Comparsion between classic PID,fuzzy and fuzzy PID controllers

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Abstract

In this paper, the performances of fuzzy, fuzzy PID and classic PID controllers are compared through simulation studies. For this purpose the level control of a two intracting tanks system was selected. The results showed that the classic PID and fuzzy PID have the same performance. But tunning of classic PID is very simpler than fuzzy controllers. Therefore for simple processes such as controlling the level of two interacting tanks, using classic PID controllers are prefered.

Keywords: fuzzy method, PID controller, fuzzy controler, fuzzy PID controller.

Introduction

Zadeh introduced fuzzy set theory in 1995, and the first fuzzy logic control algorithm was implemented by Mamdani on a steam engine in 1974. In the following years, fuzzy logic control has been widely used in many industrial applications successfully and has gained significant achievements [1].

Nowadays, conventional proportional-integral-derivative (PID) controllers are commonly used in industry due to their simplicity, clear functionality, and ease of implementation. Meanwhile, fuzzy control, an intelligent control method imitating the logical thinking of human and independent of accurate mathematical model of the controlled object, can overcome some shortcomings of the traditional PID. However, the fuzzy is a nonlinear control and the output of the controller has the static error [2].

There are two conventional methods for controlling and setting the level of tanks, which are use in industries such as power plants and refineries. In one of these methods, an on-off controller controls the tank level. In the other method, a PID controller is use for controlling and exact setting of the level. This method applies a proper PID controller in a feedback loop and controls the level of the tank with a convenient accuracy [3].

Fuzzy controller design is composed of three important stages, namely, I. knowledge base design, II. tuning of controller parameters, and III. membership functions. In order to make

the fuzzy controller achieve the prospective target, we have to adjust these three stages of the fuzzy controller [4].
There have been numerous articles investigating different schemes of applying fuzzy logic to the design of PID controllers, which are generally termed as fuzzy PID controllers. Fuzzy PID controllers can be classified into two types: the gain scheduling and the direct action [5, 6].
Three PID parameters K_p, K_i, and K_d were respectively calculated through fuzzy logic based on error and error rate [7, 8].
The purpose of this paper is to study the fuzzy PID controller, which combines the traditional PID controller and fuzzy control algorithm and using it for controlling the level of two interacting tanks system.

Experimental setup and modeling

a) Experimental setup

Fig.1 shows a photo of experimental setup of two intracting tanks system. The schematic diagram of this system is also shown in Fig.2.

Fig.1. Experiment setup

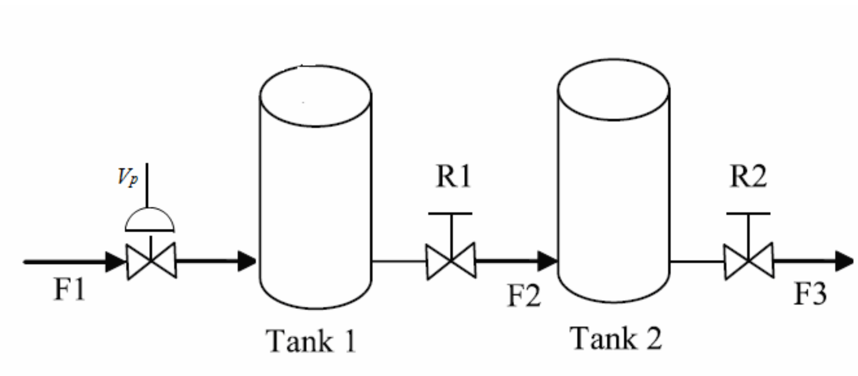

Fig. 2. Schematic diagram of two interacting tanks system.

In this expermental setup, the cross sectional area of tank 1 and 2 are 187.29 and 100 cm^2 respectively. Signal inlet to control valve (V_P) is variable from 4 to 20 mA, variable M is the percentege of valve opening and range from zero to hundered percent. The models of inlet flow rate to first tank ($F_1(t)$) and the resistance of manual valves 1 and 2 that obtained through the tests are shown in table 1.

