SIMPLER FUZZY LOGIC CONTROLLER (SFLC) DESIGN FOR 3DOF LABORATORY SCALED HELICOPTER

Arbab Nighat Khizer*, Dai Yaping & Xu Xiang Yang
School of Automation, Beijing Institute of Technology, Beijing, China, 100081

ABSTRACT
Generally helicopter dynamics are highly nonlinear, mutually coupled and time varying therefore a big challenge for control designers is to design their stable control with less complexity. In this paper, a methodology is proposed to attain the stable control as well as to reduce the complexity of a controller using fuzzy logic. The three degree of freedom (3DOF) laboratory helicopter is a multi input multi output (MIMO), under actuated mechanical system is used as a controlled object. This work is motivated by the increasing demand from the industrial site to design highly reliable, efficient and low complexity controllers. This fuzzy controller with triangular membership functions and simple tuning method leads to a simpler fuzzy logic controller (SFLC). Performance of proposed SFLC is evaluated against the conventional controllers. Simulation results show that proposed controller has superior performance in steady state (reducing 8-10% overshoot and 2-6% settling time) as compared to the performance of traditional PID, LQR and conventional fuzzy controller**.** Introducing simpler approach in conventional fuzzy controller gives stable control with no more controller design complexity.

Keywords: *3DOF laboratory helicopter, helicopter dynamics, PID, LQR, Simpler Fuzzy logic control (SFLC).*

1. INTRODUCTION

The advantages of small unmanned aerial helicopter (UAH) are observed through their flying capabilities in any direction i-e taking off, hovering and landing. Due to these distinctive characteristics and maneuverability, the helicopter study plays a vital role in different areas such as military and civil. Small unmanned helicopter also considered as main research application in the academic field. Therefore the study of the helicopter optimization has great importance in automation technology [1-2]. The 3DOF laboratory helicopter is an example of under actuated mechanical system which consist few independent control inputs than its degree of freedom [3].

In recent years, many researchers devoted their work to 3DOF laboratory helicopter to obtain a stable control using different control algorithms [4-8]. Sometimes conventional controller fails to achieve the desired control due to imprecise mathematical model and bad parameters tuning. In that situation, conventional control theory proves helpless and gives motivation to intelligent control, which is considered as an extension and development of the traditional control. Due to wonderful progress of intelligent control in control theory, it is successfully applied in the field of aerospace control. The fuzzy logic control belongs to the intelligent control class and proves an efficient way to realize the intelligent control [9]. It can be used for too nonlinear process to control which is too ill-understood through conventional control designs. Briefly saying, a fuzzy logic is mainly dealt with complex systems and enables control designer to implement control strategies obtained from human knowledge in easy way. It is expert computer based system based on the fuzzy rules and sets, fuzzy linguistic variables, membership functions and fuzzy logic reasoning. Once the membership functions and the rule base of the fuzzy logic controller determined, the next step is relating to the tuning process, which is sophisticated procedure since there is no general method for tuning the fuzzy logic controller [10-11].

For 3DOf helicopter simulator, fuzzy logic control was proposed in [12]. In the work, elevation and travel controller were designed using fuzzy inference rules. Excessive rules for both axes were used which results in excessive simulation time; therefore real time implementation of this fuzzy logic controller becomes not feasible. Another approach using fuzzy control of 3DOF helicopter is addressed in [13]; in this research only elevation attitude is considered, pitch and travel axes had not been taken in account. In [14] fuzzy logic control was used parallel to PID controllers in order to get better stable and quick control effect using Static performance of PID controller and dynamic performance of fuzzy controller. Another work has been reported in [15], where optimal tracking control strategy for the 3DOF helicopter model was proposed using the method based on fuzzy logic and LQR. Fuzzy logic control was also used to tune the PID gain parameters of 3DOF helicopter in [16]. This fuzzy-self adaptive PID controller used the error signals as inputs, modifying PID parameters through the fuzzy control rules at any time.

Until now, autopilot design for 3DOF helicopter is achieved through considerable theoretical concepts including prior knowledge of complex mathematics. Even after that, the controller design seems to be more complex to obtain the desired performance. And mostly researchers were supposed to use the Quanser helicopter system. The role of fuzzy control in related research is only to tune the gains of conventional controller and used as parallel control agent with other control algorithms.

In this paper, a controller design is proposed to reduce the design complexity of a controller based on fuzzy if-then rules using nonlinear 3DOF helicopter model designed by Googol Technology (Hong Kong) Ltd. Firstly pitch, elevation and travel axis dynamics are analyzed, on the basis of dynamics; a mathematical model is then developed for the three axes. Initially this 3DOF model offered PID control theory as a basis for the controller design. After observing PID control, LQR control strategy is applied. Finally, fuzzy inference method, known as one of the most advanced intelligent control is applied to get the stable control. Tuning of fuzzy controller itself is a big challenge; therefore the motivation to design this fuzzy logic control with triangular membership functions and fuzzy rules leads to a simpler fuzzy logic control (SFLC). Because of, now many fuzzy controllers are able to learn and to tune its parameters using genetic algorithm and neural networks. However, this approach requires the understanding of genetic algorithm and neural networks before it can be used as optimizers. It is time consuming process and the controller design may become more complicated. Therefore to avoid this design complication of controller, a simpler approach using trial and error will be used here until acceptable results are obtained. Again this approach is time consuming task, but it is easy method of tuning the fuzzy logic controller to a desired response using simplicity and less complexity design.

The organization of this paper is as follows. Section II described the dynamics of 3DOF helicopter and development of mathematical model for three axes. Section III covered controller design including PID, LQR and fuzzy logic controller. Section IV covered simulation results. Finally section V presented the conclusion.

2. 3DOF-LABORATORY HELICOPTER

2.1 3DOF Laboratory Helicopter System Components

3DOF helicopter system is an experimental system designed for the study of automatic control and aviation aerospace. The main part consists of motor, motor driver, position encoder, motion controller and terminal board, etc. The whole system is divided into helicopter main body, electric control box and control platform including motion controller and PC as shown in the Figure-1.

