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Design and Implementation of Temperature Control for a Mini-chamber using Self-Tuning PID Controller

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ABSTRACT

Despite its popularity in industrial application, PID controller suffers parameters setting difficulty due to set point change, disturbance, and ageing. This paper proposed Self-tuning PID controller using Dahlin method for temperature control of a laboratory scale mini-chamber. Experimental results show that the proposed controller has better performance compared to the conventional PID controller in term of rise time settling time and maximum overshoot. It also shows that the algorithm can compensate the changing environment and robust toward the existence of disturbance. Using self-tuning PID controller, the output temperature returns to the original desired value in a considerably short time (around 50 seconds).

Keywords: PID controller, self-tuning, Dahlin method, mini-chamber.

1. INTRODUCTION

Proportional Integral Derivative (PID) controllers are one of the oldest control methods for closed-loop systems. However, around 97% of industrial controllers are still dominated by PID controllers [1]. Research related to the PID controller is still an active research field so far, such as in [2]–[5]. Analysis of the performance of the PID controller and its future development is discussed in [6]. Various variations of the PID controller including the tuning method are described in detail in [7].

Despite its popularity, PID controller has some disadvantages. It has poor performance for controlling integrator processes and a process with considerable delay time. Besides that, the PID controller is also not able to overcome changes in ramp-type set points and slow disturbance [8]. Chidambaram, M and Sree, R.P. [9] in addressing integrator and large delay time process proposed matching the coefficient of numerator and denominator. On the other hand, Atic, S. et al. [10] proposed Generalized Stability Boundary Locus to solve the same problems. A similar approach is proposed by [11] with a numerical approach to ease solving the problem. While many approaches have been proposed, the ultimate goal was finding the proper parameters of a PID controller and a proper mechanism to implement the controller. Hence, an idea to make the controller adaptive attract many researchers.

Generally, the adaptive controller falls into three classes, namely Heuristic Algorithm, Model Reference Adaptive Control, and Self-tuning controller [12]. The first two approaches need detailed knowledge of the dynamic behaviour of the controlled system, which is not possible in some cases. On the contrary, the self-tuning controller discovers the dynamic of the controlled system as well as its disturbance from recursive estimation (identification) of unknown parameters [13]. A considerable number of successful applications as well as theoretical aspect development of self-tuning controller are still emerging in recent years, such as in [14]–[19]. According to their identification method, self-tuning controller falls into two categories, i.e. explicit self-tuning controller and implicit self-tuning controller. In explicit self-tuning controller, the identification result obtained from mathematical relationships between process input and output is the process model. While in the implicit self-tuning controller, the identification process directly calculates the parameters of the controller.

We proposed to employ an explicit self-tuning PID control to obtain the desired performance of a temperature controlled system. This system is naturally an integrative process. Hence the conventional PID control strategy cannot yield satisfactory performance. Moreover, due to over ageing, the process parameter is slightly changing.

2. TEMPERATURE CONTROLLED SYSTEM

A temperature controlled of a mini-chamber system is used in this research. Main elements to manipulate temperature is a heater (halogen lamp 24 volts) located inside mini-chamber with a diameter of 4.045 cm as shown in Figure 1. A ventilator motor (fan) located at the opening of mini-chamber is operated by adjusting a potentiometer to set movement at a certain constant speed. This fan must suck outside air flows inside the chamber. A PTC KTY temperature sensor is placed beside the heater to measure hot wind which flows toward the chamber. An adjustable flap is placed at the end of mini-chamber to regulated hot wind leaving the mini-chamber. Based on the feedback signal provided by a temperature sensor a heating power (control action signal) is generated according to a particular control strategy.

