Optimization of PID Controller with Supervisory Fuzzy Control for Industrial Robots

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Abstract

It is difficult to control the movement of the robot arm due to its nonlinear structure. PID controller is still in the world because of its simplicity in designing this controller as the main controller. The nonlinear control technique is very complicated, and this is not very interesting in the controller. While fuzzy control has a better performance, it incorporates a fuzzy control with the PID controller to use the PID fuzzy control system to monitor the robot arm system with 5 DOF. This online control proposal is provided to get the best performance, which is possible with fuzzy supervisory control according to the simulation results in MATLAB.

Keywords: PID fuzzy control**,** supervisory**,** 5 DOF robot**,** manipulators

1. Introduction

Today robots are widely used in industry and dangerous environments. Robot control is critical to make robots succeed and to innovate them. Robot arm can be utilized to do certain tasks requiring high level expanded controlling systems.

Robot arm has a nonlinear internal feature in its structure, in a way that, it requires a proper model to represent nonlinear characters, indefiniteness in parameters, and precise time. To avoid obstacles and robot decay or its elements, the roadmap should be followed with a high precision.

PID control has been proposed as the most popular controlling algorithm utilized in industry due to its simple structure and its simple design. For example, more than %90 of control program uses PID or some other forms of PI or PD. There are some active models in appropriating proper amounts for controller parameters of PID such as Ziegler-Nichols Cohencan and some other software programs. Fuzzy logic can be used as an observer controller to adjust the amount of PID coefficients.

In traditional amount decision such as those proposed by Ziegler-Nichols, PID parameters are first selected and then are fixed to accord with active time, although the fixed amounts of PID can not produce satisfactory results within the performance for nonlinear or complicated systems. Therefore, this method is not proper for nonlinear systems. To avoid nonlinear parameters, PID parameters should be identified online. Here, PID parameters are given amounts through observer fuzzy controller and the specialists' experiences and this is done through the integration of both alternates to appropriate amounts for PID parameters.

Lotfizadeh proposed fuzzy rules and fuzzy logic in 1965 and Mamdani utilized this logic to control the systems in 1973. He designed several fuzzy controllers for applied samples. Fuzzy control makes it possible to use a formal system to represent, manipulate, and administer mental knowledge of human beings regarding how a system can be controlled.

Fuzzy control has introduced a successful method for nonlinear systems. Using this method in complicated processing, we can achieve a better performance of PID controllers. Through integrating the simplicity of PID and strength of Fuzzy Logic Control (FLC), we can reach a high control performance in a simple status. This integration is done by using two well-known controllers of PID observer fuzzy logic controller or fuzzy self-control for PID controllers. In several articles such as [1.6], some issues were proposed regarding self-regulation problems of PID parameters.

Self-regulated controller should be adjusted in two stages:

1) Using Z-N amount appropriation to arrange interest, integral interest, and root interest simultaneously.
2) Using fuzzy controller as self-regulated controller to arrange PID parameters online and being processed. Recently some papers dealing with fuzzy observation have been among the most common articles [8] stressing on the fact that programming idea for PID fuzzy controller online has been developed to grow PID controller parameters.

The results showed that FGS controller part processing has led to better results compared with traditional PID results and thus it led to more satisfaction. Although the online adjustment of PID parameters proposed in [11-12] means the improvement of results compared to the traditional systems, the observer fuzzy controller has led to better results in comparison with both previous models and it has resulted in consumers' satisfaction.

The present research deals with controlling the arm of a robot. In this proposed controller, the major compensator has used fuzzy logic to appropriate amounts to PID parameters to control robot arms.

The paper is comprised of the following: the second part has described the simple structure of PID controllers, third part deals with the description of FLC structure, observer control technique has been explained in fourth part, the fifth part has represented results of controller simulations, and finally the conclusions have been presented in sixth part.

2. Experimental Part

I. PID controller

PID controller transmission function can be represented in either of the two formats below:

$$G_{PID}(s) = K_P + {}^{K_I}/_{s} + K_D s \quad (1)$$

K_p, K_I, K_D stand for proportion, integral, and derivative interests.

