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A Single Link Flexible Manipulator Control using Fuzzy Logic

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Abstract: Conventional control techniques are often unable to achieve the design objectives of flexible manipulator because of nonlinear and time-varying plant dynamics, significant noise and disturbances, time-consuming gains selections. Therefore, new methods to achieve the design objectives of flexible manipulators should be developed. For that reason, in this paper Fuzzy Logic Controller has been presented where its practical applications are demonstrated via active vibration control and position regulation experiments of a very flexible link manipulator. It has been considered to control by using the Fuzzy for single link flexible manipulator because of the flexibility of the link, rotating the base of the link causes the entire link to oscillate. The controller has been tested with 10, 30 and 45 degrees to estimate the overshoot, settling time, rise time, and steady state error. A comparative study has been carried out to show the performance and accuracy with conventional controller LQR and Fuzzy Logic Controller in terms of overshoot, settling time, rise time, and steady state error.

Keywords: Single link, fuzzy logic, fuzzy rule base, membership function

1. INTRODUCTION

Flexible manipulators offer significant operational advantages over the commonly used rigid robots, such as higher operation speed and lower energy consumption shown in Figure 1. However, these advantages come only at the expense of rendering an accurate control of these manipulators more difficult to attain [1]. A control system for this type of robotic manipulators should be able to effectively cope with the adverse effects of transient vibrations and link deflections due to external loads. Since the equations governing the dynamics of a flexible manipulator consist of complex nonlinear partial differential equations, this kind of controllers, therefore, become very complicated. Among various control methodologies for nonlinear systems, the fuzzy logic approach distinguished itself by its capability of systematically

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incorporating human linguistic information into controller design [2,3]. In spite of impressive successes in a wide spectrum of practical applications, the use of the fuzzy logic approach to control of flexible link manipulators [4,5,6] is relatively new, and far from mature: many challenges are still open, and must be addressed. Hence, the main objective was to design a fuzzy logic controller for single link flexible manipulator to evaluate the performances of the designed PID controller performance by using: settling time, rise time, overshoot, and the vibration suppression at the tip.

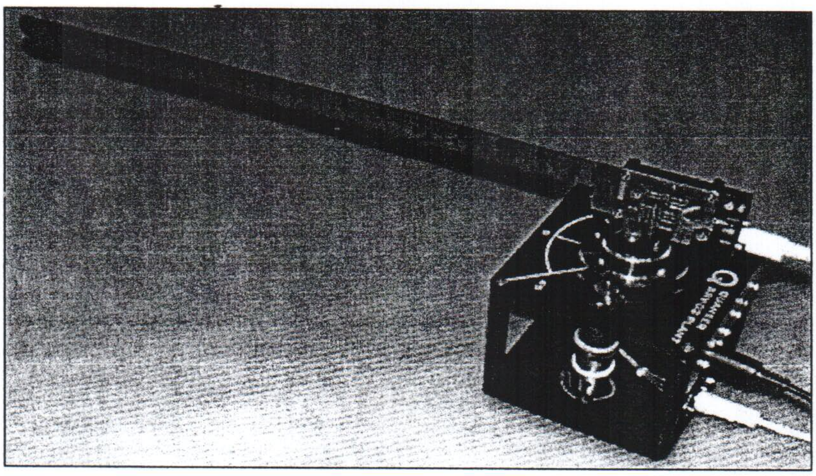

Figure 1: Single Link Flexible Manipulator

A Fuzzy Logic Controller describes complex systems with linguistic descriptions. The information is described in terms of fuzzy sets. Unlike conventional controllers, three steps have to be performed by a Fuzzy Logic Controller before it may generate desired output. These three steps are considered Fuzzification of the input; Fuzzy inference based on the knowledge base; Defuzzification of the fuzzy control signal. The Fuzzy Logic Controller has been considered four inputs and one output. The four inputs are Theta (current position), Theta-Dot (angular speed), Alpha (tip deflection), and Alpha-Dot (tip deflection rate of change). The output had been considered as a torque (to the plant). Performance of Fuzzy Logic Controller is extremely dependent on proper selection of inputs and outputs with proper membership function and finally more depends on proper rule base developed. Therefore, the performance of Fuzzy Logic Controller can be improved by assessment of the related constraints.

