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Fuzzy-PID Controller for Coupled Tank Systems

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ABSTRACT

Combined tank systems are widely used in industrial applications. It can be difficult to control the liquid level in tank systems. In double tank systems, the liquid may need to be stored in tanks and then pumped to another tank. Liquid level controls are controlled by Proportional-Integral Derivative (PID) controllers. In this article, the Kp, Ki and Kd parameters of the PID controller are determined by using fuzzy logic with appropriate fuzzy rules. It is seen that the performance of the system realized with the determined parameters is significantly better than the traditional PID controller.

1. Introduction

PID control is widely used in industrial applications. Today, PID control applications are widely used in every field where practical control systems are located and help to obtain the desired outputs in a short time, with minimum overshoot and low error value [1]. Therefore, it is a good method for liquid control applications between tanks.

Although PID control is an accessible and cheap method, it can sometimes not give the desired performance. The reasons for this can be shown as not being able to set the PID parameters (Kp, Ki and Kd parameters) properly [2]. If these parameters are not set properly, errors and undesirable situations can occur in the desired output values from the system. Alternative control methods can be showen Fuzzy Logic Controller and Fuzzy-PID controller. In a study, Fuzzy logic controller method can give more attention to various parameters such as the time of response, the error of steadying and overshoot. Fuzzy logic controller significantly reduced overshoot and steady state error in results [3]. In another study, fuzzy and PID controller is designed and applied to the water level system. Then the fuzzy controller is used to make the system fast and stable. In result a comparison between two controllers was presented and fuzzy controller faster response with the more ability to reach the stability than conventional PID controller which assistances in increase the performance of the system [4]. In other study say that industries use mainly conventional controller i.e., PID (Proportional Integral Derivative) controller because of their performance and hence it is called as work-horse of

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process industries. But in level controlling task of conical tank, PID fails to give fast response because of the non – linearity present in the system. To overcome this drawback, industries use a heuristic method-based controller called Fuzzy Logic Controller [5]. In other study, controller comparison shows that the effect of single baroceptor PID control is somewhat poor, the double baroceptors PID control is better than single baroceptor PID control, and the fuzzy control can greatly correct deficiency of the PID control and can further improve the control effect for the tank level [6]. In other study, Fuzzy Logic is told about advantages These; Fuzzy Logic has been successfully applied to a large number of control applications [7]. The most commonly used controller is the PID controller, which requires a mathematical model of the system. A fuzzy logic controller provides an alternative to the PID controller. The control action in fuzzy logic controllers can be expressed with simple "if-then" rules. Fuzzy controllers are more sufficient than classical controllers because they can cover a much wider range of operating conditions than classical controllers and can operate with noise and disturbances of a different nature. Liquid level system applications can used PID, Fuzzy Logic and Fuzzy-PID controller for controlling water level. In a study, In order to get rid of the bad effects of PID parameters, Fuzzy-Logic controller is used by creating if-then rules for control [8].

Difference approach in the control system is the fuzzy PID controller. This method is designed a new implementation method of fuzzy control arithmetic is put forward. Of both theoretical and experimental results inside a study show that the fuzzy PID controller has the nonlinear properties of higher control gains when the system is away from its steady states; and lower control profile when set-point changes occur. As a result, these nonlinear properties provide the fuzzy PID control system with a superior performance over the conventional PID control system [9]. In other study, The simulation results suggest that the fuzzy-PID proposed controller can be applied to the liquid level control process in the chemical industry, where noise is always presented. The fuzzy-PID controller can improve quality of the liquid level coupled-tank control system, increase the process efficiency and bring economic benefit to end-user [10].