Table 1. Parameters of experimental setup

Valve opening(%)	$M = 0.071429V_p - 0.42857$
Inlet flow rate	$F_1(t) = -2.5093\times10^5 M^{10} + 1.1568\times10^6 M^9 - 2.2236\times10^6 M^8 + 2.3059\times10^6 M^7 - 1.3977\times10^6 M^6 + 5.0919\times10^5 M^5 - 1.1889\times10^5 M^4 + 23828\times M^3 - 5357.3\times M^2 + 911.01\times M + 0.0087447$
Resistance of manual valve 1	$R_1 = -1055.4\times M^3 + 2152.9\times M^2 - 1535.6\times M + 448.82$
Resistance of manual valve 2	$R_2 = -64.719\times M^4 - 7.1464\times M^3 + 333.12\times M^2 - 419.05\times M + 169.12$

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b) Mathematical Modeling of experimental setup

The basic model equation of interacting two-tank system is given by

$$F_1(t) - F_2(t) = A_1 \frac{dh_1}{dt} \quad (1)$$

$$F_2(t) = \frac{h_1 - h_2}{R_1} \quad (2)$$

$$F_2(t) - F_3(t) = A_2 \frac{dh_2}{dt} \quad (3)$$

$$F_3(t) = \frac{h_2}{R_2} \quad (4)$$

Where $F_1(t)$ is the tank1 inflowing liquid (cm^3/s), $F_2(t)$ is the tank1 outflowing liquid or the tank2 inflowing liquid (cm^3/s), $F_3(t)$ is the tank2 outflowing liquid (cm^3/s), A_1 is the tank1 cross sectional area (cm^2), A_2 is the tank2 cross sectional area (cm^2) , h_1 is the liquid level in tank1 (cm), h_2 is the liquid level in tank2 (cm), R_1 and R_2 are linear resistances of tank1 and tank2 (cm/(cm^3/s)).

In this paper, the nonlinear model of two-tank system is simulated in Matlab/simulink software. Then the control algorithms are applied on the simulated process.

Controllers structures

In this research, the control problem is considered for systems which have single control input and single output. It is known that, PID controller is the most widely used in industry due to its simple control structure and easy design. The control signal for a system using a conventional PID controller can be expressed in the time domain as:

$$u_{PID} = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \quad (5)$$

where e is the error between desired variable and measured variable, u_{PID} is the deviated control signal, K_p, K_i and K_d are the proportional, integral, and the derivative gains, respectively[10,11,12].

In fuzzy PID controllers, the three parameters of PID controller (K_p, K_i and K_d) to be tuned by using fuzzy tuners. The detailed fuzzy PID scheme is clearly shown in Fig. 3 and 4. There are two inputs to the fuzzy controllers: absolute error e and absolute derivative of error de.

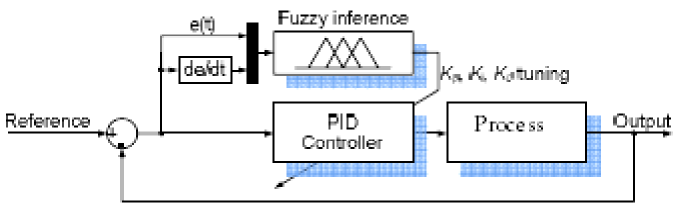


Fig.3. The configuration of fuzzy PID control.

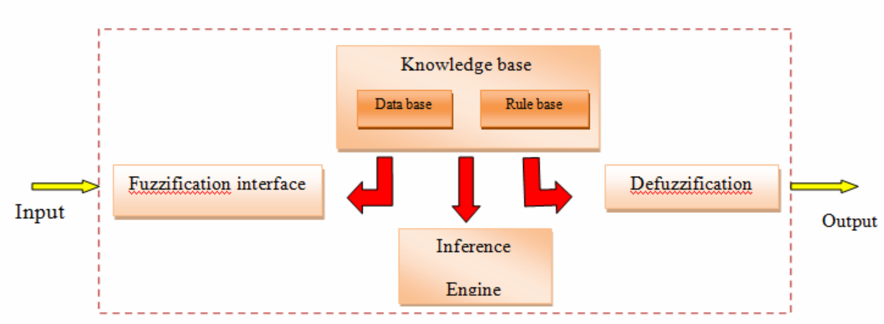


Fig. 4. Fuzzy inference system

For each input variables, triangle membership functions (MFs) are requested to use. Because all of the MFs are triangle shapes, so we can express these MFs as follows:
The triangular curve is a function of vector *x*, and depends on three scalar parameters a, b, and c, as given by

