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Aircraft Pitch Control System Using LQR and Fuzzy Logic Controller

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ABSTRACT : *This paper presents a comparative assessment of modern and intelligent controllers based on time response specification performance for a pitch control of an aircraft system. The dynamic modeling of pitch control system is performed and an autopilot that controls the pitch angle of an aircraft is designed using two controller design methods.The transfer function for pitch control surface is derived and two separate controllers, Proportional integral Derivative and Fuzzy Logic Controller (FLC) are designed for controlling the pitch angle. The effectiveness of each controller is tested and verified using Matlab/Simulink platform. It is found from simulation, fuzzy logic controller give the best performance compared to PID controller.*

Keywords : *Aircraft Flight control system, PID Controller, Fuzzy logic controller.*

1. INTRODUCTION

Today's aircraft designs heavily based on automatic control system to monitor and control many of aircraft's subsystems. The development of automatic control system has played an important role in the growth of civil and military aviation. The architecture of the flight control system, essential for all flight operations, has significantly changed throughout the years. Soon after the first flights, articulated surfaces were introduced for basic control, operated by the pilot through a system of cables and pulleys. This technique survived for decades and is now still used for small airplanes. The introduction of larger airplanes and the increase of flight envelopes made the muscular effort of the pilot, in many conditions, not sufficient to control the aerodynamic moment's consequent to the surface deflection. The first solution to this problem was the introduction of aerodynamic balances and tabs, but further grows of the aircraft sizes and flight envelopes brought to the need of powered systems to control the articulated aerodynamic surfaces. Modern aircraft include a variety of automatic control system that aids the flight crew in navigation, flight management and augmenting the stability characteristic of the airplane. The autopilot is an element within the flight control system. Designing an autopilot requires control system theory background and knowledge of stability derivatives at different altitudes and Mach numbers for a given airplane .The number and type of aerodynamic surfaces to be controlled changes with aircraft category. Aircraft have a number of different control surfaces: the primary flight controls, i.e. pitch, roll and yaw control [7] basically obtained by deflection of elevators, ailerons and rudder .Pitch is controlled by the elevator. In this paper, the control system design for pitch control is presented. A very popular controller (PID) and intelligent fuzzy logic controller (FLC) is developed for control the pitch of an aircraft system. Performance of both control strategy with respect to the pitch angle is examined. Comparison of performance of both controllers is verified.

1.1 Proportional Integral Derivative (PID)

PID control is the basic control scheme of the classical control system. It is mainly used for industrial control of a number of processes due to its simplicity [3]. The performance of the system can be enhanced by tuning the proper value of gainK_p, K_d and K_i. The variation in the values of gain cause for variation in output response $y(t)$. The mathematical equation for PID controller of an plant with input u(t) output y(t) and the error, e(t) is expressed as (1.1), (1.2) and (1.3) whereK_p is proportional gain, $K_i$integral gain, K_d derivative gain, T_i integral time and T_d derivative time. PID control is combination of proportion (P), integral (I), differential (D) of the error $e(t)$. The block diagram of analog PID control system is shown in Figure 1.1.

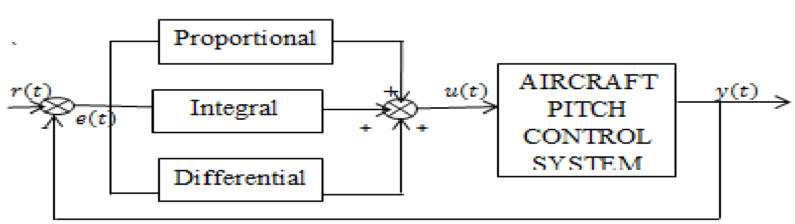

Figure 1.1 PID controllers with aircraft pitch control system

$$u(t) = K_p e(t) + K_i + K_d \frac{de(t)}{dt} \quad (1.1)$$

$$u(t) = K_p \left(e(t) + +T_d \frac{de(t)}{dt} \right) \quad (1.2)$$

$$e(t) = r(t) - y(t) \quad (1.3)$$

Proportional gain K_p helps in increasing the loop gain of the system to make it immune to load disturbance. The integral gain (K_i) helps to reduce steady state errors. The derivative gain (K_d) helps to enhance the stability of closed loop system. The parameters of PID controller have to be chosen properly to achieve the desired performance.