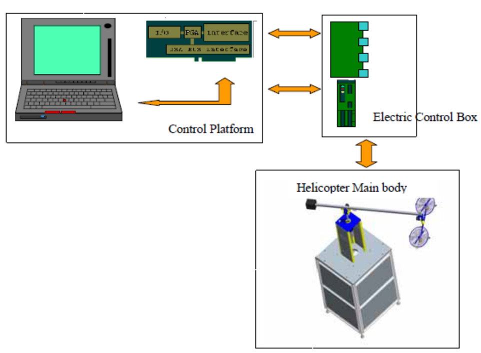

Figure-1 3DOF helicopter Experimental System Diagram

The helicopter main body system is showing in Figure-2 is composed of the base, leveraged balance, balancing blocks and propellers. Balance posts to base as its fulcrum, and the pitching. Propeller and the balance blocks were installed at the two ends of a balance bar. The propellers rotational lift turning a balance bar around the fulcrum to do pitching motion. Using the difference between two propeller speeds caused a balance bar turning along the fulcrum to do rotational movement. Two poles installed encoder, used to measure the rotation axis and pitch axis angle. The role of the balance block is to reduce the helicopter rises. An encoder is installed over the rod connecting the two propellers which is used to measure overturned axis angle. Two propellers, using brushless DC motors, provide the momentum for the propeller. By adjusting the balance rod installed in the side of the balance blocks to reduce propeller motor output. All electrical signals to and from the body are transmitted via slip ring thus eliminating the possibility of tangled wires and reducing the amount of friction and loading about the moving axes[17].

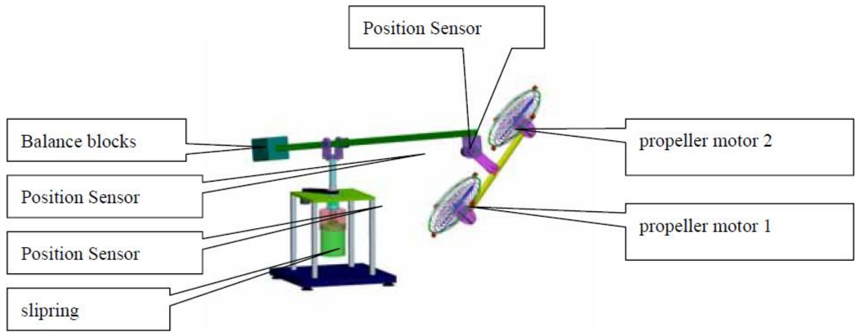

Figure-2 3DOF helicopter System designed by Googol Technology Ltd

2.2 System Modeling

The mathematical model for 3DOF helicopter as shown in Figure-2 is described by three differential equations.

I Elevation Axis Model Dynamics

Consider a free body diagram with respect to elevation axis as shown in Figure-3, height of shaft torque from before and after the two propellers lift F_1 and F_2 control. When the propeller axis total lift ($F_h = F_1 + F_2$) is greater than the effective gravity (G), the helicopter begins to rise, instead the helicopter dropped. Assumed that the helicopter hanging empty.

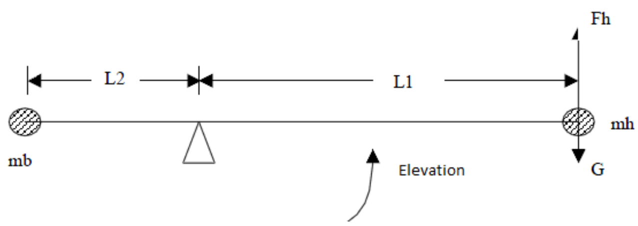

Figure-3 Simplified Elevation Axis model dynamics

According to the moment of momentum theorem, a high degree of axial movement differential equations are as follows:

$$Je\ddot{\varepsilon} = l_1F_h - l_1G = l_1(F_1 + F_2) - l_1G \quad (1)$$
$$Je\ddot{\varepsilon} = K_cl_1(V_1 + V_2) - T_g = K_cl_1(V_s) - T_g \quad (2)$$

Where Je is the moment of inertia of the system about the pitch axis, m_b is the mass of balance blocks, m_h is the total mass of two propeller motor, V_1 and V_2 are the voltages applied to the front and back motors resulting in force, K_c is the force constant of the motor/propeller combination, $l_1$is the distance f rom the pivot point to the propeller motor, $l_2$is the distance from the pivot point to the balance blocks, T_g is the effective gravitational torque due to the mass differential G about the pitch axis and $\ddot{\varepsilon}$ is the angular acceleration of the elevation axis.

II Pitch Axis Model Dynamics

Consider the diagram in Figure-4. The control of pitch axis is done by the differential of the forces generated by the propellers. If the force generated by the left motor is higher than the force generated by the right motor, the helicopter body will clockwise overturned. The differential equation becomes:

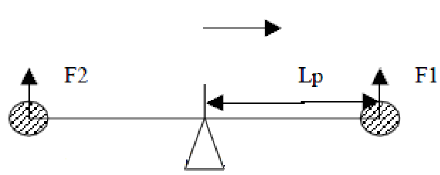

Figure-4 Simplified Pitch Axis model dynamics

$$J_p \ddot{P} = F_1 l_p - F_2 l_p \quad (3)$$
$$J_p \ddot{P} = K_c l_p (V_1 - V_2) = K_c l_p V_d \quad (4)$$

Where J_p is the moment of inertia of the system about the pitch axis, l_p is the distance from the pitch axis to either motor and $\ddot{P}$ is the angular acceleration of the pitch axis.

III Travel Axis Model Dynamics

When the pitch axis is tilted and overturned, the horizontal component of G will cause a torque about that the travel axis which results in an acceleration about the travel axis, Assume the body has pitch up by an angle p as shown in Figure-5:

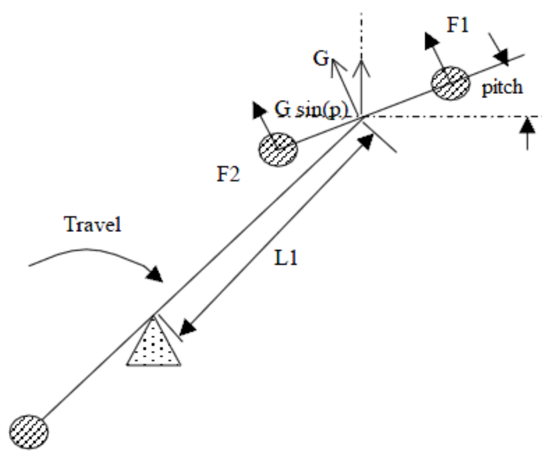

Figure-5 Simplified Travel Axis model dynamics

$$J_r \dot{r} = -G \sin(p)\, l_1 \quad (5)$$
$$J_r \dot{r} = -K_p \sin(p)\, l_1 \quad (6)$$

Where:

J_r is the moment of inertia of the system about the travel axis, $\dot{r}$ is the travel rate in radian/sec and $\sin(p)$ is the trigonometric sine of the pitch angle.

