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On the Auto Tuning of Fuzzy PID Controller

Yoon Sang KIM[a], Hyun Cheol OH[b] and Doo Soo AHN[c]

a. Dept. of Electrical Engineering, SungKyunKwan University
300 Chunchun-dong, Jangan-gu, Suwon, 440-746, Korea
Tel:+82-331-290-7167 Fax:+82-331-290-7170 Email:yskim@nature.skku.ac.kr
b. ohcl@chollian.net
c. dsahn@yurim.skku.ac.kr

Abstract

This paper presents an auto tuning method of PID controller based on the application of fuzzy logic. The proposed method combines the principles of PID control with fuzzy control, which can considerably improve the performance index of PID controller. Simulation results show that higher performance and accuracy of overall system for desired value is achieved with our manner when compared to widely-used conventional tuning method.

Keywords: Auto Tuning, Fuzzy PID Controller

1. Introduction

Fuzzy control is a major application field of fuzzy theory, which can substitute the model-based conventional control methodologies. It is mainly due to the fact that mathematical modeling is not required and the computation can be reduced by using the lookup tables obtained from input-output information via fuzzy inference based on fuzzy logic[1-4]. Despite of these advanteges, the fuzzy contoller involves some difficulties which cannot guarantee the desired performance such as rise time and maximum overshoot when the plant or its parameters is changed abruptly.

In most process industries, although the modern control theory has developed considerably, the Proportional-Integral-Derivative(PID) controller is still used widely because of its smple structure and easiness of implementation[5,6]. However, since most plants are changed continuously by process environments including disturbance, noise and *etc*, the PID controller cannot satisfy all the desired performances. To complement these problems, various approaches have been attempted.

For the tuning of the controller gain, methods using system estimation[7], fuzzy logic[8] and each step response characteristics[9] are presented previously. Especially, method of [9] is used widely because controller parameters can be updated by five special characteristics to meet the desired performance.

This paper presents an auto tuning method of PID controller based on fuzzy logic, which can satisfy the above five characteristics selected as performance index of closed-loop system. The proposed method is to update the controller parameters, which combines the PID structure with fuzzy control. By reducing the computational burden required for real-time implementation via smaller rule-base obtained from the proposed method, the higher convergence speed can be achieved when compared to the widely-used conventional method.

2. PID Control Algorithm

There are three well-known methods such as MMGM(min max gravity method), PSGM(product sum gravity method) and SFRM(simplified fuzzy reasoning method) for fuzzy reasoning[3,4]. SFRM offers advanteges of reducing computation and facilitating implementation when compared to the other methods such as MMGM and PSGM. Therefore, we would the PID control algorithm for the auto tuning using this SFRM.

2.1 SFRM

The fuzzy reasoning by SFRM is

$$\begin{array}{ll} Rule\ 1: & A_1 \text{ and } B_1 \rightarrow C_1 \\ Rule\ 2: & A_2 \text{ and } B_2 \rightarrow C_2 \\ Rule\ 3: & A_3 \text{ and } B_3 \rightarrow C_3 \\ \vdots & \vdots \qquad\quad \vdots \\ \vdots & \vdots \qquad\quad \vdots \\ Rule\ k: & A_k \text{ and } B_k \rightarrow C_k \\ Fact\ : & e \text{ and } de \rightarrow u \\ \hline Cons: & \qquad\qquad C' \end{array} \tag{1}$$

where, A_i is a fuzzy set of error e and C_i is of control input u.

h_i of e and de, element of previous term [A_i and B_i], is

$$h_i = \mu_{A_i}(e) \cdot \mu_{B_i}(de) \tag{2}$$

For h , Z_0 obtained by weighting average is

$$Z_0 = \frac{h_1 z_1 + h_2 z_2 + h_3 z_3 + \cdots + h_k z_k}{h_1 + h_2 + h_3 + \cdots + h_k} \tag{3}$$

