Real Time Temperature Control of Oven Using Matlab-SIMULINK

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Abstract: - Matlab-SIMULINK based real time temperature control of oven using different kinds of auto-tuning PID (Proportional-Integral-Derivative) methods is presented in this paper. Ziegler Nichols Step Response Method (P,PI), Relay Tuning Method (P,PI) and Integral Square Time Error (ISTE) disturbance criterion (PI) method are used to control temperature of the experiment set. Controller parameters are defined by simulations of auto-tuning methods. These parameters are used to implement the real time control of the oven designed as an experiment set. Three set point changes are realized during the experiments and the responses of the oven to these methods are observed. Finally the results are discussed to decide which controller is the best for set point changes.

Key-Words: - Real time control, adaptive control, auto-tuning PID methods, temperature control

1 Introduction

PID controllers have been used for industrial processes because of their simplicity and robustness. But it is difficult and time consuming to define the controller parameters accurately. Therefore, it becomes impracticable. So, auto-tuning techniques are developed to define these controller parameters. It has auto-tuning button and by means of this button PID parameters are computed and transferred to the controller. Thus PID controller has been faster, more practical and reliable [1]. Auto-tuning methods used in this study are Ziegler-Nichols Step Response, Relay and ISTE Tuning method. Because Matlab-SIMULINK based real time control is realized in this study, to control the temperature of the experiment set (oven) is more practical. To implement real time temperature control of the oven, a PIC based card is used. This card enables the real time temperature control of the oven through both PIC18F4585 and Matlab-SIMULINK. This card provides the communication between the oven and Matlab-SIMULINK simulation software through RS-232. Designed controllers using auto-tuning techniques are simulated in Matlab-SIMULINK by using mathematical model of the oven first. Then experiments through Matlab-SIMULINK and PIC based card are realized using the same controllers. Finally the results are discussed.

2 Auto-Tuning Techniques

In this study, three kinds of auto-tuning methods are used. They are Ziegler-Nichols Step Response Method, Relay Tuning Method and ISTE Tuning Method. Ziegler-Nichols Step Response Method is based on transient response experiments. Many industrial processes have step responses of the type shown in Fig. 1, in which the step response is monotonous after an initial time.

$$G(s) = \frac{k}{1+sT} e^{-s\tau} \tag{1}$$

$$a = k \frac{\tau}{T} \tag{2}$$

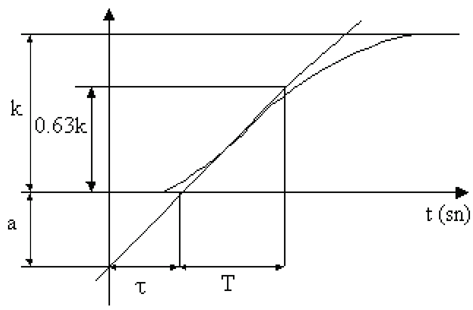

Fig. 1. Unit step response of a typical industrial process [2].

A system with step response of the type shown in Fig. 1 can be approximated by the transfer function as in equation (1). where k is the static gain, τ is the apparent time delay, and T is the apparent time constant. The parameter *a* is given in equation (2) [2].

Closed loop control system with disturbance input is shown in Fig 2. G(s) is the transfer function of the plant and q(t) is disturbance input. The transfer function of the PID controller is given in equation (3).

$$G_C(s) = K_P\left(1 + \frac{1}{T_I s} + T_D s\right) \quad (3)$$

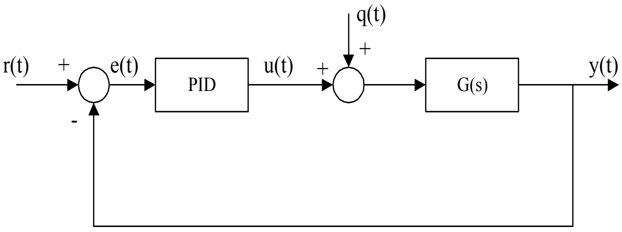

Fig. 2. Closed loop control system with disturbance input [3].