If the pitch angle is zero, no force is transmitted along the travel axis. A positive pitch causes a negative acceleration in the travel direction. Since the travel axis is driven though the power component of inclined propellers along horizontal direction, therefore the output of the travel axis controller is the input of the pitch axis controller. The overall control block diagram is showing in Figure-6.

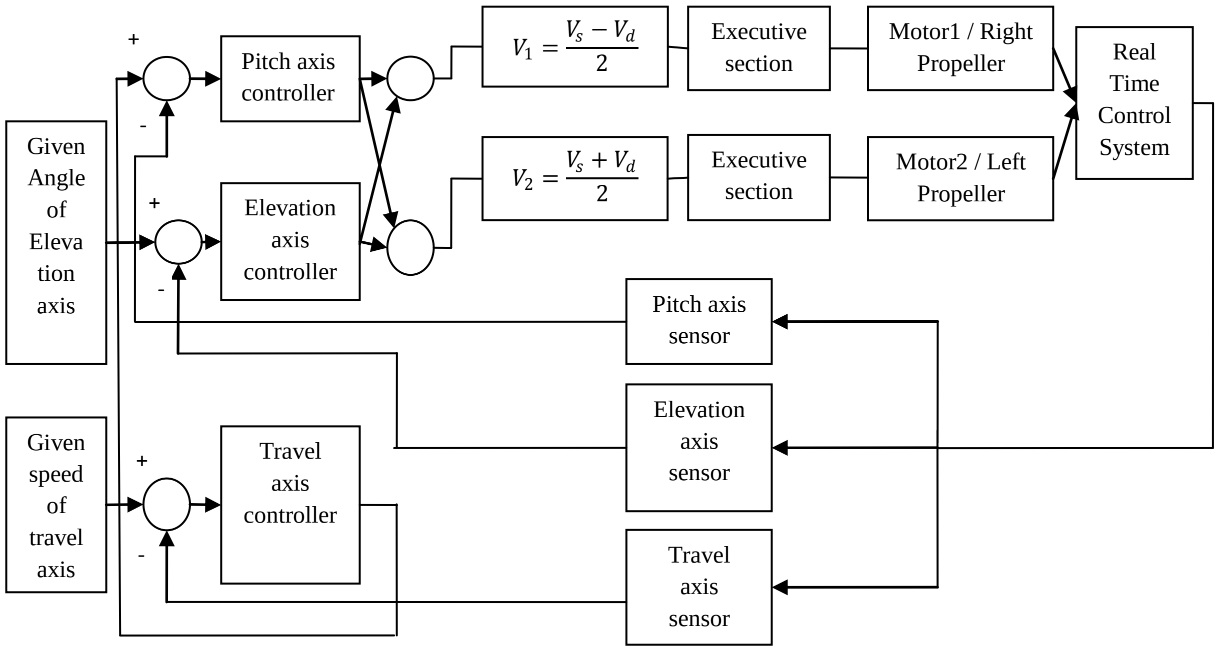

Figure-6 Control Block diagram of 3DOF Helicopter

3. CONTROLLER DESIGN

3.1 PID control

Initially PID controller is introduced to this laboratory helicopter model, which has three degrees of freedom i-e travel, elevation and pitch axes. Since it is observed that travelling and pitch axes are coupling with each other, therefore only two command signals (travel/pitch and elevation) are required. Three separate PID controllers were initially implemented in this setup. Transfer functions of three axes are used to model the PID controller. Following are the transfer functions derived from dynamics of each axis mode after ignoring the gravity torque disturbance "T_g" .

$$\frac{\varepsilon(s)}{\varepsilon_c(s)} = \frac{-\frac{K_c K_{ep} l_1}{J_e}}{S^2 - \frac{K_c K_{ed} l_1}{J_e} S - \frac{K_c K_{ep} l_1}{J_e}} \tag{7}$$

$$\frac{P(s)}{P_c(s)} = \frac{-\frac{K_c K_{pp} l_p}{J_p}}{S^2 - \frac{K_c K_{pd} l_p}{J_p} S - \frac{K_c K_{pp} l_p}{J_p}} \tag{8}$$

$$\frac{r(s)}{r_c(s)} = \frac{-\frac{K_{rp} G l_1 S + K_{ri} G l_1}{J_r}}{S^2 - \frac{K_{rp} G l_1}{J_r} S - \frac{K_{ri} G l_1}{J_r}} \tag{9}$$

The overall simulink diagram using PID controller and model transfer function for each axis is showing by Figure-7.

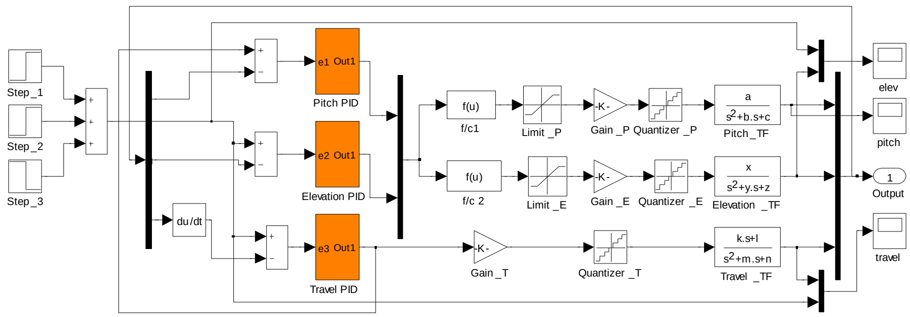

Figure-7 Simulink model diagram using PID controller

3.2 LQR control

The LQR optimal control principle is given by system equations:

$$\dot{X} = AX + Bu \tag{10}$$

$$Y = CX + Du \tag{11}$$

for this system $X = [\varepsilon \;\; p \;\; \dot{\varepsilon} \;\; \dot{p} \;\; r \;\; \int \varepsilon \;\; \int r]^T$ is the state vector, $u = [V_1 \;\; V_2]^T$ is the control input vector and $Y = [\varepsilon \;\; p \;\; r]^T$ is the output vector. In state vector ε, p, r are the elevation, pitch and travel angle. The state space matrices for 3DOF helicopter after substituting the values shown in Table-1 are as follows:

$$\begin{bmatrix} \dot{\varepsilon} \\ \dot{p} \\ \ddot{\varepsilon} \\ \ddot{p} \\ \dot{r} \\ \dot{\gamma} \\ \dot{\tau} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2.0656 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} \varepsilon \\ p \\ \dot{\varepsilon} \\ \dot{p} \\ r \\ \int \varepsilon \\ \int r \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 5.8199 & 5.8199 \\ 63.9386 & -63.9386 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

Using state feedback control: $u(t) = -K * x(t)$ (12)

Where K is the state feedback control gain, calculated by minimizing the cost function:

$$J = \int_0^{\infty} (X^T * QX + u^T * Ru)dt \tag{13}$$

Where Q and R is positive definite hermitian or real symmetric matrix [18]. When designed a linear quadratic optimal controller, the selection of Q is major designing criteria. Generally, when Q is bigger, the time required for the system to reach its stable state is shorter. Here Q is selected as:

$Q = diag([2.0 \;\; 0.2 \;\; 0.02 \;\; 0.02 \;\; 2.0 \;\; 0.02 \;\; 0.01])$ and $R = diag([1 \;\; 1])$

Using the Matlab LQR command, state feedback gain "K" can be calculated as:

$$K = \begin{bmatrix} 1.0426 & 0.8661 & 0.4349 & 0.1534 & 1.0292 & 0.1000 & 0.0707 \\ 1.0426 & -0.8661 & 0.4349 & -0.1534 & -1.0292 & 0.1000 & -0.0707 \end{bmatrix} \tag{14}$$

The system inputs can be obtained by summing (V_s) and difference (V_d) of two rows of above as:

$$V_s = V_1 + V_2 = -2k_{11}(\varepsilon - \varepsilon_c) - 2k_{13}\dot{\varepsilon} - 2k_{16} \int (\varepsilon - \varepsilon_c) \tag{15}$$

$$V_d = V_1 - V_2 = -2k_{12}P - 2k_{14}\dot{P} - 2k_{15}(r - r_c) - 2k_{17} \int (r - r_c) \tag{16}$$

Equation-22 can be re-written as:

$$V_d = V_1 - V_2 = -2K_{12}(P - P_c) - 2K_{14}\dot{P} \tag{17}$$

This is PD loop to command the pitch for desired pitch tracking. The desired pitch is defined as:

$$P_c = -\frac{2k_{15}}{2k_{12}}(r - r_c) - \frac{2k_{17}}{2k_{12}}\int(r - r_c) \tag{18}$$

This is PI loop for controlling the travel position. Now voltages for front and back motors can be obtained easily by Equation-19:

$$V_1 = \frac{V_s - V_d}{2} \text{ and } V_2 = \frac{V_s + V_d}{2} \tag{19}$$

Figure-8 is simulink diagram of model using LQR optimal control.

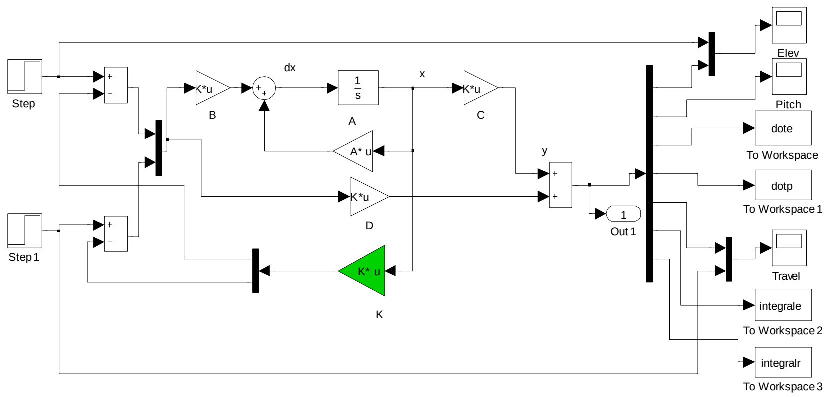

Figure-8 Simulink model diagram using LQR controller

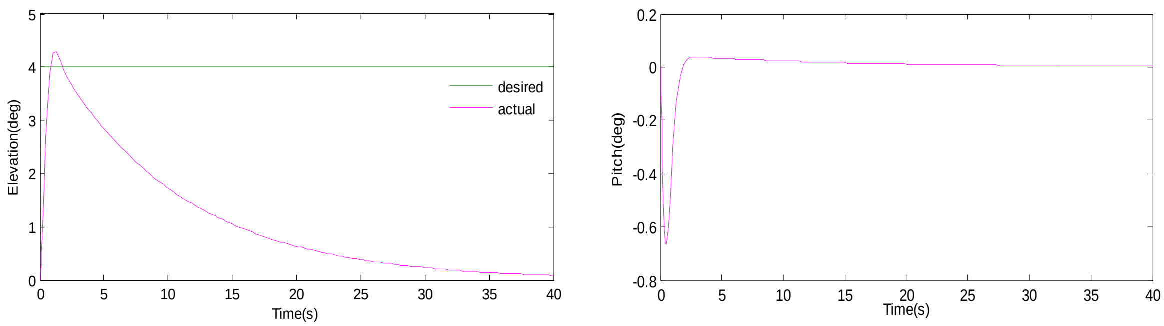

Figure-9 Elevation and pitch output step response using optimal control

It is observed from Figure-9 that both curves (elevation angle and pitch angle) approaches zero. When compared this optimal control with open loop control of the system, improvement regarding dynamical performance of the system is largely increased after introducing state feedback gain (K). Time for transition process and overshoot is also reduced. The main advantage of this quadratic design method is that it doesn't require peak value time estimation and damping ratio. There is only need to select the appropriate value for states in weighting matrix (Q and R). Then, after choosing the proper Q and R, some tuning of controller is required.