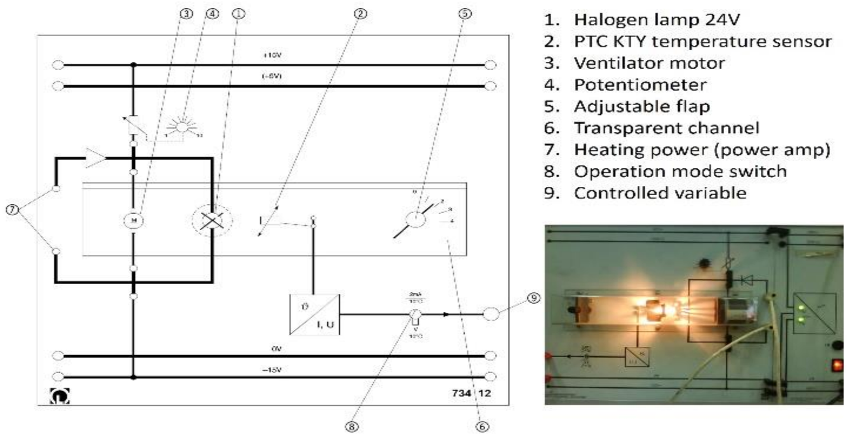

FIGURE 1. Temperature controlled mini-chamber system (by Leybold Didactic GmbH)

Controlled plant in Figure 1 is naturally an integrator plant, so giving constant control action would increase the temperature of mini-chamber.

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3. SELF TUNING PID CONTROLLER

A self-tuning PID controller being considered in this study (depicts in Figure 2) is an explicit self-tuning controller, hence the identification (estimation) process is yielding dynamical model of the process (process parameters) in the form of a discrete transfer function relating process output and process input. Based on the process parameter, a particular control law will calculate or adjust the controller parameters.

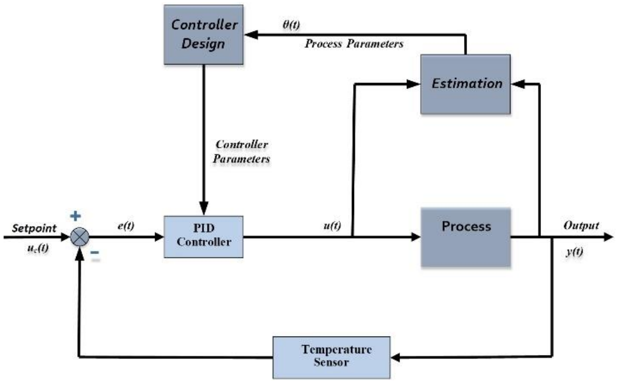

FIGURE 2. Block Diagram of Self-tuning PID Controller in this study

Supposed that the estimated model is defined by the following transfer function

$$G(z) = \frac{B(z^{-1})}{A(z^{-1})} = \frac{b_1 z^{-1} + b_2 z^{-2} + \cdots + b_m z^{-m}}{1 + a_1 z^{-1} + a_2 z^{-2} + \cdots + a_n z^{-n}} z^{-d} \qquad (1)$$

where m, n, and d are input order, output order and time-delay of the system, respectively. The system model is given by

$$A(z^{-1})y(k) = B(z^{-1})u(k) \qquad (2)$$

where $u(k)$ and $y(k)$ are the process input and output, respectively.

The estimated output of the process then given by

$$\begin{aligned} \hat{y} &= -\hat{a}_1 y(k-1) - \cdots - \hat{a}_n y(k-n) + \hat{b}_1 u(k-d-1) \\ &\quad + \cdots + \hat{b}_m u(k-d-m) \\ &= \theta^T(k-1)\Phi(k) \end{aligned} \qquad (3)$$

where $\theta(k-1)$ is estimated process parameters from the previous iteration and $\Phi(k)$ is the regression vector containing process input and output.

Consider of Recursive Least Square Method [12], the estimated process parameters $\theta(k-1)$ is updated according to

$$\theta(k) = \theta(k-1) + \frac{C(k-1)\Phi(k)}{1+\Phi(k)^T C(k-1)\Phi(k)} \left(y(k) - \theta(k-1)^T \Phi(k)\right) \qquad (4)$$

$$C(k) = C(k-1) - \frac{C(k-1)\Phi(k)\Phi(k)^T C(k-1)}{1+\Phi(k)^T C(k-1)\Phi(k)} \quad (5)$$

where $C(k)$ is the covariance matrix of regression vector $\Phi(k)$.