2.1 The Ziegler-Nichols Step Response Method

A simple way to determine the parameters of a PID regulator based on step response data was developed by Ziegler and Nichols and published in 1942. The method uses only two of the parameters shown in Fig. 1, namely, a and τ. The regulator parameters are given in Table 1. The Ziegler-Nichols tuning rule was developed by empirical simulations of many different systems [2].

Table 1. Regulator parameters obtained by the Ziegler-Nichols step response method [2].

Controller	K_P	T_I	T_D
P	1/a	-	-
PI	0.9/a	3 τ	-
PID	1.2/a	2 τ	τ /2

2.2 Relay Tuning Method

The relay method is attractive since a control-relevant excitation signal is generated automatically, and many tuning rules exist to utilize the resulting process information [3,6]. The relay feedback is an efficient method of obtaining the critical point of a process with the critical point made available. PID types of controllers are easily tuned using classic Ziegler-Nichols rules and variants [3,7]. The arrangement for a relay feedback auto-tuner is shown in Fig. 3 [3,8]. The input and output signals obtained when the command signal r is zero are shown in Fig. 4.

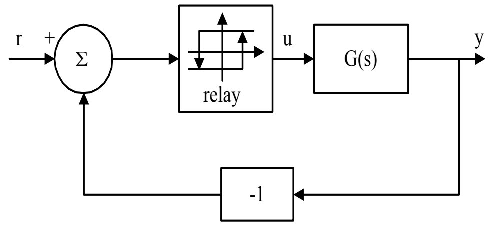

Fig. 3. Block diagram of the relay auto-tuner [3,4]

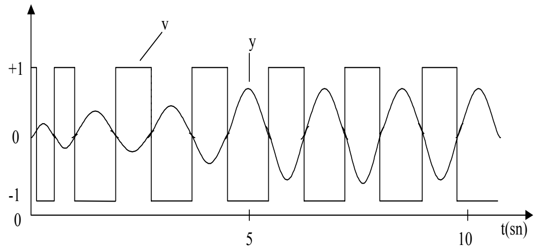

Fig. 4. Linear system with relay control [3,4].

The Fig. 4 shows that a limit cycle oscillation is established quite rapidly. The output is approximately sinusoidal, which means that the process attenuates the higher harmonics effectively. Let the amplitude of the square wave be d, then the fundamental component has the amplitude 4d/π. The process output is a sinusoidal with frequency ω_u and amplitude is shown as in equation (4).

$$a = \frac{4d}{\pi}\left|G(i\omega_u)\right| \quad (4)$$

To have an oscillation, the output must also go through zero when the relay switches. We can conclude that the frequency ω_u must be such that the process has a phase lag of 180^o. The conditions for oscillation are shown in equation (5).

$$\arg G(i\omega_u) = -\pi \quad \text{and} \quad a = \frac{4d}{\pi}\left|G(i\omega_u)\right| \quad (5)$$

Table 2. PID parameters used in relay tuning method [3,4]

Controller	K_P	K_I	K_D
P	0.5 K_C	-	-
PI	0.4 K_C	1.25 / T_C	-
PID	0.6 K_C	2 / T_C	0.12T_C

K_c can be regarded as the equivalent gain of the relay for transmission of sinusoidal signals with amplitude a. This parameter is called ultimate gain. It is the gain that brings a system with transfer function G(s) to the stability boundary under pure proportional control. The period $T_c=2\pi/\omega_u$ is similarly called the ultimate period. The controller settings are given in Table 2. These parameters give a closed loop system with quite low damping. Systems with better damping can be obtained by slight modifications of numbers in the table. When a stable limit cycle is established, the PID parameters are computed, and the PID controller is then connected to the process [3,4]