2. MODELING OF SINGLE LINK MANIPULATOR

Modeling and control of flexible manipulators has been an active research field in recent years. Lightweight flexible link manipulators with motion speed, better energy efficiency, safer operation and improved mobility are highly desirable. In this paper, the concepts of Fuzzy Logic with the parameters are described in the following section.

2.1. Fuzzy Logic Control

The Fuzzy Logic Controller describes complex systems with linguistic descriptions and three steps have to be performed by a Fuzzy Logic Controller before it may generate desired output for the conventional controllers. The block diagram of a typical Fuzzy Logic Controller has been shown in Figure 2, where, it considered the Fuzzification of the input; fuzzy inference based on the knowledge base; Defuzzification of the fuzzy control signal. Finally, the Fuzzy Logic Controller has been applied to the desired plant.

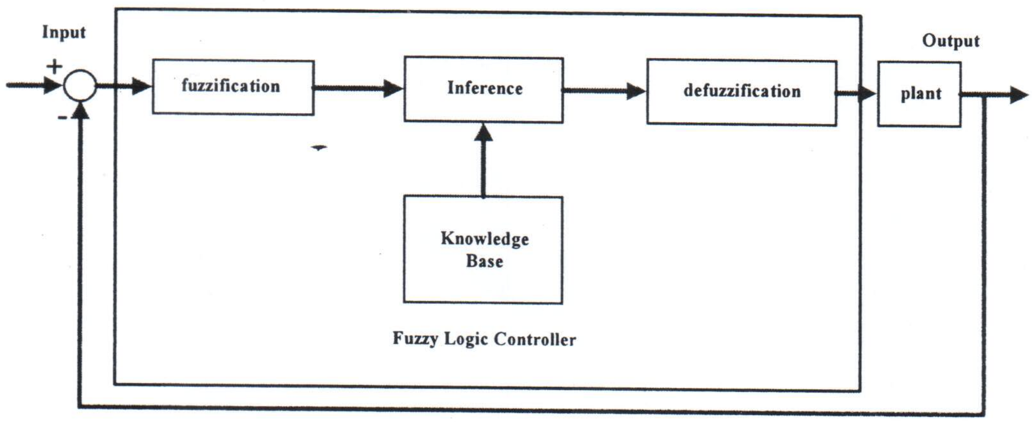

Figure 2: The Block Diagram of Fuzzy Logic Controller

2.1.1. Fuzzy Inference System

For the Fuzzy Inference System it has been considered the mamdani method, where the implication has been assumed to min and the aggregation has been considered to max. In addition, the Defuzzification method has been considered to the centroid method.

2.1.2. Input and Output Variables

According to the research scope and goal, in this paper, four inputs and one output have been considered. The four inputs are Theta (current position), Theta-Dot (angular speed), Alpha (tip deflection), Alpha-Dot (tip deflection rate of change) and the output is torque (to the plant).

2.1.3. Membership Function for Input and Output Variables

The membership functions are assumed for the flexible manipulator is NL = Negative Large, NM = Negative Medium, NS = Negative Small, Z0 = Zero, PS = Positive Small, PM = Positive Medium. Only the membership function for Theta has shown in Figure 3, where the range is assumed -1 to 1.

2.1.4. Fuzzy Rule-Base

Fuzzy control rules are the heart of a fuzzy logic controller. Determining the suitable fuzzy control rules is the major part of a fuzzy controller design. Each of these control rules has

