than inside temperature, then temperature inside the room will tend to be colder, likewise contrarily. This is caused by heat characteristic, that is heat always move from high-temperature object to lower temperature object. When the temperature on outside colder than inside the room, then the heat which inside the room will move to outside. This kind moving heat are known as convection and conduction [1]. Therefore, if the temperature outside the room is unstable, then this will make the temperature inside the room become unstable too. That is make the temperature from the outside will become a disturbance towards a heating system.

This problem often occurs in the breeding of plants in the green house [2]. In green house, plants are conditioned at a certain temperature. One of the case is the temperature problem of mushroom nursery [3]. There are some mushrooms that have a specific room temperature in its growth. This temperature must be stable at a certain value. Researchers have tried to create a fuzzy control to maintain the temperature [4]. But the results indicate that the controller that has been created, has not be able to reject the outside air temperature interference. Another example is the temperature problem in the water bath system. This system is usually used in industry or laboratory. In a study [5], researcher also used fuzzy to regulate the temperature of the system. The absolute error that generated by this controller is still very large.

On the other research [6], researcher tried to use simple method, which is PID method to maintain temperature inside a CPU. PID method has been used to reduce CPU temperature in order to match it with the temperature setting which desired. The result showed that CPU temperature can drop close to the temperature setting that researcher's desire, but this temperature still can't stable. The problem of instability because external disturbance has been investigated in research on DC Motor [7]. The plant is given an external disturbance which is increased load on motor axis. Researcher used the disturbance observer method to reject the external disturbance that occurred at DC Motor. The result showed that disturbance observer method can compensate the disturbance that coming from outside of plant – in this case, come from load changes on motor axis.

In this research, the researcher has an idea by using this PID-DOB method, to solving external disturbance on room heating system. This PID-DOB method is tested on a room heating system using Simulink MATLAB R2014a. There are several steps that must be passed on this research. They are room heating system modeling, disturbance design, PID-DOB design, and PID-DOB testing.

II. METHOD

A. Room Heating System Modelling

In the simulation testing of a controller using Simulink MATLAB R2014a, the first thing to make is a mathematic model of the plant. Therefore, in this research, we will first make a mathematical model of room heating system. In a room heating system, there is three main components, specifically are a heater, temperature sensor and room [8]. The relation between all three of them can be seen in Figure 1

Figure 1 shown workflow of the heater when heat up the room temperature. Air from the inside of room being absorbed into a pipeline. After that, the air will flow through the heater. The air that has been heated, will flow back to the room.

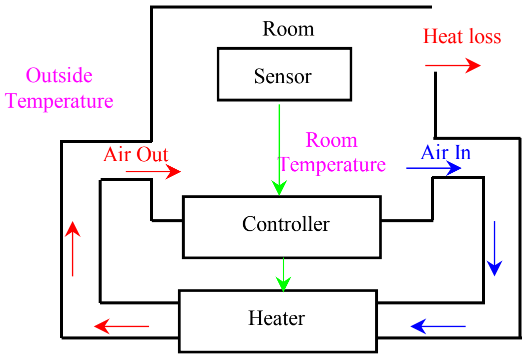

Fig. 1. Room Heating System

There are several things that important to know in create mathematic model for room heating system. They are a room thermal characteristic, a heater thermal characteristic, temperature control, temperature outside the room, and temperature inside the room. From five-point that affects a room heating system, we can conclude that there are four variables which corresponds. They are thermal energy which comes from heater to the room (Q_{gain}), thermal energy which comes from room to the surroundings (Q_{loss}), room temperature (T_{room}), and temperature outside of the room(T_{out}). If the heater is turned on until reaching the certain temperature i.e T_{heater}, and initial room temperature i.e T_{room}, then the increase of thermal energy that flow by convection from the heater to the room (Q_{gain}) can we calculated by using (1).

$$Q_{gain} = m_{heater\ air} c_{air} (T_h - T_r) \qquad (1)$$

Where:

Q_{gain} = Thermal energy from heater to the room (J)