The second one is as follows:

$$G_{PID}(s) = K_P(1 + 1/(T_I s) + T_D s) \quad (2)$$

Where, $T_I = K_P / K_I$, $T_D = K_D / K_P$ represent fixed time for integral and derivation, respectively.

To adjust the amounts of PID parameters there are the following overall and major rules:

1) If the input is a big positive number, the proportional interest should be high, integral (K_I) is small and the derivation (K_D) is small too. In this case, the system output would be rapid.
2) If the input is so small, the PID parameters of (K_P) would be small and terms such as derivation (K_D) and integral (K_I) will become big. In this state, the output overshoot will decrease and there would be a more rapid response.
3) The rules related to the third part could not be devised as easily as the one regulated regarding the administration of traditional systems. Anyway, the appropriation of amounts is done through the use of smart methods such as fuzzy rules.

II. Fuzzy controller

Controlling through the use of fuzzy logic has four major parts:

1) fuzzification,
2) fuzzy databases,
3) fuzzy inference,
4) defuzzification [2] based on membership functions and fuzzy rules, Crisp input signals fuzzifier to change them into fuzzy signals. Fuzzy database entails principal rules and basic data. In this way, the controlling inference rules are represented and then system inputs are decided on. Finally, through the defuzzification of the fuzzy output, it is changed into a Crisp controller signal.

III. PID fuzzy controller is categorized into two samples:

Direct fuzzy control order or observer fuzzy control. In direct order model, the PID controller is replaced by a feedback controlling loop to identify certain controlling activities through the use of fuzzy inference to calculate the act using fuzzy logic or directly through controlling activities. These types of fuzzy controllers are represented as PID-like controllers. On the other hand, observer fuzzy model tries to propose a nonlinear activity for controller output using fuzzy inferences when PID is adjusted as an inference system instead of common approaches.

Designing fuzzy controller processor as predetermined will be described below:

1) The identification of input and output variables through fuzzy control rules. In this research, the error (e(t)) and (Δe(t)) are used as two inputs for FLC and K'_P, K'_I, and K'_D are known as three outputs, respectively.
2) The fuzzification of input and output variables through the identification of fuzzy sets and membership functions. Each of fuzzy input variables has 7 sets between big negative and big positive and FLC output has the following fuzzy set: K'_P and K'_D entail two fuzzy sets and K'_I contains three fuzzy sets. Figure (1) represents inputs of FLC.
3) The design of inference mechanism rules to find out about the relationships between inputs and outputs. In this article we have used the methods proposed by Mamdani regarding inference mechanisms.

4) Defuzzification of output variables. Here we have used COG method, the most commonly utilized method. The activities are controlling ones

$$u = \frac{\sum_{i=1}^{m} \mu(x_i).x_i}{\sum_{i=1}^{m} \mu(x_i)} \quad (3)$$

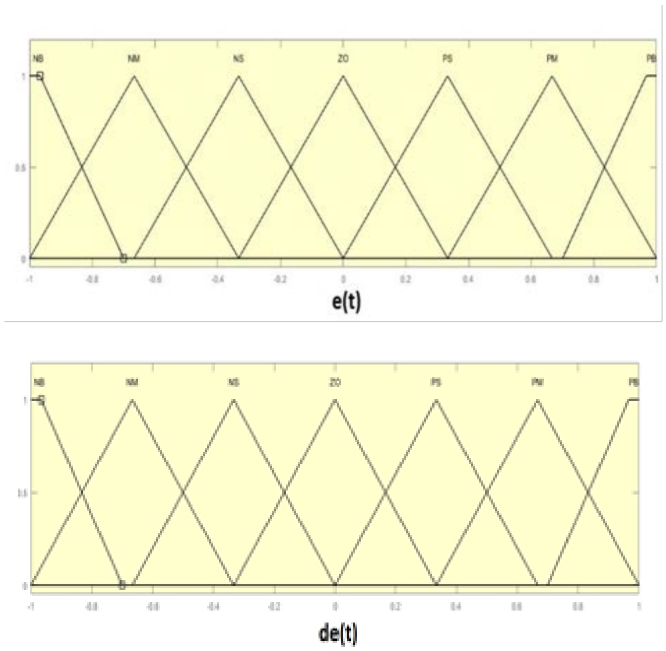

Fig.1. Membership functions of e(t) and Δe(t)

IV. Observer fuzzy controller

The closed loop system with observer PID fuzzy controller has been represented in figure (2). The controlling system entails a fuzzy part and a PID part.

