Controlling 3-DOF Helicopter via Fuzzy PID Controller

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Abstract

In this paper, the real time tracking performance of the fuzzy PID controller has been evaluated on nonlinear 3-DOF helicopter system. Quanser 3-DOF helicopter system has been utilized as experimental setup. Three separate fuzzy PID controller have been employed so as to control three state of the system. The dynamics of the system has been altered via counterweight in order to examine the performances of the both controller for parametric uncertainty in system parameter. The results reveal that the fuzzy PID controller leads to a good tracking performance and has better parametric uncertainty rejection capability than LQR.

1. Introduction

Aircraft control system has improved a lot with the recent technological advances in the computer science and improvements in the control theory. There are main difficulties in designing a controller for the aircrafts: parametric uncertainty and high nonlinearity of the aircraft are one of them. Fuzzy control is often used in order to overcome these kind of difficulties due to its nonlinear nature. It can provide an effective solution to the control of plants which are complex and uncertain. Moreover, LQR controller can be used in order to control a system which has parametric uncertainty and nonlinearity.

There are many control methods in order to control 3-Dof helicopter. A fuzzy controller is designed in order to control the elevation axis [2]. Fuzzy logic controller and LQR controller is used in together in order to control 3-Dof helicopter [1]. 3-Dof helicopter system is controlled by using a PID controller, a fuzzy controller and LQR controller separately [4].

In this paper, fuzzy controller and LQR controller are compared. First of all, the linear quadratic regulator controller designed by Quanser firm is investigated and 3-Dof helicopter is controlled by using the LQR controller. Then, three separate fuzzy PID controllers have been employed so as to control three axes of the system. Finally, robustness of LQR controller and fuzzy controllers to model uncertainties are tested and the results are compared.

2. 3-Dof Helicopter

Figure 1. 3-Dof Helicopter System

The 3-DOF Helicopter system is shown in Figure 1. The elevation, pitch and travel axes of helicopter are shown as ε, θ and ϕ respectively. The positions of three axes are measured by three encoders. The output of the system are positions of 3 axes and the inputs of system are voltages which are applied to front and back motors. The motors attach two propellers and drive them, so motor force is generated. The positions of 3-Dof helicopter is changed by moving the propellers. There is a counterweight on the helicopter in order to test parameter uncertainty. The nonlinear equation of elevation, pitch and travel axes are given below [5].

2.1. Mathematical Model of Elevation axis

Free body diagram of elevation axis can be shown in Figure 2. Direction of elevation axis is like to gravitational axis. Mathematical model of elevation axis is given in Figure 2. J_ε is moment of inertia of the system about elevation axis, L_a is distance from the middle point to the base point, V_f *and* V_b are the voltage applied to the front and back motor. The mathematical equation of elevation axis is given in equation (1).

$$\begin{aligned} J_\varepsilon \ddot{\varepsilon} = & -(M_f + M_b) g \frac{L_a}{\cos \delta_a} \cos(\varepsilon - \delta_a) \\ & + M_c g \frac{L_c}{\cos \delta_c} \cos(\varepsilon + \delta_c) - \eta_\varepsilon \dot{\varepsilon} \\ & + K_m L_a (V_f + V_b) \cos \theta \end{aligned} \tag{1}$$

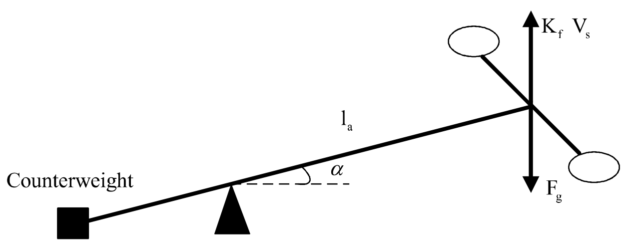

Figure 2. Elevation axis

2.2. Mathematical Model of Pitch axis

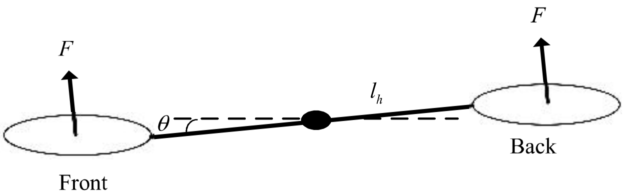

Figure 3. Pitch axis

Free body diagram of pitch axis is shown in Figure 3. The pitch model symbol is θ. J_θ is the moment of inertia of the system about pitch axis. Mathematical equation of the pitch axis is given in equation (2).