Control systems are used other applications like mechanical system, electrical system in industrial. A example can be shown in a study. The study presents a development of position control of electro-hydraulic actuator by using a self-tuning fuzzy PID controller to overcome the appearance of nonlinearities and uncertainties in the systems [11]. Using method is difference from Fuzzy Logic Controller. Because Fuzzy-PID Controller tries to create the most suitable PID parameters using Fuzzy Logic. In a study, Fuzzy-PID composite parameters controller is put forward. The dynamic and static performance were both better than PID controller [12]. In other study, the author discusses fuzzy control theory and provides a cascade liquid-level control system based on fuzzy self-tuning PID controller. The result indicates that the double water-tank system adopts fuzzy self-tuning PID controller as main controller which combines advantages of fuzzy control system from ordinary computer digital control system. Temperature, water level, pH level and other parameters can control in the only system [13]. Adaptive Fuzzy-Pid controllers can solved like this problem. Tuning of conventional PID parameter remains a difficult task due to insufficient knowledge of the analytical process dynamics; as a result, fuzzy controller is suitable tool for control. If don't have a mathematical model for system control, system can be controlled via Fuzzy System and Neural Network but input and output of system database is need for this. Advantages of this method is can be easily controllable without need mathematical models. In a study, the dynamical system is controlled with ANFIS [14]. In different studies, paper is summarized PID control theories of traditional PID, fuzzy PID, BP neural network PID and RBF neural network PID. By setting coupled-tank as an example, it simulated water tank level under the four PID controllers by adopting MATLAB software [15]. Other papers, also design and simulate the fuzzy self-tuning PID controller, then compare the control effect of those three kinds of controller, the single loop PID control system, the cascade control system and the cascade control system based on fuzzy selftuning PID [16,17].

There are different control methods as PID, Fuzzy logic and Fuzzy-PID according to studies. If there is a mathematical model suitable for input and output of the system for system control, the system can be controlled with the 3 methods mentioned. The most optimum system control can be obtained compared to other methods with Fuzzy-PID controller, which is a hybrid of PID controller and fuzzy logic controller. By using the Fuzzy-PID controller that contains the fuzzy logic structure, the most optimum parameters for the system are obtained by creating fuzzy rules in this article. For the Fuzzy-PID controller, the Fuzzy Logic Toolbox in the MATLAB program is used, and the Simulink/MATLAB program is used to design the PID controller and the system. The obtained results are compared and given in the results section of the article.

1.1 Mathematical Model of Tank System

As seen in Figure 1, the model of the connected tank system is given. The liquid flow rate entering tank-1 is q_{in}, the flow rate from tank-1 to tank-2 is q_1 and the volumetric flow rate in tank-2 is q_0. The liquid height of tank-1 is h_1, the liquid height of tank-2 is h_2, and the cross-sectional area of both tanks is A_1 and A_2, respectively [1].

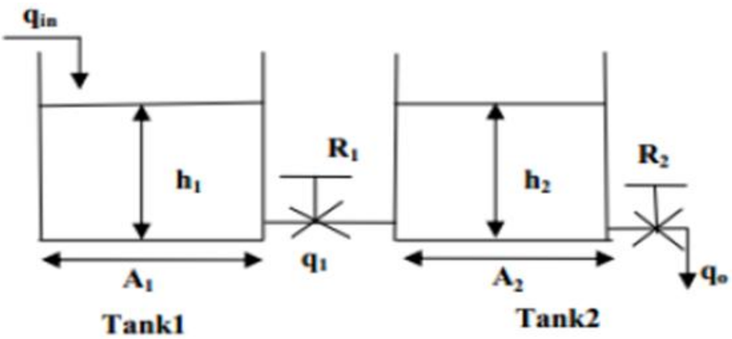

Fig. 1. Model of tank system

When trying to create a mathematical model for Tank-1, equation (4) is obtained.

$$A_1\frac{dh_1}{dt} = q_{in} - q_1 \tag{1}$$

$$q_1 = \frac{h_1 - h_2}{R_1} \tag{2}$$

$$R_1 A_1 \frac{dh_1}{dt} = R_1 q_{in} - h_1 + h_2 \tag{3}$$

$$h_1(s)(R_1 A_1 S + 1) - h_2(s) = R_1 q_{in}(s) \tag{4}$$

When the same operations are done for Tank-2, equation (8) is obtained

$$A_2\frac{dh_2}{dt} = q_1 - q_0 \tag{5}$$

$$q_0 = \frac{h_2}{R_2} \tag{6}$$

$$R_2 A_2 \frac{dh_2}{dt} + h_2 + \frac{R_2}{R_1}h_2 = \frac{R_2}{R_1}h_1 \tag{7}$$

$$h_2(s)\left(R_2A_2S+\frac{R_2}{R_1}+1\right)=\frac{R_2}{R_1}h_1(s) \tag{8}$$

Equation (9) is obtained from equation (4) and equation (8).