The observer fuzzy controller is a form of PID control [15.16], but here three PID controller parameters are devised through fuzzy rules based on error base and error changes as the input for FLC.

The input signal to the system is like to a step. The input to PID fuzzy observer controller feeds error signal and the output of PID fuzzy observer controller of robot arm through PID fuzzy observer controller as represented in figure (3).

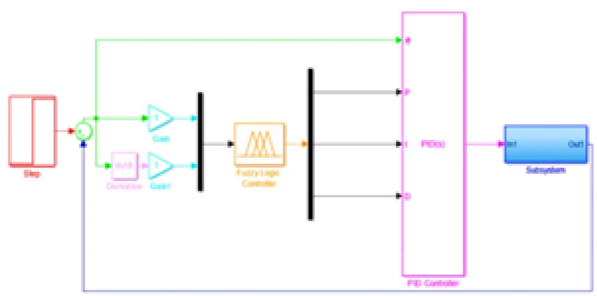

Fig2.

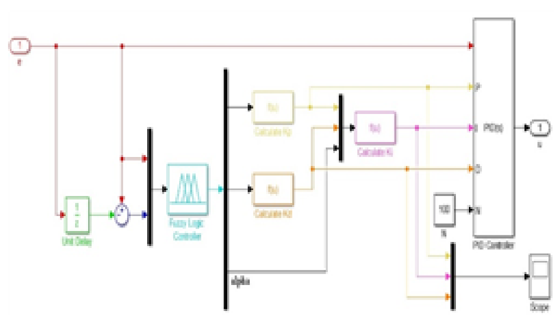

Fig.3. The structure of PID fuzzy observer controller

Two input signals into the fuzzy controller are known as e(t) and Δe(t), where:

$$e(t) = r(t) - y(t) \quad (4)$$

$$\Delta e(t) = e(t) - e(t-1) \quad (5)$$

The outputs of fuzzy logic controllers are K'_P, K'_D, and K'_I. We presuppose that the range of these parameters are $[K_{P_{min}}.K_{P_{max}}]$, $[K_{D_{min}}.K_{D_{max}}]$, and $[K_{I_{min}}.K_{I_{max}}]$. The limitation of these parameters have been identified as $K_P \in [0.15]$, $K_I \in [0.001\,.\,0.005]$, $K_D \in [0.1\,.\,0.2]$ experimentally. These parameters were defined as follows:

$$K'_P = (K_{P_{min}} - K_P)/(K_{P_{max}} - K_{P_{min}}) \quad (6)$$

$$K'_I = (K_{I_{min}} - K_I)/(K_{I_{max}} - K_{I_{min}}) \quad (7)$$

Where, K'_P, K'_D, and K'_I are output variables of fuzzy control.

Figure (4) represents K'_P, K'_D, and K'_I, respectively. The membership functions utilized in the method to adjust PID fuzzy parameters are triangular, bow, and arch functions. The output K'_P and K'_D entail two membership functions in the form of an arch for K'_P and K'_D. And the fuzzy variables are as follows: small (S) and big (B). The equation K'_I has three triangular membership functions covered with the variables of three fuzzy sets with linguistic amounts: small (S), medium (M), and big (B).

On the whole, the basis of fuzzy rules depends on the characteristics of the type of the controller and the controller system. These rules identify the opinions of specialists or experimental agents [14]. The overall rules of controller include two types: the first one is multiple input, multiple output (MIMO) fuzzy rules such as:

if e is A_1 and Δe is A_2 then K'_P is B_1 .
K'_D is B_2 and K'_I is B_3

The second method is multiple input, single output (MISO). Each part of PID has a free adjustment like the following:

if e is A_1 and Δe is A_2 then K'_P is B_1

Where, e and Δe are the inputs of FLC. A_1, A_2, B_1, B_2, and B_3 are known as linguistic variables for e, Δe, K'_P, K'_D, and K'_I.