2.2 Control algorithm

Since the integral term is ignored, the conventional approach is usually performed by transcient control and detailed control, which makes the design procedure difficult. To complement these problems, the fuzzy reasoning and PID structure are used by

$$du = K_p \cdot e + K_i \cdot ie + K_d \cdot de \tag{4}$$

Assuming that maximum and minimum of e are described by e_m and e_0, following equation such as eq(5) is obtained by

$$e_0 \le e \le e_m \tag{5}$$

Similarly, the maximum and minimum of de and ie are described by

$$de_0 \le de \le de_m \tag{6}$$

$$ie_0 \le ie \le ie_m \tag{7}$$

Therefore, using SFRM, PID controller can be expressed by fuzzy rule as

$$\begin{array}{lclll} Rule\ 1 & : & e_1 & \text{and } de_0 & \text{and } ie_0 \rightarrow f_1 \\ Rule\ 2 & : & e_2 & \text{and } de_0 & \text{and } ie_m \rightarrow f_2 \\ Rule\ 3 & : & e_3 & \text{and } de_m & \text{and } ie_0 \rightarrow f_3 \\ Rule\ 4 & : & e_4 & \text{and } de_m & \text{and } ie_m \rightarrow f_4 \\ Rule\ 5 & : & e_5 & \text{and } de_0 & \text{and } ie_0 \rightarrow f_5 \\ Rule\ 6 & : & e_6 & \text{and } de_0 & \text{and } ie_m \rightarrow f_6 \\ Rule\ 7 & : & e_7 & \text{and } de_m & \text{and } ie_0 \rightarrow f_7 \\ Rule\ 8 & : & e_8 & \text{and } de_m & \text{and } ie_0 \rightarrow f_8 \\ Fact & : & e & & \text{and } ie \\ \hline Cons & : & & & \qquad\quad f \end{array} \tag{8}$$

f_i of eq(8) are real vaues and can be described as

$$\begin{array}{l} f_1 = K_p \cdot e_0 + K_d \cdot de_0 + K_i \cdot ie_0 \\ f_2 = K_p \cdot e_0 + K_d \cdot de_0 + K_i \cdot ie_m \\ f_3 = K_p \cdot e_0 + K_d \cdot de_m + K_i \cdot ie_0 \\ f_4 = K_p \cdot e_0 + K_d \cdot de_m + K_i \cdot ie_m \\ f_5 = K_p \cdot e_m + K_d \cdot de_0 + K_i \cdot ie_0 \\ f_6 = K_p \cdot e_m + K_d \cdot de_0 + K_i \cdot ie_m \\ f_7 = K_p \cdot e_m + K_d \cdot de_m + K_i \cdot ie_0 \\ f_8 = K_p \cdot e_m + K_d \cdot de_m + K_i \cdot ie_m \end{array} \tag{9}$$

Also, output estimate f f of fuzzy controller can be written from eq(3) by

$$\begin{aligned} f &= \frac{f_{11} + f_{22}}{h_{11} + h_{22}} \\ &= f_{11} + f_{22} = K_p \cdot e + K_d \cdot de + K_i \cdot ie \end{aligned} \tag{10}$$

where

$$f_{11} = abc \cdot f_1 + ab(1-c) \cdot f_2 + a(1-b)c \cdot f_3 + a(1-b)(1-c) \cdot f_4$$

$$f_{22} = (1-a)bc \cdot f_5 + (1-a)b(1-c) \cdot f_6 + (1-a)(1-b)c \cdot f_7 + (1-a)(1-b)(1-c) \cdot f_8 \quad (11)$$

$$h_{11} = abc + ab(1-c) + a(1-b)c + a(1-b)(1-c)$$

$$h_{22} = (1-a)bc + (1-a)b(1-c) + (1-a)(1-b)c + (1-a)(1-b)(1-c)$$

$$h_{11} + h_{22} = 1 \quad (12)$$

$$a = \mu_{e_0}(e) = \frac{e_m - e}{e_m - e_0} \quad (13)$$

$$b = \mu_{de_0}(de) = \frac{de_m - de}{de_m - de_0} \quad (14)$$

$$c = \mu_{ie_0}(ie) = \frac{ie_m - ie}{ie_m - ie_0} \quad (15)$$

3. Auto Tuning of Fuzzy PID Controller

Fuzzy controller is not generalized because of model dependance although various tuning schemes are developed. Therefore, this chapter presents an algorithm which can satisfy desired performance and ensure the overall stability of control system conpensated by the fuzzy PID controller.

