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Control of 5DOF Robot Arm using Feed Forward ANFIS Controller

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Abstract: Lynx6 Robot has been widely used in manufacturers of robot kits, including robot arms, biped walking robots, quadrupeds, hexapods, tracked and wheeled vehicles, and more. Thus to provide the necessary campaign in robot arm broadly linear motors are used. In this paper linear servo motor is considered, which will act as actuator. In order to perform actuator precisely and robustly, the robot controller should be designed suitably. Controlling of robot manipulator is challenging due to their nonlinearity nature and the modeling problem is necessary before applying control techniques to guarantee the execution of any task according to a desired input with minimum error.

This paper presents the control of five degrees of freedom robot arm (Lynx Robot) using using new technique which is familiarly known as Feed forward ANFIS Controller.Using the Feed-forward technique to five DOF robot arm shows the effectiveness of the approach in minimum error during disturbances and load variations. Comparative evaluations with respect to PID, Fuzzy, And Fuzzy Supervisory are presented to validate the controller design. The results presented emphasize that to reduce the computational time and flexibility during disturbances, load variations that occur in robot manipulator can be minimized using Feed forward ANFIS Controller than PID, Fuzzy, and Fuzzy Supervisory controllers.

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

I. 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, modeling 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.

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. Fuzzy supervisory is used to reduce the amount of tuning the PID controller with a fuzzy system. It is considered as an attractive method to solve the nonlinear control problems, one of the advantages of fuzzy supervisory that the control parameters changed rapidly with respect to the variation of the system response. The fuzzy supervisor operates in a manner similar to that of the FLC and adds a higher level of control to the existing system. Fuzzy supervisory is to overcome the problem of tuning PID in nonlinear systems using FLC as an adaptive controller. The basic structure of FSC resembles the structure of PID controller, but the controlled parameter of PID controller depends on the output of the fuzzy controller. In this paper applied control is FSC, 49 rule bases was designed for the PID parameters, numbers and types of membership function for the FSC controller are chosen to give the desired performance.

The primary weakness of previous methods for determining acceptable trajectories is the massive amount of computer time needed to obtain a solution. Neuro fuzzy systems offer not only the

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benefit of the parallel nature of its computations, but also the ability to learn the control of an arm by following a human's example.

Fuzzy Logic Controller can very well describe the desired system behavior with simple “if-then” relations owing the designer to derive “if-then” rules manually by trial and error. On the other hand, Neural Networks perform function approximation of a system but cannot interpret the solution obtained neither check if its solution is plausible. The two approaches are complementary. Combining them, Neural Networks will allow learning capability while Fuzzy-Logic will bring knowledge representation (Neuro-Fuzzy).

The technique used in this work replaces the rule-base of a traditional fuzzy logic system with a back propagation neural network. Using neuro-fuzzy techniques, a robotic arm can be trained to plan its movements to avoid a collision with obstacles in its vicinity.

In many control systems, attention of disturbance is a necessary concern. Any control system may have unpredictable inputs that affect the plant output. Disturbance is denoted as an external inputs added to the control system, which drive system away from its desired task. In many cases, it is possible to measure disturbances before they influence the processes. Therefore, many control techniques are used to reject the disturbance before they create control error. One of these techniques is the feed forward method.

This paper presents the control of five degrees of freedom robot arm (lynx6 Robot) using feed forward ANFIS Controller.

The paper is organized as follows: section 2 describes DC Motor modeling, section 3 describes the structure of simple PID controller, section 4 presents FLC, section 5 presents FSC, section 6 presents Neuro fuzzy, section 7 presents the results, and finally section 8 concludes this paper.

II. DC MOTOR MODELLING

Generally, modelling refers to system (e.g. plant) description in mathematical terms, which characterizes the input-output relationship [39]. Direct current (DC) motor is a common actuator found in many mechanical systems and industrial applications such as industrial and educational robots. DC motor converts the electrical energy to mechanical energy. The motor directly has a rotary motion, and when combined with mechanical part it can provide translation motion for the desired link. The fig.2.1 shows the schematic diagram of D.C. Motor is shown.

