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Robust PID Performance for Temperature Regulation of Herb Drying System

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Abstract: Temperature regulation is important in every aspect of system process. Many industrial designs also depend on heating process which requires an efficient temperature regulation system. Hence, to overcome such problems, implementing a system controller that can automatically tuning, regulate and monitor the temperature of heating process is proposed. Robust proportional integral derivative (PID) can be used for temperature regulation of herb drying is system. This paper develops and analyze the PID controller with robust performance to obtain a robust controller on regulating the process control of heating element. Based on the comparative studies, PID controller with robust performance of Td Anti-windup scheme produce a better performance in terms of rise time, overshoot percentage and settling time as compared with the normal PID controller as the result of the lowest overshoot percentage of 8.152% in normal condition and 2.577% in load disturbance and set point changes conditions. Next, the settling time is fastest than other controller to reach the steady state condition with 657.157s in normal condition and 595.219s in load disturbance and set point changes condition. Also, the rise time with 173.808s in normal condition and 272.731s in load disturbance and set point changes condition.

Keywords: Heating Process, PID Controller, Regulation Temperature, Herb Drying System

1. Introduction

Drying processes is one of the most common and oldest in the industrial processes, and recently have been demanding in the world trading exports and imports. Chemical, agricultural, pulp and paper, mineral processing, and wood sectors and others sectors are mostly process and utilised the drying process [1]. The component of a plant that have been utilised for medicinal, culinary, or cosmetic purposes also known as herbal spice. Fresh herbs, on the other hand are particularly perishable because of their high moisture content [2]. As for the result, the herbs need to be dried in order to extend their shelf life [3].

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There are several methods that is used in the drying processes. The Sun-drying is a traditional method for drying herbs that involves hanging them outside [4]. The hot air-drying is a common method that is simple and effective and an inexpensive solution but the process can entirely dehydrate the product surface that cause cracks or heterogeneous on the product. Other than that, contact-drying is a method that consists the product to contact with the heated wall and mostly used in heavy industry drying process, but the method can lead to denaturation of the dried product. Besides, infrared-drying is method that evaporated at high temperature and will concentrated on the surface of the treated product, but can cause roasting effect.

Another drying procedure, the solar drying procedure, but that process might cause final product deterioration, including colour and scent of dried herbs [5]. There are others drying process, dielectric-drying that dry with microwave and radio frequency to heat the entire product simultaneously and widely most sectors. There are so many great numbers of research on herbs drying have been undertaken as a result of this aspect to control the drying heat temperature, which is the most essential parameter in industrial applications. As a result, managing heat systems for drying heat temperature is an excellent option [6].

2. Methodology

This section will discuss on method and process of retrieving initial open-loop system data, develop a transfer function model, and develop the block circuit of P, PI and PID of normal controller and with robust controller by the implementation of data that have been collected in temperature regulation of herb drying system.

2.1 Flowchart

Figure 1 shows the process of project workflow where there are three primary phases. The work begins in the first phase with the definition of the aim and project scopes, the second phase of study focuses on simulating the data. The third phase, which involves in designing the simulation.

