Vibration Control Comparison Of A Single Link Flexible Manipulator Between Fuzzy Logic Control And Pole Placement Control

Auwalu M. Abdullahi, Z. Mohamed, Mustapha Muhammad, AA Bature

Abstract: Vibration is an unwanted phenomena and difficult to handle in the control of flexible manipulators and it becomes more difficult with increased in the payload values to the system. In this work two control schemes- fuzzy logic control and pole placement control are designed and compared for the control of both vibration and tip deflection which occurs during its operation as a result of both rigid-body motion and elastic (flexible) motion of a single link flexible manipulator. The fuzzy logic control scheme was designed with the joint angle error and its derivative as the input of the controller. By computing the control signal using the error and its derivative, the fuzzy controller add damping to the joint thereby controlling the vibration and tip deflection of the system. On the other hand, a model based pole placement control scheme was designed to place the system poles at a desired location based on design specification to overcome the vibration and achieve precise tip deflection of the flexible link. In both control scheme a MATLAB Simulink environment is used to investigate the effects of the controls and a comparison of the simulation results was conducted.

Index Terms: Flexible manipulator, pole placement control, fuzzy logic control, vibration and tip deflection control.

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1 INTRODUCTION

Flexible manipulators have been expressively useful machines in many industrial applications in a wide range. They are developed to undertake most industrial applications that could not be easily solve by heavy rigid robots. This is due to their advantages such as; low electric power consumption, light weight and cheap as compare to the heavy rigid industrial robots. However on the other hand they are associated with some disadvantage which makes their control a challenging and difficult task, some of which are; high oscillation and vibration as a result of rigid body motion at the motor hub angle and the flexible (elastic) motions, also the systems are high order systems and the existence of non-minimum phase dynamic between the applied torque and the tip position [1]. These problems become more difficult especially when there is an increased in the payload [2]. Another well-known problem is the presence of multiple modes which results in generating resonant frequencies close to or at the desire natural frequencies. To overcome this problem, a multi-mode control scheme that can add damping and suppress the vibration close to or at natural frequencies is suggested in [3].

1.1 PREVIOUS WORKS

Several control schemes were designed and implemented by different researchers, from different angle of view and reasoning, in order solves the problems stated above. In [4] an experimental study was conducted using fuzzy logic and neural networks, for vibration control of a single link flexible manipulator system. An active way for the tip position manipulation of single link flexible link using pole placement was presented in [5]. In [6] a PD-type fuzzy logic control scheme with non-collocated proportional integral derivative (PID) was developed to control vibration of flexible manipulator. In [7] an experimental study was conducted using two feedback controllers, polynomial based pole placement controller and integral controller for the control of both vibration and tip positioning. [8] Presented an input shaping for vibration and trajectory tracking with PD-type fuzzy logic control for flexible arm robot. A comparative study has been conducted by [9, 10] between pole placement and LQR for reduction of tip vibrations and system stability control. Parallel connections of high–Q resonant controller were experimentally used for the resonant control of flexible link in [11]. A controller developed using fuzzy Lyapunov synthesis (FLT) [12] is proposed to control vibration of a flexible manipulator. An adaptive control was developed to control tip position of a single flexible manipulator in [13]. Different control schemes were presented in [14] PID, Pole placement and linear Quadratic regulator (LQR) for tip position and vibration control.

1.2 AREA OF WORK

In this work, a comparison between fuzzy logic control and a pole placement control is presented. The fuzzy logic controller is as described in [15], it is designed for the control of rigid-body motion at the joint linking the hub and the flexible link, this causes the flexible link to vibrate and oscillate. In addition also to control tip deflection as a result of flexible motion (elastic motion) of a single link flexible manipulator. The controller has two inputs; the hub angle error and its derivative, each with seven membership functions giving 49 rules based. On the other hand the pole placement controller was designed to generate gains based on the design specification such as the desired overshoot and settling time so as to control both vibration and tip positioning of the flexible

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manipulator. The rest of this paper is as follows; section II presented the model description, section III presented controller design, Simulink implementation and results comparison are presented in section IV finally the conclusion is made in section V.

2.0 MODEL EXPLOSION

In this paper, the flexible manipulator model used for the design of the controller is as described in [16]. The model is made from a piece of a thin aluminum alloy. It has the following parameters and corresponding values used during the experiment; the length of the flexible link is L=0.9 m, young modulus of the system is E=71 ×10^9 N/m^2, width of the link 19.008 mm, thickness of 3.2004 mm, second moment of inertia I=5.1924 m^4, and mass density per unit volume ρ=2710 kg/m^3. A test-rig with U9M4AT type circuit is used with motors' shaft driving the flexible link at the hub. A motor was chosen for the experiment due to its low inductance and low inertia [16]. The schematic diagram of the single link flexible manipulator system is shown as Figure 1.