Table-1 3DOF-Laboroatory helicopter Model parameters value

Symbol	Name	Value	Units
J_e	Moment of inertia about elevation axis	1.8145	$Kg.m^2$
J_t	Moment of inertia about travel axis	1.8145	$Kg.m^2$
J_p	Moment of inertia about pitch axis	0.0319	$Kg.m^2$
m_h	Mass of two propeller motor	1.800	Kg
m_b	Mass of counterweight	3.433	Kg
m_g	Effective mass of helicopter	0.4346	Kg
G	Force required to keep body aloft	4.2591	N
l_1	Distanced from either motor to elevation axis	0.88	m
l_2	Distance from counterweight to elevation axis	0.35	m
l_p	Distance from either motor to pitch axis	0.17	m
K_c	Motor force constant	12	N/V

3.3 Conventional Fuzzy Logic control

When designed a fuzzy logic controller, one important issue is the development of fuzzy if-then rules to produce stable and effective controllers [19]. Firstly, conventional fuzzy logic controllers for elevation and pitch axis of 3DOF helicopter are designed using two inputs (error (e) and rate of error (e_c)) and one output (u). The variable $'e'$ is error between the reference elevation/pitch angle and their respective feedback angle and variable $'e_c'$ is defined as ratio of $'e'$. The input and output universe domain is normalized within the range of -1 and 1. Input member function used for both controllers are triangular membership function. Every input and output membership function takes seven linguistic variables (Negative big (NB), Negative middle (NM), Negative small (NS), zero (ZR), positive small (PS), positive middle (PM) and positive big (PB)). Figure-10 shows the input membership function of elevation/pitch controller. The output membership functions are designed narrower around zero for both controllers as shown in Figure-11. This is because of decreasing the gain of the controller near the set point in order to obtain a better steady state control and avoiding excessive overshoot [20].

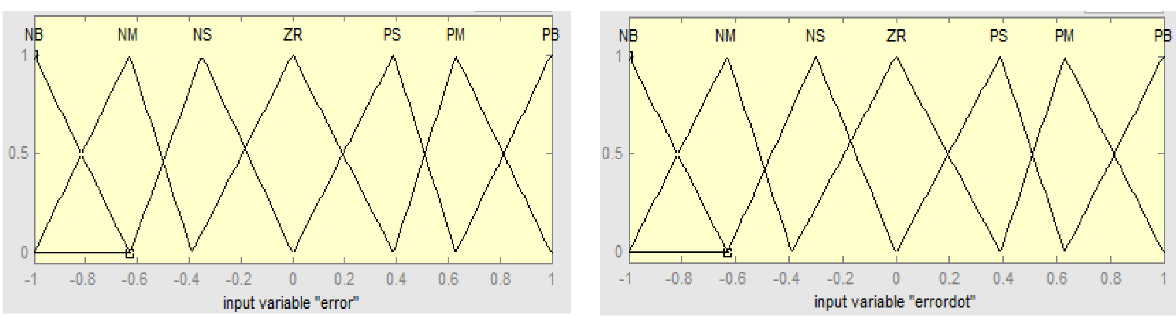

Figure-10 Input membership function of elevation/pitch controller

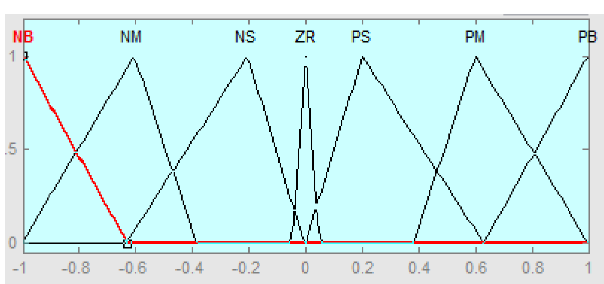

Figure-11 Output membership function of elevation/pitch controller

Behavior of the system is defined by fuzzy logic rules using relation between the error signal (e), error derivative signal ($\dot{e}$) and the control signal of the controller (u). These rules constitute the knowledge base of the fuzzy controller. The same rule base array is used for elevation as well as pitch fuzzy controller. Each rule base is a 7X7 array, since there are seven fuzzy sets on the input and output universes of discourse. The fuzzy rule base is represented by a sequence of the form IF premise THEN consequent. For example: IF error is zero and change-in-error is positive-small THEN output is positive-small.

Table-2 Rule base for fuzzy controller

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

3.4 Simpler Fuzzy Logic control

The mapping of inputs and outputs using scaling factors are linear, but it has a strong impact on the performance of the controller because the scaling factors has directly influence on the value of the open loop gain coefficient. These scaling factors are subjected to the tuning process, which is considered the last part in fuzzy design. Tuning the scaling factors is quite difficult, and takes much more time and effort than choosing fuzzy sets, membership functions, and constructing the rules. Usually, reasonable scaling factors can be achieved after a series of tests. When tuning the fuzzy controller, one must also have the knowledge of existing algorithms (neural networks and genetic algorithm). Further, addition of rules gives the complexity in the fuzzy controller design. Therefore to avoid this time taking task and the complexity of the controller design, a simpler approach using trial and error method is proposed to tune the gains of controller. In the SFLC, trial and error method is used to select the best scaling factors for elevation as well as pitch fuzzy controller. In this method space state equation of the model is used to represent the controlled object. After applying this method for optimizing the parameters of fuzzy logic controller, controller complexity design criterion is to be reduced due to no more addition of rules in fuzzy design. In this context, the gains error (e), error derivative signal ($\dot{e}$) and the control signal of the controller (u) for the elevation and pitch controller are tuned using space state model of system. The tuning process of gains will continue until the scaled value of gains for the elevation and pitch controller obtained satisfactory results (minimum over shoot and settling time).