$m_{heater\ air}$ = Total air mass (Kg)

c_{air} = Heat capacity (J/kg °C) = 1005.4 J/kg °C

T_h = Heater temperature (°C)

T_r = Room temperature (°C)

From Figure 1, air that inside the room will absorb by a fan. Then that air flows through the heater and flows back to the room. The rapidity of thermal energy which comes from heater can we formulated in accordance to (2)

$$\frac{Q_{gain}}{d_t} = \frac{m_{heater\ air}}{dt} c_{air} (T_h - T_r) \qquad (2)$$

Because air mass per time that coming from heater always constant then (2) can we change into (3).

$$\frac{Q_{gain}}{d_t} = \dot{M}_{heater} c_{air} (T_h - T_r) \qquad (3)$$

Where:

$\dot{M}_{heater}$ = Constant rate of air mass passing through heater (kg/hour) = 3600 kg/hour

Room thermal energy which has obtained from the heater will reduce as big as Q_{loss}. This because heat transfer is by conduction through the room wall or window. The rate of thermal energy loss can formulate into (4).

$$\frac{Q_{loss}}{dt} = \frac{kA(T_r - T_{out})}{D} \qquad (4)$$

Where:

Q_{loss} = Thermal energy loss (Q_{loss}).

k = Thermal conductivity coefficient (W/m °C) =

A = Cross section area (m^2)

D = Wall thickness (m)

T_r = Room temperature (°C)

T_{out} = Temperature outside of the room (°C)

If seen in the (4), k, A, and D variable are constants. To simplify (4) then kA/D has to replaced with 1/R where R is heat resistant coefficient, so that (5) become simpler.

$$\frac{Q_{loss}}{dt} = \frac{(T_r - T_{out})}{R} \qquad (5)$$

Where:

R = heat resistant coefficient (hour °C/J) = 4.27×10^{-7} hour °C/J

To measure the rapidity of room temperature change, a heater to room thermal energy subtracted to thermal energy that loss from inside the room to surroundings. The rapidity of room temperature change value is formulated as in (6).

$$\frac{dT_r}{dt} = \frac{1}{m_{room\ air} c_{air}} \left(\frac{dQ_{gain}}{dt} - \frac{dQ_{loss}}{dt} \right) \qquad (6)$$

Where:

$m_{roomair}$ = mass of air in the room or heater (kg) = 1470 kg

B. Disturbance Design

To examine how effective this PID-DOB control will resistant to disturbance, so we need giving some disturbance to the room heating system. This research will use four model variation of outside temperature air. The model variation of outside temperature air is shown in Figure 2 up to Figure 5.

