Design of a Self-Tuning PID Controller for a Temperature Control System Using Fuzzy Logic

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Abstract Temperature plays a significant role in industrial realm, especially in metallurgy and chemical industries. As maintaining optimal conditions in manufacturing can make a huge difference to its profitability and efficiency. Without providing a proper temperature control, the entire production lines can fall apart. Every product needs to be manufactured in an individual and specific conditions. If the temperature is too high or too low then it can affect the output product, potentially it may ruin completely and leads to wasting of raw materials. To maintain the stability of temperature requiring in any situation a temperature control system is needed. Typically classical conventional PID controllers are being used but these controllers have some lack of efficiency in controlling. These controllers exhibit higher overshoot, long rise time and settling time. Self- tuning Fuzzy PID controllers are more efficient than those classical PID control- lers. In this paper we proposed a design of Fuzzy Logic based self-tuning PID controller to reduce overshoot and conquer long rise time and settling time. This design provides more suitable and effective control to the temperature control system in industries.

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1 Introduction

Temperature control systems are being used in a wide variety of industries to manage various operations or processing of manufacture. A temperature controller controls temperature so that the process value matches the set point, but the response differs due to the characteristics of the controlled object and the controlling method of the temperature controller.

Various strategies can be exerted to the temperature control system, like PI, PD, PID [1, 2], Artificial Intelligence (AI) [3], Fuzzy Logic [3], Genetic Algorithm (GA) [1, 4], Fuzzy Self-tuning PID [3] etc. Recently, some strategies based on PID controlling and tuning method have been proposed in order to ameliorate system performances. Gani et al. have proposed an ameliorated design using Genetic Algorithm (GA) on optimal PID tuning of temperature system [1]. Salsbury proposed a feed forward control method as a replacement of conventional PI feedback control [5]. Some has also done with self-tuning fuzzy PID controllers [3]. However those classical conventional PID controllers are less effective and some with modern strategies like GA or AI, there is no doubt about their effectiveness but these strategies are too hard to implement and costly too. Among these Self-tuning Fuzzy PID controller's algorithm is the easiest strategy to implement and it has better effectiveness [4, 6]. This paper predominantly focuses on designing a new self-tuning Fuzzy PID controller to maintain required temperature.

The proposed design of self-tuning Fuzzy PID controller is mainly based on Fuzzy Interference System (FIS). The procedure of fuzzy interference system includes three phases: (i) Fuzzification: In this phase, crisp inputs are transposed into degrees of membership. The degree of membership is discerned by plugging crisp inputs into the membership function affiliated to the fuzzy set. (ii) Rule evaluation: In this phase, each and every fuzzy rule is imposed with a strength value. The strength is discerned by the degrees of memberships of the crisp inputs in the fuzzy sets of preceding portion of the fuzzy rules. (iii) Defuzzification: In this phase the fuzzy outputs are transposed into crisp outputs [7, 8] (Fig. 1).

2 Model of the System

In this paper we are modeling a temperature control system of an industry. Considering a first order transfer function for the controlling system:

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

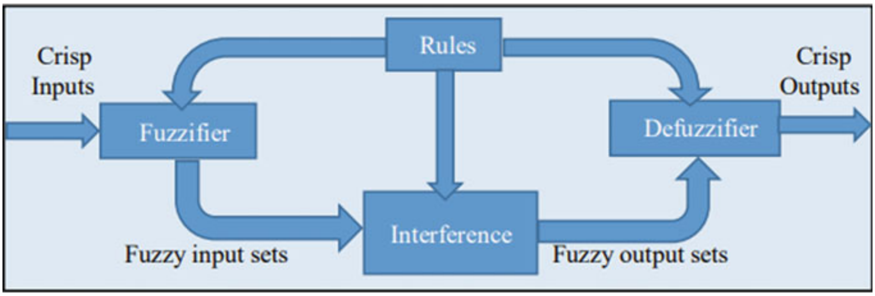

Fig. 1 Block diagram of fuzzy interference system

where, $K = 1$ is defined as the static gain and $\tau = 2.8$ as pure lag time, $T = 3$ as time-constant of the controlled object [9, 10].

2.1 Conventional PID

PID controller is vastly used in every controlling system. The first letter of the name of three controlling terms make up unitedly PID. It is actually a total combination of proportional, integral and derivative terms of controlling system. Here PID controller is used for controlling initially for the system. Equation of conventional PID can be expressed as follows:

$$u(t) = K_P e(t) + K_i \int e(t) + K_d \frac{de(t)}{dt} \tag{2}$$

where, K_P is proportional gain, K_i is integral gain, K_d is derivative gain and e is error present in the controller. These are the tuning parameters of the controller (Fig. 2) [11, 12].