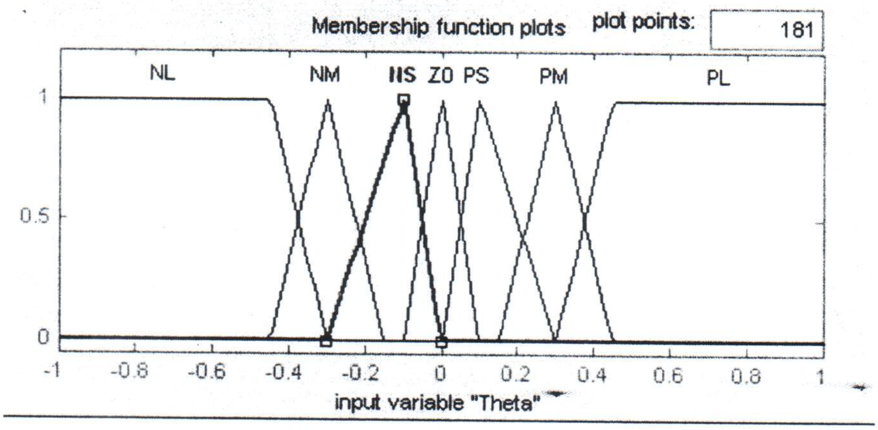

Figure 3: Membership Function Plots for Theta Variable

IF....THEN.... statement. By matching the fuzzified inputs with each control rule will generate a set of control signals. Here, 2 sets of inputs for fuzzy controller have been assumed. The first set of inputs is angular tip displacement error ℓ and the other is angular velocity tip displacement error $\overset{\circ}{\ell}$. In the similar way, for the tip vibration and the tip vibration rate of change had been assumed same concept. Actually, the control signal applied to the system depends on how large the error and its derivative are. Therefore, a complete set of fuzzy control rules can be established. In this research, 98 rules have been used and the Fuzzy Logic Control rules space shown in Figure 4.

Error rate $(\dot{e})$

Error (e)	NL	NM	NS	Z0	PS	PM	PL
NL	PL	PL	PL	PL	PM	Z0	Z0
NM	PL	PL	PL	PM	PS	Z0	Z0
NS	PM	PM	PM	PS	Z0	NS	NS
Z0	PM	PM	PS	Z0	NS	NM	NM
PS	PS	PS	Z0	NS	NM	NM	NM
PM	Z0	Z0	NS	NM	NL	NL	NL
PL	Z0	Z0	NM	NL	NL	NL	NL

Figure 4: Fuzzy Control Rule Space

2.1.5. Defuzzification

Since the above control signal is in fuzzy mode, Defuzzification is required to transform fuzzy control signal into exact control output. The weighted centroid method is applied to defuzzify the fuzzy control signal. This method can be expressed as:

$$Z_{COA} = \frac{\int_{z} \mu_A(z)zdz}{\int_{z} \mu_A(z)dz} \quad (1)$$

Where, $\mu_A(z)$ is aggregated output Membership Function.

3. EXPERIMENTAL SETUP

In this research, to make the experimental setup, it has been considered the hardware and software part where the hardware part was assumed that the Quanser flexible link manipulator, Sensors: Encoder, potentiometer and tachometer. In addition, the software part, the controller is considered the Simulink-based controller implementation. A simple diagram for flexible link manipulator is shown in Figure 5, where the arm length is L and the arm moves from xi position to yi position.

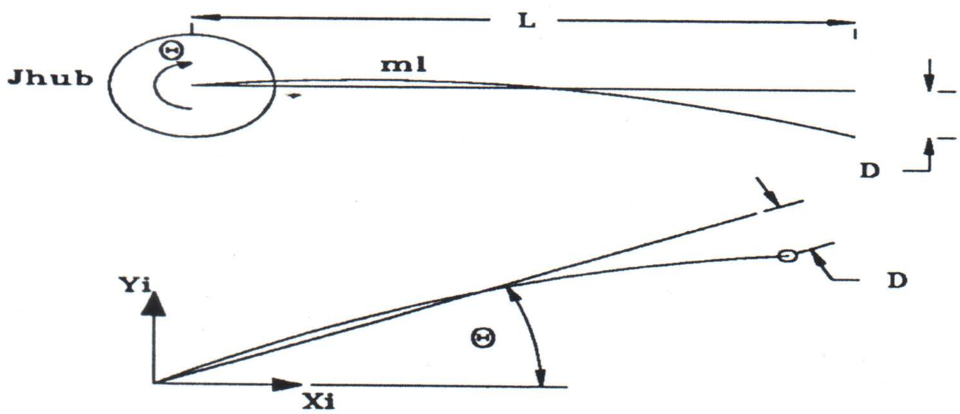

Figure 5: Flexible Link Manipulator

3.1. Result from FIS editor (Fuzzy Tool Box)

According to rules and membership functions value, the surface viewer from the FIS editor of MATLAB shown in Figure 6 for Theta and Theta-Dot.