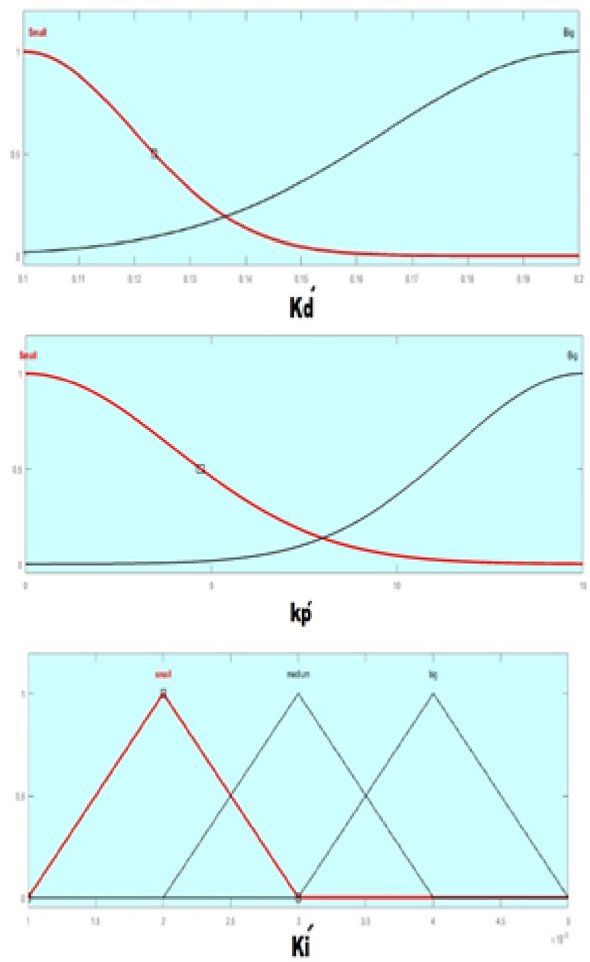

Fig.4. Membership functions of K'_P, K'_D, and K'_I

The adjustment of PID proportion has been carried out precisely in a way that the basic fuzzy rules for K'_P, K'_D, and K'_I should be selected to guarantee a system with a rapid expansion time, smaller overshoot, and a permanent errorless state. Figure (5) represents the step response of the controlled system. The basic rules should be devised regarding step responses. The step response is divided into four regions.

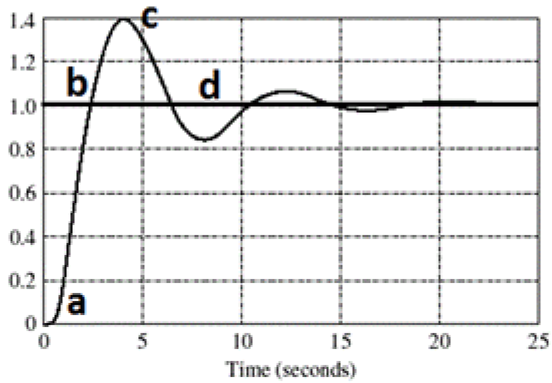

Fig.5. Step response

For region 1 around the point (a) we need a big controlling signal to foster expansion time. To eliminate errors, we should emphasize on integral proportion and to enhance the response speed we should have a derivation proportion. In order to produce a big controlling signal for PID controller we should have a big proportionate. The basic rules to represent case 1 can be found as below:

$$if\ e\ is\ PB\ and\ \Delta e\ is\ Z\ then\ K'_P\ is\ B.K'_D\ is\ Sand\ K'_I\ is\ S$$

When the error moves forwards in region 2 around the point (b) towards negative, the system should slow down to reduce overshoot. This is done through the reduction of proportion, reduction of integral proportion, and the excess of derivative proportion. Therefore, the basic rules to represent this case would be as follows:

$$if\ e\ is\ Z\ and\ \Delta e\ is\ NB\ then\ K'_P\ is\ S_1.K'_D\ is\ B\ and\ K'_I\ is\ S$$

Another case can also be adjusted. The basic rules of K'_P, K'_D, and K'_I are represented in tables (1), (2), and (3), respectively.

