Comparison between FSC and PID Controller for 5DOF Robot Arm

G.U.V.Ravi Kumar and Mr.Ch.V.N.Raja

Abstract: Scara Robot has been widely used in manufacturing industry as a part of automation systems, typical applications of robot in industry include welding, painting, assembly pick and place and so on. Thus to provide the necessary movement of robot arm for linear motion broadly linear motors are use. In this paper DC linear servo motor is taken, which will acts as actuator. In order to perform actuator accurately and robustly, the robot controller should be designed suitably.

This paper presents a fuzzy supervisory controller to control the robot arm. Although conventional PID controllers are widely used in industry due to its simple control structure and ease of implementation, these controllers possess difficulties under the conditions of nonlinearity, load disturbances and parametric variations.

Keywords: - 5DOF Robot Arm, DC Servo motor, PID Controller, Fuzzy, Fuzzy Supervisory control.

1. INTRODUCTION

In recent years, industrial and commercial systems with high efficiency and great performance have taken advantages of robot technology. Large number of control researches and numerous control applications were presented during the last years, concentrated on control of robotic systems. Robot manipulator field is one of the interested fields in industrial, educational and medical applications. It works in unpredictable, hazard and inhospitable circumstances which human cannot reach. For example, working in chemical or nuclear reactors is very dangerous, while when a robot instead human it involves no risk to human life. Therefore, modelling and analysis of the robot manipulators and applying control techniques are very important before using them in these circumstances to work with high accuracy.

When the need arises for linear motion or positioning there are many choices. One can use a linear motor. Some of the common linear motors are Stepper, DC motor, synchronous, Hybrid, Induction motors. The DC servo motor was one of the first linear motors.

A servo motor is an electric motor with a built in rotation sensor, they are needed for robotics. Say a robot moves its arm by turning a servo motor, the motor would send information concerning the degree of rotation on its axis back to the robot so the robot can keep tabs on the position of its arm, so if something bumps its arm it will know it and so-on.

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Electric motors are the commonly used actuator in electromagnetic systems of all types. They are made in a variety of configurations and sizes for applications ranging from activating precision movements to powering diesel-electric locomotives. The laboratory motors are small servomotors, which might be used for positioning and speed control applications in a variety of automated machines. They are DC (direct current) motors. The armature is driven by an external DC voltage that produces the motor torque and results in the motor speed. The armature current produced by the applied voltage interacts with the permanent magnet field to produce current and motion.

The servo DC motor is basically a transducer that converts electric energy into mechanical energy. The torque developed on the motor shaft is directly proportional to the field flux and the armature current. The dc servo motors are very expensive in comparison to ac servo motors because of brushes and commutators .These motors have relatively low torque to volume and torque to inertia ratio, however the characteristics of dc motors are quite linear and are easy to control.

In Gaza strip, many industrial applications can utilize robot technology and develop robot manipulators. It is an attractive field to be applied and developed for industrial applications. This thesis is meant to be suitable for these applications. On the other side, some universities and colleges offers, some courses related to robotics. These courses mainly focus on the theoretical concepts without giving much attention for controlling different robot manipulators in the practical side. This thesis may be considered as a valuable educational tool in their laboratories.

The goal of this paper is to present an engineering approach to control 5DOF robot arm. The performance of the controllers will be based on high precision eliminating the overshoot, achieving zero steady state error, damping the unwanted vibration of the robot manipulator, and handling the unpredictable disturbances using controller techniques.

Control motion of the robot manipulator, it is considered one of the most vital and powerful issues in robotics fields because the robot operation must be accurate, without affected surrounding circumstances. Various controllers have been designed and applied in the robot manipulator. Proportional Integral Derivative (PID) controller may be the most widely used controller in the industrial and commercial applications for the early decades, due to its simplicity of designing and implementation.