$$f(x,a,b,c)=\begin{cases} 0 & x\le a \ \text{or}\ x\ge c \\ \dfrac{x-a}{b-a} & a\le x\le b \\ \dfrac{c-x}{c-b} & b\le x\le c \end{cases} \qquad (6)$$

or, more compactly, as

$$f(x,a,b,c)=\max(\min(\frac{x-a}{b-a},\frac{c-x}{c-b}),0) \qquad (7)$$

The parameters a and *c* locate the "feet" of the triangle and the parameter *b* locates the "peak"[13,14].

Simulation Results

In this paper Zeigler-Nichols (Z-N) tuning method [12] is used to find the controller parameters of classic PID. The resulted parameters are shown in the table 2.

Table 2. Values of classic PID parameters.

	$K_p(K_C)$	$K_i\,(K_C/\tau_i)$	$K_d\,(K_C{*}\,\tau_D)$
value	2.346167	0.0387	4.3582

In fuzzy PID, the controller parameters must be calculated by fuzzy tuner. This tuner has two inputs: error *e* and derivative of error *de*, and three outputs: K_p, K_i and K_d as shown in Fig.5. For the input variables (*e* and *de*) five membership functions NH, NL, ZO, PL and PH are used. They are NH, Negative high, NL, Negative low, ZR, Zero, PL, Positive low and PH, Positive high.

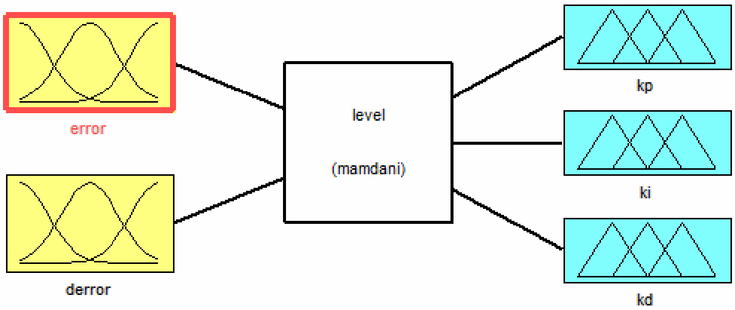
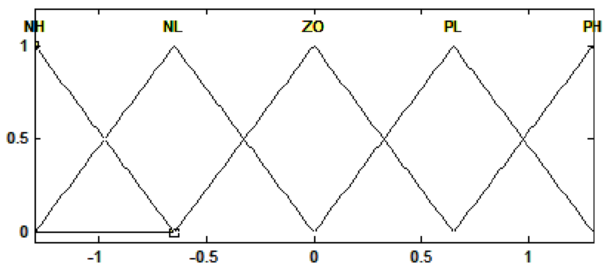
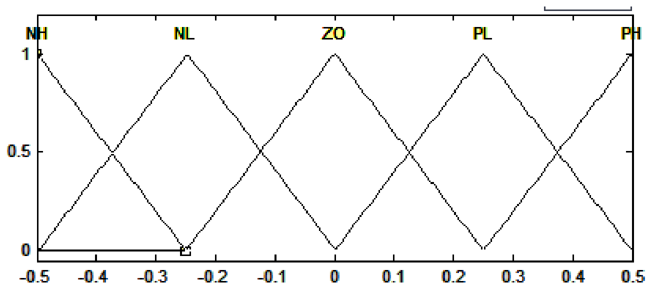


Fig.5 The configuration of fuzzy PID control block in the Toolbox MATLAB/fuzzy.