$$\frac{h_2(s)}{q_{in}(s)}=\frac{R_2}{A_1R_1A_2R_2S^2+S(A_1R_{1+}A_1R_{2+}A_2R_{2)}+1} \tag{9}$$

When the variables given in Table 1 are used in equation (8), the transfer function of the system is as in equation (10).

$$\frac{h_2(s)}{q_{in}(s)}=\frac{0.01}{6.25s^2+7.5s+1} \tag{10}$$

Table 1
Parameters

Parameters	Value	Unit
A_1	250	cm^2
A_2	250	cm^2
R_1	0.01	cm^2/sec
R_2	0.01	cm^2/sec
H_1	30	cm
H_2	15	cm

2. Methodology

When the mathematical model of the tank system is created in Simulink, it looks like Figure 2. As can be seen, the transfer function of the system is controlled by a PID controller and a Fuzzy-PID controller.

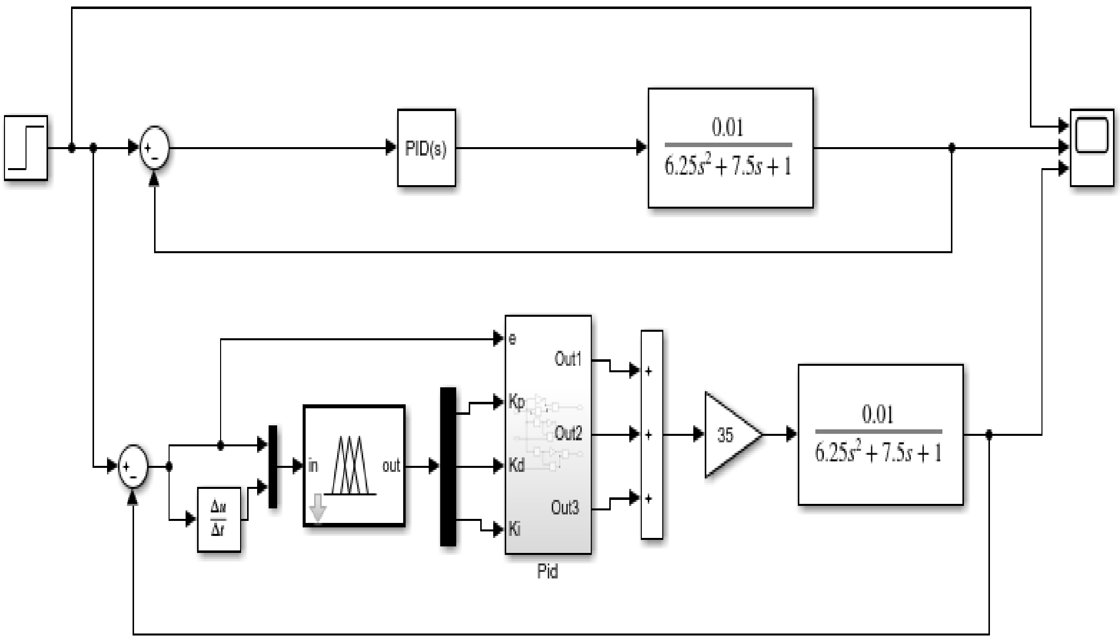

Fig. 2. Simulink model of tank system

2.1 PID Controller

Proportional integral derivative controller PID, which is accepted as the standard control structures of classical control theory, is a general control loop feedback mechanism widely used in industrial control systems. The performance feature of the system is improved by adjusting the Kp, Ki and Kd gain values. The selection of these values will cause variation in the observed response because each component has its own characteristics. The controller output is expressed with the mathematical description of the linear relationship between u(t) and the error, e(t). Here, Kp= Proportional gain, Ki= Integral gain Kd= Derivative gain is expressed. The U(t) sign can be expressed mathematically in equation (11) [18].

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{e(t)}{d(t)} \tag{11}$$

In this study, PID parameters were determined as Kp=10, Ki=15, Kd=0.