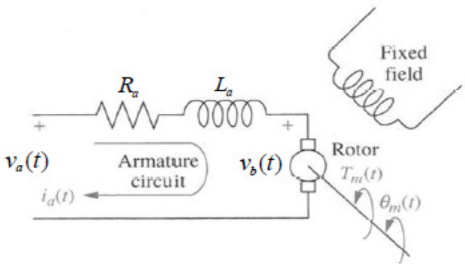

Figure 2.1: Schematic of DC motor system

The transfer function of motor speed is derived as

$$G_{speed}(s)=\frac{\dot{\theta}(s)}{V(s)}=\frac{K_t}{J_m L_a s^2+(L_a B_m+R_a J_a)s+K_t K_b}$$

In addition, the transfer function of the motor position is determined by multiplying the transfer function of the motor speed by the term 1/*s*.

$$G_{position}(s)=\frac{\theta(s)}{V(s)}=\frac{K_t}{s\left[J_m L_a s^2+(L_a B_m+R_a J_a)s+K_t K_b\right]}$$

Fig.2.2 shows the block diagram of D.C. motor.

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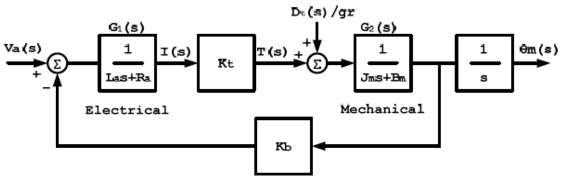

Figure 2.2: Block diagram for DC motor system

The state space model of DC motor could be expressed as follows:

$$\begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \\ \dot{x}_3(t) \end{bmatrix} = \begin{bmatrix} \frac{-R_a}{L_a} & 0 & \frac{-K_b}{L_a} \\ 0 & 0 & 1 \\ \frac{K_t}{J_m} & 0 & \frac{-B_m}{J_m} \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \end{bmatrix} + \begin{bmatrix} \frac{1}{L_a} \\ 0 \\ 0 \end{bmatrix} v_a(t)$$

$$y(t) = \begin{bmatrix} 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \end{bmatrix}$$

The following table shows DC motor parameters and values chosen for motor simulation.
DC Motor parameters and values

Table 2.1: DC motor parameter and values

Parameter	Value
Moment of inertia	J_m = 0.000052 Kg.m2
Friction coefficient	B_m = 0.01 N.ms
Back EMF constant	K_b = 0.235 V/ms-1
Torque constant	K_t = 0.235 Nm/A
Electric resistance	R_a = 2 ohm
Electric inductance	L_a = 0.23 H
Gear ratio	gr
Load torque	$\tau_l(t)$
Angular speed	ω_m rad/sec

On substituting the parameter values in the transfer function we get

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

III. PID CONTROLLER

PID controller is considered the most control technique that is widely used in control applications. A huge number of applications and control engineers had used the PID controller in daily life. PID control offers an easy method of controlling a process by varying its parameters. Since the invention of PID control in 1910, and Ziegler-Nichols' (ZN) tuning method in 1942 [7] and [38], PID controllers became dominant and popular issues in control theory due to simplicity of implementation, simplicity of design, and the ability to be used in a wide range of applications [40]. Moreover, they are available at low cost. Finally, it provides robust and reliable performance for most systems if the parameters are tuned properly. According to different sources like JEMIMA2, PID controllers or PID variations (P, PD, and PI) are widely used in more than 90% to 95% of control applications. However, the PID controller has its own limitation; the PID performances can give only satisfactory performance if the requirement is reasonable and the process parameters variation are limited. The general form of the PID controller in continuous time formula given as:

$$u(t) = K_p e(t) + K_I \int e(t) + K_D \frac{de(t)}{dt}$$

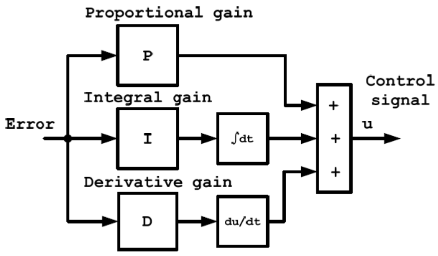

Fig. 3.1 PID controller structure

The transfer function of the PID controller in parallel is:

$$G_{PID\_Parallel}(s) = K_P + \frac{K_I}{S} + K_D s = \frac{K_D s^2 + K_P s + K_I}{s}$$

For the robot manipulator if the PID controller is used as controller plant, the final transfer function of the disturbance compensator $G_{cd}(s)$ is given by:

$$G_{cd}(s) = \frac{L_a s^2 + R_a s}{K_t (K_D s^2 + K_p s + K_I)}$$

Using SIMULINK, the DC motor model with disturbance rejection control using PID controller is created as shown in Figure 5. This model includes all transfer functions that are derived previously. The feed forward transfer function is also added to this model.Fig. Block diagram of PID controller.The following simulated model represents IJC for N joint robot manipulator (e.g. revolute or prismatic) joints is accomplished by using N block diagrams with respect to the number of the independent joints. Designing these controllers accomplished using SIMULINK. The main system consists of several levels. As a case study, the independent joint control is implemented to 5DOF robot arm. For each individual motor the angle and load disturbance are given and position each motor is observed. The following plots show the positions of each individual motor for step input with various values of disturbances. We can also observe the specifications like the overshoot, rise time, steady state error etc.