Moreover they are available at little costs. One of the drawbacks for using PID control techniques is that, they are not sufficient to obtain the desired tracking control performance because of the nonlinearity of the robot manipulator due to unpredictable environment. Hence, a lot of time is required to tune PID parameters. Fuzzy logic control provides a formal methodology for representing, manipulating and Implementing human's heuristic knowledge about how to control a system. Fuzzy control proves to be a successful methodology to deal with nonlinearities in systems. It achieves better performance than PID controller in complex processes. So the simple computation and robustness of FLC may be effective to overcome the previous problem in robot control system.

In recent years, hybrid between fuzzy and classical controllers has combined to design a controller such as fuzzy plus PID and fuzzy logic supervisory (FLS) creates more appropriate solution to control robot manipulator. Through the thesis, FSC is considered as an important controller for on-line tuning of PID parameters. FSC may design to monitor and enhance the PID parameters online. In this paper applied control is FSC, 49 rule base was designed for the PID parameters, numbers and types of membership function for the FSC controller are chosen to give the desired performance.

The paper is organized as follows: section 2 describes the structure of simple PID controller, section 3 presents FLC, section 4 covers supervisory control technique, section 5 presents the results, and finally section 6 concludes this paper.

II. PID CONTROLLER

PID controller transfer function takes one of the two formats: the first format is given such as

$$G_{PID}(s) = K_P + \frac{K_I}{s} + K_D\, s \qquad (1)$$

with K_P, K_I and K_D are the proportional, integral, and derivative gains respectively. The second format is given as

$$G_{PID}(s) = K_P\left(1 + \frac{1}{T_I s} + T_D\, s\right) \qquad (2)$$

with $T_I = K_P / K_I$ and $T_D = K_D / K_P$ are known as integral and derivative time constant respectively.

There are general rules of thumb for tuning PID parameters. Below are examples of such roles:

1. If the input is positive large, then the proportional gain K_P must be large, integral term K_I small` and the derivative term K_D is small; thus, speeding the system output.
2. If the input is very small, then the PID parameters K_P should be smaller, K_I larger, and K_D larger; thus, the output will have reduced overshoot and faster response.
3. These types of rules are not easy to implement using traditional tuning methods; however, they are treasure using intelligent tuning methods such as fuzzy logic.

III. FUZZYLOGIC CONTROL

FLC has four main components: the fuzzifier, knowledge base, inference mechanism and defuzzifier [6]. Based on membership functions and fuzzy logic, the fuzzifier converts a crisp input signal to fuzzified signals. The knowledge base houses rule base and the data base. The inference mechanism fires relevant control rules and then decides what the input to the plant should be. Finally the defuzzification process converts the fuzzy output into crisp control signal. Fuzzy PID controllers are classified into two types: the direct action fuzzy control [13] and the fuzzy supervisory control. The direct action type replaces the PID control with a feedback control loop to compute the action through fuzzy reasoning where the control actions are determined directly by means of a fuzzy inference. These types of fuzzy controllers are also called PID-like controllers. On the other hand, the fuzzy supervisory type attempts to provide nonlinear action for the controller output using fuzzy reasoning where the PID gains are tuned based on a fuzzy inference system rather than the conventional approaches.

The design process of the fuzzy controller [14] is described as follows:

- Define the input and output variables of FLC. In this paper, there are two inputs of FLC, the error e (t) and error change Δ e(t) and three outputs K'_P, K'_I ,and K'_D respectively.
- Fuzzify the input and output variables by defining the fuzzy sets and membership functions. Each variable of fuzzy control inputs has seven fuzzy sets ranging from negative big (NB) to positive big (PB), and the output of FLC has the following fuzzy sets: K'_P and K'_D has two fuzzy sets. K'_I has three fuzzy sets. Fig. 1 shows the inputs of FLC.
- Design the inference mechanism rule to find the input-output relation. This paper uses Mamdani (max-min) inference mechanism.
- Defuzzify the output variable. Here, the center of gravity (COG) method, the most frequently used method, is used. The control action is:

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

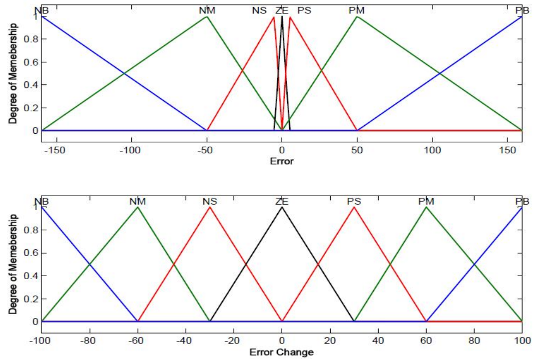

Fig 1. Membership function of e (t) and Δe(t) .