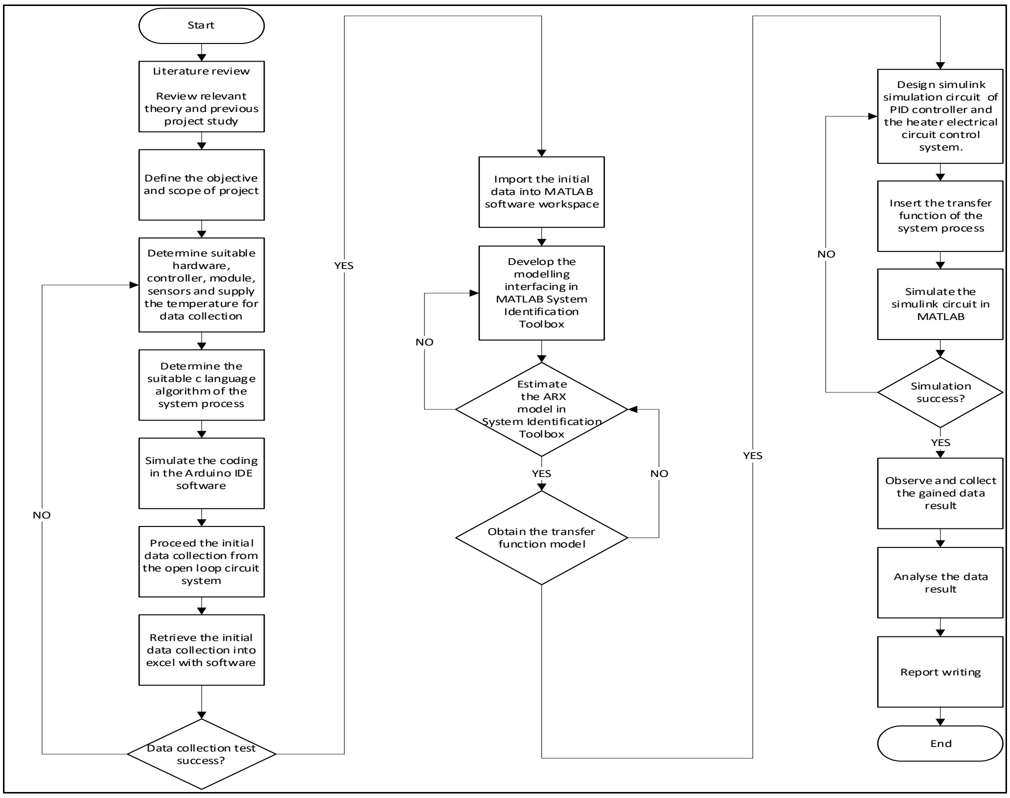

Figure 1: Flowchart of the project workflow

2.2 System Architecture construction for data collection

The basic system's connections are shown in the diagram, as shown in the Figure 2. The input in this system procedure that is connected to the Arduino ESP8266 is the temperature sensor. During the drying process, the temperature will measure the heat rate in Celsius and transmit the signal to the Arduino ESP8266. Finally, to monitor display, the Arduino ESP8266 will link to a computer, the Arduino ESP8266 will then retrieved the data using appropriate software. The data collection will be used in MATLAB software for the simulation interfacing.

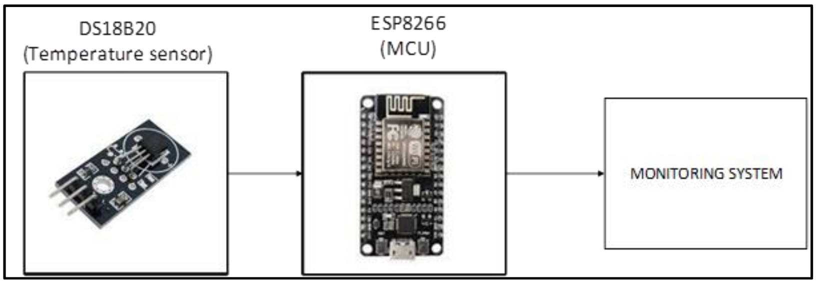

Figure 2: The block diagram of connection of Arduino ESP8266 temperature monitoring system.

2.3 Modelling phase

In the modelling phase, the Auto-Regressive with Exogenous (ARX) model is used to model the closed loop system, ARX model is one of the models under system identification. System identification toolbox is one of the sub disciplines of control engineering that is concerned with creating a mathematical model of the system [7]. The model created includes the system's dynamics, which are generated from the experiment's data. The methods for creating system models using a system identification approach is illustrated below in the flowchart in the Figure 3.

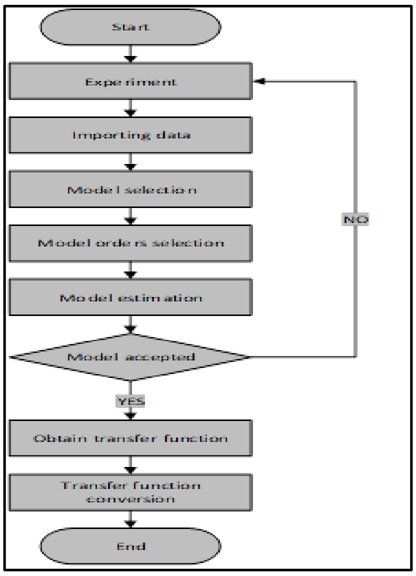

Figure 3: Flowchart of modelling phase.

2.4 PID Controller

Figure 4 shows the circuit of PID controller, normal controller does not require any additional parameters because it operate in nominal operation where it is only requiring the constant value of $32°C$ that represent as initial temperature. The disturbance step input parameter value is set to -15 number of axes at final value and 1000 for step time are used for the controller. The disturbance is added to investigate the system robustness. The set point changes step input parameter value is set to 57 number of axes at final value, 40 number of axes at initial value and 1000 for step time. The set point changes are adjusted to investigate the system robustness.