$$\begin{aligned} J_\theta \ddot{\theta} &= -M_f g \frac{L_h}{cos\, \delta_h} \cos(\theta - \delta_h) \\ &+ M_b g \frac{L_h}{cos\, \delta_h} \cos(\theta + \delta_h) \\ &- \eta_\theta \dot{\theta} + K_m L_h (V_f - V_b) \end{aligned} \tag{2}$$

2.2. Mathematical Model of Travel axis

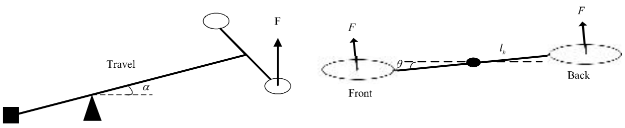

Figure 4. Travel axis

Free body diagram of travel axis is shown in Figure 4. The elevation model symbol is ϕ. J_ϕ is the moment of inertia of the system about travel axis. Mathematical equation of travel axis is given below in equation (3).

$$J_\phi \ddot{\phi} = -\eta_\phi \dot{\phi} - K_m L_a (V_f + V_b) sin\, \theta \tag{3}$$

3. Design of a Fuzzy PID Controller for 3-Dof Helicopter

Fuzzy PID control mechanism obtained in order to control the system is shown in Figure 5 Three separate fuzzy PID controllers are used in order to control elevation, pitch and travel axes of the helicopter. As it can be seen in Figure 6, inputs of PID controllers are determined as position error and angular velocity. Also, output of the fuzzy controllers are voltages which are applied to the motors.

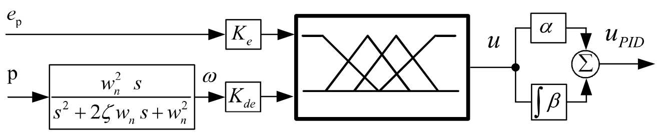

Figure 6. Fuzzy PID controller Structure

The K_e, K_{de}, α and β are scaling factors of fuzzy controller. Takagi-Sugeno fuzzy model is used in order to control the system. A second order low pass filter is used before the derivative term in order to attenuate high frequencies.

$$H(s) = \frac{{w_n}^2}{s^2 + 2\zeta w_n s + {w_n}^2} = \frac{15791.37}{s^2 + 226.195s + 15791.37} \tag{4}$$

Input membership functions of fuzzy controller is determined as triangular shapes and output membership function of fuzzy controller is determined as singleton. (In Figure 7, NH: negative high, NL: negative low, Z: zero, PL: positive low and PH: positive high.)

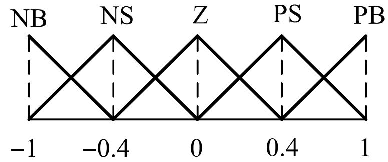

Figure 7. Membership functions of Inputs

In table 1, the rule table of fuzzy controllers is given [6]. Defuzzification method is chosen as "weighted average".

Table 1. Fuzzy Rule Table

ω \ e	NH	NL	Z	PL	PH
NH	-1	-0.7	-0.5	-0.3	0
NL	-0.7	-0.4	-0.2	0	0.3
Z	-0.5	-0.2	0	0.2	0.5
PL	-0.3	0	0.2	0.4	0.7
PH	0	0.3	0.5	0.7	1

The input universe of discourse for position error is [-25, +25], hence scaling factor of position error input (K_e) is 0.04[7]. Scaling factor of angular velocity input (K_{de}) is determined as 0.07 by doing some test on the simulation. Scaling factor of pitch and travel axes fuzzy PID controllers for position error input (K_e) are found as 0.04 and 0.05 by doing experiment on the real system. Also, scaling factor of pitch and travel axes fuzzy PID controllers for angular velocity input (K_{de}) are found as 0.07 and 0.02 by doing experiment on the real system. The output scaling factors fuzzy PID controllers are determined as α=20 and β=15 for elevation axis, α=10 and β=1 for pitch axis and α=12 and β=6 for travel axis.

