Design of Automatic Flight Control System for general Aviation with a Fuzzy System and Enhancement Controller

*Mazin Al-Saegh * and Qusay Hassan***
**University of Technology, Iraq*
Baghdad, Iraq
***University of Diyala*
Diyala, Iraq

Abstract

Recent advances in aviation have motivated improvements in automatic flight control systems. While the autopilot is an important component in the flight control system, the demand for robust controllers that are effective and applicable in more complex systems is increasing. Thus, this paper designs and simulates a pitch controller based on the design of the autopilot that can control the pitch of the aircraft using the standard motion equation. Four different controllers are considered, namely, proportional integral derivative (PID) controller, fuzzy proportional derivative (PD) controller, fuzzy proportional integral (PI), and fuzzy PID controller that are also discussed under different conditions including the Mach number, the angle of attack, true airspeed, and weight. Finally, a comparison between the performances of the controllers is conducted.

Keywords: Pitch control, automatic flight control, PID, fuzzy logic.

1. Introduction

As the complexity of aircrafts increase, classical methods become unsatisfactory to yield acceptable performance [1]. Fuzzy Logic controllers have been successfully applied in a large number of control applications. The most commonly used controller is the PID controller. Fuzzy logic controllers provide an alternative to PID controllers, as they are a good tool for the control of systems that are difficult to model. Fuzzy systems have different kinds of applications (regulating the velocity of a freight train, optimization trip time and energy consumption of a high-speed railway, helicopter flight control system) [2] [3]. In this paper fuzzy PD, fuzzy PI, fuzzy PID controllers used to control pitch angle of flight control system for different conditions and compare it with classical PID controller. .

1.2 Equations

$$\dot{X} = Ax + Bu \qquad (1)$$

Where:

$\dot{X} = [\dot{u}, \dot{\alpha}, \dot{q}, \dot{\theta}]$

$X = [u, \alpha, q, \theta]$

u: *linear velocity* $\qquad$ q: *Pitch rate*

α: *Angle of attack* $\qquad$ θ: *Pitch angle*

$u = [\delta_e]$ $\qquad$ δ_e: *Elevator*

Aircraft parameters	first condition	second condition	third condition
True airspeed (ft./s)	170	677	677
Weight (lb.)	13000	13000	9000

Table 1: aircraft parameters [4]

2. Controllers design

I. PID controller layout.

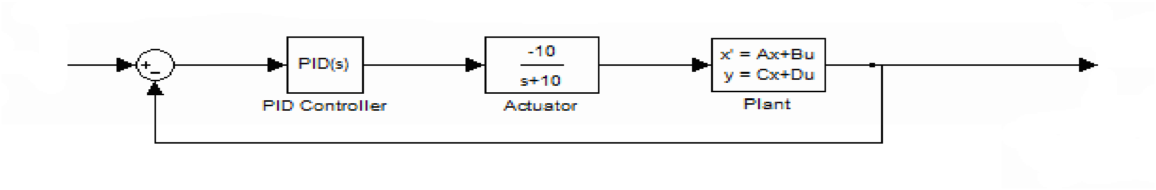

Figure 1: PID block diagram

The family of PID controllers is constructed from various combinations of the proportional, integral and derivative terms as required to meet specific performance requirements. The formula for the basic parallel PID controller is:

$$U_c(s) = \left[K_P + K_I \frac{1}{s} + K_D s\right] E(s)$$

II. Fuzzy PID controller layout.

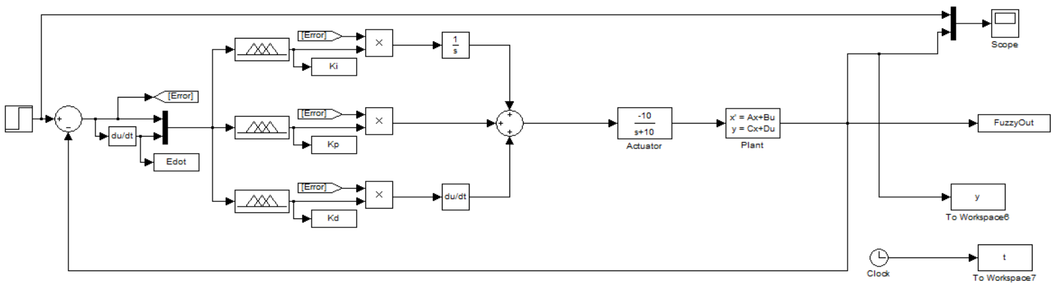

Figure 2: Fuzzy PID block diagram

As showed above block diagram of fuzzy PID controller will be used in this paper as well as fuzzy PD controller use the same block, but without integral gain coefficient. The fuzzy rules will be used for gains (K p, Ki, KD) illustrated below:

Edot / E	NB	NS	ZE	PS	PB
NB	VB	VB	VB	VB	VB
NS	B	B	B	MB	MB
ZE	ZE	ZE	MS	S	S
PS	B	B	B	MB	VB
PB	VB	VB	VB	VB	VB

Table 2: Rule base for K_p

Edot / E	NB	NS	ZE	PS	PB
NB	ZE	S	MB	MB	VB
NS	S	B	MB	VB	VB
ZE	M	MB	MB	VB	VB
PS	B	VB	VB	VB	VB
PB	VB	VB	VB	VB	VB

Table 3: Rule base for K_D

Edot / E	NB	NS	ZE	PS	PB
NB	M	M	M	M	M
NS	S	S	S	S	S
ZE	MS	MS	ZE	MS	MS
PS	S	S	S	S	S
PB	M	M	M	M	M

Table 4: Rule base for K_i

3. Results and Discussion

The step response for first condition is illustrated in figure (3) below. Notice that the PID controller have slower raising and settling time than Fuzzy PID and Fuzzy PD controller as well as Fuzzy controllers shows smooth response than conventional PID controller, but PID controller have small overshoot while no overshoot for Fuzzy PD controller with very small steady state error. In contrast Fuzzy PID has no steady state error, so Fuzzy shows better characteristics. For Fuzzy PI the system will be not stable because of the error so that there is no sense to show its response.

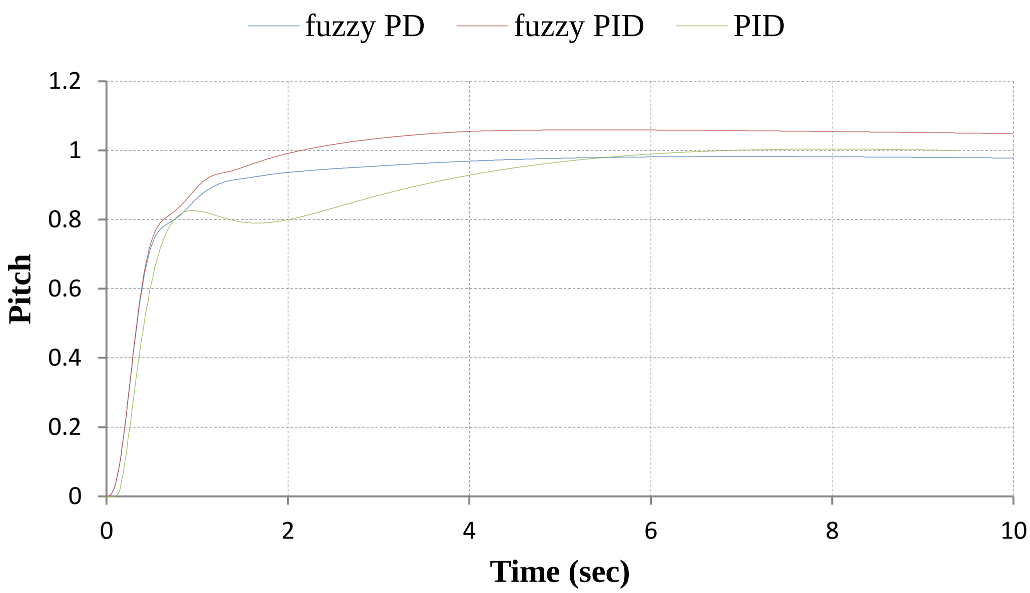

Figure 3: Step response of controllers for first condition

The step response for second condition illustrated in figure (4) below. The same rules used for Fuzzy PD and Fuzzy PID as well as the same number, type of membership functions in first condition will be used in second condition. From the figure (4) below notice that Fuzzy PD and Fuzzy PID have faster raising time than PID controller while settling time for Fuzzy PID slower than other controllers, also there is small overshoot for PID and slightly higher for Fuzzy PID controller while no overshoot for Fuzzy PD. Fuzzy PD have very small steady state error, but for Fuzzy PID and PID controllers steady state error equal zero. So Fuzzy shows better characteristics and again Fuzzy PI unstable.