4. THE SIMULATION AND RESULTS

To evaluate the performance of 3DOF helicopter's elevation and pitch motion with conventional fuzzy logic controller, it should analyze and compared with conventional PID controller. The PID controller is manually tuned controller, therefore first increasing proportional gain (K_p), until a desired response is achieved. Then integral gain (K_i) and derivative gain (K_d) are required to adjust in order to obtain the optimal response of the system. After many manual efforts, three controller gains are selected which are showing in Table-3.

Table-3 PID Gain Values

Controller	K_p	K_d	K_i
Elevation	5.0	3.8	0.9
Pitch	0.08	0.0005	0.002
Travel	0.5	0.2	0.08

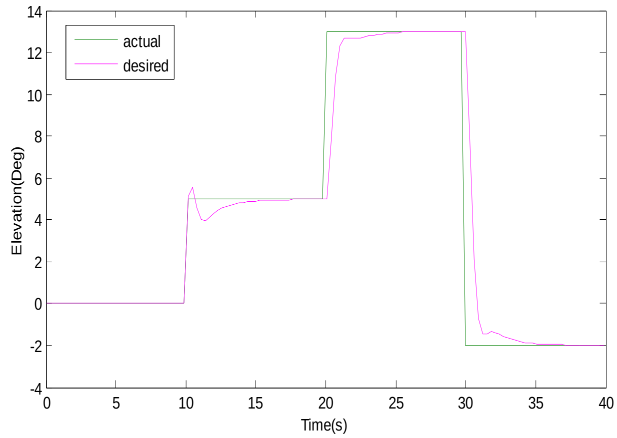

Figure-12(a) Elevation response using PID controller

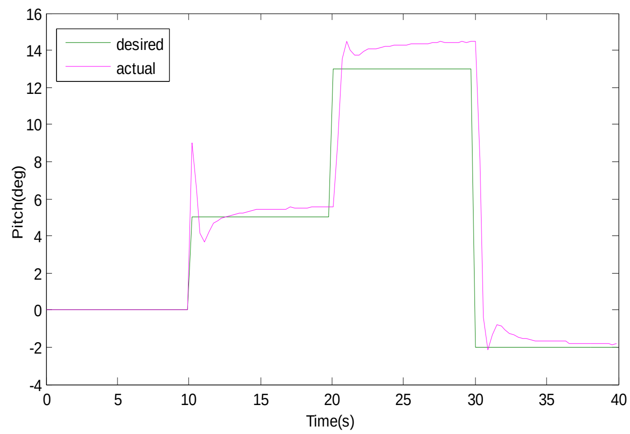

Figure-12(b) Pitch response using PID controller

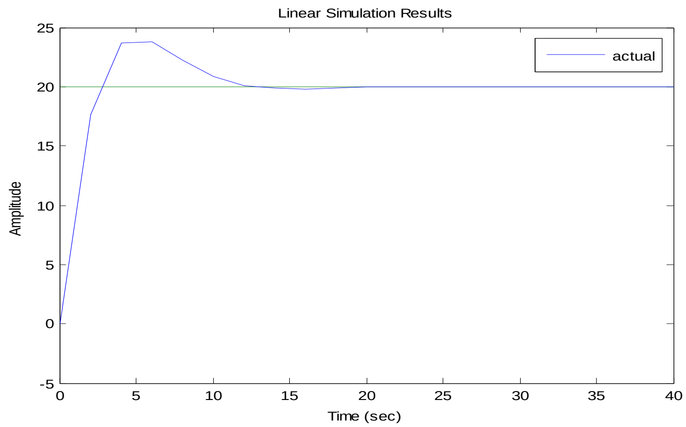

Figure-12(c) Travel step response curve using PID controller

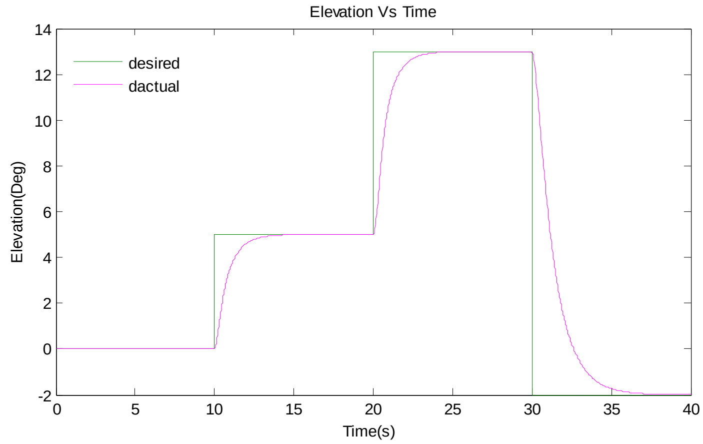

Figure-13(a) Elevation response using FL controller

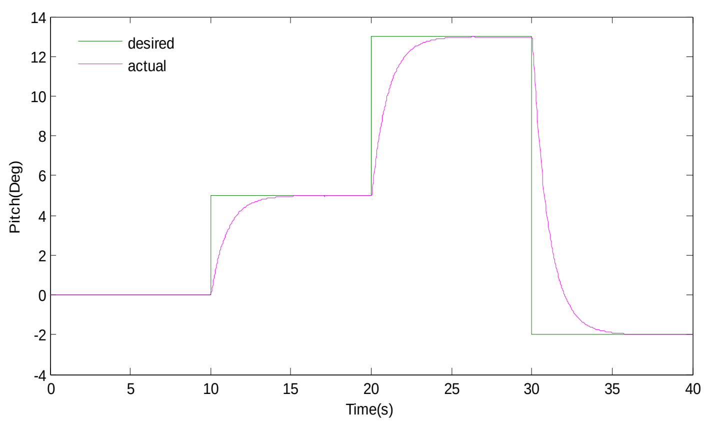

Figure-13(b) Pitch response using FL controller

The Figures-12(a, b, c) and 13(a, b) showed the 3DOF helicopter's control results using two different controllers. According to the simulation results, the helicopter system is required to adjust the attitude in the controlled process. Different magnitude of input variable is given to the model during simulation. The performance analysis of two controllers has been done and given by Table-3.

