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Fuzzy self-tuning PID control of an unstable continuous stirred tank reactor

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Abstract

In this paper, a fuzzy self tuning PID controller for unstable continuous stirred tank reactor is proposed. The essential idea is the on-line controller's gain tuning based on the error pattern (difference of controlled variable and its set point) and fuzzy rules. The performance of the proposed controller is compared with conventional PID. Simulation results show that when the gain of nonlinear process has a big change, proposed controller has better performances than PID controller.

Keywords: Fuzzy self-tuning PID, PID control, unstable CSTR reactor

Introduction

Many important industrial process including high purity distillation column, highly exothermic chemical reaction, pH neutralization, and batch systems can exhibit highly nonlinear behavior. These processes may be required to operate over a wide range of conditions due to large changes in process inputs or set points. When conventional PID controllers are used to control highly nonlinear process, the controllers must be tuned very conservatively in order to provide stable behavior over the entire of operation conditions. There are situations where the conventional PID control is inadequate, for example when the process gain change sign. Other approaches for controlling the nonlinear process by using linear controller are model-based control strategies. These strategies for nonlinear process have traditionally been based on local linearization and linear control design based on the linearized model. If the model updated online the controller should be effective over wide range of operating conditions [1].

The gain scheduling technique has been widely used to compensate for nonlinear process characteristics [2]. In this approach the controller settings are adjusted to compensate for known nonlinearities so that the loop gain is kept as constant as possible [3]. A similar idea has been proposed by Babuska .et al [4]. They used a fuzzy self tuning PI controller for pH control in a fermentation system. Their idea is to tune the gain of PI controller by means of a parameter that results from fuzzy inference mechanism. In that work, there is one output from fuzzy system and this output is used for designing PI controller by using some correlations.

Temperature control of unstable continuous stirred tank reactors (CSTR) is generally crucial and complicated due to system nonlinearity [5]. Many different controllers have been used for controlling the unstable CSTR by researchers. In some of them, the traditional PID controllers tuned based on the linearized reactor model [6]. Furthermore, based on feedback linearization technique, several controllers either adaptive or non adaptive have been proposed [7-11]. Also nonlinear model predictive control strategy is used by Khaksar et.al [12] and a dynamic neural network control (DNNC) is used by Nikharavesh et.al [13].

In this paper, we consider temperature control problem of CSTR in which an unstable first order exothermic reaction takes place. A fuzzy self tuning PID controller for on-line updating the PID parameters is used. The rest of paper is organized as follows: first the fuzzy self-tuning PID controller is described. Then the performance of the proposed controller is compared with a conventional PID controller via simulation.

Fuzzy self-tuning PID controller

The control system consists of an adaptive PID controller and a fuzzy self tuning mechanism as depicted in Figure (1). The PID controller has the following standard form:

$$u(t) = u_s + K_C e(t) + K_I \int_0^t e(t)dt + K_D \frac{de(t)}{dt} \qquad (1)$$

Here K_C, K_I and K_D are proportional, integral and derivative gains to be adjusted on-line by fuzzy mechanism. The fuzzy self-tuning block has two inputs, the control error and its derivative, and three outputs, the PID controller parameters (K_C, K_I and K_D).

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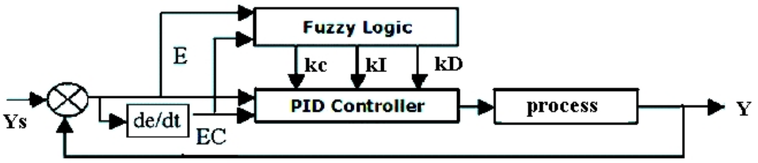

Figure1: Fuzzy self tuning PID controller scheme

Fuzzy adaptation

The first step performed in the fuzzy mechanism is scaling the input variables into the domain between a_i and b_i. The second step is the calculation of membership value of the fuzzy input variable in each fuzzy set. Five fuzzy set (NL, NS, ZO, PS, PL) are used for both input variables (error and error derivative). Here NL, NS, ZO, PS and PL stand for negative large , negative small, zero, positive small and positive large. Each fuzzy set is represented by fuzzy membership function as shown in Figure (2).