IV. FUZZY SUPERVISORY CONTROL

The closed loop system with fuzzy supervisory PID control is shown in Fig. 2. The control system consists of a fuzzy logic part and a PID part.

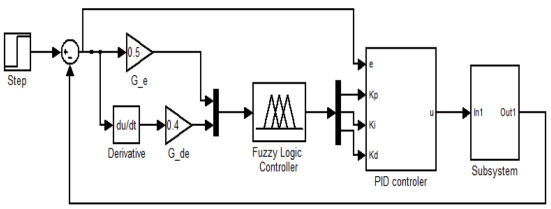

Fig 2. Fuzzy supervisory control

The FSC has the form of PID control [15, 16] but the three parameters of PID control are tuned using fuzzy controller based on the error and change of error as inputs to FLC.

The input signal is step input. The input to PID control is the error signal and the output of PID controller fed to the robot arm was obtained from the PID controller as shown in Fig. 3.

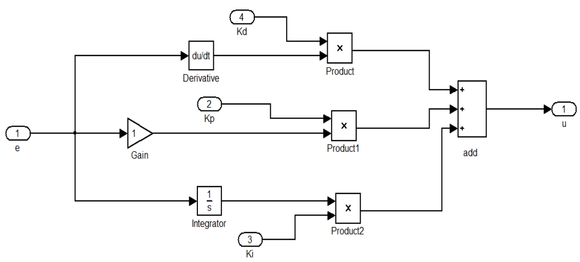

Fig 3. Structure of PID controller

The two input signals to the fuzzy controller are e (t) and Δ e (t), where:

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

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

The output of fuzzy logic control is $K_P^{'}, K_I^{'}$, and $K_D^{'}$ .Suppose the ranges of these parameters are $\left[K_{P_{\min}}, K_{P_{\max}}\right]$, $\left[K_{I_{\min}}, K_{I_{\max}}\right]$ and $\left[K_{D_{\min}}, K_{D_{\max}}\right]$ respectively. The range of these parameters is determined experimentally such as, $K_P \in [0,15]$ $K_I \in [0.001,\ 0.005]$ and $K_D \in [0.1,\ 0.2]$ .The parameters are described as follows:

$$K_P^{'} = \left(K_{P_{\min}} - K_P\right)\left(K_{P_{\max}} - K_{P_{\min}}\right) \quad (6)$$

$$K_D^{'} = \left(K_{D_{\min}} - K_D\right) \Big/ \left(K_{D_{\max}} - K_{D_{\min}}\right) \quad (7)$$

$$K_I^{'} = \left(K_{I_{\min}} - K_I\right) \Big/ \left(K_{I_{\max}} - K_{I_{\min}}\right) \quad (8)$$

where, $K_P^{'}, K_D^{'}$, and $K_I^{'}$ are output variable of fuzzy control.

Fig. 4 shows the membership functions of $K_P^{'}, K_D^{'}$, and $K_I^{'}$ respectively. The membership functions used in the proposed method for the fuzzy PID parameters tuner are triangular, Gaussian, and sigmoid membership functions. $K_P^{'}$ and $K_D^{'}$ output has two membership functions in sigmoid shape chosen for the $K_P^{'}$ and $K_P^{'}$ and $K_D^{'}$, and the fuzzy set variables are: Small (S) and Big (B). The term $K_I^{'}$ has three membership functions in triangular and it covered by three fuzzy set variables have the linguistic values: S, M (Medium), and B Big.