3.2. Result from Simulation (Simulink Tool Box)

The Fuzzy Logic Controller simulation architecture is very similar with the simulation architecture of LQR controller shown in Figure 7.

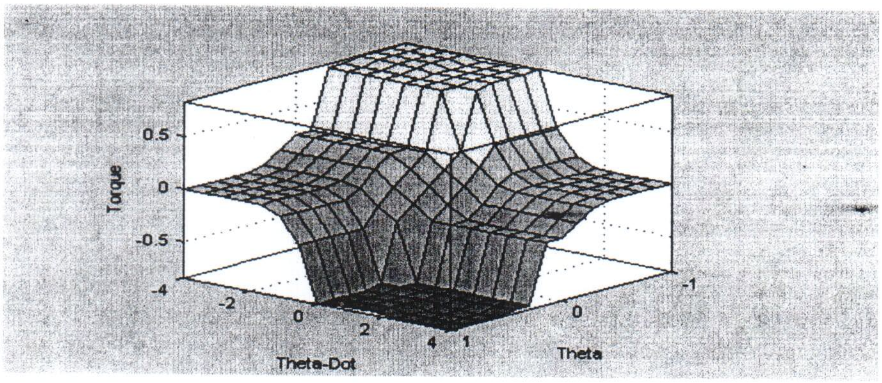

Figure 6: The Surface Viewer Output for Theta and Theta-Dot

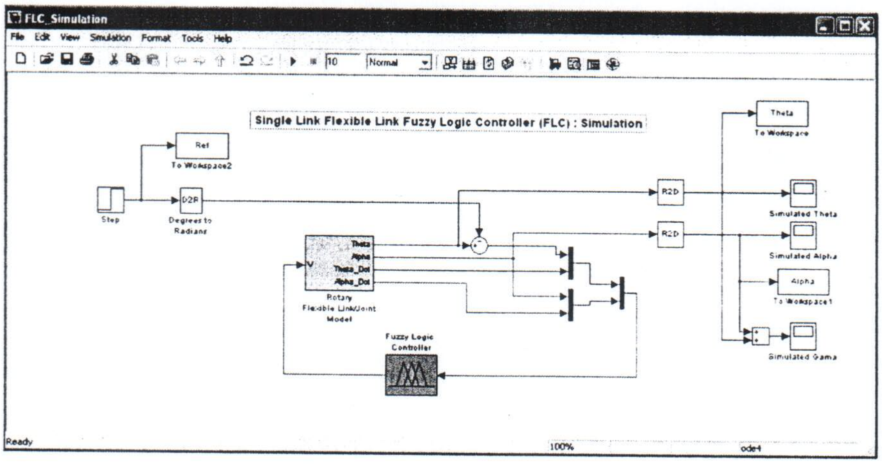

Figure 7: The FLC Simulation Architecture

By using the Simulink toolbox, the design model was simulated for Fuzzy Logic Controller in three different step responses such as 10 degree, 30 degree, and 45 degree. The controller for 10 degree has shown in Figure 8. By calculating the performance, it has been found the overshoot 0.0059%, the settling time 1.8820 sec, the rise time 1.2490 and, the study state error -5.9217e-004.

Similarly, the controller for 30 degree it was found the overshoot 0.0020%, the settling time 2.3680 sec, the rise time 1.6560 sec and, the steady state error -5.8654e-004. And for 45 degree it was found the overshoot 0.0013 %, the settling time 2.3950 sec, the rise time 1.5490 sec and, the steady state error -5.8729e-004.