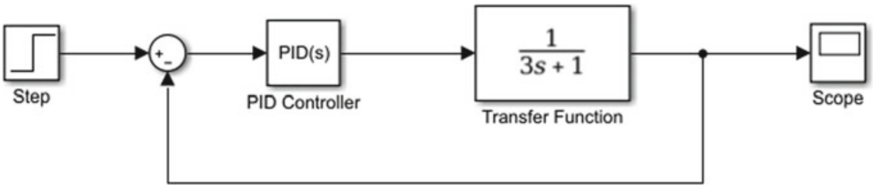

Fig. 2 Block diagram of conventional PID

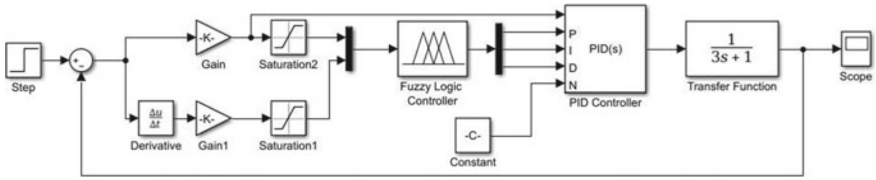

Fig. 3 Block diagram of self-tuning -fuzzy PID

2.2 Self-Tuning Fuzzy PID

The block diagram of the proposed system is shown in Fig. 3. The system is designed in MATLAB through Simulink. Firstly, a Fuzzy Interference System is designed by defining membership functions, universe of discourse and fuzzy rules in MATLAB through Fuzzy Logic Toolbox. Then this FIS system has been implemented in the de- signed block system in Simulink.

In this paper Mamdani method of Fuzzy Interference system (FIS) is used to process the fuzzy system. In MATLAB, there is a tool named Fuzzy logic toolbox which is used to create membership functions, universe of discourse and fuzzy rules. Here, in this interference system, the crisp inputs are system error (***e***) and rate of system error changing (***ec***) and the crisp outputs are proportional gain (K_P) integral gain (K_i) and derivative gain (K_d). The range for the system error (***e***) is taken as [−1 1], rate of change of error (***ec***) is [−1 1] and range for the output is considered as proportional gain (K_P) at [1 5], integral gain (K_i) at [0 1] and derivative gain (K_d) at [0 1.5]. These ranges are obtained from the observations of conventional PID controller since the conventional tuning gives as K_P 1.285, K_i as 0.27 and K_d as 0.9 (Fig. 4) and (Table 1).

3 Result and Analysis

The proposed design has been simulated in MATLAB through Simulink. Figure 5 shows the step response of both the conventional PID controller and proposed PID controller. The step response is determined at the step input temperature of 500 °C.

The comparison of performance and robustness between these two controller is shown in Table 2.

The analysis of the simulation result and comparison table exposes that the proposed self-tuning controller overshoots 0.63% with peak value of 503.16 whereas the conventional PID controller overshoots 13.82% with peak value of 569.13. The proposed method reduced the overshooting problem as well as providing better dynamic performance and robustness. So, It is clear that the proposed self-tuning Fuzzy PID controller for temperature control system provides better efficiency in controlling.