2.2 Fuzzy-PID Controller

The fuzzy PID controller that adjusts its own parameters obtains the parameters Kp, Ki and Kd according to the error (e) and the derivative of the error (e) using the Fuzzy Inference System (FIS) [19]. The structure of the self-tuning fuzzy PID controller is shown in the sub-model in Figure 3.

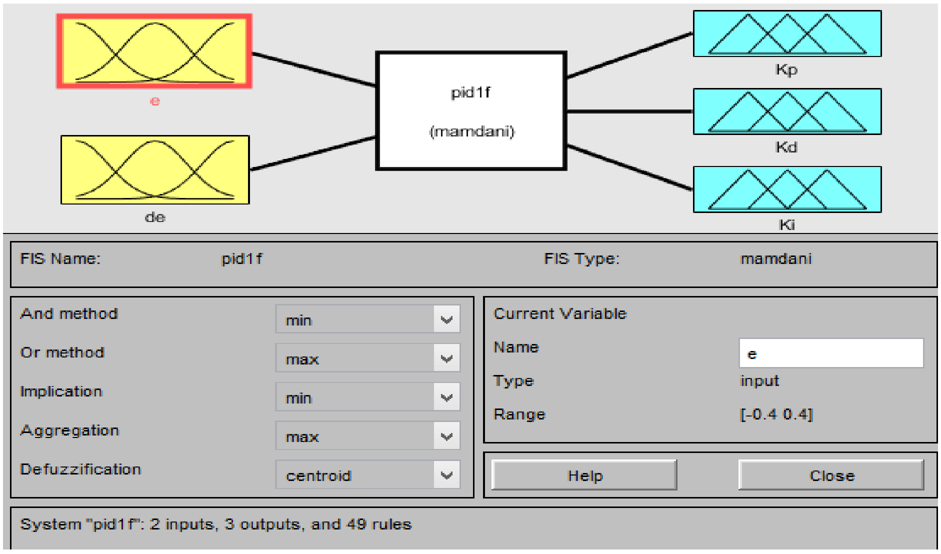

Fig. 3. Fuzzy inference system

As seen in Figure 3, the Fuzzy Inference System consists of 2 inputs and 3 outputs. The inputs are the error signal e(t) and its derivative with respect to time. On the other hand, the output of the system includes the parameters Kp, Kd and Ki.