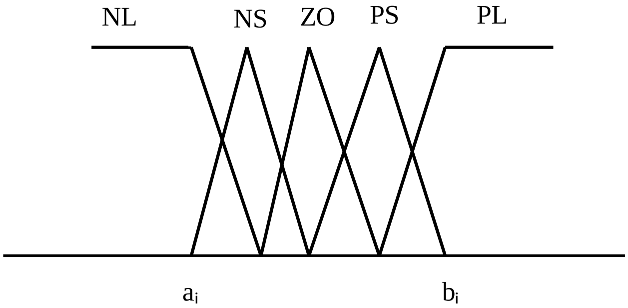

Figure 2: Fuzzy sets and their corresponding membership functions for input variables

The third step of the fuzzy adaptation mechanism is mapping of input variables to output variables. The membership functions of outputs are shown in Figure (3). Four fuzzy sets (ZO, S, H, BH) are used for output variables (Kc, K_I , K_D). Here ZO, S, H, BH stand for zero, small, high and big high.

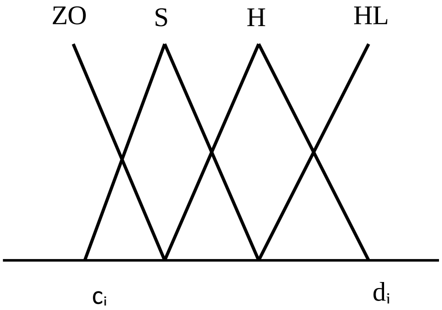

Figure 3: Fuzzy sets and their corresponding membership functions for output variables

The fuzzy mapping of the input variables to the output variables is represented by the fuzzy if-then rule of the following form:

$$\text{If } e \text{ is } A_i \text{ and } \Delta e \text{ is } B_i \text{, then } K_p \text{ is } C_i ,\, K_I \text{ is } D_i ,\, K_D \text{ is } E_i \qquad (2)$$

The CSTR model

Consider a continuous stirred tank reactor in which an exothermic first order reaction takes place (A g B). The material and energy balances based on the assumptions of constant volume inside the reactor, perfect mixing and constant physical properties allow obtaining the dynamic model. The differential equations can be written in dimensionless form as follows [14].

$$\frac{dx_1}{dt} = q(x_{1f} - x_1) - j\ x_1 k \tag{3}$$

$$\frac{dx_2}{dt} = q(x_{2f} - x_2) - d\,(x_2 - x_3) + b\ j\ x_1 k \tag{4}$$

$$\frac{dx_3}{dt} = d_1\left[q_c\,(x_{3f} - x_3) + dd_2\,(x_2 - x_3)\right] \tag{5}$$

With

$$k = \exp\left(\frac{x_2}{1 + \frac{x_2}{g}}\right) \tag{6}$$

The variables x_1, x_2 and x_3 stand for the dimensionless reactant concentration, reactor temperature and cooling jacket temperature. The symbols q and q_c represent the reactor flow rate and the cooling jacket flow rate. The numerical values of model parameters are shown in Table (1).

Table 1: CSTR model parameters

Parameter	Value
φ	0.072
β	8
δ	0.3
γ	20
q	1
δ_1	10
δ_2	1
x_{1f}	1
x_{2f}	0
$x_{3\mathrm{f}}$	-1

The main objective is controlling the reactor temperature with manipulating the coolant flow rate (q_c). Steady state behavior of the system is shown in Figure (4). The process exhibits three steady state points with middle one being unstable. These points are shown in Table (2).