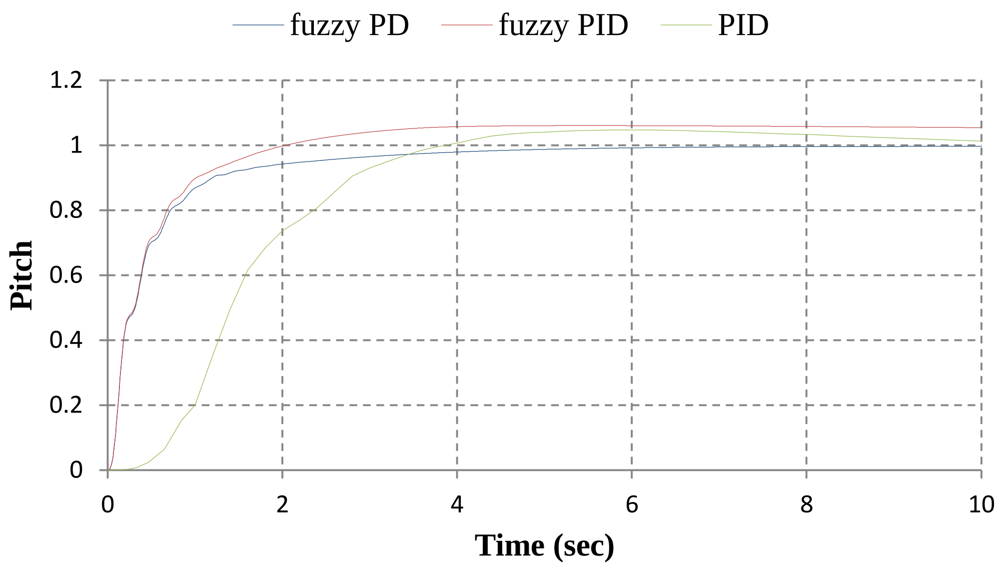

Figure 4: Step response of controllers for second condition

The step response for third condition in figure (5) below. Again with the same configuration for Fuzzy controllers used before will be repeated for third condition, also the fuzzy controllers will shows better raising time than PID controllers except fuzzy PID will have slower settling time than PID controller. There is no overshoot with fuzzy PD while PID has small overshoot as well as fuzzy PID have slightly higher overshoot.

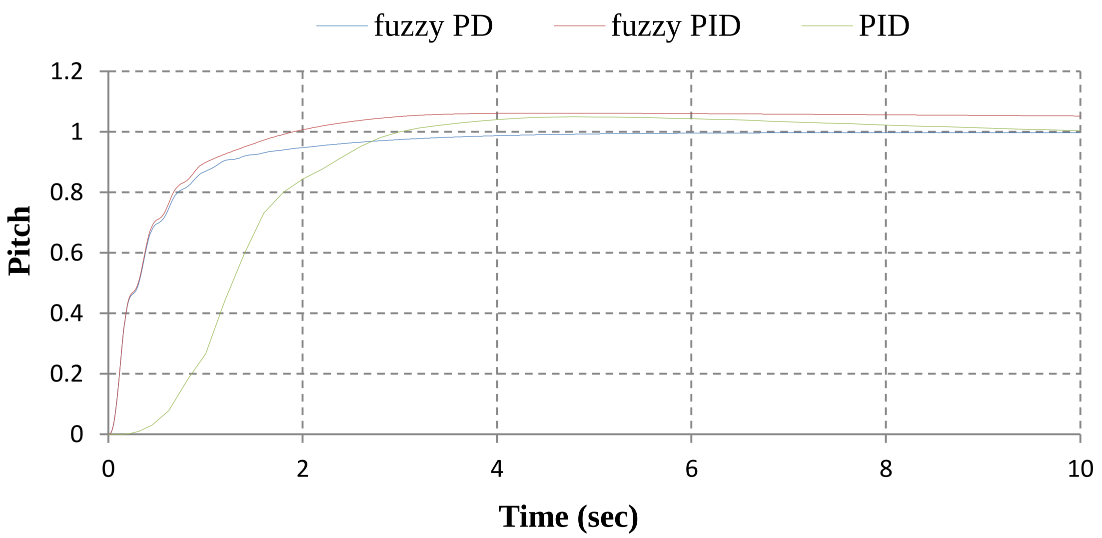

Figure 5: Step response of controllers for third condition

Comparing fuzzy controllers to the classical PID controller, in each condition the gains of PID controller must be adjusted to get proper response for our system while in fuzzy controllers the same rules and membership functions used in three conditions with good response, also it can be mentioned that this type of aircraft has narrow space to change with gains, so the response of classical PID controller that showed in figures above consider the best response from the time specifications view for aircraft as well as it can be concluded that using fuzzy with classical controllers will give good response than PID in linear systems and to control systems that are difficult to model it, but in nonlinear systems fuzzy controllers preferred than PID controllers.

4. Conclusion

From the design and simulation results, the fuzzy PD controller exhibits the best performance under the three flight conditions because of the following:

1. Fuzzy PD controller has better characteristics and simulation results than conventional PID, although PID easier to build than fuzzy logic controllers. However, each condition requires a new PID design and different values of gains (KP, KI, KD) are tuned. Thus, conventional PID cannot be appropriate as an autopilot for all flight envelopes.

2. Fuzzy PID and fuzzy PD controllers have good responses and characteristics, whereas fuzzy PI is unstable and is not suitable for our work.

3. Fuzzy PID has a smooth transition and low rising time, but high settling time and overshoot, and uses the same rules as fuzzy PD in the three conditions. However, fuzzy PD has a larger steady-state error than fuzzy PID.

References

[1]] S. Poorani, T.V.S.U. Priya, K.U. Kumar, and S. Renganarayanan, "FPGA Based Fuzzy Logic Controller for Electric Vehicle", Journal of the Institution of Engineers, Singapore, Vol. 45 Issue 5 2005.Magin, T., and G. Degrez. 2004. Transport algorithms for partially ionized and unmagnetized plasmas. J. Comput. Phys. 198:424–449.
[2] L. Reznik, "Fuzzy Controllers", Newnes, first edition, 1997.
[3] Mathworks, "Fuzzy Logic Toolbox User's Guide ", Mathworks, Inc., 1999.
[4] Thomas R. Yechout “Introduction to aircraft flight mechanics: performance, static stability, dynamic stability, and classical feedback control”. American institute of aeronautics and astronautics, Reston, 2003.