Table-3 Comparison of Performance indicators of PID and FLC

Metrics	PID controller			Conventional Fuzzy Logic controller		
	Elevation axis	Pitch axis	Analysis	Elevation axis	Pitch axis	Analysis
Rising Time (s)	3.01	0.24	Maximum peak and overshoot during pitch motion, and long settling time in elevation and travel motion. Overshoot in travel axis also.	1.8	2.2	Smooth output curve with zero overshoot but settling time still maximum.
Overshoot (%)	0.16	8.38		0.00	0.00	
Settling time(s)	3.3	2.7		3.88	4.30	
Peak	12.98	14.46		13.01	13.08	

From simulation result, it is cleared that pitch PID controller has large overshoot and could not track the desired output. Even elevation and travel PID controllers have also some overshoot and long settling time. When introduced fuzzy controllers to control the model, outputs have no more overshoot in elevation as well as pitch motion and could well track the desired response smoothly. But conventional fuzzy controller required long time to settle down the output; therefore it is required to scale its gain through simpler approach. Figure-14 shows the response of experiencing different scaling values to unit step input after introducing simpler approach in fuzzy control. From the curve the best scaling values of error (e), error derivative signal ($\dot{e}$) and the control signal of the controller (u) are selected through B as it shows better settling time and smooth tracking. The same design method is applied for pitch fuzzy controller to scale the gains. For pitch FLC, gain parameter A is chosen as shown in Figure-15 because it will track the output well; however it has more settling time than parameter B and C, but still it has less settling time as compared to earlier designed fuzzy controller.

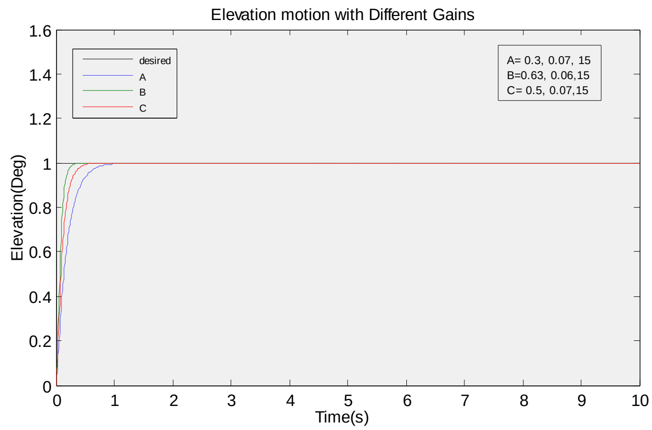

Figure-14 Step input responses when tuning elevation FLC

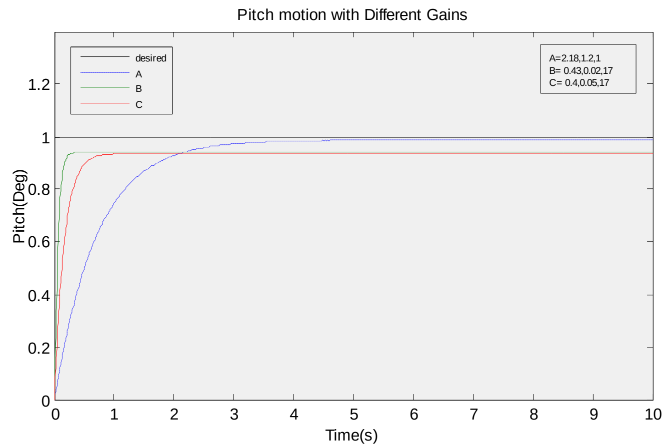

Figure-15 Step input responses when tuning Pitch FLC

Figure-16 shows the overall simulink helicopter space state model using simpler fuzzy controller with input and output gains.

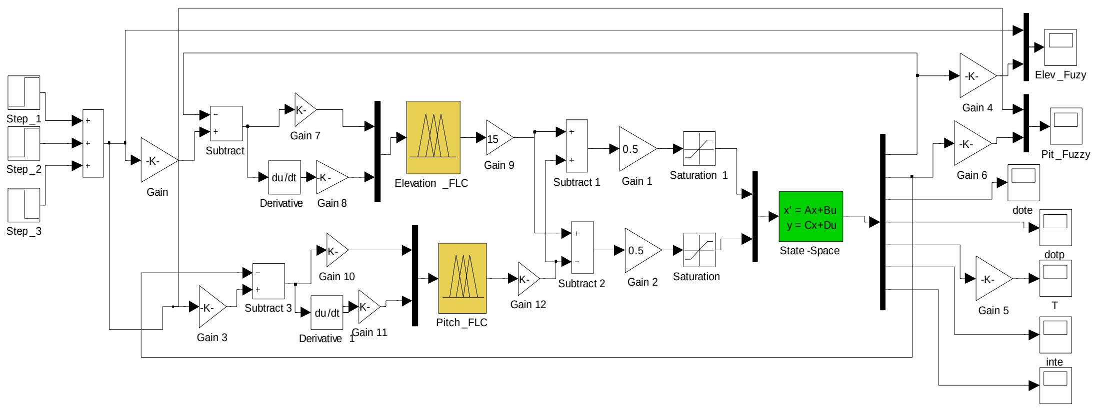

Figure-16 Simulink model using SFLC

However, incorporating the scaled I/O gains, FLC design still simpler, having no design complexity. The elevation and pitch output response of SFLC are showing by Figure-17(a, b). Compared to conventional fuzzy control, better response of elevation and pitch SFLC is observed. Briefly saying, over all response of controller becomes more stable in terms of settling time (minimized) and output tracking response.