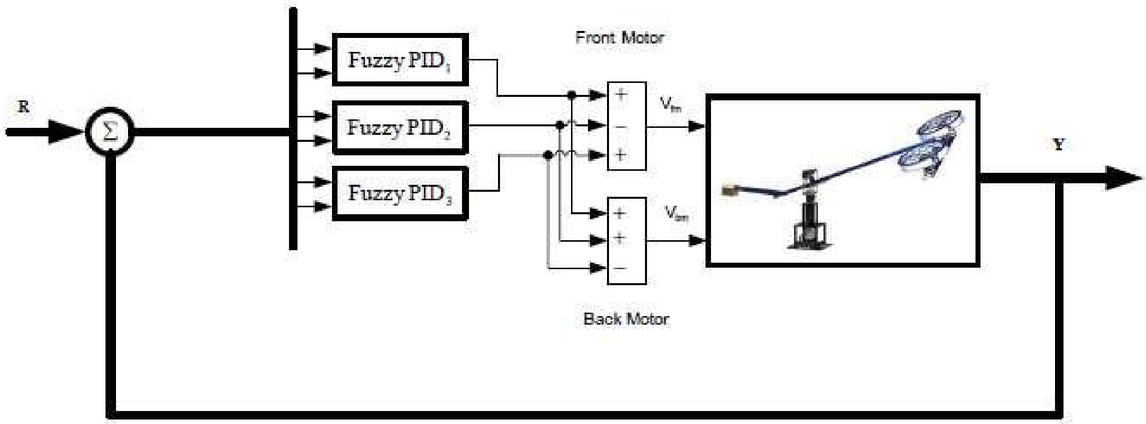

Figure 5. Closed – loop system

4. Simulation and Test Results

The fuzzy PID controller which the parameters were obtained is compared with LQR controller. The performance of controllers are tested under model uncertainties. Firstly, the nonlinear model of the system is controlled by using Fuzzy controller in Matlab/Simulink. After that, the controller is applied to the real system. In order to do a comparison between fuzzy controller and LQR controller a scenario is created. According to the scenario, a square wave is given as reference to the travel axis for different elevation positions and the system responses are investigated. Firstly, the elevation axis of the helicopter is pulled up from -27.5 to 10 degree and a square wave reference is given to travel axis. The system responses of LQR controller and fuzzy controller are shown in the left side of Figure 8. As it can be seen from the Figure 8(a), the system response of nonlinear model and real system are almost identical to each other for elevation axis. Also, it is observed that from the Figure 8(b), settling time of travel axis is approximately 20 sec for LQR controller and there is a high overshoot on the system response. On the other hand, the settling time and overshoot ratio of travel axis for fuzzy controller is smaller than LQR controller. In Figure 8(c), system responses of pitch axis are shown. It is seen that fuzzy PID controller is reached the reference with lower angle change than LQR controller for pitch axis.

There is a counterweight on 3-Dof helicopter system. The dynamic of the system can be altered by changing place of counterweight. . In the following figures, the system responses of LQR controller and fuzzy PID controller are shown with respect to changing the place of counterweight. System responses in the left side of Figure 8 are obtained, when the counterweight is at the 71 g mark.

After the real time results are obtained for 71g mark, counterweight is placed 158g mark. Elevation axis is pulled up from -27.5 to -25 degree and square wave reference between -30 and 30 degree is applied to travel axis in order to test the system. As it can be seen from the right side of Figure 8, system responses of Fuzzy PID controller are better than LQR controller.

Next, the place of counterweight is moved 158g to 104 mark. Elevation axis is pulled up from -27.5 to 10 degree and the reference of travel axis is not changed. The system responses of LQR controller and Fuzzy PID controller are shown in the left side of Figure 9. It is observed that Fuzzy PID controller has better system responses than LQR controller in terms of overshoot ratio and settling time.

Finally, the place of counterweight is adjusted as 35g mark. The system responses are shown in the right side of Figure 9. Elevation axis is pulled up from -27.5 to 10 degree and the reference of travel axis is not changed [-30, 30]. The settling time of elevation axis is approximately same for LQR controller and Fuzzy PID controller. However, there is no overshoot on the system response of Fuzzy PID controller, although there is high overshoot on the system response of LQR controller for elevation axis.