3.1 fuzzy PID parameter

For the auto tuning of controller parameters, the following elements including scaling factor, peak value, membership functions of width value and rule must be considered as

(1) scaling factor is considered as maximum peak value defined by universe of discourse.
(2) peak value is defined as the interval crossing $(0,0) \rightarrow (1,0) \rightarrow (0,0)$.
(3) rule of membership function is defined by fuzzy level including THEN part.
(4) width value of membership function is defined by the interval from (0,0) to (1,0).

3.2 structure of auto-tuner

Auto-tuner for auto tuning of PID controller is composed of three parts such as FE(feature extractor), FIR(fuzzy inference engine) and RB(rule-base), and the overall system is shown in the Fig 1.

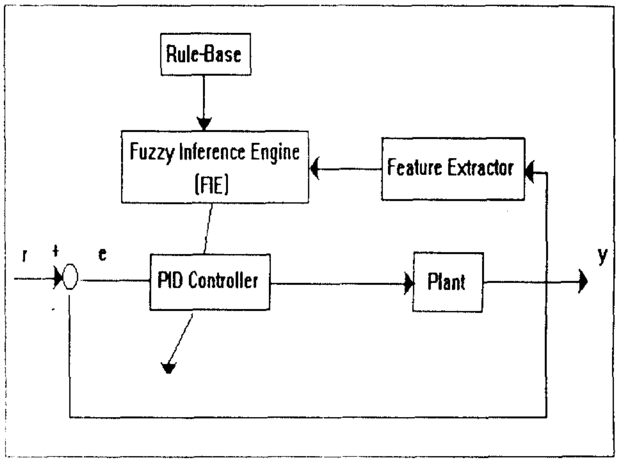

Fig. 1. Block diagram of overall controlled system

1. FE(feature extractor)

FE is a part which extracts the characteristics of system numerically after trancient response and is characterized such as

(1) Percent Overshoot
(2) Damping Ratio
(3) Rise Time
(4) Settling Time
(5) Overshoot Height Ratio.

Also, FE excites output signals using above five factors and following two factors as

(1) desired value
(2) weighting

Therefore, the output signal of FE is as following

$$P^i_o = [\ (P^i_d - P^i_r)\ /\ P^i_d\ ] \times W_a \qquad (16)$$

where $i = 1, 2, 3, 4, 5$, P^i_o is output of FE, P^i_d desired value, P^i_r real value and W_a weighting

2. RB(rule-base)

The rule-base is chosen for auto tuning of PID controller to satisfy desired performance index as

$$\boxed{\text{If } P^i_o \text{ is A , then U is B}} \qquad (17)$$

where P^i_o is output of FE, $A: P, Z, N$ ***value*** and $U: U^k_c,\ U^k_i,\ U^k_d$, output of FIE

3. FIE(fuzzy inference engine)

The parameters of PID controller is updated at each iteration such as

$$\begin{aligned} K^{k+1}_c &= K^k_c \times U^k_c \\ T^{k+1}_i &= T^k_i \times U^k_i \\ T^{k+1}_d &= T^k_d \times U^k_a \end{aligned} \qquad (18)$$

where K^k_c, T^k_i, T^k_d are k-th value of PID controller at each iteration and U^k_c, U^k_i, U^k_d outputs of FIE

The Singleton method is used for fuzzyfication of this output and fuzzy linguistic variable $A: P, Z, N$ ***value*** is chosen such as Negative, Zero, Positive. The Center of Area method is for defuzzification and the form of membership function is such as

$$U^k_{c\ or\ i\ or\ d} = \sum_{m=-1}^{1} m \times \mu_m \Big/ \sum_{m=-1}^{1} \mu_m \qquad (19)$$

where μ_m is memership value

4. Simulation

To demonstrate the availability of the proposed method, the system described by 2nd order is simulated. The classical method based on *Ziegler/Nichols* is used to compare the performance of controlled result. The unit step is used for reference input.

Consider following plant

$$G_p(s) = \frac{1}{(1+10s)^2} \qquad (20)$$

Table 1 summarizes conditions used for simualtion, and $K_c = 15$, $T_i = 6.75$, $T_d = 1.69$ are used for the initial values of controller parameters.