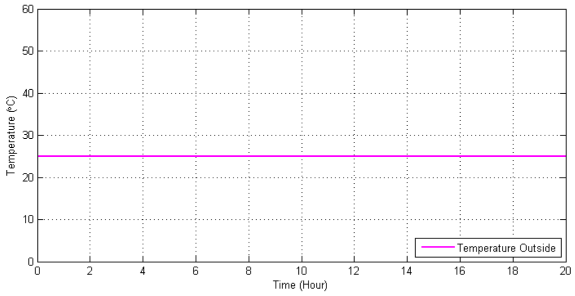

Fig. 2. Outside Temperature Air Model I

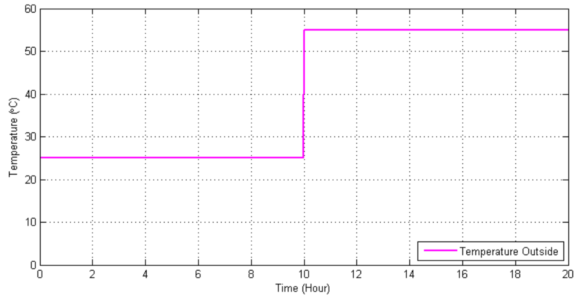

Fig. 3. Outside Temperature Air Model II

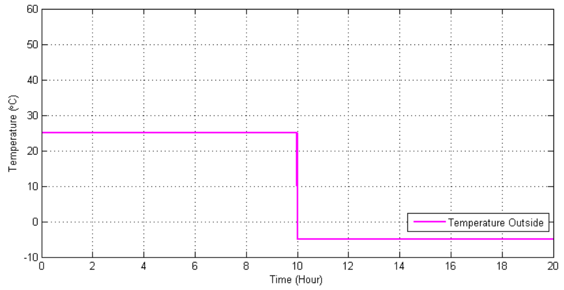

Fig. 4. Outside Temperature Air Model II

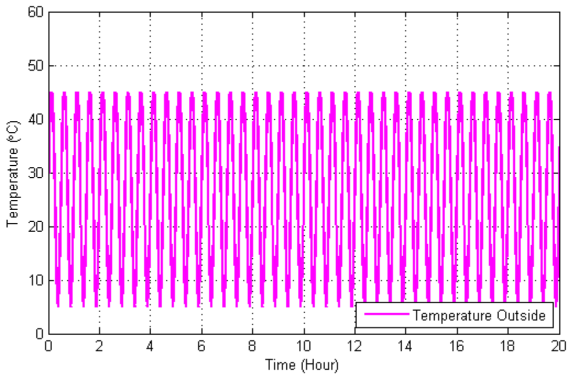

Fig. 5. Outside Temperature Air Model IV

Equation (4) shows that thermal energy will loss depend on the difference between room temperature and air temperature outside the room. The bigger the difference between this two variable, then the loss of thermal energy from that room will be bigger too. Because of that, by varying the temperature from the outside will give disturbance to room heating control system. On Figure 2, outside temperature air we made fixed on 25°C for 20 hours. While in Figure 3, on first 10 hours, the outside temperature air we made fixed on 25°C and after that the temperature will rise to 55°C for second 10 hours. On Figure 4, the outside temperature air we set on 25°C on first 10 hours, then we lowered the temperature to -5°C on second 10 hours. While on Figure 5, we raised the temperature to 45°C then lowered it to 5°C. This outside temperature changes will form a sine with the period value of temperature changes is 0.5 s or frequency value is 2 Hz. In this research, the four model variation of outside temperature air will be applied to PID controller and PID-DOB to observe the effectiveness of the two controllers to endure the disturbance in which because of outside temperature air. To understand the work index of two controllers, then we use ITAE criterion [9]. On ITAE criterion, timing element are into integration factor. So ITAE value will increases as time goes by. The value of ITAE is formulated to (7).

$$ITAE = \int_0^\infty t|e(t)|dt \tag{7}$$

where:

ITAE = integral time absolute error.
t = time (s)
e(t) = error time

C. PID-DOB Design

There are 3 steps that must be done to design PID-DOB. **First it starts with PID Design**. The utility of PID is to control temperature room to match with the reference temperature that we provided. In this research, reference temperature will be set to 40°C. Reference temperature will not be changing. Outside temperature air is same as the air temperature mode I where temperature air we made fixed on 25°C like shown in Figure 2. It is considered that the average of outside air is 25°C. Process of PID constants selection is done by choosing constants that makes room temperature equal to the reference temperature. From this step, the value of the constants is proportional constant is 10, the integral constant is 15, and the derivative constant is 1. **The second is inverse model of room heating system modelling.** According to (6), the rate of air room temperature is equivalent with difference between thermal energy that coming from the heater and thermal energy loss. If we defined (8) and (9),

$$N = \frac{1}{m_{room\ air} c_{air}} \tag{8}$$

$$W = \dot{M}_{heater} c_{air} \tag{9}$$

then (6) will become to (10).

$$\frac{dT_r}{dt} = N\left(\frac{dQ_{gain}}{dt} - \frac{dQ_{loss}}{dt}\right) \tag{10}$$

If (3) and (4) inserted into (10) then it will make a new equation. That is (12).

$$\frac{dT_r}{dt} = N\left(W(T_h - T_r) - \frac{(T_r - T_{out})}{R}\right)$$

$$T_h = \frac{1}{NW}\left(\frac{dT_r}{dt} + N\left(W + \frac{1}{R}\right)T_r - \frac{N}{R}\,T_{out}\right) \tag{11}$$