A simple yet powerful incremental version of the PID controller, Dahlin PID controller [20], assumed that the estimated process parameters and regression vector are as in Equation (6) and (7)

$$\theta(k-1) = [\hat{a}_1, \hat{a}_2, \hat{b}_1]^T \quad (6)$$

$$\Phi(k) = [-y(k-1), -y(k-2), u(k-1)]^T \quad (7)$$

moreover, formulate the control law according to Equation (8)

$$u(k) = K_p + \left\{e(k) - e(k-1) + \frac{T_0}{T_I}e(k) + \frac{T_D}{T_0}[e(k) - 2e(k-1) + e(k-2)]\right\} + u(k-1) \quad (8)$$

where K_p, T_I, T_D are the proportional, integral, and differential parameters of PID controller, respectively. These parameters are depending on the process parameters as in Equation (9) - (11)

$$K_p = \frac{(\hat{a}_1 + 2\hat{a}_2)Q}{\hat{b}_1} \quad (9)$$

$$T_I = \frac{T_0}{\frac{1}{(\hat{a}_1+2\hat{a}_2)} + 1 + \frac{T_D}{T_0}} \quad (10)$$

$$T_D = \frac{T_0 \hat{a}_2 Q}{K_p \hat{b}_1} \quad (11)$$

where $Q = 1 - e^{-\frac{T_0}{B}}$, with B is an adjustment factor specifies the dominant time constant of the close loop step response.

3. EXPERIMENTS AND THE RESULTS

Temperature reading of the mini-chamber provides by PTC KTY temperature sensor, is fed into signal conditioning circuits. The output signal of this circuit acts as the analogue input signal to the ADC circuit of the STM32F4 Discovery microcontroller. The microcontroller STM32F4 Discovery then proceed self-tuning controller algorithm described in section 3. This microcontroller has 82 I/O pins as depicted in Figure 3, and powered by ARM Cortex™-M4 STM32F407VGT series

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processor with the maximum clock 168MHz. Having such powerful computing capability, it can perform several mathematical floating point 32-bit operations in 1 machine cycle accurately. The output signal, i.e. control action signal calculated by the algorithm, is PWM signal at pin A0 of STM32F4 Discovery

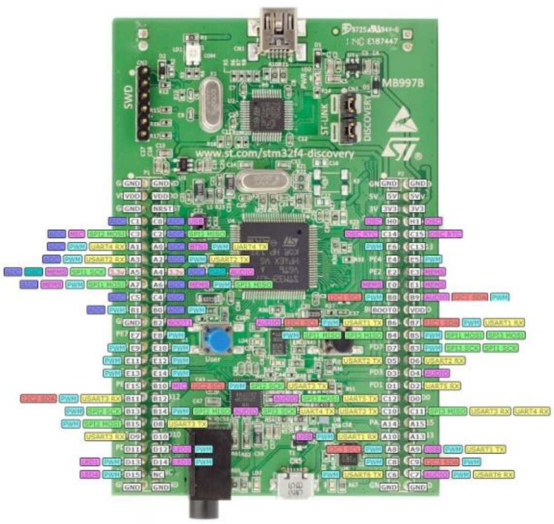

FIGURE 3. A Microcontroller STM32F4 Discovery

microcontroller. The signal then flows to L298 driver to finally actuate halogen lamp to the corresponding heating power. The Graphical User Interface (GUI) was developed using Processing 3.2.3 software to show sensor reading as well as calculation results of the algorithm in real-time.

There are two types of the experiment reported in this paper, the experiment of set value changing and the experiment of robustness against disturbance. Due to sensor capability and linearity issue, the maximum temperature will be set less than 40^{o} C. As an explicit self-tuning, parameter changing will also be shown to demonstrate adaptability in a changing environment.