Table 1.K_P Fuzzy control rules

KP		ERROR						
		NB	NM	NS	Z	PS	PM	PB
CANGE OF ERROR	NB	B	S	S	S	S	S	B
	NM	B	B	S	S	S	B	B
	NS	B	B	B	S	B	B	B
	Z	B	B	B	B	B	B	B
	PS	B	B	B	S	B	B	B
	PM	B	B	S	S	S	B	B
	PB	B	S	S	S	S	S	B

Table 2. K_D Fuzzy control rules

KP		ERROR						
		NB	NM	NS	Z	PS	PM	PB
CANGE OF ERROR	NB	S	B	B	B	B	B	S
	NM	S	B	B	B	B	B	S
	NS	S	S	B	B	B	S	S
	Z	S	S	S	B	S	S	S
	PS	S	S	B	B	B	S	S
	PM	S	B	B	B	B	B	S
	PB	S	B	B	B	B	B	S

Table 3.K_I Fuzzy control rules

KP		ERROR						
		NB	NM	NS	Z	PS	PM	PB
CANGE OF ERROR	NB	S	M	B	B	B	M	S
	NM	S	M	M	B	M	M	S
	NS	S	S	M	M	M	S	S
	Z	S	S	S	M	S	S	S
	PS	S	S	M	M	M	S	S
	PM	S	M	M	B	M	M	S
	PB	S	M	B	B	B	M	S

Results

Self-regulated fuzzy PID controller has been used for robot arm with a 5 DOF. The robot has a 5 DOF, each of which has a DC motor with a specific change function. To represent the effectiveness of such an approach, the response of the output in first freedom degree of the robot arm has been represented through the proportion change of PID. The output response of other motors could be observed using the same method.

The change function of the intended DC motor has been defined as follows:

$$G(s) = \frac{19649}{s^3 + 201s^2 + 6290s} \quad (8)$$

Results entail the use of MATLAB and SIMULINK to represent the output response of the change function above for the first freedom degree of the robot with the targeted controller.

Results of simulation in figures (6) and (7) represent the response of the targeted controller output regarding the step input signal. The two figures represent the performance of traditional adjustment control system of PID (without fuzzy adjustment) and using the observer to appropriate amounts. Additionally, they represent the effect of both controllers to eliminate the input noises.

If a load of $0.5^{N/m}$ enters the first robot arm, the result shows the disturbance effect on output response after one second and the effect of FSC controller to adjust the amounts of PID parameters and the elimination of the effect of noises are represented after that.