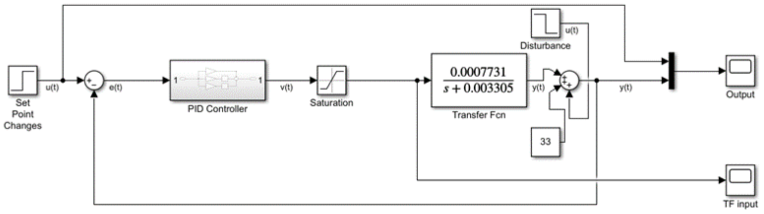

Figure 4: PID Controller with normal, disturbance and set point changes.

2.5 Robust PID controller

The process of modelling will used first order system with the controller is set to 57°C setpoint value and gain of Kp, Ki, and Kd with additional of 32°C initial temperature and Anti-windup gain (Ta) that is feedback with different gain. The disturbance step input parameter value is set to -15 number of axes at final value and 1000 for step time. The set point changes step input parameter value is set to 57 number of axes at final value, 40 number of axes at initial value and 1000 for step time, while for disturbance step input parameter value is set to -15 number of axes at final value and 1000 for step time. The additional Anti-windup gain (Ta) is change into three different values based on Ti, Td, and √TiTd value to obtain the desired output value. Figure 5 shows the circuitry of Robust PID controller.

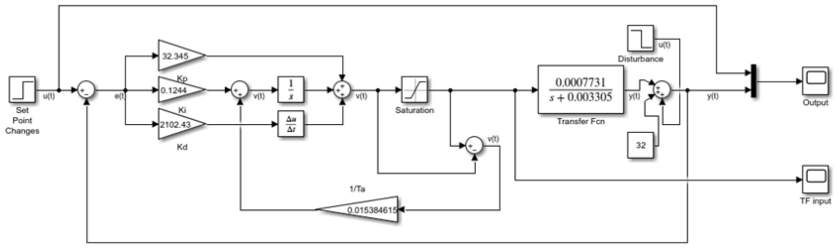

Figure 5: Robust PID Controller in normal, disturbance and set point changes with Anti-windup gain.

2.6 Transient response analysis

Transient response analysis with 2% band is used to calculate the performance behaviour of the system and contain much information about it with respect to time response specification as overshooting, settling time, rise time and steady state response [8]. Figure 6 shows the waveform of second order transient response performance.

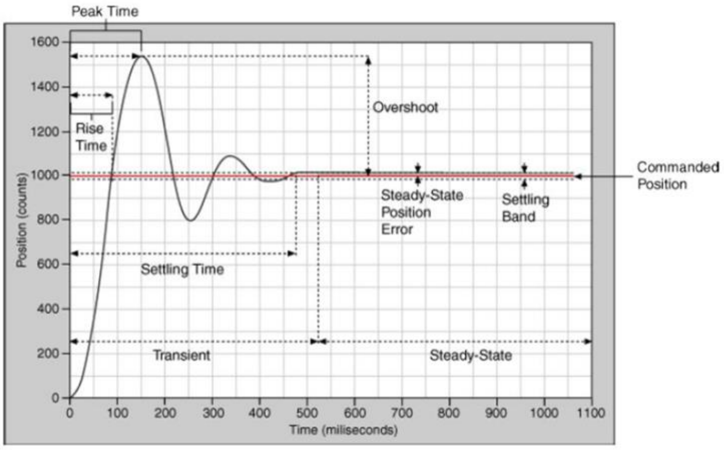

Figure 6: Transient response analysis.

2.6.1 Rise time

Rise time (Tr) is a time taken for the response to rise from 10% to 90% from initial point to set point. Eq.1is given as:

$$Tr = \frac{\pi - \cos^{-1}\zeta}{\omega_s\sqrt{1-\zeta^2}} \qquad \text{(Eq.1)}$$

2.6.2 Settling time

Settling time (Ts) is the time taken for transient to finalize. The settling time is measured as a time required for the transient damped oscillation to reach and stay within ±2% or ± 5%. The equation of Eq.2 and Eq.3 shows the ζ damping ratio and ω_s is natural frequency settling time formular.