Figure 4 shows response comparison of the conventional PID controller and Self-tuning PID controller when the desired output is set to 32^{o} C. It is seen that self-tuning

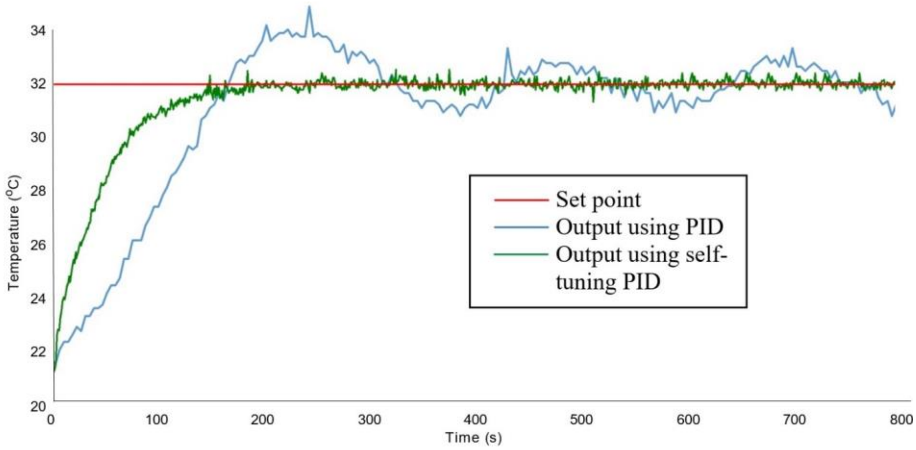

FIGURE 4. Comparison of PID and Self-tuning PID Controller Performance

PID controller outperform of the conventional PID controller in term of rise time settling time and maximum overshoot. Parameter estimation and PID parameter setting during the iteration were shown in Figure 5 and Figure 6, respectively. Identic with the output response in Figure 4, the estimation processes were also high-speed. Figure 7 shows PID parameters calculation results when the desired temperature is set to 36^{o} C. Comparing to that of Figure 6; it is clearly shown that self-tuning controller algorithm provides proper controller parameters for different setpoint value. Robustness proves under disturbance is shown in Figure 8. The algorithm returns output temperature to the original desired value in a considerably short time (around 50 seconds).