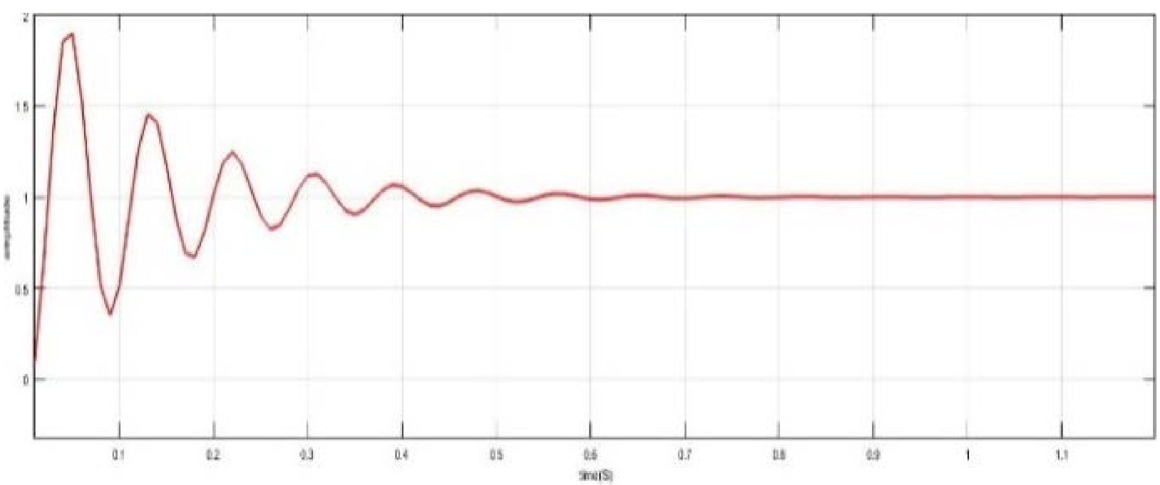

Fig.6 Output response using the classic method

It can be observed that fuzzy control rules lead to better results considering the achievement of PID proportion compared to the traditional amount proportion methods such as overshoot, expansion time, and static error amount.

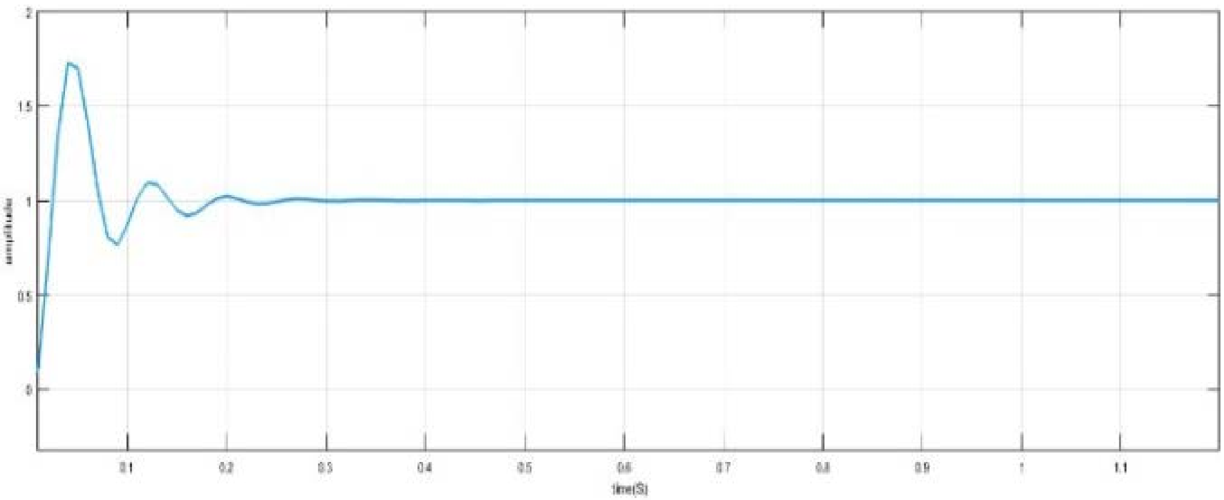

Fig.7. Output response using the fuzzy observer control method

Figure (8) represents the effect of a small disturbance after one second and the effect of a fuzzy observer controller to eliminate the effect of the presence of a disturbance.