2.3 ISTE Tuning Method

In recent years there has been much interest in the relay auto-tuning technique for determining the parameters of a PID controller. In this method, the PID controller is replaced by a relay so that the loop has a limit cycle. Tuning parameters of the controller are then calculated from measured values of the amplitude and frequency of the limit cycle. Here, we therefore define the formulate for the FOPDT (First Order Plus Dead Time) plant models which enable the optimum ISTE tuning parameters to be found from these measurements of the oscillation frequency and amplitude. The equations used in this method have been developed based on known critical point data, namely the critical frequency and critical gain. When performing relay auto-tuning, the approximate critical point data is found from the limit cycle data, namely the oscillation frequency ω_o and the peak amplitude a_o, which is used to calculate K_C, the approximate critical gain. K_C is found using the describing function for the relay, that is $K_C = 4d/a_o\pi$. For the FOPDT plant, the exact value of ω_o and K_C can be calculated using the Tsypkin method so that their relationship to ω_c and K_C can be found. It is therefore possible to obtain the above formulate in terms of the values of ω_o and K_C which will be found from the limit cycle measurement when using relay auto-tuning. The normalized gain is calculated by κ_C=K*K_C [3,5]. These tuning equations for disturbance are seen in Table 3.

Table 3. PI tuning formulae for ISTE criterion [3,5]

Controller	Disturbance criterion
K_P	$\frac{4.126\,\kappa_C - 2.610}{5.848\,\kappa_C - 1.06} K_C$
T_i	$\frac{5.352\,\kappa_C - 2.926}{5.539\,\kappa_C + 5.036} T_C$

3 Experimental Study

Fig. 5 shows the block diagram of the experiment set. PIC based card gets the temperature data by using the temperature sensor, thermocouple. PIC based card makes this data suitable and takes it to Matlab-SIMULINK environment through RS-232 serial connection. In Matlab-SIMULINK environment, this data is used to produce control signal. This control signal is applied to the oven through RS-232 serial connection and PIC based card. Debugger is used to program PIC microcontroller. It is practicle to make experimental studies by using this experiment set. Because PIC based card enables the oven to be controlled by both Matlab-SIMULINK and PIC18F4585.

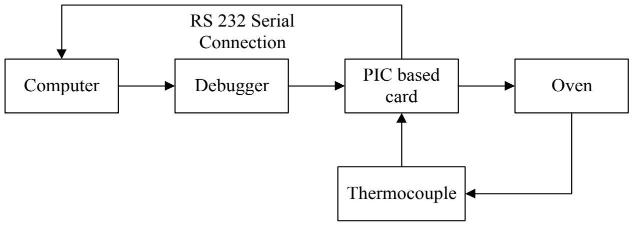

Fig. 5. Block Diagram of the experiment set.

Fig. 6 presents photo of the oven and PIC based card. In this figure, 1: thermocouple (temperature sensor), 2: oven, 3: fan, 4: two holes for disturbances. In Fig. 5, PIC based card includes these hardware specifications: three temperature sensor inputs (0-1000 ^{o}C), two different independent phase controlled resistance supply outputs (40 + 40 Amper-rms), three different relay outputs (10 Amper-rms), RS-232 output (up to 256 Kbit) and microcontroller (PIC18F4585). PIC based card is composed of two basic parts. These parts are functionally different from each other and named as base card and microcontroller card. Microcontroller card contains PIC 18F4585, MAX232 and RJ MPLAB ICD2 connection. Microcontroller has 10MIPS processing speed. Base card has two main parts as sensor units and heater controller outputs [7].