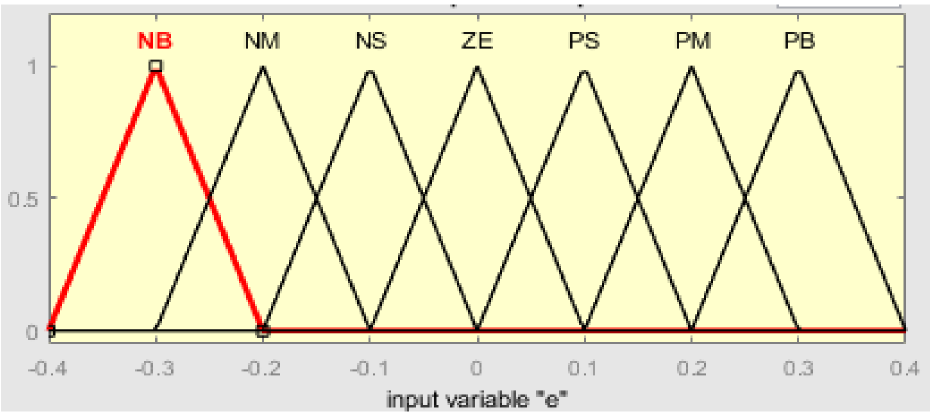

Fig. 4. Membership functions of error signal

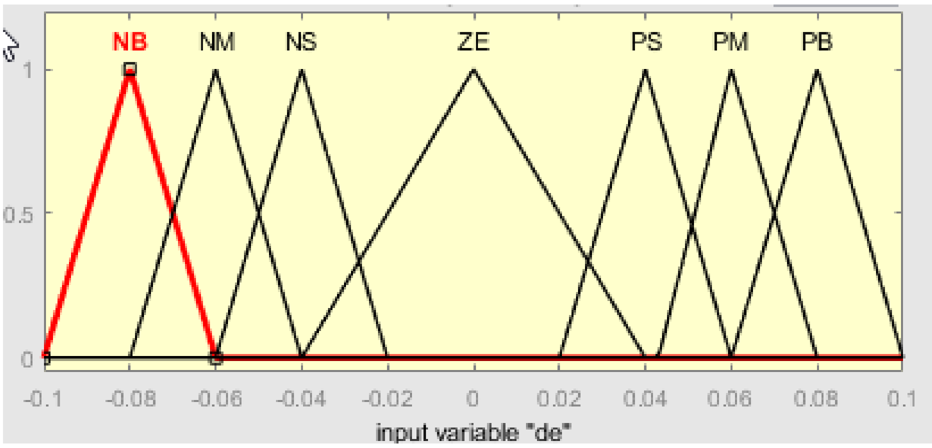

Fig. 5. Membership functions of derivative error signal

The membership functions of the error signal and its derivative are given in Figures 4 and 5. The input variables have 7 linguistic values. These are expressed as NB, NM, NS, ZO, PS, PM and PB, negative big, negative middle, negative small, zero, positive small, positive middle and positive big.

The membership functions of the output Kp, Kd and Ki are given in Figures 6, 7 and 8. This output parameters have 3 linguistic values and are expressed as P(positive), N(negative) and Z(zero), respectively [13].