5. Conclusion

In this paper, a nonlinear three degree of freedoms helicopter set is controlled by using fuzzy PID controller and LQR controller which is designed by Quanser firm. Also, whether they are robust or not are tested in the presence of parametric uncertainties and the results are compared and interpreted. In order to test whether the controllers are robust or not, place of counterweight is changed. It is seen that fuzzy controller is more robust than LQR controller because it has better parametric uncertainty rejection capability. Moreover, fuzzy controller leads to a better tracking performance than LQR controller.

6. References

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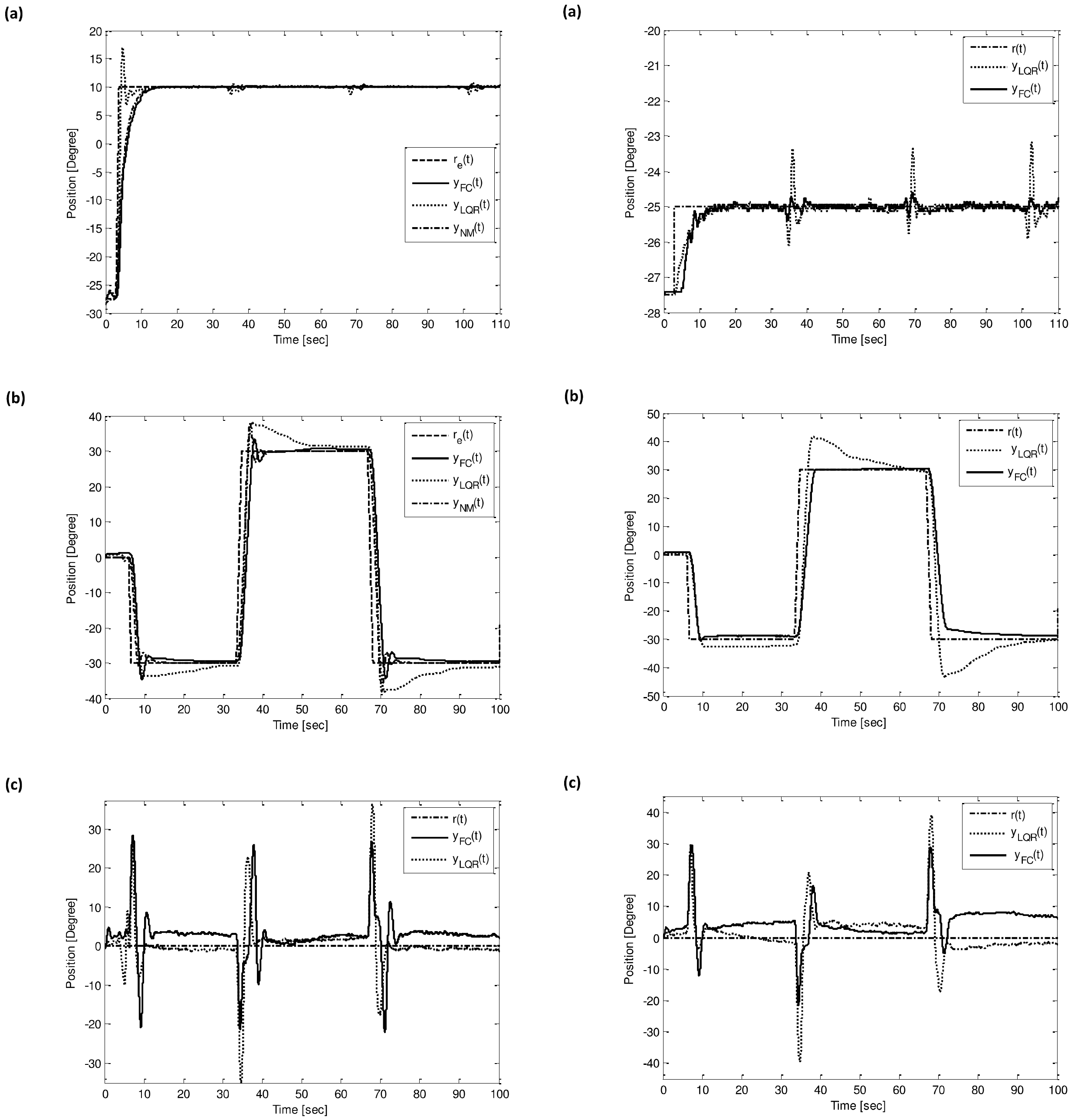