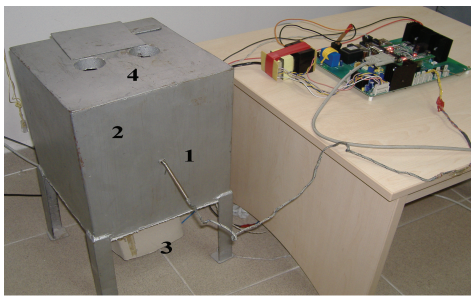

Fig. 6. Experiment setup (oven and PIC based card)

The oven used in this study is a First Order Plus Dead Time (FOPDT) plant. An FOPDT system has a transfer function as in equation (1). In this equation, the parameters should be known are k, τ and T. These parameters are k=106,τ =64.14s and T = 1494.7s [7]. Transfer function of the oven is given in equation (6).

$$G(s) = \frac{106}{1495s+1} e^{-64,14s} \qquad (6)$$

4 Experimental Results

In this section, the parameters of Ziegler-Nichols P, PI, Relay Tuning Method P, PI and ISTE Tuning Method PI (for disturbance input) are calculated first. To be able to define P and PI parameters of Ziegler-Nichols Step Response Method, step response of the oven was examined. Simulation result of the open loop step response of the oven is seen in Fig. 7. a and τ parameters shown in Fig 1 are designated using this step response of the oven. To be able to calculate P and PI parameters of Relay and ISTE tuning methods, the oven was oscillated. Simulations of this oscillation and relay output are shown in Fig. 8 and Fig. 9 respectively. Calculated P and PI parameter for all types of tuning methods are given in Table 4. All tuning methods are are implemented using both PIC based card and Matlab-SIMULINK. Three different set points are used in 5000 seconds. First set point is 80 °C, second set point is 100 °C and the third set point is 120 °C. The second set point change occurs at 1520th second and the third set point change occurs at 3120th second.

Table 4. Calculated P and PI parameters of all auto-tuning methods used in experiments.

	Step P	Relay P	Step PI	Relay PI	ISTE Dist. PI
K_p	0.2199	0.1434	0.19792	0.11472	0.19932
T_i	-	-	192.4281	202.2	232.8609

Experimental results are seen between Fig.10 and Fig. 16. Settling time, settling temperature and ISE (the integral of the square of the error) for all the method used in this study are compared in Table 5. Experimental results of P control of the Ziegler Nichols Step Response and Relay tuning method are given in Fig. 10 and Fig. 11 respectively. In the last set point change for P control of the Ziegler Nichols Step Response Method, 3.2 °C overshoot occurs while 0.5 °C overshoot occurs in P control of the Relay Tuning Method. But, P control of Ziegler Nichols Step Response Method with 3213.5 s settling time, 117.7 settling temperature and 1.9755e+006 ISE values is better than P control of the Relay Tuning Method.

Experimental results of PI control of the Ziegler Nichols Step Response, Relay Tuning Method and ISTE Disturbance criterion are given in Fig. 12, Fig. 13 and Fig. 14 respectively. In the last set point change for Step PI control 0.7 °C overshoot, for Relay PI control 1.5 °C overshoot and for ISTE disturbance criterion 0.5 °C overshoot occur. Among these PI controllers, PI control of Relay Tuning Method with smallest settling time (3214.05 s), smallest ISE (2.3936e+006) and exact settling temperature (120 °C) is the best controller for the oven used in this study.

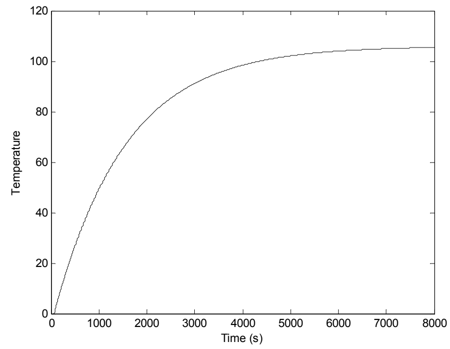

Fig. 7. Open loop step response of the oven.