Table 2: Steady state points

	x_1	x_2	x_3
stable	0.8971	0.4752	-0.6825
unstable	0.4737	3.1702	-0.2968
stable	0.240	4.6596	-0.0508

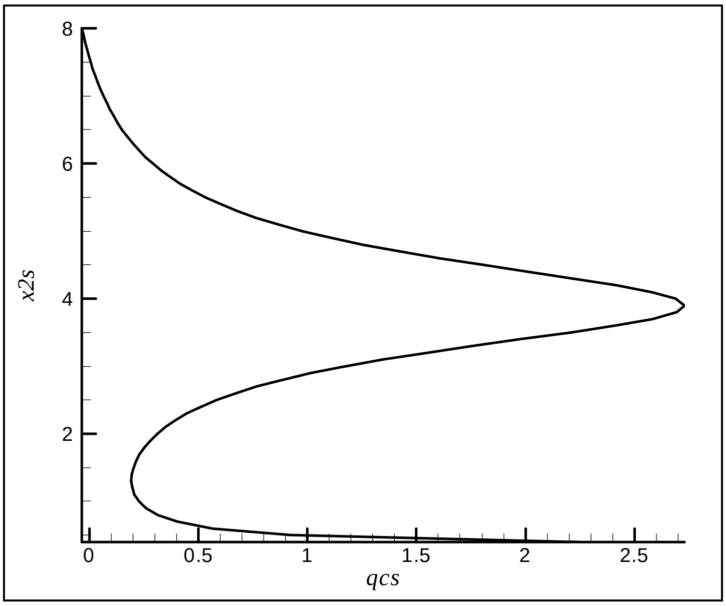

Figure 4: Steady state behavior for the CSTR

Simulation results

In order to show the effectiveness of the proposed controller, set point tracking and load rejection problems are considered. Figure (5) shows the performance of temperature tracking for proposed controller. As can be seen from the results, the fuzzy self-tuning PID controller has better performance than PID when the gain of process is changed. The conventional PID controller is tuned by try and error.

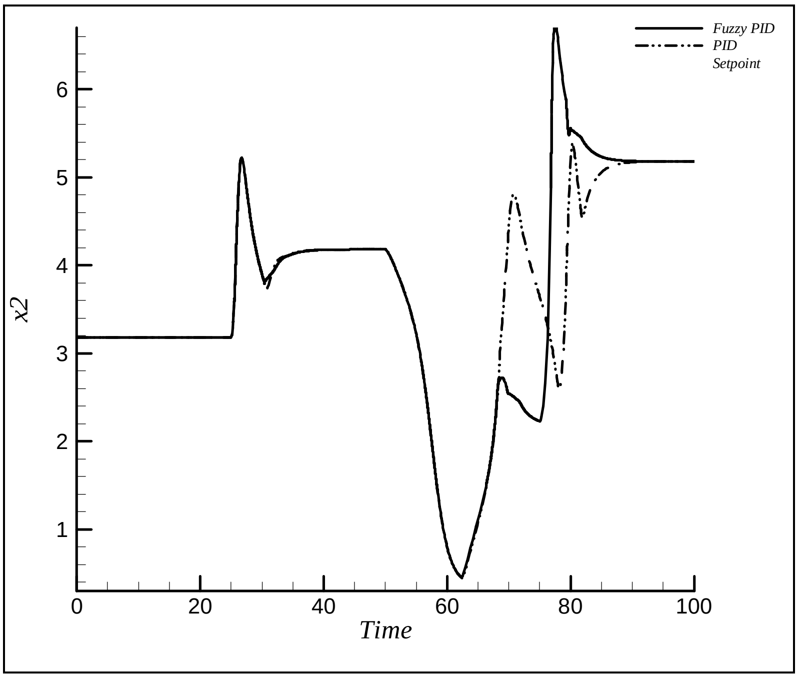

Figure 5: Set point tracking

Next, we investigate the transient response of the system for load rejection. The temperature transient responses for the controllers are shown in Figures (6) and (7). The results show that the proposed controller has better performance than PID controller.