This (11) are the inverse model of room heating system equation. **The third is filter design**. This filter must be low pass filter. This low pass filter use for reject the external disturbance that come to the system [10]. The low pass filter is made by referring to (12).

$$\mathrm{Q(s)} = \frac{1+\sum_{k=1}^{N-r} a_k(\tau s)^k}{1+\sum_{k=1}^{N} a_k(\tau s)^k} \tag{12}$$

Where:

N = order of Q(s)
R = relative degree of Q(s)
τ = cutoff frequency parameter
a_k = coefficient Q(s)

The higher the order of filter, the bigger filter bandwith to reject the disturbance. However, with higher filter order, the phase will fall behind. It must be considered that the filter must have order as small as possible, thus the phase will not fall behind. Equation (3), (5), and (6), show that room heating system plant is a first-order system. So the LPF which will this research use is the first-order filter. The disturbance frequency that occurs assumed are not more than 100 Hz so the created filter has 100 Hz cut-off frequency.

Because the filter is the first-order filter, then on selection of filter coefficient, it will refer to first-order Butterworth filter coefficient. The first order Butterworth filter coefficient is s+1 so a_k value is 1. With 100 Hz cut-off frequency then (13) will become to (13).

$$\mathrm{Q(s)} = \frac{1}{1+a_k \tau s}$$

$$\mathrm{Q(s)} = \frac{1}{1+\frac{1}{1/(2*\pi*100)}s}$$

$$\mathrm{Q(s)} = \frac{1}{1+0.0016s} \tag{13}$$

Equation (13) is LPF first-order equation. The relation between the inverse model of room heating system and low pass filter are shown in Figure 6.

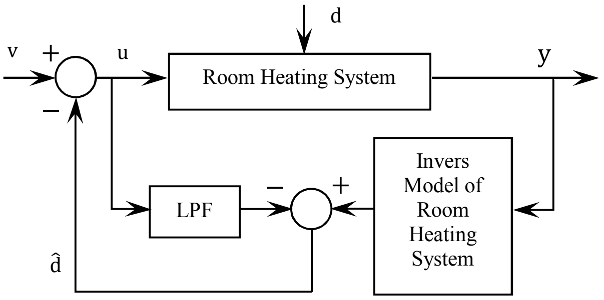

Fig. 6. Disturbance Observer

III. RESULT AND DISCUSSION

It has been pointed out earlier that the controller will be tested with four model variation of outside temperature air like shown in Figure 2.2 to 2.5. This four variation of temperature will be a disturbance to room heating system. The test performed by using Simulink in MATLAB 2014a.The test is performed on two different controllers, which is PID and PID-DOB controller. This two controller generated four different responses towards four variations of temperature disturbances.

After we get the result response, then we will calculate the both of controller performance index by using (8). By using this perform index value, we will find out which controller are the most resistant towards disturbance that coming from outside air temperature. After performing the simulation, we got a response that shows on Figure 7 to 10. There are three charts in each Figure. Those charts are reference chart and system response charts which uses PID and PID Disturbance Observer controller.