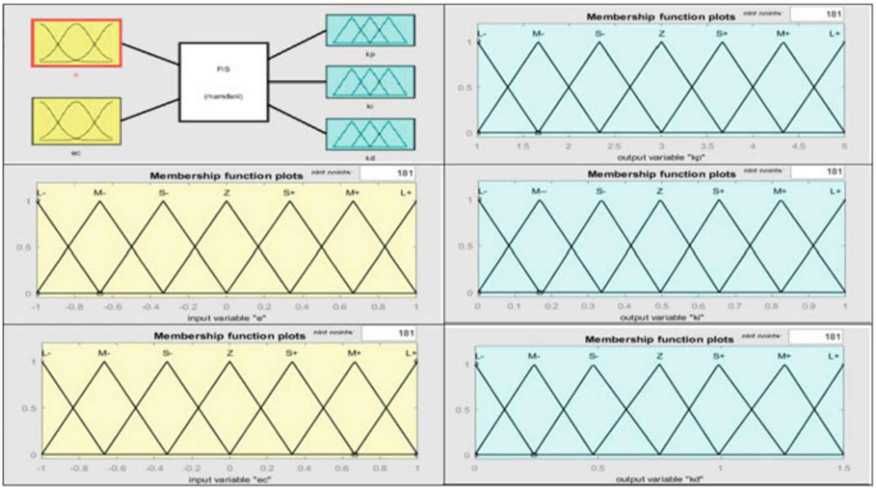

Fig. 4 FIS system and input–output membership functions

Table 1 Fuzzy rules

	ec							
e		L−	M−	S−	Z	S+	M+	L+
L−	*Kp* *Ki* *Kd*	L+ S+ L−	L+ S+ L−	M+ Z L−	M+ Z M−	S+ Z M−	S+ L+ Z	Z Z Z
M−	*Kp* *Ki* *Kd*	L+ S− L−	L+ S− L−	M+ S− M−	M+ S− M−	S+ Z S−	Z Z Z	S− M− Z−
S−	*Kp* *Ki* *Kd*	M+ L− M−	M+ L− M−	M+ M− S−	S+ S− S−	Z Z Z	S− S+ S+	M− M+ S+
Z	*Kp* *Ki* *Kd*	M L− M−	S+ M− M−	S+ M− S−	Z S− Z	S− Z S+	M− S+ S+	M− M+ M+
S+	*Kp* *Ki* *Kd*	S+ L− S−	S+ M− S−	Z S− Z	S− S− S+	S− Z S+	M− S+ M+	M− S+ M+
M+	*Kp* *Ki* *Kd*	S+ M− Z	Z S− Z	S− S− S+	M− S− M+	M− Z M+	M− S+ L	L− S+ L+
L+	*Kp* *Ki* *Kd*	Z S+ Z	S− Z S+	S− Z S+	M− Z M+	M− Z L+	L− L+ L+	L− L+ L+

Where (L−) = Negatively large, (M−) = Negatively Medium, (S−) = Negatively Small, Z=Zero, (S+) =Positively Small, (M+) = Positively Medium, (L+) = Positively Large. And these are the linguistic variables.

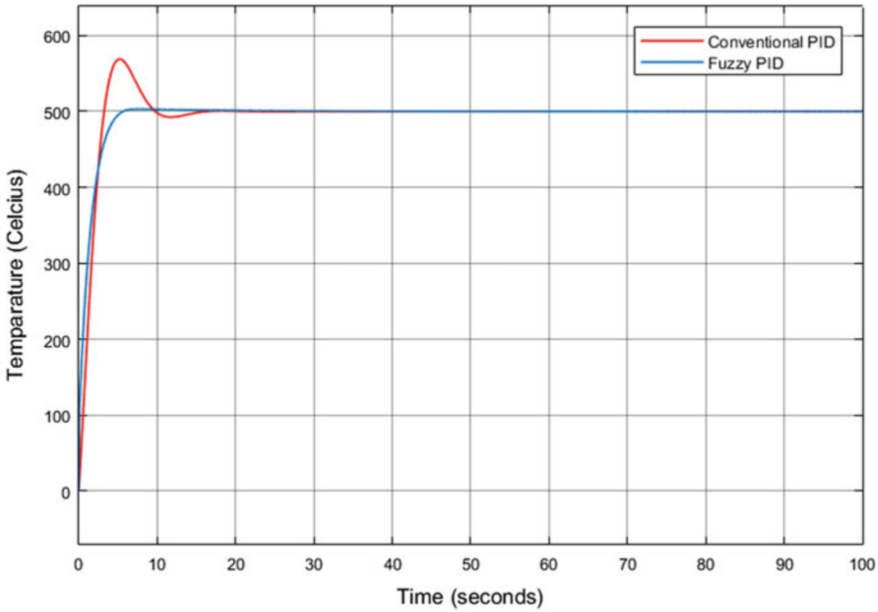

Fig. 5 Response graph after simulation

Table 2 Comparison table of performance and robustness

Parameter	Conventional PID	Fuzzy PID
Rise time	2.43 s	2.99 s
Settling time	8.87 s	4.56 s
Overshoot	13.82%	0.63%
Peak	569.13	503.16
Peak-Time	5.21 s	7.66 s

4 Conclusion

In this paper a self-tuning fuzzy PID controller has been designed for controlling temperature system for industrial management. Fuzzy interference system (FIS) has also been described elaborately in this paper. After simulating the system in MATLAB, the results expose that this self-tuning fuzzy PID has almost zero overshoot with a better dynamic performance than conventional PID. Analyzing the proposed algorithm and results of this paper, it is concluded that fuzzy PID is more effective and it can be replaced with conventional PID. This system can be ameliorated by farther modification in the designing algorithm like membership functions, rules and gains which impacts the controlling performance by extenuating both the overshoot and dynamic response.

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Conflict of Interest
There is no conflict of interest among the authors.

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