1.1.1Performance Estimation of PID Controller

The controller design has an objective to minimize the system's error produced by certain anticipated inputs. A system error is difference between desired and actual response. Performance criteria for system are based on measure of system's error. A performance estimation of PID controller is tabulated in Table 1.1.

Table 1.1 Performance Estimation of PID Controller

Name of Criterion	**Formula---**
Integral of Absolute Error (IAE)	$IAE = \int_0^\infty \lvert e(t) \rvert dt$
Integral of square Error (ISE)	$ISE = \int_0^\infty e(t)^2 dt$
Integral of Time-weighted Square Error (ITSE)	$ITAE = \int_0^\infty te(t)^2 dt$
Integral of Time-weighted Absolute Error (ITSE)	$ITAE = \int_0^\infty t\lvert e(t) \rvert^2 dt$

The integral absolute error (IAE) and integral of square error (ISE) have a disadvantage that its minimization can result in a response with relatively small overshoot but a long settling time because IAE and ISE performance criteria weights all errors equally independent of time. But for aircraft system as to increase the transparency, settling time should be as minimum as possible. Although the ISTE performance criterion weights error with time, the derivation processes of the analytical formula are complex and time consuming.

1.2 Fuzzy Logic Controller (FLC)

Fuzzy logic controller has been applied for stabilization of the pitch control system. FLC is conceived as a better method for sorting and handling data but has proven to be an excellent choice for many control system applications because of non-linearity, complex mathematical computation and real-time computation need. It can be built into anything from small, hand-held products to large computerized process control systems. It uses an imprecise but very descriptive language to deal with input data more like a human operator. It is very robust and forgiving of operator and data input and often works when first implemented with little or no tuning. Based on these properties, fuzzy logic controller plays the best to fit the requirements in such cases. FLC incorporates a simple rule-based "If X and Y then Z" attempting to model a system mathematically. Figure1.2 shows the overall closed-loop system for FLC with the pitch control of an aircraft. The inputs to the fuzzy controller are the error (e) which measures the system performance and the rate at which the error changes (Δe), whereas the output is the change of the control signal (Δu). The error (e) is computed by comparing the reference point (desired angle) with the plant output. The change of error (Δe) is generated by the derivation of the error. The error and change of error is fed to the fuzzy controller through a multiplexer. [7]

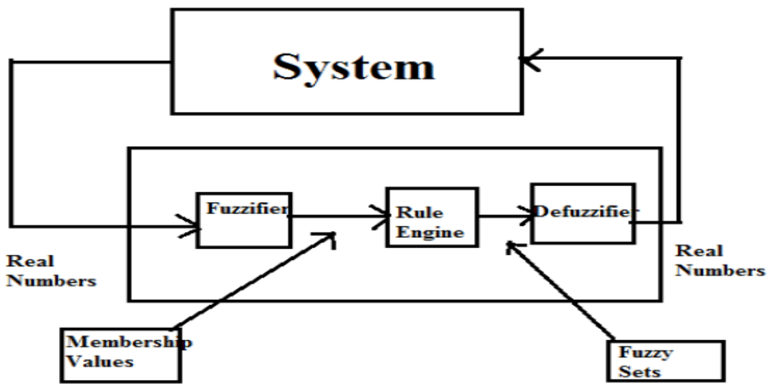

Figure 1.2The basic structure of fuzzy logic control

This fuzzy membership values are used in the rule base in order to execute the related rules so that an output can be generated. A rule base consists of a data table which includes information related to the system. A fuzzy control that has nine rules is realized. These rules have been utilized in designing the controller and the rules are defined in Table 1.2.