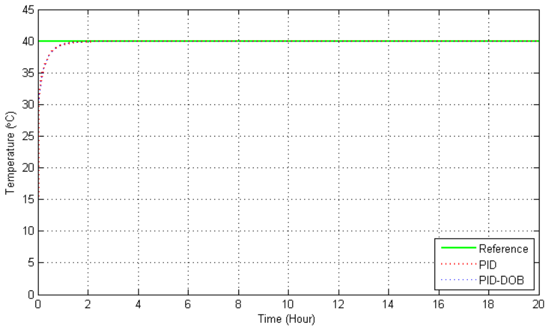

Fig. 7. Test I Result

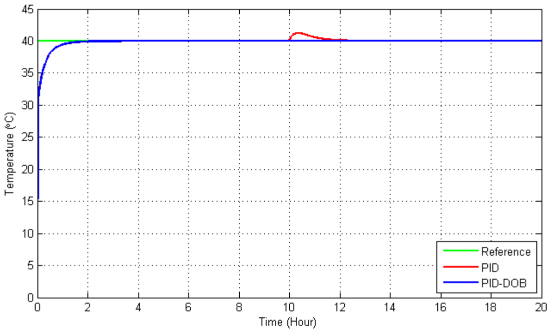

Fig. 8. Test II Result

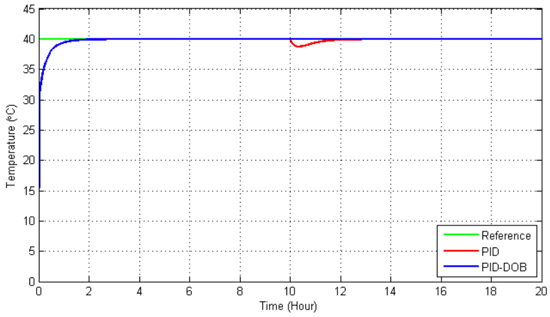

Fig. 9. Test III Result

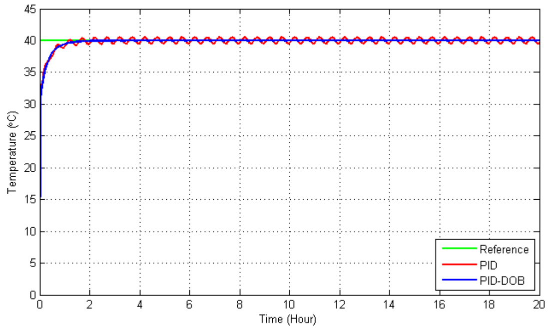

Fig. 10. Test IV Result

On Test I, Figure 7 shown that PID and PID-DOB controller system response result is nearly same. This result showed that both of controller have nearly same resistant toward disturbance that coming from outside air temperature. On test II, PID controller shows the bigger overshoot than PID-DOB. If Figure 8 were zoomed then we will see it look like Figure 11 and Figure 12.

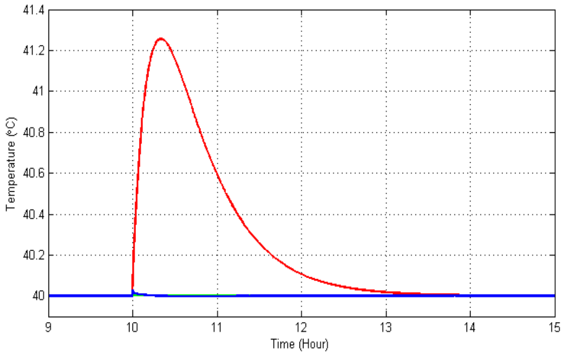

Fig. 11. Test II Result with PID

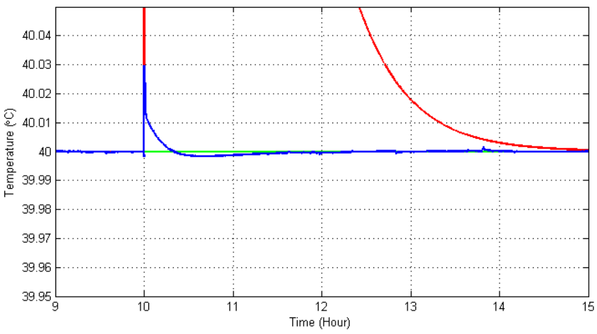

Fig. 12. Test III Result with PID-DOB

From Figure 11 and Figure 12, PID controller give overshoot value as big as 41.25°C while PID-DOB result is 40.03°C. This result showed that PID-DOB is resistant toward the increase of outside air temperature disturbance than PID controller. Then on test III, PID controller shows the bigger decreased temperature too than PID-DOB. The both of system response can be seen in Figure 13 and Figure 14.