$$Ts = \frac{4}{\zeta\omega_n} \text{ for } \pm 2\% \text{ band} \qquad \text{(Eq. 2)}$$

$$Ts = \frac{3}{\zeta\omega_n} \text{ for } \pm 5\% \text{ band} \qquad \text{(Eq. 3)}$$

2.6.3 Percentage of overshoot

Percent overshoot (%OS) is the difference between the response peak value and steady state value. The characteristics is on under damped second order system and it is given as in Eq.4.

$$\mu\% = \frac{-\zeta\pi}{e^{\sqrt{1-\zeta^2}}} \times 100 \qquad \text{(Eq.4)}$$

3. Results and Discussion

3.1 Data temperature plotting

The temperature data vs time is obtained from the previous action of data collection procedure is shown in Figure 7. Then, the temperature data reading is plotted to analyse the value of K, τ,and θ.

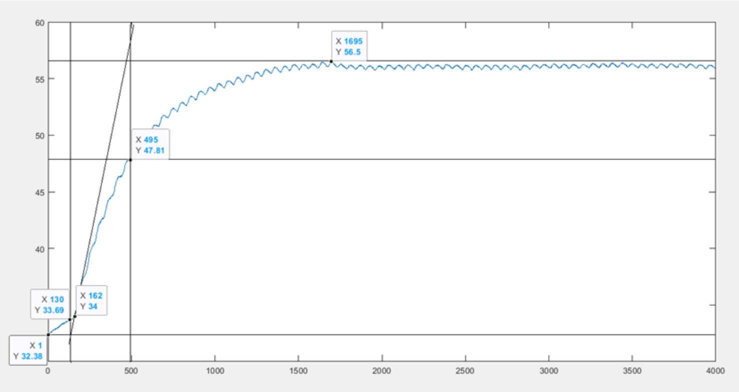

Figure 7: Temperature vs time reading data.

3.2 Transfer function and transfer function conversion

The transfer is obtained based on the ARX first order model output discrete-time equation, which is as expressed in Eq.5,

$$A(z)y(t) = B(z)u(t) + e(t) \qquad \text{(Eq.5)}$$

where the others term is state in equation Eq.6 and Eq.7, respectively:

$$A(z) = 1 - 0.9967\, z^{-1} \qquad \text{(Eq.6)}$$

$$B(z) = 0.0007718\, z^{-1} \qquad \text{(Eq.7)}$$

The transfer function for Z domain is state in equation Eq.8:

$$H(z) = \frac{0.0007718}{z\, -\, 0.9967} \qquad \text{(Eq.8)}$$

The z domain transfer function then converts into S domain transfer function as in equation Eq.9:

$$H(s) = \frac{0.0007731}{s + 0.003305} \qquad \text{(Eq.9)}$$

3.3 Controller parameter

Table 1 shows the parameters of process gain of Kp, Ki, Kd and Anti-windup gain, which have been obtained in modelling technique that have been identified in the graph plotting of first order system in temperature regulation of herb drying process**.** Table 2 shows the Anti-windup gain parameters for the robust performance, with the value gain express in the value of Ti, Td, √TiTd.

Table 1: Ziegler Nichols PID parameters

Controller Tuning	Kp	Ti	Td	Ki	Kd
P	26.954	∞	0	0	0
PI	24.258	433.33	0	0.5598	0
PID	32.345	260	65	0.1244	2102.43

Table 2: Anti-windup gain parameters

Robust Controller	$Ta = Ti$	$Ta = Td$	$Ta = \sqrt{TiTd}$
P	0	0	0
PI	0.00230771	0	0
PID	0.003846153	0.015384615	0.007692307

4. Results and analysis

The result presented in this section shows the value of rise time, overshoot percentage, and settling time on PID controller and Robust PID controller in different conditions and different Anti-windup gain conditions.

4.1 PID controller

The result presented in Figure 8 shows the value of rise time, overshoot percentage, and settling time. In this work, it can be concluded that the performance is stable but not in best performance as shown in the Table 3 with referring to the graph in Figure 8, the output reach the set point range after the overshoot phenomenon with settling time intercept at 58.13℃ at the upper band range at time of 712.327s. But, based on the observation, the overshoot seems a bit high with 11.798%. The output waveform was monitored until 3000s.