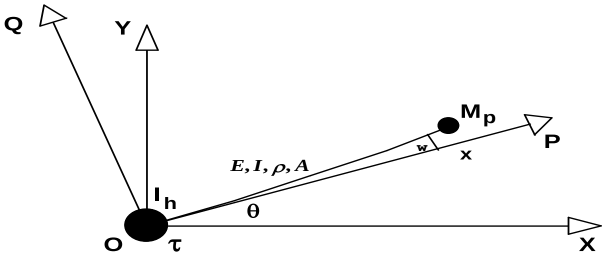

Fig.1 Description of the flexible manipulator system [16]

2.1 MODELING OF FLEXIBLE MANIPULATOR SYSTEM

The model of the flexible manipulator is obtained using finite element method as presented in [16]. In this section, a transfer function and state space model representation are obtained from the finite element program codes using one number of elements. These mathematical models are basically required for the purpose of simulation in MATLAB Simulink environment and also for the development of control strategies for input tracking and vibration suppression of the system. The mathematical models of both hub angle and tip deflection in transfer function form are represented in equations (1) and (2).

$$G_{hub}=\frac{-1492\times10^{-13}s^5+1014s^4+4553s^3+4.235\times10^7s^2+2.865\times10^7s+1.78510^{10}}{s^6+33.37s^5+9.726\times10^4s^4+1.164\times10^6s^3+7.257\times10^8s^2} \quad (1)$$

$$G_{tip}=\frac{-3.553\times10^{-14}s^5-821s^4-3880s^3-4.315\times10^7s^2}{s^6+33.37s^5+9.726\times10^4s^4+1.164\times10^6s^3+7.257\times10^8s^2} \quad (2)$$

Hence, the flexible link model transfer function as described in (3)

$$\mathrm{G}(s) = G_{hub} + G_{tip} \quad (3)$$

Similarly, the model can also be represented in state space form as described (4)

$$\dot{v} = Av + Bu$$

$$y = Cv + Du \quad (4)$$

Where

$$A = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 58209 & -27441 & 0 & -33 & -6 \\ 0 & -38548 & 16329 & 0 & -27 & 4 \\ 0 & 93918 & -58611 & 0 & 16 & -6 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1013.6 \\ -821.0 \\ 304.1 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

3.0 CONTROLLER DESIGN

In this section the two control design proposed are explained, as stated there two control schemes presented in this paper for the control of single-link flexible manipulator, the controllers are fuzzy logic controller (FLC) and pole placement controller (PPC).

3.1 FUZZY LOGIC CONTROLLER DESIGN

In this section a design method of a FLC is presented as described in [15]. The two inputs of the fuzzy controller are the hub angle error (e) and its derivatives (ė) as shown in the block diagram in figure 2, and the control output signal is generated based on the magnitude of both the hub angle error and its derivative which gives 49 possible control signal to send to the system depending on the error and error derivative as can be clearly seen from table 1. The membership function of both the two inputs and the output are chosen to be seven as was tested to give a better result, the membership function of each are [NB,NM,NS,ZE,PS,PM,PB].

Table 1 rule base

$\dot{e}/e$	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

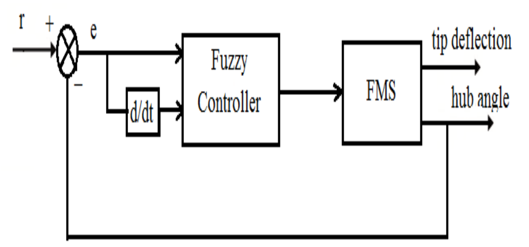

Fig. 2 fuzzy logic controller block diagram

3.2 POLE PLACEMENT CONTROLLER DESIGN

In this section a design procedure of a model based linear pole placement controller is presented. The control gains were obtained based on the system design specification and the state space model of the system. The block diagram of the controller is as shown in figure 3. The controller design procedure is as described in [17]. In this work the controller is designed to suppress the unwanted vibration at the hub joint of the motor due to rigid-body motions, and also to control the tip deflection caused due to oscillation as a result of flexible nature of the link. The control aims is to control the hub angle to track the reference angle and to regulate the tip deflection around approximately zero meters. In order to achieve this control goals, the design specification are as given in (i) and (ii).

(i) Overshoot of 2%
(ii) Settling time of 0.3 seconds

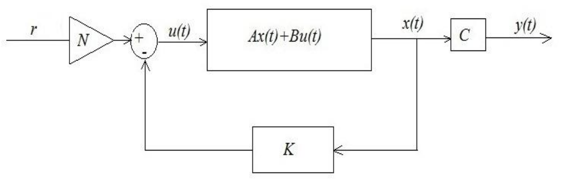

Fig. 3 pole placement controller block diagram [18]

The controller gains are found using the following method from the state space model of the flexible link as in (4)

$$\dot{v} = Av + Bu$$

$$y = Cv + Du$$

Design specification requirements are as follows;

M = 0.02

Ts = 0.3 sec.