Generally fuzzy rule base are dependent on the characteristics of the controlled plant and the type of controller. These rules are determined based on practical experience or opinion of experts [14]. The rule base of the proposed controller is constructed using two forms: first multi-input multi-output (MIMO) fuzzy rule base 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 (9)

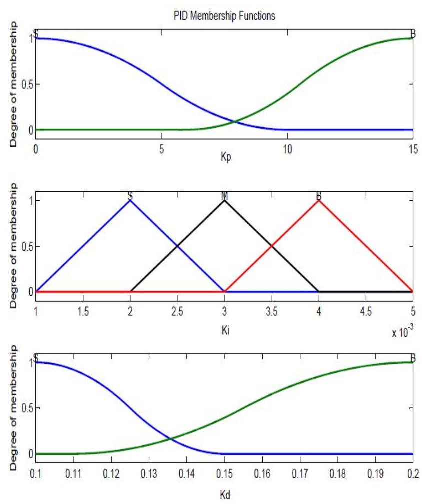

Fig 4. Membership function of, $K_P^{'}, K_D^{'}$, and $K_I^{'}$

The second method is multi-input single-output (MISO). Each component of PID gains has independent fuzzy tuner such as:

If e is A_1 and Δe is A_2 then K_p' is B_1 (10)

where e and e are the inputs of FLC. A_1, A_2, B_1, B_2 and B_3 are linguistic variable values of e, Δe, K_p', K_D' and K_I' respectively.

The tuning of PID gains are adjusted carefully, such that the rule base table of the fuzzy supervisory for K_p', K_D' ,and K_I' must be chosen accurately to guarantee a system with a fast rising time, smaller overshot and no steady state error. Fig. 5 shows the unit step response for controlled system. The rule base must be written according to the step response. The step response is divided into four regions.

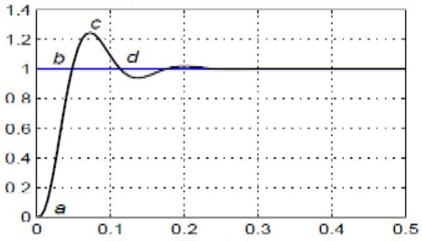

Fig 5. Unit step response

For region 1 around point (a), a big control signal to achieve fast rise time is needed. To eliminate the error, the integral gain has to be emphasized, and to speed up the response the derivative gain has to be there. To produce big control signal the PID control should have large proportional gain. The rule base which represents case 1 is written as follows:

If e is PB and Δe is Z then K_p' is B , K_D' is S and K_I' is S (11)

When the error becomes negative during region 2 around point (b), the system needs to slow to reduce the overshoot. This is accomplished by decreasing the proportional gain, small integral gain and large derivative gain. Hence the rule base that represents this case is such as:

If e is Z and Δe is NB then K_p' is S , K_D' is B and K_I' is S (12)

The other cases can be tuned as the same way. The rule base table of K_p' , K_D' and K_I' are shown in Table 1, Table 2 and Table 3 respectively.

TABLE I. FUZZY CONTROL RULE OF KP

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 II. FUZZY CONTROL RULE OF KD

KD		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 III. FUZZY CONTROL RULE OF KI

KI		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

V. RESULTS AND DISCUSSION

The fuzzy self-tuning PID controller is applied to 5 DOF robot arm. The robot has 5 DOF each of them has DC motor with specific transfer function. To show the effectiveness of this approach, the output response of the first DOF of the robot arm is shown with variation of the PID gains. The output response of the other motors can be obtained in the same way.

The transfer function of the DC motor of the first DOF considered is defined as follows:

$$G(s)=\frac{19649}{s^3+201s^2+6290s} \qquad (13)$$

The results were obtained using MATLAB and SIMULINK for the above transfer function which represents the output response of the first DOF of robot arm using the proposed controllers.

The simulation results in Fig. 6 and Fig. 7 show the output response of the proposed controllers with respect to step input signals. The two figures show the performance of the PID using conventional tuning (without fuzzy tuning) and using the supervisory tuning respectively. In addition, they show the effectiveness of the two controllers for rejection disturbance inputs.