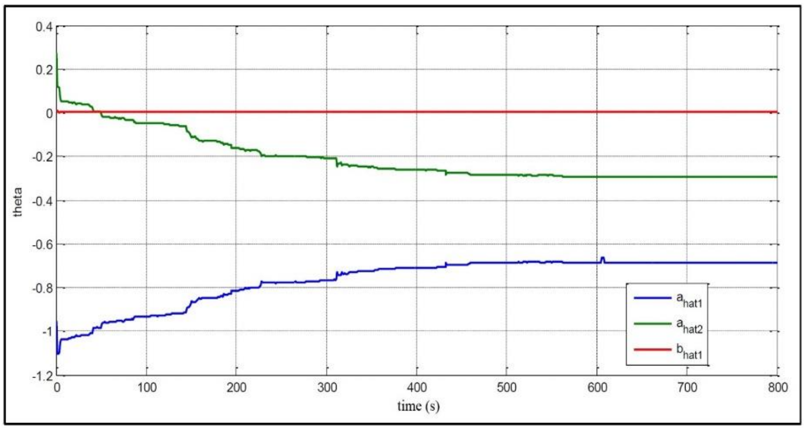

FIGURE 5. Process Parameter at Set point 32^{o} C

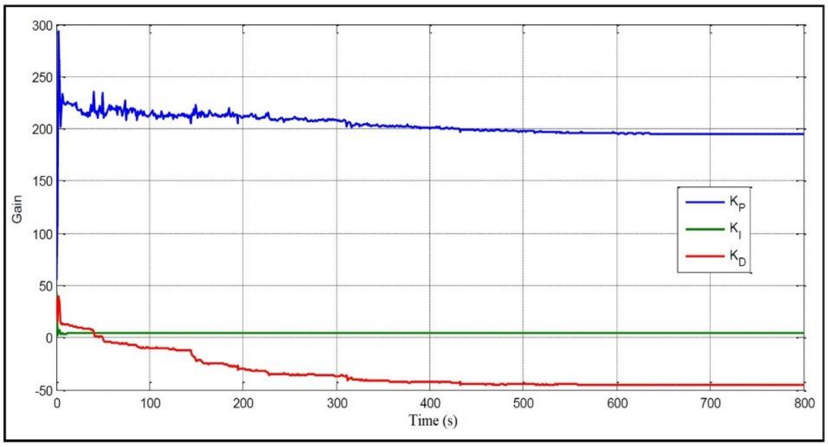

FIGURE 6. PID Controller Parameters at Set point 32^{o} C

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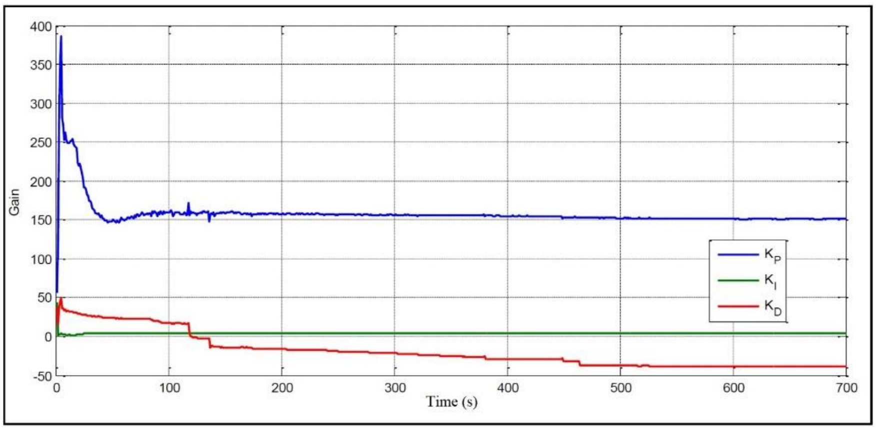

FIGURE 7. PID Controller Parameters at Set point 36° C

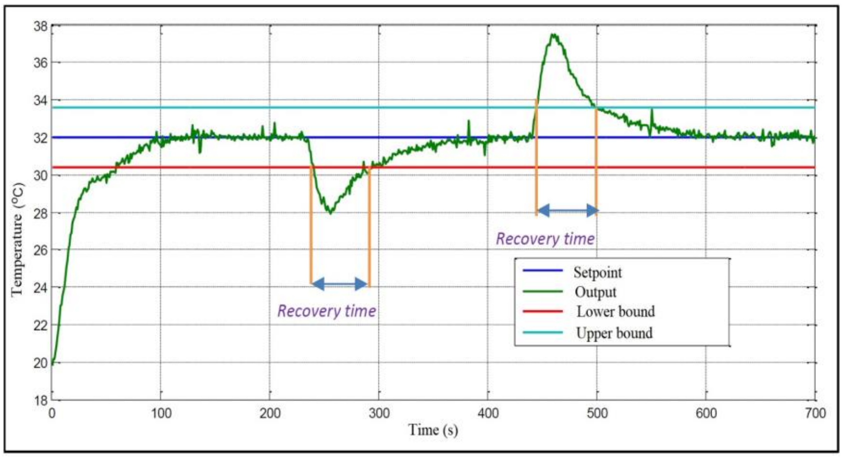

FIGURE 8. Self-tuning PID Controller Performance under Disturbance

4. CONCLUSIONS

This paper proposed Self-tuning PID controller for temperature control of a laboratory scale mini-chamber. Experimental results show that the proposed controller has better performance compared to the conventional PID controller in term of rise time settling time and maximum overshoot. It also shows that the algorithm can compensate the changing environment and robust toward the existence of disturbance. Using self-tuning PID controller, the output temperature returns to the original desired value in a considerably short time (around 50 seconds).

REFERENCES

[1] M. Chidambaram and N. Saxena, *Relay Tuning of PID Controllers*. Singapore: Springer Singapore, 2018.

[2] O. Hernandez, P. Ortiz, and J. Herrera, “Fractional PID Controller with LQR

Proportional Action Applied to Fractional Model of Cement Rotary Kiln," *IEEE Lat. Am. Trans.*, vol. 13, no. 1, pp. 37–42, Jan. 2015.