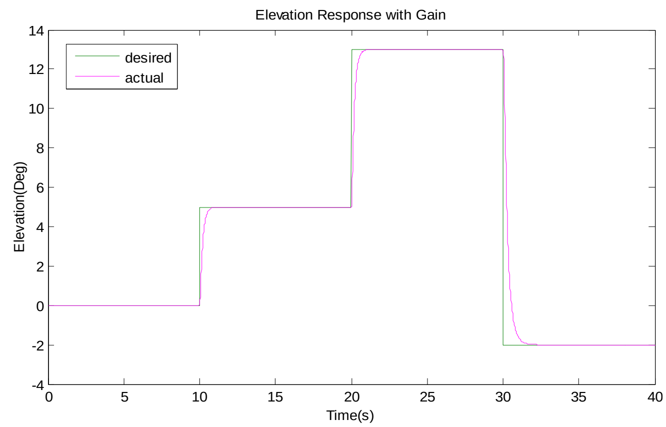

Figure-17(a) Elevation response curve using SFLC with I/O gains

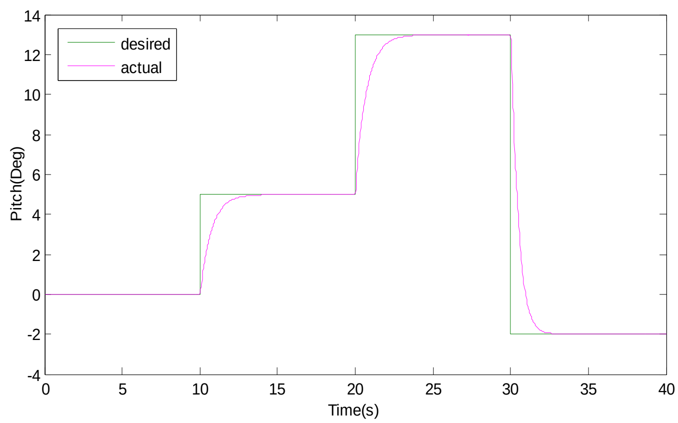

Figure-17(b) Pitch response curve using FLC with I/O gains

5. CONCLUSION

The 3DOF laboratory helicopter dynamic equations of the axis and simulation are presented in this paper. Based on the system dynamics, PID control, LQR control and conventional fuzzy control are designed and successfully applied in the simulation process. Upon the appropriate selection of parameters of controllers, the simulation experiments of the elevation and pitch controller are carried out. From the results, performance of conventional FLC is found to be superior as compared with PID controller. But still it is required to be more stable, therefore introducing simpler approach for scaling the input and output gains make the FLC more stable without hitting the design of controller. In the result this approach gives no compromise on controller design complexity. This paper presents a simpler approach for the designing the simpler fuzzy logic controller (SFLC) with satisfactory performances. The conclusion can be drawn that the robustness of designed SFLC is increased in terms of zero overshoot, shorter settling time and stable tracking of various inputs.

6. REFERENCES

[1] J Shan, H T Liu, S Nowotny, Synchronized Trajectory-tracking Control of Multiple 3DOF Experimental Helicopters, *IEEE Proceedings of Control theory Appl. (S1350-2379)*, Vol.152, No.6, 683-692 (2005).

[2] M Lopez-Martinez, M G Ortega, C Vivas, F R Rubio, Nonlinear L2 control of a laboratory helicopter with variable speed rotors, *Automatica*, Vol.43, No.4, 655-661(2007).

[3] Quanser Inc, 3DOF Helicopter system, product information, www.quanser.com, Ontario (Canada), (2006).

[4] Yu Yao, Zhong YiSheng, Robust Attitude Control of a 3DOF Helicopter with Multi-operation Points, *Journal of system Science & Complexity*, pp 207–219 (2009).

[5] Mariya A. Ishutkina , Design and Implementation of a Supervisory Safety Control for 3DOF Helicopter, Master Thesis, *Department of Aeronautics and Astronautics, MIT,(* 2004).

[6] Yue Xincheng, Yang Ying, Geng Zhi-qiang, No Steady-State Error Tracking Control of 3Dof Experimental Helicopter System, *Journal of System Simulation*, vol. 19, #18, pp 4279-4283, Sep (2007).

[7] Zhao Xiaoxiao, Dong Xiucheng, 3Dof helicopter control system based on LQR optimal controller, *Journal of Kunming university of science and technology*, vol. 30, no. 5, pp 125-127, Oct.(2005).

[8] D. Park and J. Lee, Attitude control of helicopter simulator using neural network based PID controller, *IEEE International Conf. on Fuzzy System*, vol. 1, pp. 465-469, Seoul, Aug. (1999).

[9] V A Oliveira ,L V Cossi, ,M C M Teixeira ,A M, F Silva, Synthesis of PID controllers for a class of time delay systems , *Automatica*, Vol.45, No.7, 1778-1782 (2009).

[10] B. Hu, K.I. George, and R.G. Gosine *; IEEE Trans. Fuzzy Syst;* 7 (5), 521 (1999).

[11] J. Jantzen, Tuning of Fuzzy PID Controllers, *Technical Report 98-H871*, Department of Automation, Technical University of Denmark (1998).

[12] Malgorzata *S.* Zywno, Innovative Initiatives in Control Education at Ryerson Polytechnic University Fuzzy Logic Control of the 3D-Helicopter Simulator, *Proceedings of the American Control Conference Chicago*, June (2000).

[13] Feng Zhou, Denghua Li and Peirong Xia, Research of Fuzzy Control for Elevation Attitude of 3DOF Helicopter, *International Conference on Intelligent Human-Machine Systems and Cybernetics*, pp 367-370, (2009).

[14] Le Zhang and Shaojie Bi, Hong Yang, Fuzzy-PID Control Algorithm of the Helicopter Model Flight Attitude Control , *IEEE Chinese Control and Decision Conference*, (2010).

[15] Zhichao Liu, Zouhair Choukri el haj, and Hongbo Shi, Control Strategy Design Based on Fuzzy Logic and LQR for 3-DOF Helicopter Model, *International Conference on Intelligent Control and Information Processing , China*, August 13-15 (2010).

[16] Junshan Gao, Xinghu Xu, Chen He, A Study on the Control Methods Based on 3-DOF Helicopter Model, *journal of computers*, Vol. 7, No. 10, October (2012).

[17] Googol Technology, *3DOF Helicopter Experimental manual*, product information, Hong Kong, (2007).

[18] Gu Xingsheng, Modern control theory, Shanghai, East China University of Science and Technology Press, pp. 105-110 (2008).

[19] K. Tanaka and M. Sugeno, Stability analysis and design of fuzzy control systems, *Fuzzy Sets Syst.*, vol. 45, pp. 135–156, (1992).

[20] K. M. Passino and S. Yurkovich, *Fuzzy Control*, First edition, Addition Wesley Longman Inc, USA, (1998).