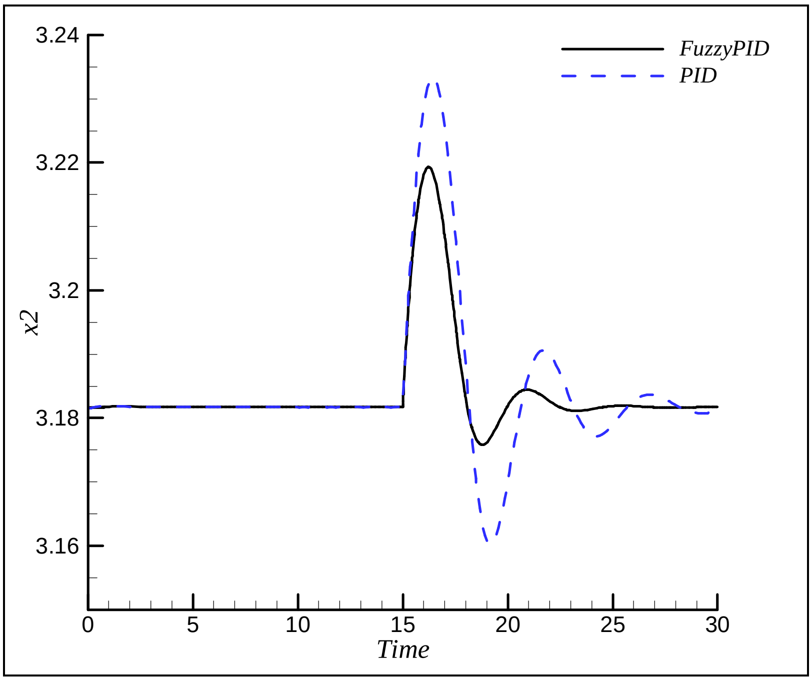

Figure 6: Load rejection performance in changing x_{2f} from 0 to 0.08

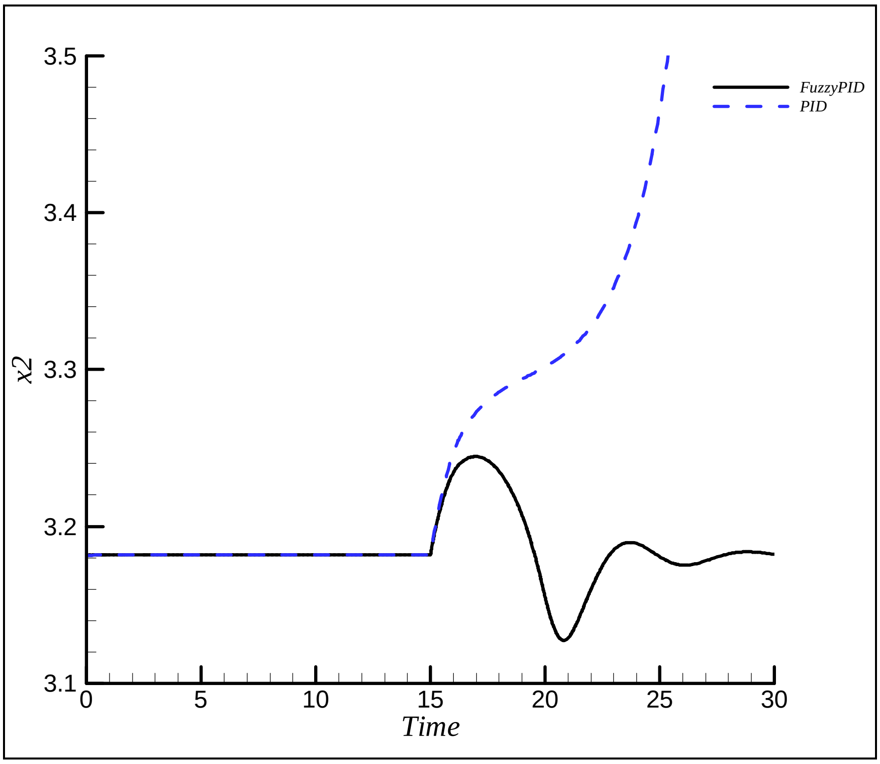

Figure 7: Load rejection performance in changing x_{2f} from 0 to 0.1

Conclusion

In this paper, fuzzy tool is used for designing the fuzzy system to determine PID's parameters by means of control error and change in control error. This controller is applied to nonlinear unstable CSTR reactor. Simulation results show that proposed controller has better performance in set point tracking and load rejection than conventional PID.

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