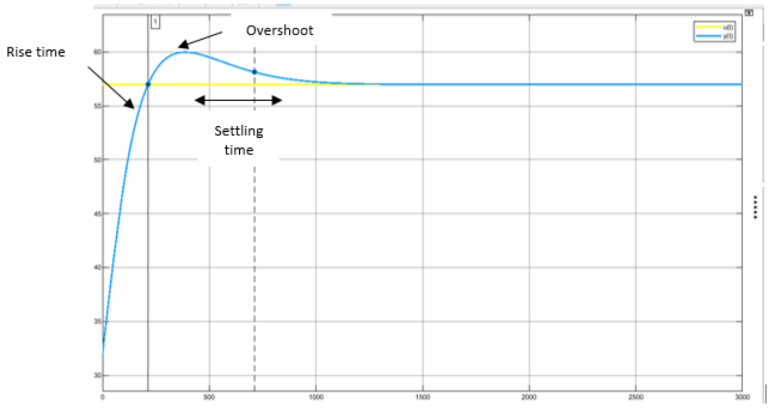

Figure 8: Step response of normal PID controller

Table 3: Step response of normal PID controller

Rise time (s)	Overshoot (%)	Settling time (s)
155.284	11.798	712.327

4.2 PID controller with load disturbance and set point changes conditions

Figure 9 shows the value of rise time, overshoot percentage, and settling time. In this work, it can be concluded that the performance is not stable because of high overshoot as shown in Table 4 after the set point changes phenomenon happen with the high overshoot rate. The output reach at the set point range and the settling time is intercept with upper band range at time 2012.110s. But the disturbance and set point changes did affect the output waveform where the initial temperature is low but suddenly increases from 40.06℃ then overshoot to 64.18℃ and eventually stable at 56.96℃, the incline time happen at 1001.449s and stabilize again at 2660.458. The output waveform was monitored until 3000s.

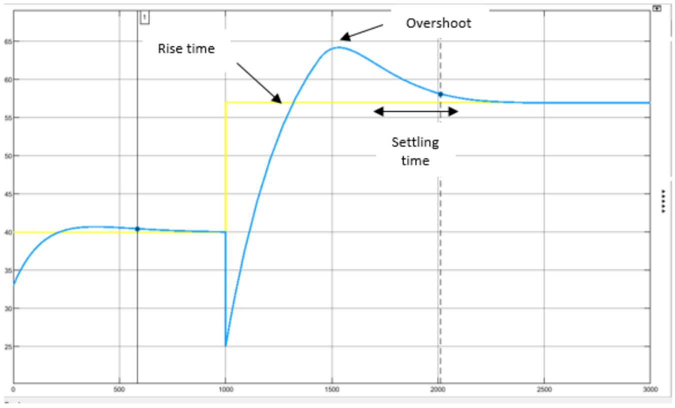

Figure 9: Step response of PID controller with load disturbance and set point changes

Table 4: Step response of PID controller with load disturbance and set point changes

Rise time (s)	Overshoot (%)	Settling time (s)
160.536	44.048	1012.110

4.3 Robust PID controller with Ta=Td

The result presented in Figure 10 shows the value of rise time, overshoot percentage, and settling time. In this work, it can be concluded that the performance is very stable and in a robust performance as shown in Table 5 by referring to the graph on Figure 10, the output reach at the set point range with lowest overshoot of 8.152% and faster settling time intercept with the range at upper band at time 657.157s. The Anti-windup gain (1/Ta) used to feedback at the Ki also equivalent to 0.015384615. The output waveform was monitored until 3000s.