3.3. Result from Simulation (Simulink Tool Box)

Form the experimental outputs, it was found that the simulation output and experimental output had some dissimilar result; so, there need some tuning by changing the different parameters to get the same output results. The experimental output for 45 degree has given in the Figure 9, where, the Flexible link is not perfectly showing 45 degrees but there is very less vibration.

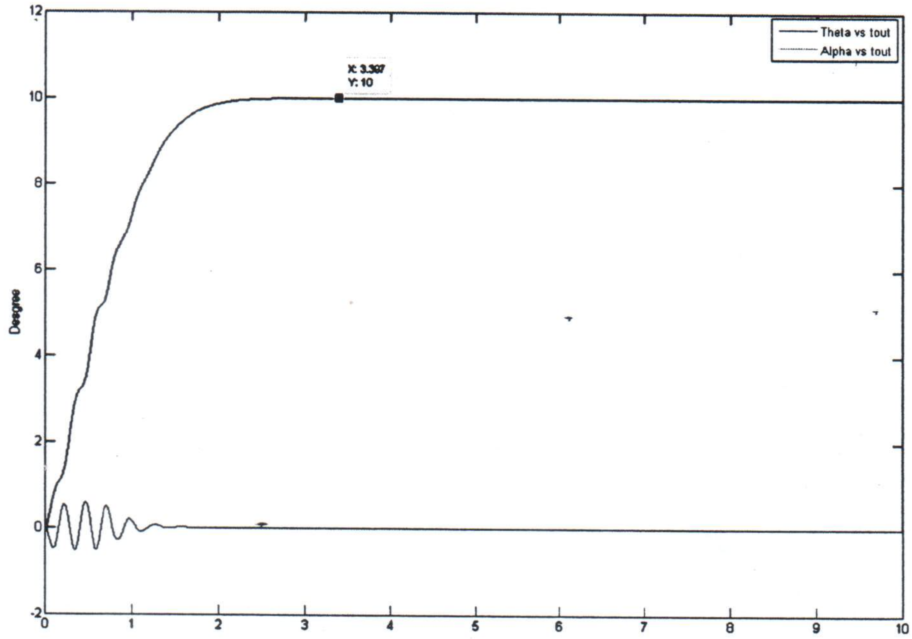

Figure 8: The FLC output for 10 Degree

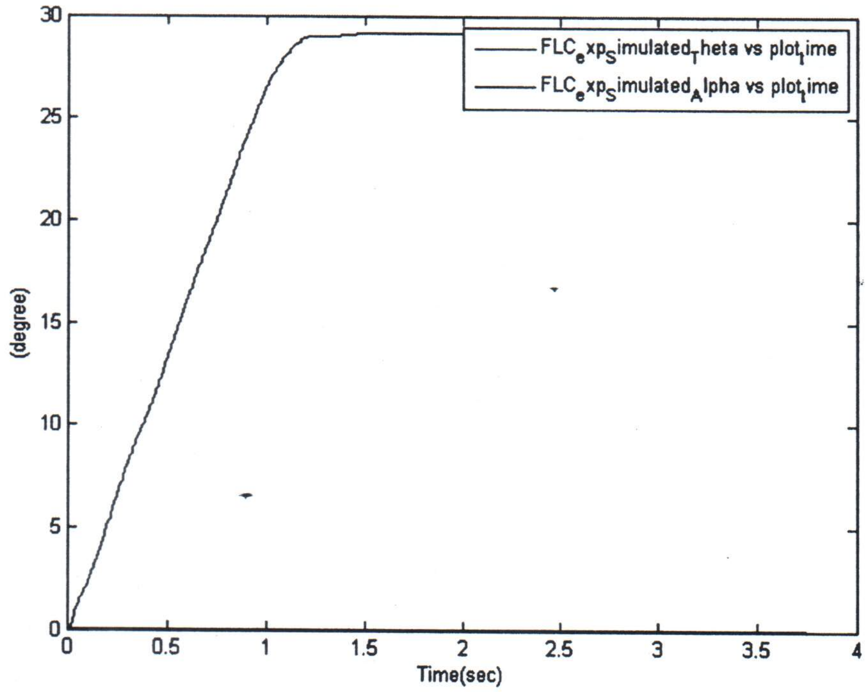

Figure 9: Experimental Output for 45 Degree

3.4. Performance Comparison

The simulation output from the FLC and LQR for 45 degree has shown in Figure 10. According to the figure, it can be said that still the performance of LQR controller is better than the performance of FLC controller for the flexible link manipulator, but with vibration to take few more time to go steady state. Finally, a summery has given in the Table 1 by comparing the simulation output for LQR and FLC from my project for 10, 30, and 45 degree position changed with respect to the settling time, rise time and over shoot properties.

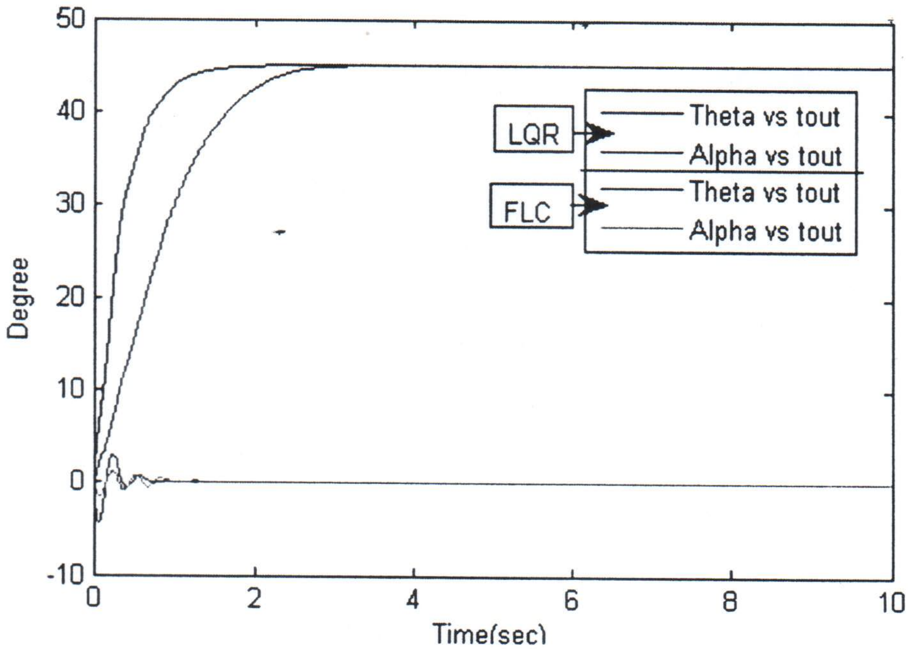

Figure 10

Table 1
Comparison with FLC and LQR Controller with Simulation Output

	10 degree		30 degree		45 degree	
	FLC	*LQR*	*FLC*	*LQR*	*FLC*	*LQR*
Over shoot (%)	0.0059	-.9686e-012	0.0020	-5.6488e-012	0.0013	-5.8738e-012
Settling time (sec)	1.8820	1.3060	2.3680	1.3060	2.3950	1.3060
Rise time(sec)	1.2490	0.7340	1.6560	0.7340	1.5490	0.7340
Steady state error (%)	-.9217 e-004	5.9686 e-013	-5.8654 e-004	1.6946 e-012	-.8729 e-004	2.6432 e-012

According to the Table 1, settling time for LQR controller fixed but for the FLC is changing from low to high respectively for the degree 10, 30, and 45. In addition, the overshoot is decreasing for FLC controller from 10, 30, and 45 degree.

CONCLUSION

The design of Fuzzy Logic Controller still need to do some work to surpass performance of the conventional LQR controller in terms of overshoot, settling time, rise time and steady state error. Performance of FLC simulation and experimental output is extremely dependent on proper selection of inputs and outputs with proper membership function and finally more depends on proper rule base developed. Therefore, the performance of FLC can be improved by assessment of the related constraints.

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