Figure 8. Elevation, Travel and Pitch axes System Responses

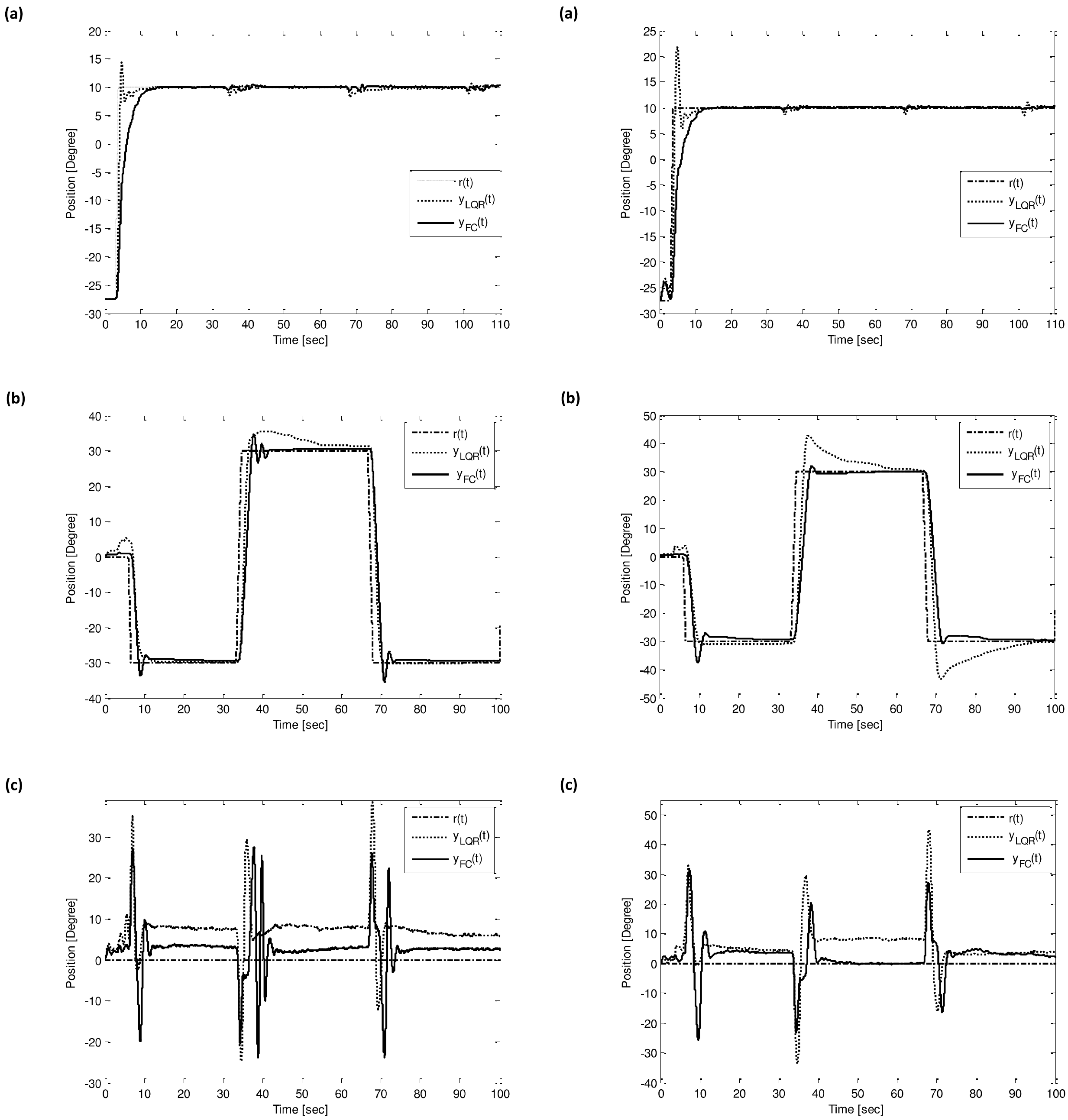

Figure 9. Elevation, Travel and Pitch axes System Responses