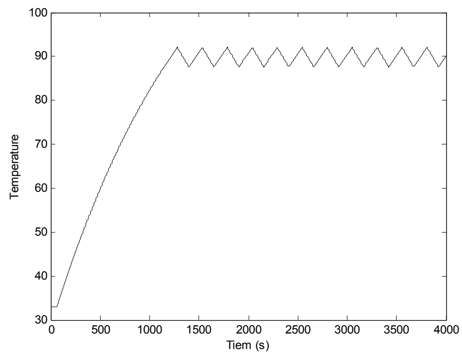

Fig. 8. Relay tuning of the oven

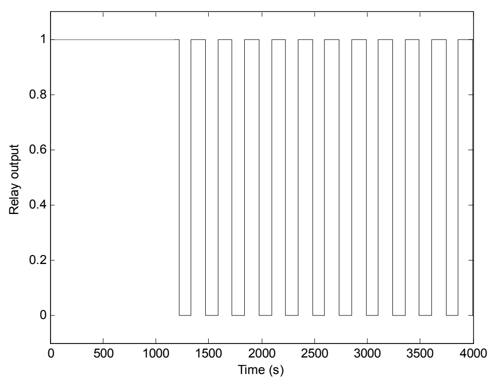

Fig.9. Relay output

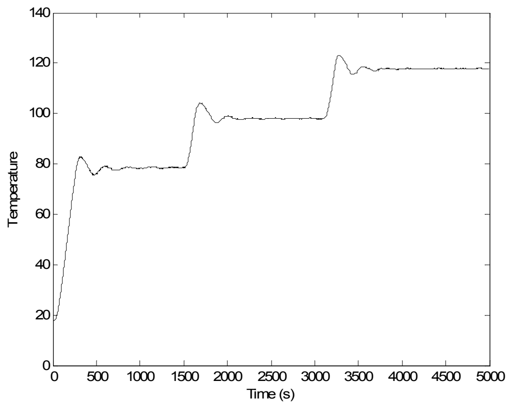

Fig. 10. Experimental result of P control for Ziegler-Nichols Step Response.

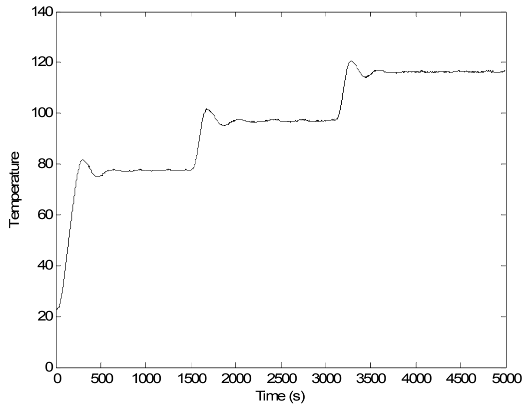

Fig. 11. Experimental result of P control for the relay method.

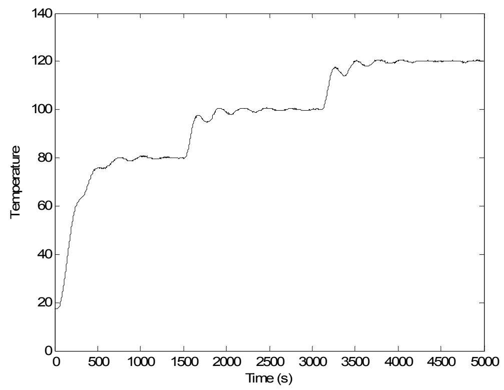

Fig.12. Experimental result of PI control for Ziegler-Nichols Step Response

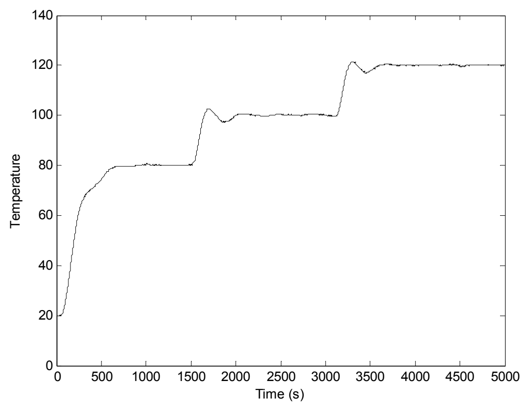

Fig. 13. Experimental result of PI control for the relay method.