IV. FUZZY LOGIC CONTROLLER

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:

Volume 03, Issue 02, [February – 2016] ISSN (Online):2349–9745; ISSN (Print):2393-8161

Define the input and output variables of FLC. In this paper, there are two inputs of FLC, the error *e* (*t*) and error change $\Delta e(t)$ 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:

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

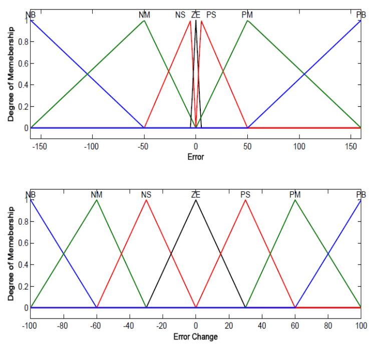

Figure 1. Membership function of e(t) and Δ ***e(t) .***

V. FUZZY SUPERVISORY CONTROL

The closed loop system with fuzzy supervisory PID control is shown in Fig. 5.1. The control system consists of a fuzzy logic part and a PID part.

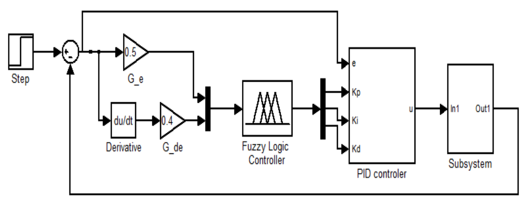

Fig 5.1. Fuzzy supervisory control

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. 5.2.

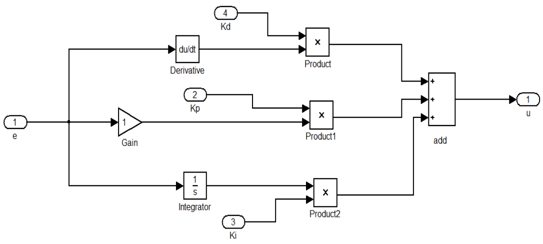

Fig 5.2. Structure of PID controller

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

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

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

The output of fuzzy logic control is K'_P, K'_I, and K'_D .Suppose the ranges of these parameters are $[K_{P_{\min}}, K_{P_{\max}}]$, $[K_{I_{\min}}, K_{I_{\max}}]$ and $[K_{D_{\min}}, K_{D_{\max}}]$ 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:

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

$$K'_D = {(K_{D_{\min}} - K_D)} \big/ {(K_{D_{\max}} - K_{D_{\min}})} \quad (7)$$

$$K'_I = {(K_{I_{\min}} - K_I)} \big/ {(K_{I_{\max}} - K_{I_{\min}})} \quad (8)$$

where, K'_P, K'_D, and K'_I are output variable of fuzzy control.

Fig.5.3.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)

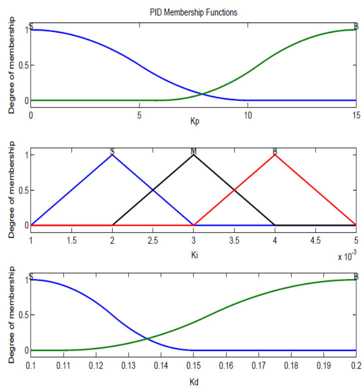

Fig 5.3. Membership function of, K'_P, K'_D, and K'_I

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 overshoot 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.

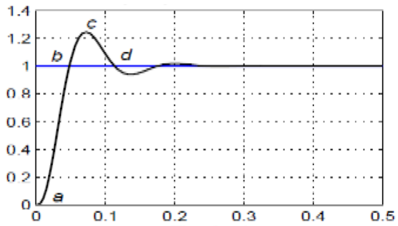

Fig 5.4. Unit step response

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

VI. DESIGN OF NEURO-FUZZY CONTROLLER.

Recently, the combination of neural networks and fuzzy logic has received attention. Neural networks bring into this union the ability to learn, but also require an excessive number of iterations for training of complex systems. Fuzzy logic offers a system model based on membership functions and a rule base, but requires an explicit stating of the IF/THEN rules. Several methods for combining neural networks and fuzzy logic have been studied (Khan, 1993) (Lin and Song, 1994) (Nauck, et. al., 1993). In this paper we implement the inference stage of a fuzzy system using a neural network. The given figure illustrates the system architecture for the described combination of neural networks and fuzzy logic. By replacing the rule base of a fuzzy system with a trainable neural network, complex input-output relationships can be achieved which cannot be easily specified by IF/THEN rules. With fuzzification and defuzzification stages augmenting a neural network, significant improvements in the training time, in the ability to generalize, and in the ability to find minimizing weights can be realized. Furthermore, the fuzzy membership functions give the designer more control over the neural network inputs and outputs. It should be noted that NN contributes to determination of constructing the fuzzy rules