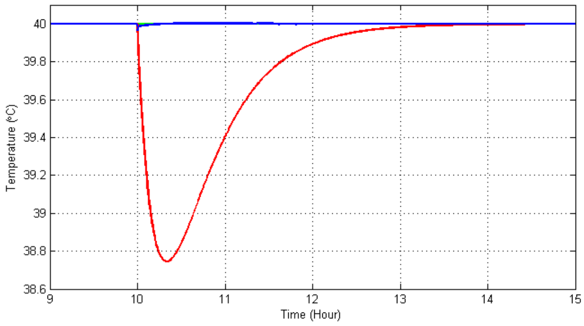

Fig. 13. Test III Result with PID

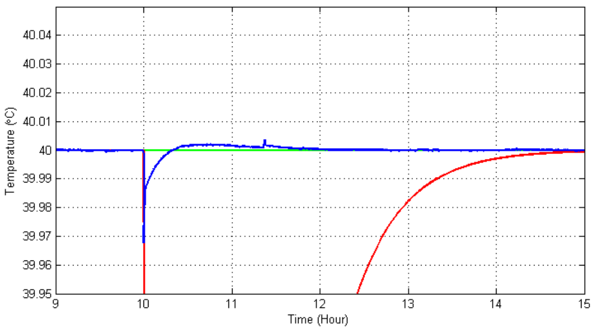

Fig. 14. Test III Result with PID-DOB

From Figure 13 and Figure 14, PID controller produced decreased temperature as 38.75°C while PID-DOB produced decreased temperature as 39.97°C. The result showed that PID-DOB is more resistant to decreased of air temperature outside disturbance than PID controller.

Then on IV test, PID showed bigger amplitude than PID-DOB. Both of this response system are shown in Figure 15 and Figure 16.

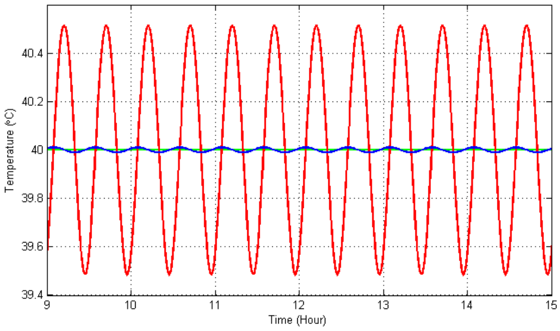

Fig. 15. Test IV Result with PID

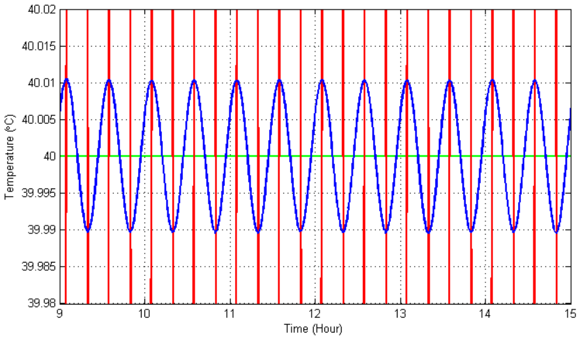

Fig. 16. Test IV Result with PID-DOB

From Figure 15 and Figure 16, PID controller produce amplitude temperature as 0.5°C while PID-DOB produces amplitude temperature as 0.01°C. The result showed that PID-DOB is more resistant to air temperature outside disturbance than PID controller.

After we perform a simulation to observe both of controller response system, this research also calculates both of controller performance index toward the four disturbances. Table 4.1 are shown ITAE Values.

TABLE I. ITAE PID &PID-DOB VALUE

Test	**Controller**	
	PID	***PID-DOB***
I	1.25	1.27
II	15.2	1.3
III	15.2	1.31
IV	10.4	3.23
Average	**10.51**	**1.78**

Table 4.1 shown that PID-DOB controller performance index is better than PID.

IV. CONCLUSION

On this research, two controllers are used as a temperature control on room heating system. These two controllers are PID and PID-DOB. This two controller are tested with four type disturbance in form of variated air temperature outside the room. The result showed that PID-DOB can be used on room heating system as a temperature control that resist to the varied temperature outside the room.

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