From the known damping ratio and natural frequency equations given in equation (5) and (6) respectively,

$$\xi = \frac{-logM/100}{\sqrt{\pi^2 + \log{(M/100)^2}}} \qquad (5)$$

$$\xi = 0.9465$$

$$w_n = \frac{4}{\xi Ts} \qquad (6)$$

w_n= 14.0876 rad/sec.

The control gains are computed using MATLAB acker command; the poles of the system are located at, a+jb, a-jb,-40, -50, -60 and -70, from which the values of the gain K and N are obtained. K is the controller gains matrix and N is the scaling factor for the achievement of zero steady state error. Where; a+jb and a-jb are the dominant poles of the system, which characterize the behavior and stability of the system. They are found to be at -13.3333 + 4.5479i and -13.3333 - 4.5479i respectively. Also the controller gains [K1, K2, K3, K4, K5, K6] are found to be as given in K and N is also found as given below.

K = [0.0934 75.1694 -38.8872 0.0195 -0.1861 0.1340] and N = 0.0934

4.0 RESULTS COMPARISON AND DISCUSSION

The proposed control schemes are implemented in Simulink and tested using bang-bang torque as the input of the flexible manipulator system. The flexible link is required to follow a trajectory within the range of ±80 degrees [15] as shown in Figure 4.

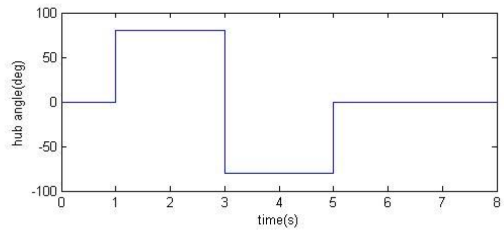

Fig.4 reference hub angle

4.1 FUZZY LOGIC CONTROLLER (FLC)

The fuzzy logic control was implemented in MATLAB Simulink environment using fuzzy tool box, the fuzzy controller has two inputs that are hub angle error and its derivative each with seven membership functions and the fuzzy control signal is generated based on rule base decision. The Simulink block diagram is as described in figure 5. The controller is tested with zero payloads and 30 grams.

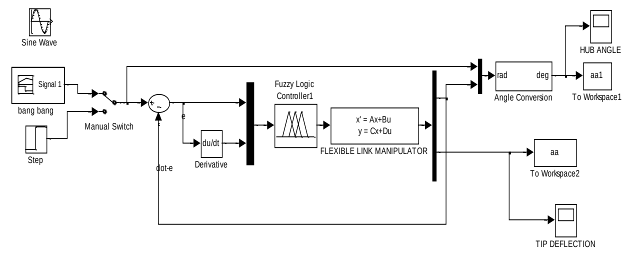

Fig. 5 Simulink block fuzzy logic control

4.2 POLE PLACEMENT CONTROLLER (PPL)

The linear pole placement controller was designed based on the model state space equations using specific design requirement such as overshoot and settling time, the MATLAB Simulink block implemented is as described in figure 6. The controller is tested with zero payload and 30 gram.

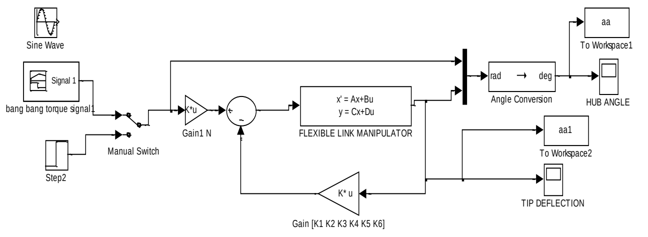

Fig. 6 Simulink block pole placement control

4.3 COMPARISON OF RESULTS

The results from the two control schemes are compared in this section. The fuzzy logic control (FLC) and the pole placement control (PPC) for both hub angle and tip deflection with zero and 30 grams of payloads are shown in figures 7a, 7b, 8a and 8b. It was observed from figure 7a the hub angle with zero payloads as it tracked the reference hub angle for both FLC and PPC almost the same except that after 3.5 seconds FLC doesn't track well as compared to PPC and figure 7b shows the tip deflection of the two control schemes with zero payloads, it was observed the maximum tip deflection in FLC is 13.4 mm and in PPC is 13.97 mm. In figure 8a it was observed when the payloads was increased from 0 g to 30 g there is an overshoot of 2.32 degree in FLC while in PPC there was zero overshoot this is because the PPC is a model based controller and the desired overshoot was already in cooperated in the design requirements. It was also observed in figure 8b the maximum tip deflection in FLC was 15.8 mm while in PPC was 16.2 mm. the summary of the results is shown in table 2.