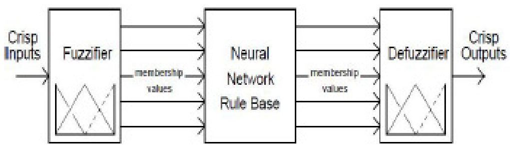

Fig. 6.1 A Fuzzy system with Neural network rule base

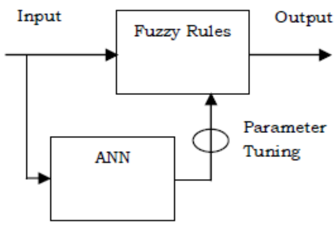

Fig. 6.2 Model of Neuro-Fuzzy controller

For Disturbance rejection, introducing a feedforward compensator in forward path of the plant and controller.This paper presents the control of five degrees of freedom robot arm (lynx6 Robot) using feed forward ANFIS Controller.

VII. RESULTS AND DISCUSSION

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

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

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.. 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 0.5 second and the efficiency of the Feed Forward ANFIS controller for tuning PID parameters and eliminating the disturbance.

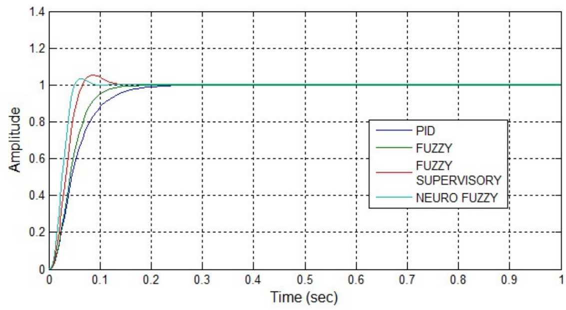

Fig 7.1. Output responses for step input using proposed controllers without disturbance

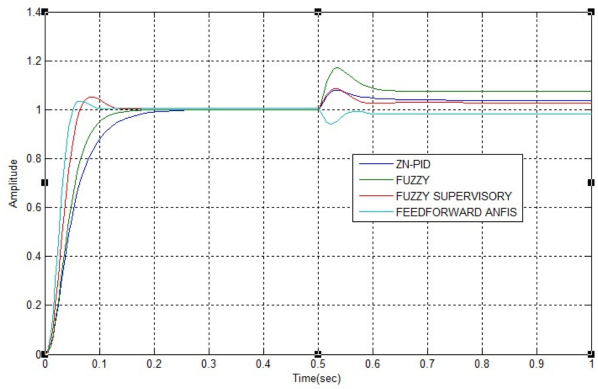

Fig 7.2. Output responses for step input using proposed controllers with disturbance

The above figures show the effect of small disturbance after 0.5 second and effectiveness of the fuzzy supervisory controller for eliminating the presence disturbances. 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. Performance of proposed controllers is summarized in Table 4.

TABLE 4 :Comparison of various controller values

Tuning Method	System characteristics		
	Overshoot (O.S)	Rising Time (t_r) sec	Steady state error (S.S.E)
PID	-	0.0905	0.009
FLC	-	0.068	0.007
FSC	0.05	0.041	0.005
Feedforward ANFIS	0.02	0.028	0.001

VIII. CONCLUSION AND FUTURE WORK

Robot manipulators have become increasingly important in the field of flexible automation. In this thesis DC linear servo motor is considered, and used as actuator .There are so many Controllers to control the actuator accurately and robustly. Appling a control technique is important to guarantee high efficiency and lower error for the motion of the robot.

The objective of this thesis was to control Lynx6 robot arm to reach the specified location with minimum error while meeting certain specification. In This thesis a new technique called Feed forward ANFIS Controller helps us to compare and shows its flexibility and its results are compared with PID, FLC and FSC. Simulation results show that the Feed forward ANFIS Controller can achieve better accuracy and has less or no deviation from the trajectory compared to the PID, FLC, FSC techniques.

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