If a load torque with -1.0 N.m is applied on the first angle, the result obtained shows the effect of the disturbance on the output response after 0.3 second and the efficiency of the FCS controller for tuning PID parameters and eliminating the disturbance.

Controller type	System characteristics		
	M_P %	t_r (sec)	SSE
Classical PID control	_	0.091	0.035
Fuzzy Supervisory control	0.06%	0.062	0.004

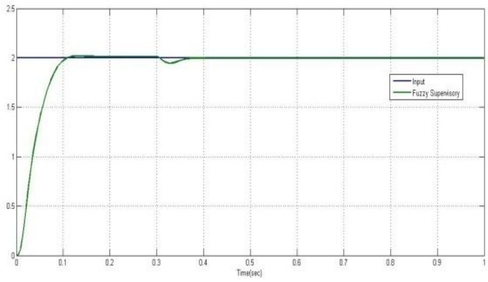

Fig 6. Output response using classical tuning methods

It is cleared that the fuzzy logic control achieve better performance for tuning the PID gains than conventional tuning methods such as eliminating overshoot, rising time and steady state error.

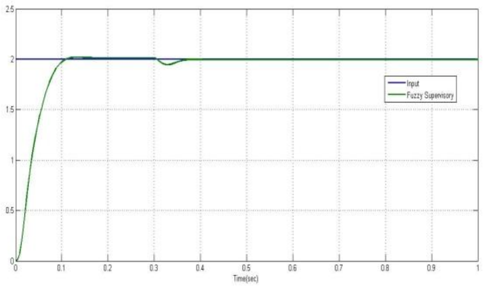

Fig 7. Output response using fuzzy supervisory control

The above figures show the effect of small disturbance after 0.3 second and effectiveness of the fuzzy supervisory controller for eliminating the presence disturbances.

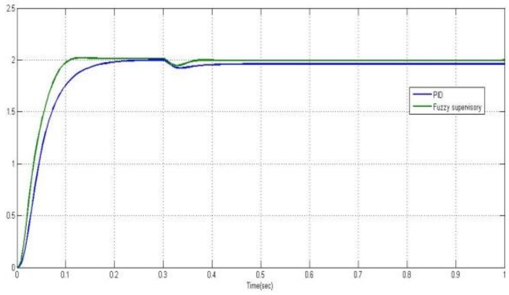

Fig 8. PID & Fuzzy supervisory controllers Step resposes with disturbance of -1 N-m at 0.3 sec.

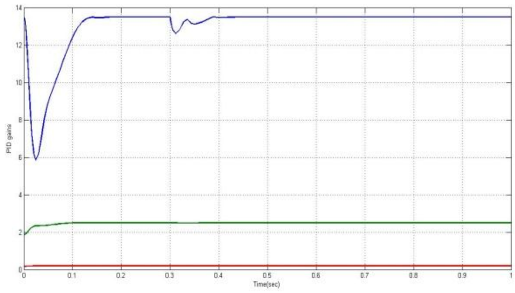

Fig 9. PID parameters variations

The fuzzy supervisory tries to vary the PID parameters during process operation to enhance the system response and eliminates the disturbances. Fig. 8 shows the variation of the PID gains during the operation using fuzzy control as supervisory controller. Performance of proposed controllers is summarized in Table 4.

TABLE 4 :Comparison of various controller values

VI. CONCLUSION AND FUTURE WORK

For linear motion of Robot arm, there are many choices. One can use a linear motor. In this paper DC linear servo motor is taken, and used as actuator .There are so many Controllers to control the actuator accurately and robustly .Although PID control is the standard control for linear systems, it faces problems dealing with nonlinear systems and is limited when we talk about robustness. Several traditional methods are available for tuning PID parameters; however, they are time consuming and depend on the starting points. Fuzzy logic is utilized in the process of turning PID's parameters; thus, leading to fuzzy supervisory control. FSC was used to optimize the process of tuning PID's parameters in order to control a 5DOF robot arm. The output response of Fuzzy supervised PID controller outperformed classical PID response. This showed that tuning PID parameters using fuzzy logic outperforms classical methods.

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