Table 2 summary of results

Control scheme type	Overshoot (degree) with 0 g payloads	Overshoot (degree) with 30 g payloads	Maximum tip deflection (mm) with 0 g payload	Maximum tip deflection (mm) with 30 g payload
Fuzzy logic control (FLC)	0	2.32	13.4	15.8
Pole placement control (PPC)	0	0.02	13.97	16.2

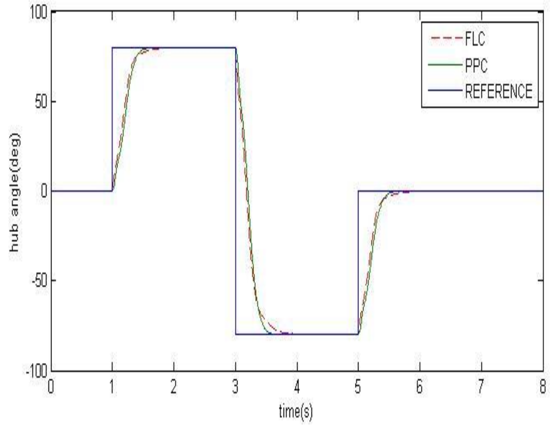

Fig. 7a hub angle with zero payloads tracking the reference with FLC and PPC

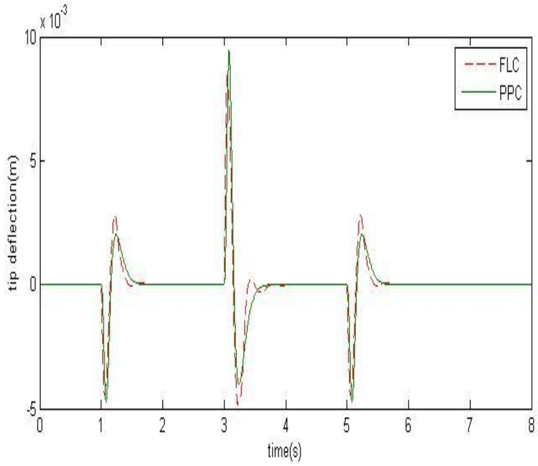

Fig. 7b tip deflection with zero payloads with FLC and PPC

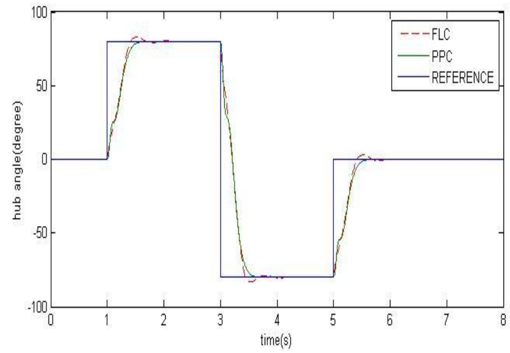

Fig. 8a hub angle with 30 g payloads tracking the reference with FLC and PPC

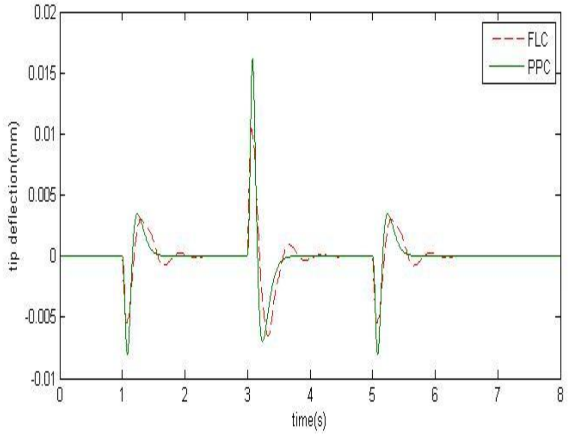

Fig. 8b tip deflection with 30 g payloads with FLC and PPC

5. CONCLUSION

In conclusions it was observed that the two proposed control schemes performed very well in the control of both vibrations which was generated due to rigid-body motion of the link and tip deflection as a result of elastic nature of the flexible link. The fuzzy logic control performed much better in the control of the tip deflection as it gives less maximum tip deflection in both tests with 0 gram and 30 grams as compared to pole placement control. However, on the other hand the pole placement control gives better control of overshoot in hub angle almost with zero overshoot in both tests with 0 gram and 30 grams as was summarized in table 2, this is because the pole placement control is a model based control and during the design process the control gains are to be obtain based on the design specification as described above.

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