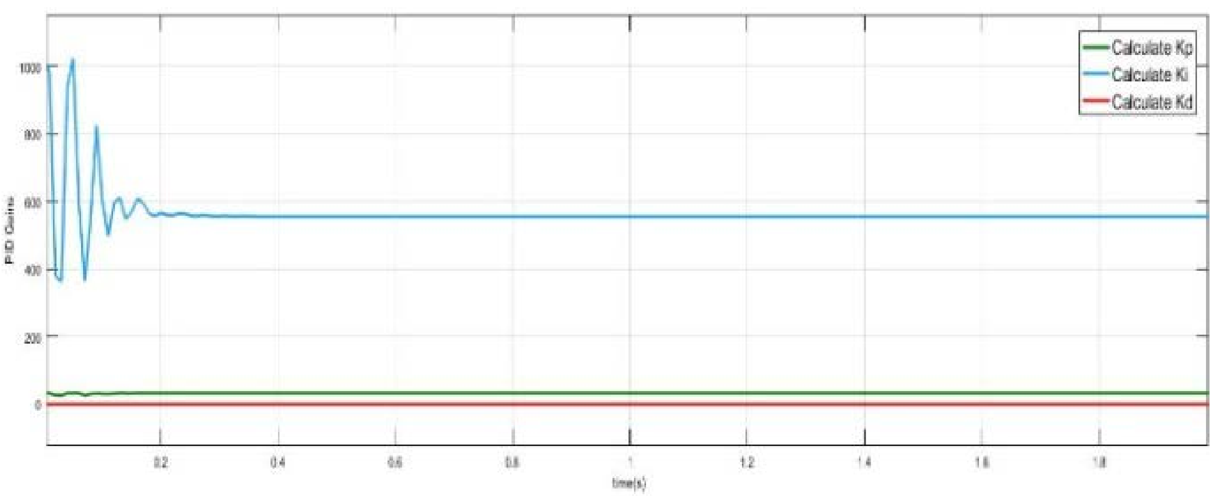

Fig.8. Changes of PID parameters

The observer fuzzy controller tries to expand system response and eliminate the disturbances through changing PID parameters. Figure (8) represents the changes of PID proportion during the system performance using fuzzy controlling as an observer. The efficiency of target control has been represented in table 4.

Table 4- Results of PID efficiency

Controller type	System characteristics		
	OS	t_r	SSE
Classical PID control	0.08	0.3	0.03
Fuzzy supervisory control	0.001	0.15	0

Conclusion

Although PID controller is a standard controller for linear systems against nonlinear systems when we talk about the resistance of the controlling system, we encounter several limitations and problems. There are several active traditional methods to adjust PID parameters and they are time-consuming and they are dependant regarding the start points. Fuzzy rules are documentary in the appropriation of the PID parameters and thus they lead to observant fuzzy control. The observer fuzzy control is utilized due to the optimization of the adjustment operations of appropriating PID parameters in controlling robot arms with a 5 DOF. The observer fuzzy controller response has had a better performance than the classic PID response. Results of figure (9) showed that using fuzzy rules leads to better results than using the traditional and old methods based on experiments.

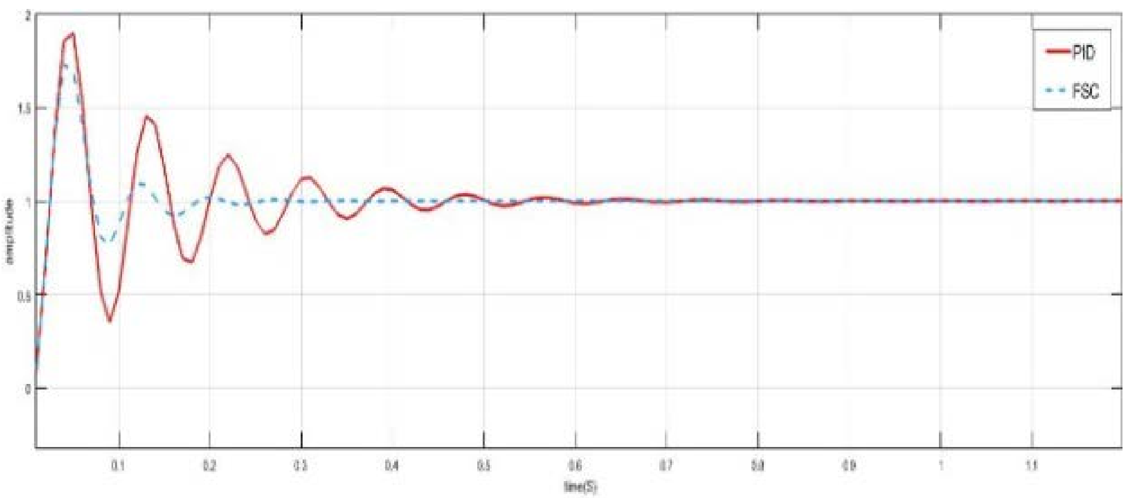

Fig. 9. Comparing PID controllers and FSC controllers

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