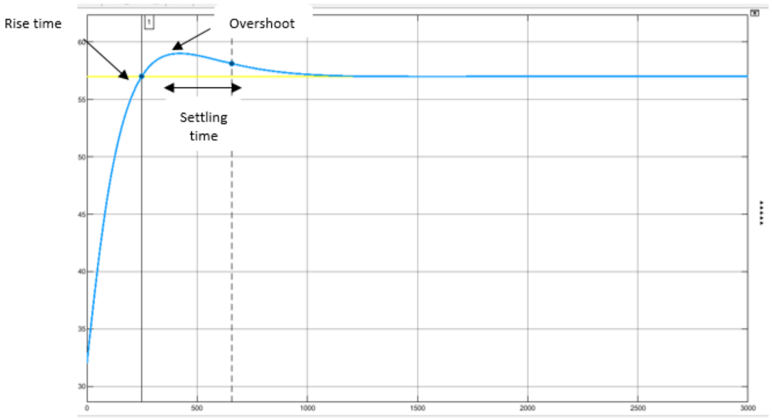

Figure 10: Step response of normal Robust PID controller at Ta = Td

Table 5: Step response of normal Robust PID controller at Ta = Td

Rise time (s)	Overshoot (%)	Settling time (s)
173.808	8.152	657.157

4.4 Robust PID controller with load disturbance and set point changes condition at Ta=Td

The result presented in Figure 11 shows the value of rise time, overshoot percentage, and settling time. In this work, it can be concluded that the performance is very stable and at a robust performance as shown in Table 6 by referring to the graph on Figure 11 after the set point changes phenomenon happen with lowest overshoot of 2.577% rate. The output reach at the set point range with the faster settling time at consider time of 1595.219s. The Anti-windup gain (1/Ta) used to feedback at the Ki also equivalent to 0.015384615. But the disturbance and set point changes affecting the output waveform where the initial temperature is low which at 40.10℃ then suddenly increases to overshoot of 57.67℃ and eventually stable at 57.01℃, the incline time happen at 1004.428s and stabilize again at 2553.097s. The output waveform was monitored until 3000s.

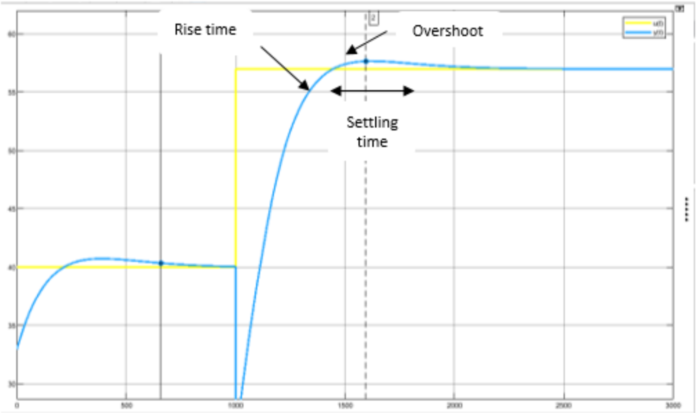

Figure 11: Step response of Robust PI controller with load disturbance and set point changes at Ta=Td

Table 6: Step response of Robust PI controller with load disturbance and set point changes at Ta=Td

Rise time (s)	Overshoot (%)	Settling time (s)
272.731	2.577	595.219

5. Discussion

By referring to the result above, the PID controller has lower rise time in normal condition with 155.284s compared to Robust PID controller in conditions of Anti-windup at Ta=Td with 173.808s. Results also prove that condition in anti-windup at Ta=Td on Robust PID controller has the lowest value of settling time with 657.157s compared to the PID controller that equal to 712.327s for it to reach the steady state condition, its prove that Robust PID controller gives the fastest time in reaching the steady state condition. For the percentage of overshoot, it can be concluded that the percentage overshoot of Anti-windup gain at Ta=Td on a Robust PID controller has the lowest overshoot percentage with 8.152% than a normal PID controller that has a higher overshoot percentage with 11.798%. Furthermore, to proves that controller performance on handling the step response output, several testing's have been conducted by applying some unwanted conditions to such as load disturbance, set point changes then compared it with normal conditions. The output of results proves that Robust PID controller can handle the system performance better than the PID controller. As shown in the results, by referring to the load disturbance and set point changes of PID controller, the rise time is 160.536s, the settling time is 1012.110s, the percentage overshoot is 44.048% while the Robust PID controller result, the rise time is 272.731s, the settling time is 595.219s, the percentage overshoot is 2.577%. Based on all this comparison, it shown that Robust PID controller with Td Anti-windup gain can handle much better in produce a better step response output and better robust performance in terms of precision and accuracy compared to the PID controller based on the comparison in normal condition or encounter in disturbance condition.

6. Conclusion

The research study of this paper is to achieve on proposing a better performance system in drying herb system heating process. By designing and evaluating the performance testing on PID controller and Robust PID controller. As compared with these controllers, based on the results, it can be concluded that Robust PID controller has the most efficient and effective output result as it can handle with normal and disturbance situation with the parameter variations and environmental changes as frequent clearly demonstrated in the results outcome. This paper also describes the behaviour of the system controlled of PID controller, Robust PID controller with Anti-windup gain in specific way in the terms of transient's performance analysis. Since the PID controller gives an unstable performance with high overshoot percentage, longer rise time and longer settling time to reach steady state condition. The additional robust performance in the PID controller prove that it has the ability to provided and produced a better performance to prevent high overshoot percentage, obtaining faster rise time and settling time on reaching the optimize steady state condition.

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