Table 1. The conditions used for simulation

Characteristics	Desired	Weighting ($0 \le W_d \le 1$)
Percent overshoot	15	0.4
Damping ratio	0.7	0.1
Rise time	1	0.4
Settling time	3	0.4
Overshoot height ratio	0.05	0.1

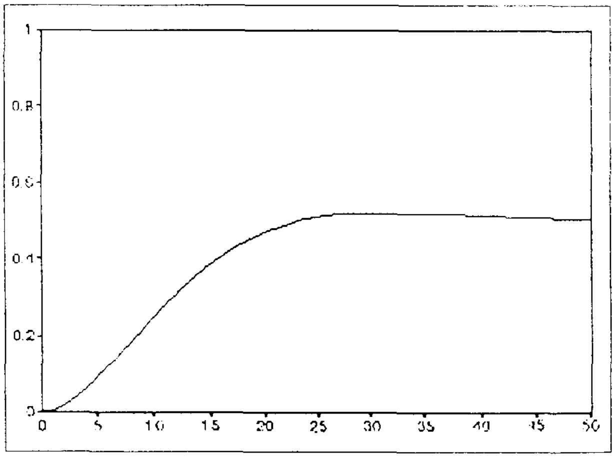

Fig. 2. Response of uncompensated

Output response of uncompensated plant is given in Fig. 2.

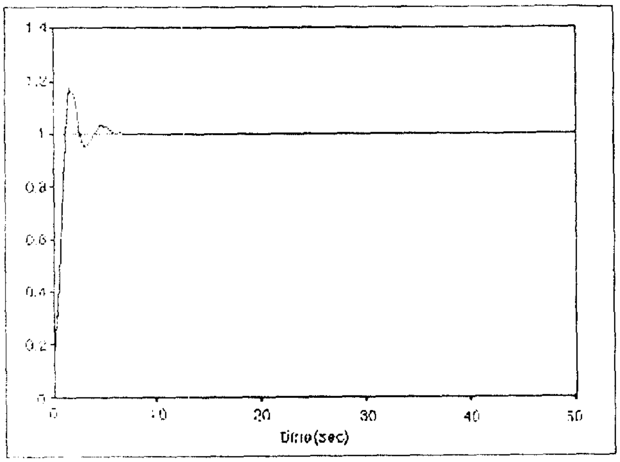

Fig. 3. Output response of compensated plant by conventional method

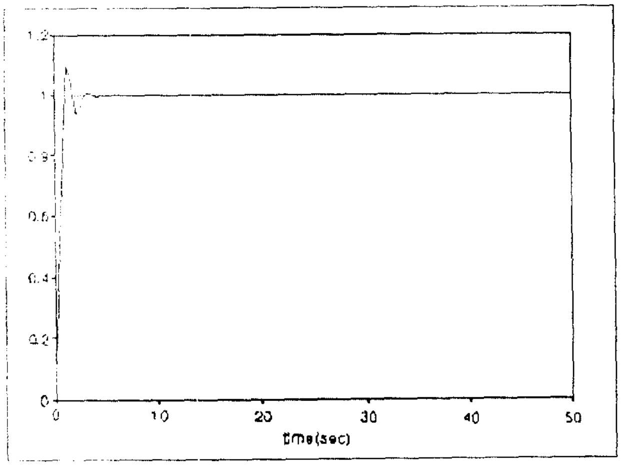

Fig. 4. Output response of compensated plant by the proposed method

Fig 3 shows the output response of controlled system by conventioal method, and the output response of controlled system by the proposed method is shown by in the Fig. 4.

As can be seen in the figures, the maximum overshoot and rise time can be reduced via the proposed method when compared to conventional approach. Also, it is shown that the performance can be improved by proposed method.

By smaller rule-base of our proposed method compared to conventional method, the computational burden can be reduced considerably. Therefore, it is expected that the proposed method is effective for the auto tuning of fuzzy PID controller.

5. Concluding remarks

In this note, simple and efficient method for auto tuning of fuzzy PID controller is presented. The proposed method is to update the parameters of PID controller using fuzzy logic, which allows to be real-time implementation for auto tuning. By reducing the computatioal burden considerably, the higher convergence speed can be achieved when compared to widely-used conventioal method. It does not involve any additional procedure, hence the difficulties of conventioal approach can be avoided. Therefore, it is expected that the proposed method is very effective for the auto tuning of PID controller when applied to various process industries.

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