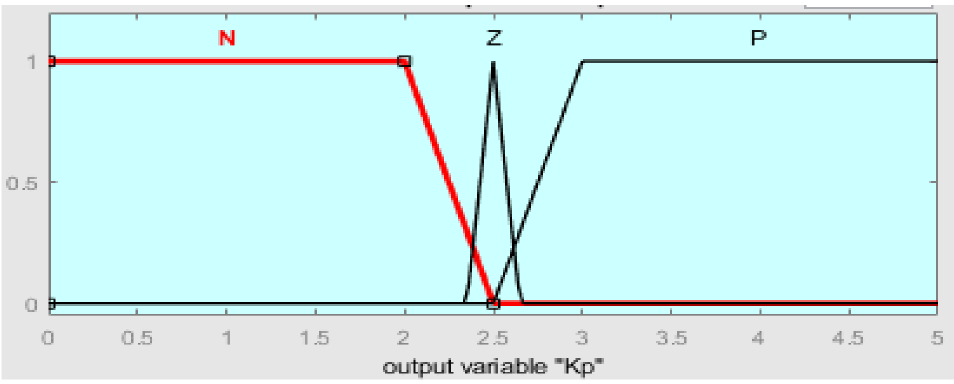

Fig. 6. The membership functions of Kp

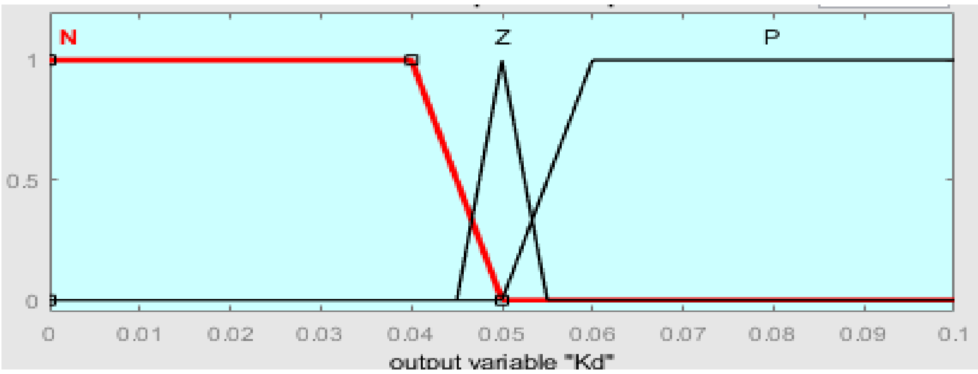

Fig. 7. The membership functions of Kd

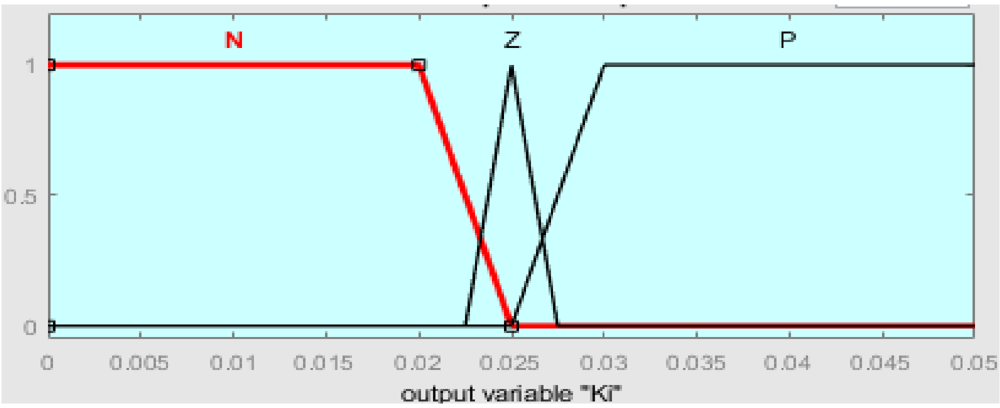

Fig. 8. The membership functions of Ki

It is shown in Table 2 by connecting the rules and connectors of fuzzy logic.

Table 2
Rules of Fuzzy Logic

de	Kp, Kd, Ki	NB	NM	NS	ZE	PS	PM	PB
NB		P N P	Z P Z	N P N	N N N	N P N	Z P Z	P N P
NM		P N P	P Z Z	Z P Z	N P N	Z P Z	P Z Z	P N P
NS		P N P	P N P	Z Z Z	N P N	Z Z Z	P N P	P N P
ZE		P N P	P N P	P N P	Z Z Z	P N P	P N P	P N P
PS		P N P	P N P	Z Z Z	N P N	Z Z Z	P N P	P N P
PM		P N P	P Z Z	Z P Z	N P N	Z P Z	P Z Z	P N P
PB		P N P	Z P Z	N P N	N P N	P N P	Z P Z	P N P

The surface representation created by the rule and input-output membership functions is shown in Figure 9.

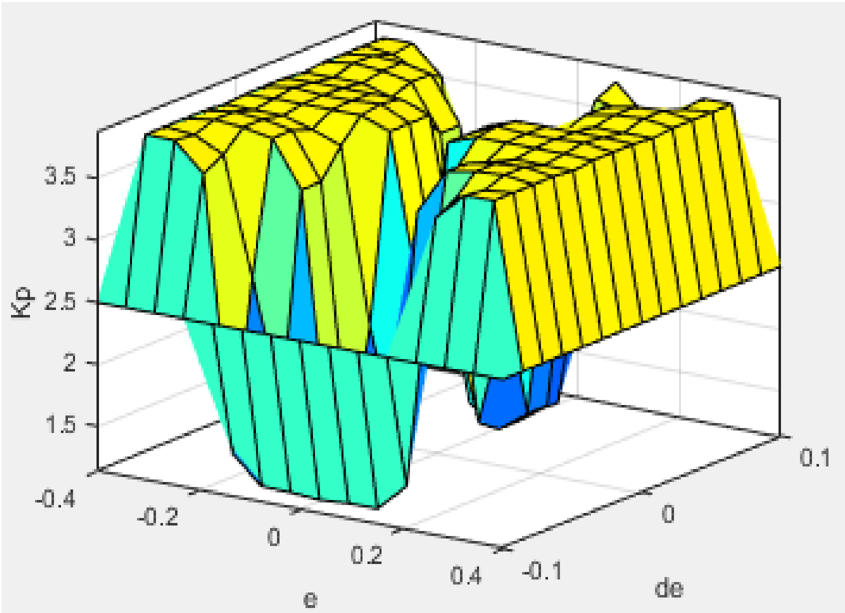

Fig. 9. Created surface

3. Results

The self-tuning fuzzy PID controller shown in Figure 2 consists of a Fuzzy and PID block as a subsystem. The PID block is shown in Figure 10.