[3] A. Marin Cano A. Marin, J. A. Hernandez Rivero J. Hernand, and J. A. Jimenez Builes J. Jimenez, "Tuning Multivariable Optimal PID Controller for a Continuous Stirred Tank Reactor Using an Evolutionary Algorithm," *IEEE Lat. Am. Trans.*, vol. 16, no. 2, pp. 422–427, Feb. 2018.

[4] J. J. Castillo-Zamora, K. A. Camarillo-Gomez, G. I. Perez-Soto, and J. Rodriguez-Resendiz, "Comparison of PD, PID and Sliding-Mode Position Controllers for V–Tail Quadcopter Stability," *IEEE Access*, vol. 6, pp. 38086–38096, 2018.

[5] Z. Pan, F. Dong, J. Zhao, L. Wang, H. Wang, and Y. Feng, "Combined Resonant Controller and Two-Degree-of-Freedom PID Controller for PMSLM Current Harmonics Suppression," *IEEE Trans. Ind. Electron.*, vol. 65, no. 9, pp. 7558–7568, Sep. 2018.

[6] K. J. Astrom and T. Hagglund, "The future of PID control," *Control Eng. Pract.*, vol. 9, pp. 1163–1175, 2011.

[7] R. Vilanova and A. Visioli, *PID Control In The Third Millennium*, no. 1412. Springer London Dordrecht Heidelberg New YorkSpringer, 2012.

[8] Su Whan Sung and I.-B. Lee, "Limitations and Countermeasures of PID Controllers," *Ind. Eng. Chem. Res.*, vol. 38, no. 8, pp. 2596–2610, Aug. 1996.

[9] M. Chidambaram and R. Padma Sree, "A simple method of tuning PID controllers for integrator/dead-time processes," *Comput. Chem. Eng.*, vol. 27, no. 2, pp. 211–215, Feb. 2003.

[10] S. Atic, E. Cokmez, F. Peker, and I. Kaya, "PID Controller Design for Controlling Integrating Processes with Dead Time using Generalized Stability Boundary Locus," *IFAC-PapersOnLine*, vol. 51, no. 4, pp. 924–929, 2018.

[11] M. M. Ozyetkin, C. Onat, and N. Tan, "PID Tuning method for integrating processes having time delay and inverse response," *IFAC Pap.*, vol. 51, no. 4, pp. 274–279, 2018.

[12] J. Bobál, V., Böhm, J., Fessl, J., Machácek, *Digital Self-tuning Controllers*. London, UK: Springer Verlag - London, 2005.

[13] A. Kirecci, I. Eker, and L. C. Dulger, "Self-tuning control as conventional method," *Electr. Eng.*, vol. 85, no. 2, pp. 101–107, 2003.

[14] A. Alexandrov and M. Palenov, *Self-tuning PID-I controller*, vol. 44, no. PART 1. IFAC, 2011.

[15] A. Alexandrov and M. Palenov, *Self-tuning PID-I controller with a new algorithm of tuning of test signal*, vol. 46, no. 9. IFAC, 2013.

[16] Z. Yingling and Z. Quanmin, "Self-tuning PID controller design for a continuously stirred tank reactor," *2015 7th Int. Conf. Model. Identif. Control*, no. Icmic, pp. 1–5, 2015.

[17] J. Mendes, L. Osório, and R. Araújo, "Self-tuning PID controllers in pursuit of plug and play capacity," *Control Eng. Pract.*, vol. 69, no. December 2016, pp. 73–84, 2017.

[18] Y. Ashida, S. Wakitani, and T. Yamamoto, "Design of an Implicit Self-tuning PID Controller Based on the Generalized Output," *IFAC-PapersOnLine*, vol. 50, no. 1, pp. 13946–13951, 2017.

[19] L. Fu, L. Zhou, J. Liang, and M. Lin, "PID Parameters Self-tuning Based on Simplex Method," *2018 Chinese Control Decis. Conf.*, pp. 4769–4774, 2018.

[20] A. B. Corripio and P. M. Tomkins, "Industrial Application of Self-tuning Feedback Control Algorithm," *ISA Trans.*, vol. 20, pp. 3–10, 1981.

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