Table 1.2 The Fuzzy rule base

S.NO.	INPUT1	INPUT2	OUTPUT
1	NEG	NEG	NEG
2	NEG	ZR	NEG
3	NEG	PG	NEG
4	ZR	NEG	NEG
5	ZR	ZR	ZR
6	ZR	PG	PG
7	PG	NEG	PG
8	PG	ZR	PG
9	PG	PG	PG

Figure 1.3 and 1.4 defines the membership functions for input1 and input2 variables. Each input contains three membership functions. Triangular membership function for zero (ZR) and trapezoidal function for negative (NEG) and positive (PG).

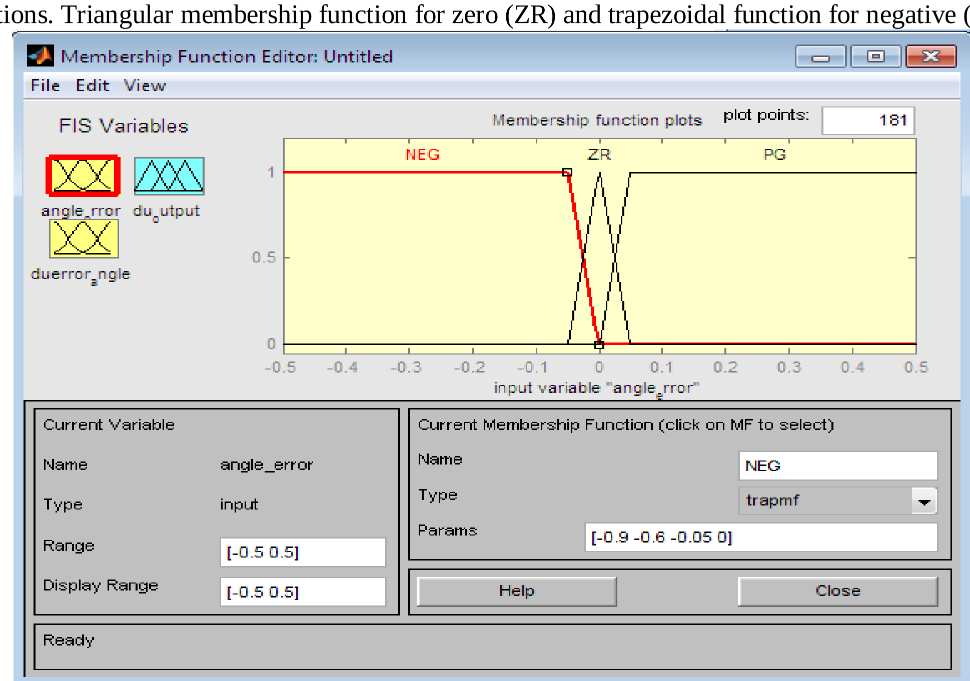

Figure 1.3The basic input1 membership function

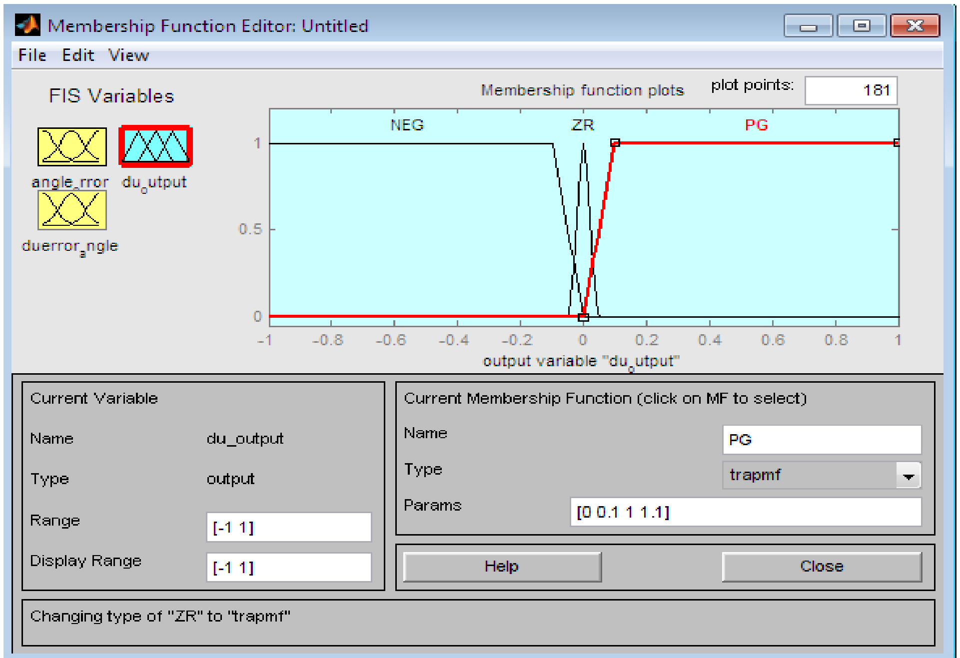

Figure 1.4The basic input2 membership function

Figure 1.5 defines the membership function for output. Output has also three membership function. Triangular membership function for zero (ZR) and trapezoidal function for negative (NEG) and positive (PG).

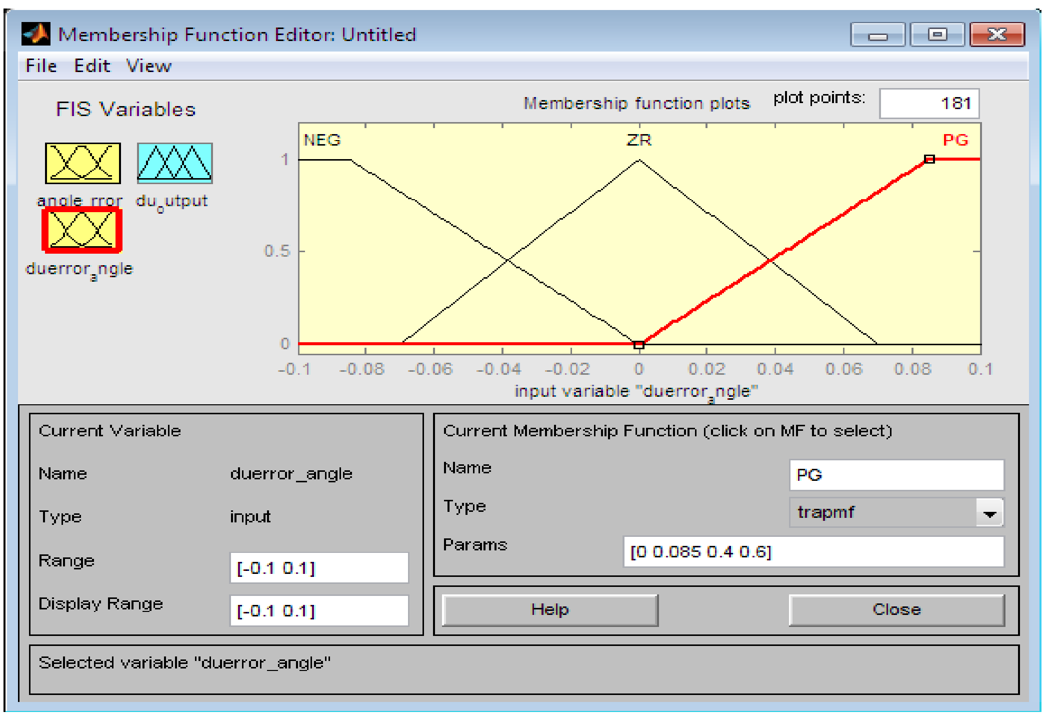

Figure 1.5The basic output membership function

Matlab Simulink Model of FLC

The fuzzy Logic Control is realized using matlab simulink model as shown in Figure 1.6. In this model the input is square wave generator with low frequency. The Fuzzy Logic Controller have FIS(Fuzzy inference system) system which is designed with the input and output. Each input and output has membership functions which are related from input to output through relationships and this relation is called Fuzzy rules as shown in table 1.2. There are many kinds of membership functions viz. triangular, trapezoidal, Gaussian etc. In this model triangular and trapezoidal membership functions are used in the inputs and the output function. This Model also have PID controller multiplexed with the FLC. The output is drawn on the scope with infinite time of simulation with 0.2 step size. The system is realized using the functions as shown in Figure 1.6.