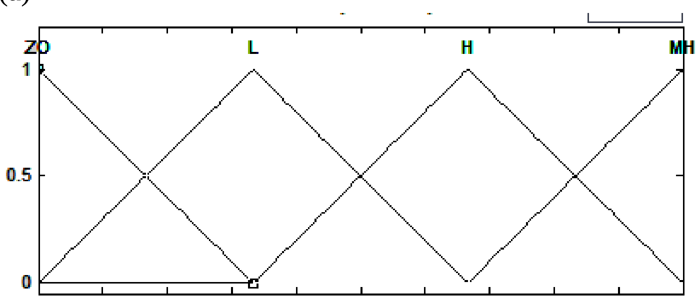
For each output variables (K_P , K_i and K_d), four membership functions are used as shown in Fig.6. Here, "ZO", "L", "H" and "PH" are "Zero", "Low", "High" and "Positive High", respectively.



(a)



(b)



(c)

Fig.6. (a) Membership function for error $e(t)$,(b) Membership function for derivation of error $de(t)$, (c) Membership function for Kp $\varepsilon[0,2.5]$, K_i $\varepsilon[0,0.05]$ and K_d $\varepsilon[0,5]$

Generally, fuzzy rules are dependent on the control purpose and the type of a controller. The rules are determined from the intuition or practical experience in order to obtain high performance for the control system. In this study, the rules designed are based on the characteristic of interacting two-tank system such as slow response, non-linearity, disturbances, and properties of the PID controller. Consequently, the fuzzy reasoning results of outputs are gained by aggregation operation of fuzzy sets of inputs and the designed fuzzy rules, where MAX-MIN aggregation method is used.

Because definite values of outputs are needed for application, the fuzzy results should be defuzzified. In this paper, the "Centroid" method is used for defuzzication to gain the accuracy of K_p , K_i and K_d which are later sent to PID controller to control the two interacting tank system. The rule sets that are used, are shown in surfaces in Fig. 7 and 8.

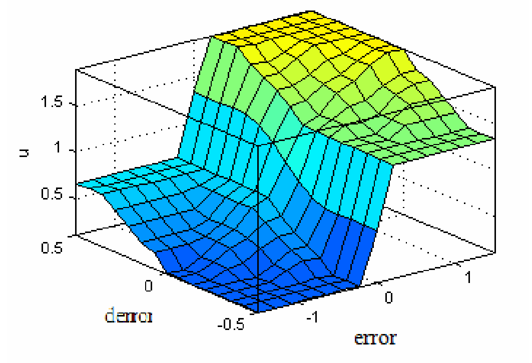


Fig.7. Control surface showing between u_i, e and de for fuzzy control

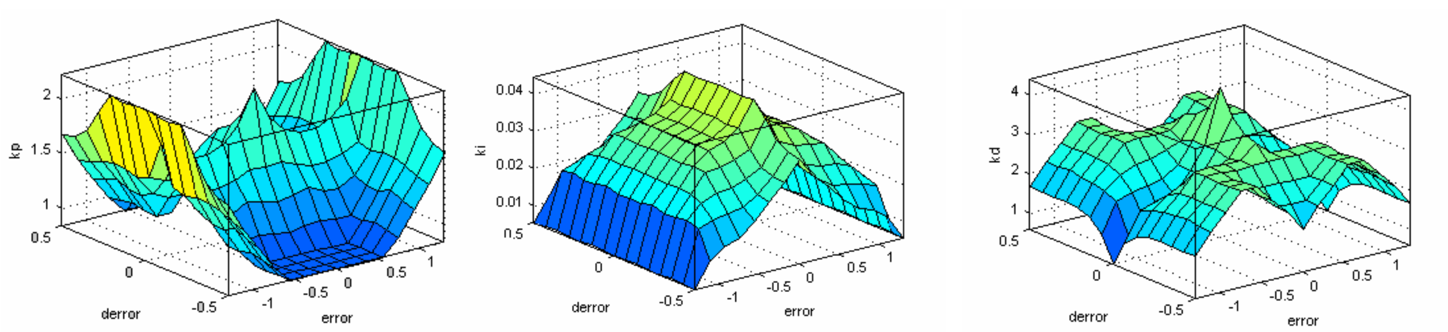


Fig.8. Control surfaces showing relationship between K_p, K_i, K_d , e and de

According to proportional gain calculated by Z-N method which is 2.34667, membership function was considered [0, 2.5] and amount of integral and derivation gain was considered [0, 0.05] and [0, 5] based on classic PID control respectively.