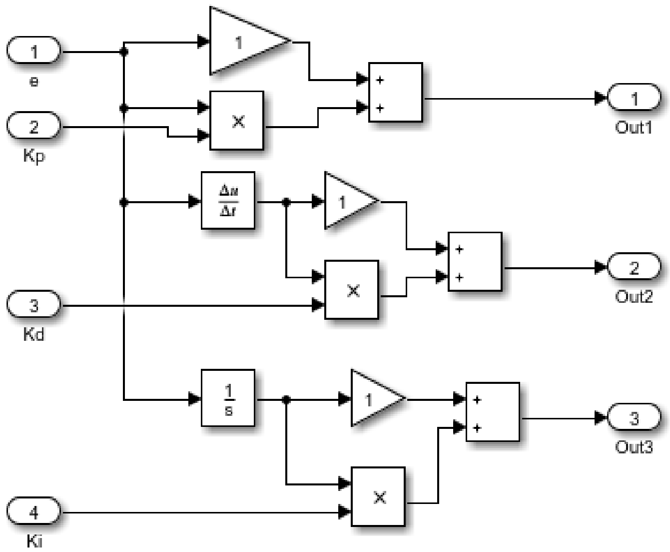

Fig. 10. PID sub block

The values of the parameters Kp, Ki and Kd are adjusted using signals from the fuzzy logic block depending on the changes in the error between the reference signals and the output signals [20]. A unit step input signal is applied to realize the output of the system. The outputs of the simulation are shown in Figure 11 below.

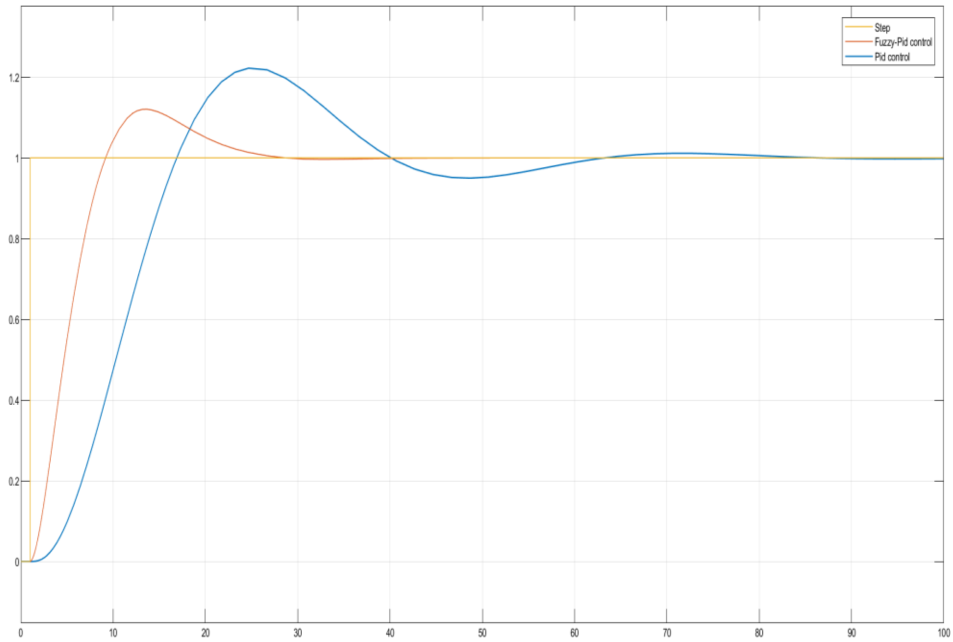

Fig. 11. Output of The Coupled Tank System

Modeling was done on connected tank systems and self-tuning fuzzy PID controller was successfully obtained.

4. Conclusions

As seen in Figure 11, Fuzzy-PID controller had less overshoot percentage and less settling time compared to PID controller. This shows that Fuzzy-PID controller gives better results compared to traditional PID controller. Better results can be obtained by manually changing the parameters of PID controller and by trial and error, but this is a disadvantage compared to Fuzzy-PID control.

In Fuzzy-PID controller, there will be no need to constantly change Kp, Ki and Kd parameters in order to get better results compared to traditional controller, these parameters will be formed automatically within themselves depending on fuzzy rules. This shows that control provided with fuzzy logic is superior to traditional control.

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Conflicts of Interest

The authors declare no conflicts of interest.

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