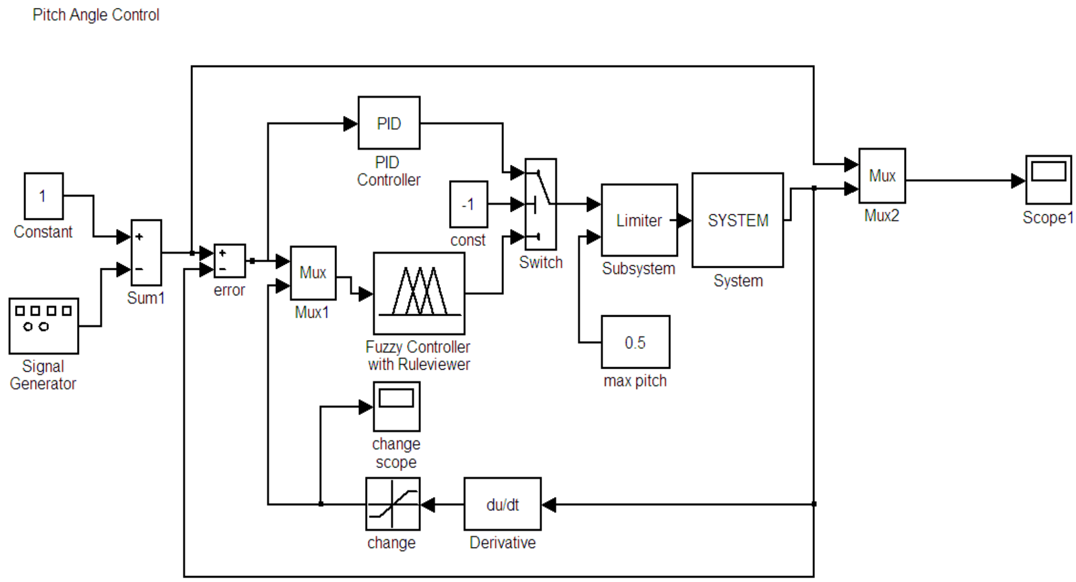

Figure 1.6 Matlab simulink model for fuzzy logic controller

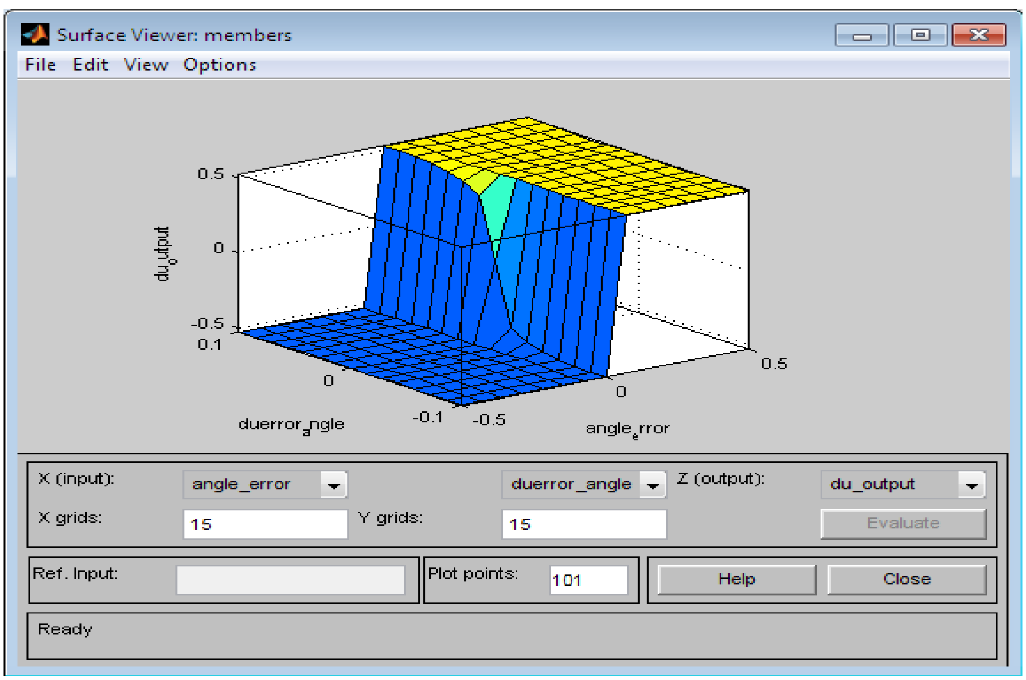

Figure 1.7 Surface viewer of FLC

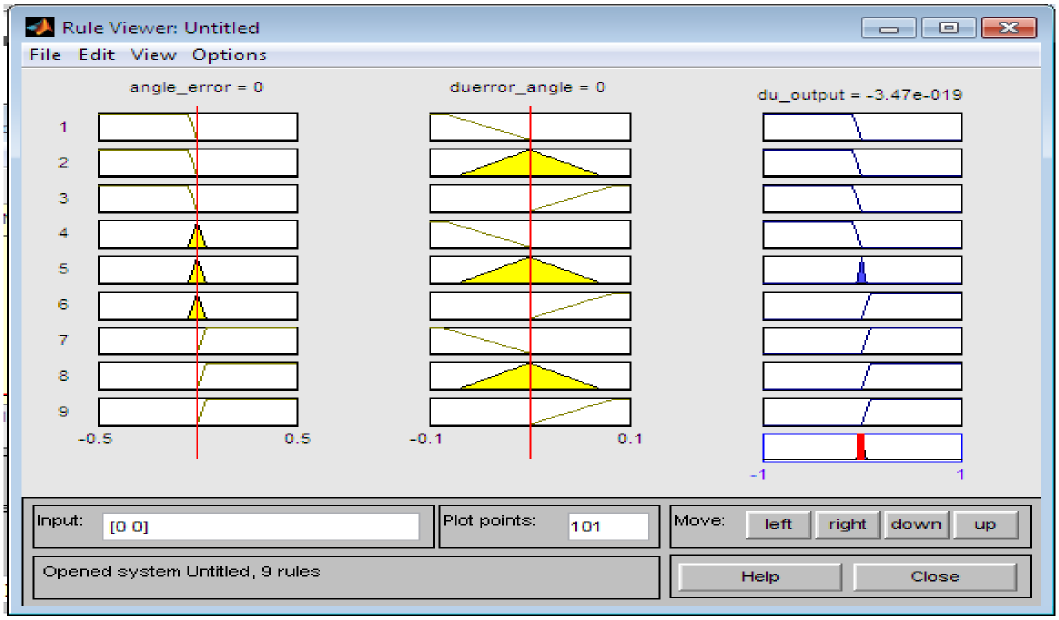

Figure 1.8 Rule viewer of FLC

2. APPLICATION AND RESULTS

An aircraft pitch control system is simulated using PID and FLC and the related simulation results are presented and discussed. Matlab/Simulink model block diagram of this system is shown in Figure 2.1 Response is plotted on the graph In Figure 2.1.

Figure2.1. Pitch angle response using FLC control in Matlab Simulink Model

From the responses, it is clear that the settling time of FLC is smaller than that of PID controller. PID controller is slower than FLC, but it has a drawback of overshoot. The steady-state error of PID controller is equal to that of FLC, which indicates the disturbance rejection capabilities of both controllers are same. The performance characteristics of both controllers are summarized in table 2.1.

Table 2.1 Comparison of Response Characteristics of pitch angle

Response characteristics	Pitch angle (PID)	Pitch angle (FLC)
Rising time(T_r)	0.15s	0.4s
Settling time(T_s)	1.6s	0.68s
Disturbance rejection (T_S)	3.67 s	1s
Percentage overshoot (%Os)	4.3%	0
Steady state error (e_{ss}%)	0.01	0.01

3. CONCLUSION

In this paper, the model of an aircraft pitch control system was designed in Matlab/Simulink environment and control methods were proposed for this system. PID and FLC are successfully designed and responses are verified. The results from PID are compared with those obtained using FLC controller. It was observed that both FLC and PID have different steady-state error and same overshoot. Analysis of obtained results shows that FLC controller relatively gives the best performance in comparison to PID and using such controller increases speed of the time response and helps in the efficient controlling of the system.

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