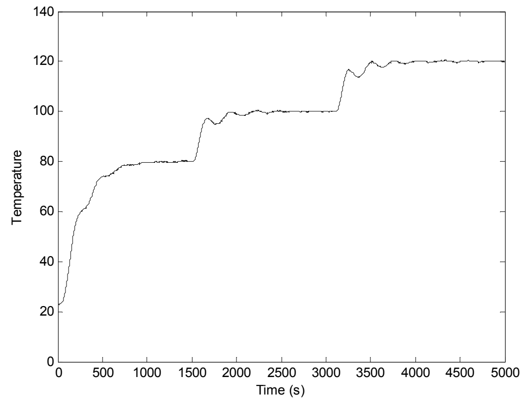

Fig.14. Experimental result of the ISTE disturbance criterion PI control.

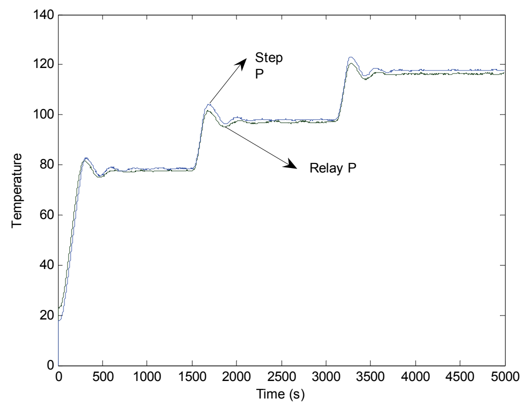

Fig. 15. Comparison of P controllers

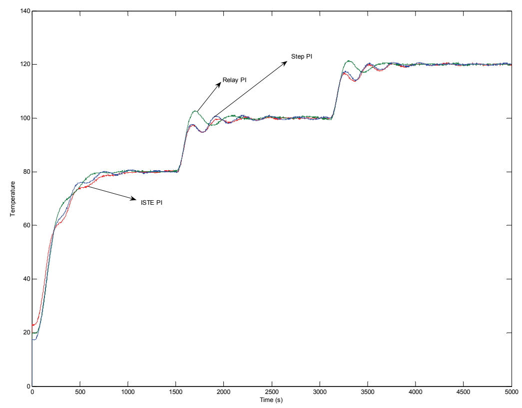

Fig. 16. Comparison of PI controllers.

In Fig. 15, comparison of P control of Ziegler Nichols Step Response Method and Relay Tuning Method are given graphically. In Fig. 16, comparison of PI control of Ziegler Nichols Step Response, Relay Tuning Method and ISTE Disturbance criterion are shown graphically.

Table 5. Comparison of the experimental results. ISE : (the integral of the square of the error)

Controller	Settl. time (s)	ISE	Settl. Temp. (°C)
Step P	3213.5	1.9755e+006	117.7
Relay P	3220	2.4723e+006	116.7
Step PI	3370.5	2.7450e+006	120.2
Relay PI.	3214.05	2.3936e+006	120
ISTE Dist. PI	3216.15	3.0249e+006	120

5 Conclusion

This paper presents Matlab-SIMULINK based real time temperature control of the oven. A PIC based card is used between the oven and the computer (Matlab-SIMULINK) to provide their communication through RS-232. Ziegler-Nichols Step Response P, PI, Relay Tuning P, PI and ISTE disturbance criterion PI methods are used to control the oven. Three set point changes are applied as 80 °C, 100 °C and 120 °C. These methods are implemented using Matlab-SIMULINK simulation software through PIC based card. Ziegler-Nichols Step Response is better among P controllers while Relay Tuning PI controller is the best among PI controllers.

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