The performaces of three controllers (classic PID, fuzzy and fuzzy PID) are compared through simulation results when a setpoint change is applied. The closed loop responses of second tank level for three controllers are shown in Fig.9. The values of integral absolute error (*IAE*) are also shown in table 3.

Table 3. Integral absolute error for process

	PID controller	Fuzzy control	Fuzzy PID contoller
IAE	35.3335	51.4317	38.6659

As can be seen from the results, the classic and fuzzy PID controllers have the same performances. But tuning the classic PID is very simpler than the fuzzy PID, therefore for controlling the simple processes such as two interacting tanks, classic PID is prefered.

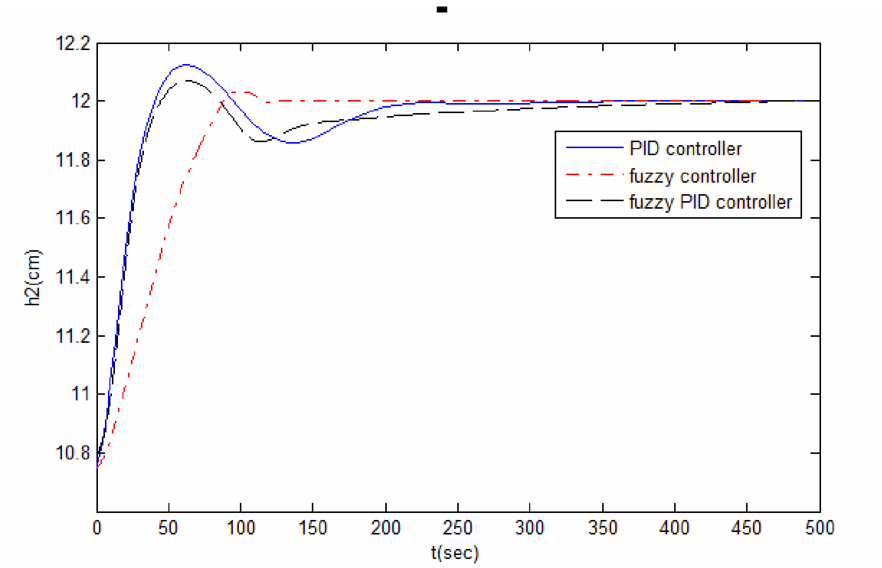


Fig.9. The closed loop respose of level using classic PID, Fuzzy and fuzzy PID controllers

Conclusions

In this paper, two interacting tanks system was simulated by Matlab/simulink software and then the level of second tank is controlled by Classic PID, fuzzy and fuzzy PID controllers. The results showed that the classic and fuzzy PID controllers have the same performances. In addition, we spend a lot of time on regulation of fuzzy PID controller and writing fuzzy rules, so in this process classic PID controller is better than fuzzy and fuzzy PID controllers.

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مقایسه کنترل کننده PID کلاسیک با کنترل کننده فازی و PID فازی

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چکیده

در این مقاله، کارآیی کنترل کننده های PID کلاسیک، فازی و PID فازی با استفاده از شبیه سازی مورد مقایسه قرار گرفت. بدین منظور، کنترل سطح یک سیستم دو تانک تداخلی پشت سرهم انتخاب شد. نتایج نشان داد که کارآیی کنترل کننده PID کلاسیک و PID فازی تقریباً یکسان است. ولی تنظیم کردن کنترل کننده PID کلاسیک خیلی راحتتر از کنترل کننده فازی و PID فازی می باشد. بنابراین برای فرآیندهای ساده مانند کنترل ارتفاع مایع در دو تانک تداخلی، استفاده از کنترل کننده های PID کلاسیک ترجیح داده می شود.

واژه‌های کلیدی: روش فازی،کنترل کننده PID، کنترل فازی،کنترل کننده PID فازی.

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