Malaysian Simulation SOCIETY
APPLICATIONS OF MODELLING AND SIMULATION
http://amsjournal.ams-mss.org
eISSN 2600-8084
VOL 2, NO. 1, 2018, 17-25

A Comparative Analysis of Intelligent and PID Controllers for an Aircraft Pitch Control System

Zakarya Mohammed Motea, Herman Wahid*, Junaid Zahid, Swan Htet Lwin and Abbas Musa Hassan

School of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.

*Corresponding author: herman@fke.utm.my

Abstract: Aircraft pitch control system is one example of nonlinear complex systems which requires feedback control. Fuzzy logic controllers (FLC) have emerged as intelligent method in controlling such system by utilizing fuzzy logic principle. This paper presents a comparative analysis for the performance of proportional-derivative-integral (PID) controller and fuzzy logic controller in controlling the aircraft pitch angle. The input is the elevator deflection angle and the output is the pitch angle of the aircraft. For the fuzzy controller, it is governed by five membership functions and seventeen rules which were tuned repeatedly according to the actual output of the controller corresponding to the customized set point. The procedures of the PID and the FLC design are discussed in methodology section. In general, both PID and FLC perform within the design requirements. However, FLC outperforms PID in three design parameters namely the settling time, the percentage of overshoot and the steady state error, with improvements of 12%, 98% and 97%, respectively.

Keywords: Aircraft; Fuzzy logic controller; PID controller; Pitch control.

1. INTRODUCTION

The primary flight control surfaces consist of ailerons, elevator and rudder which are required to control an aircraft safely during flight. The flight control surfaces are operated by the pilot through connecting linkage to the rudder pedals and a control yoke. The aircraft can rotate around one, two, or all three axes simultaneously. These directions are as shown in Figure 1; the axis of yaw (vertical), the axis of roll (longitudinal) and the axis of pitch (lateral) [1]. Lateral (pitch) axis is an imaginary line from wingtip to wingtip and the rotation about it is controlled by the elevator. The rotation is similar to a seesaw. The bar holding the seesaw is the lateral axis. This is known as the airplane's pitch attitude. The equations governing the motion of an aircraft are a very complicated set of six nonlinear coupled differential equations. However, under certain assumptions, they can be decoupled and linearized into longitudinal and lateral equations. Aircraft pitch is governed by the longitudinal dynamics. The basic coordinate axes and forces acting on an aircraft are shown in the Figure 2.

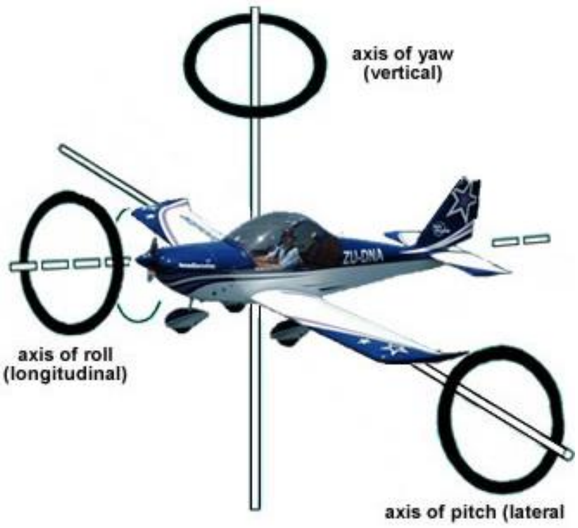

Figure 1. Aircraft flight control surfaces [1]

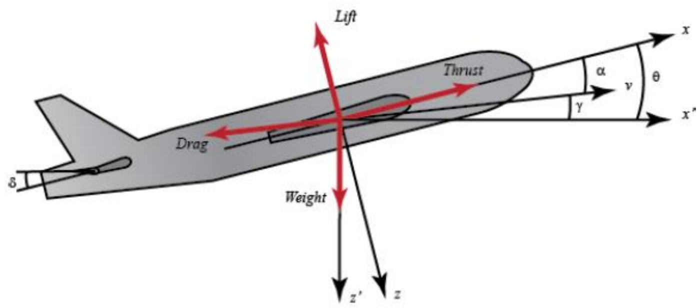

Figure 2. An aircraft flight dynamics [13]

Recently, many control approaches have been proposed by researcher for aircraft pitch system control, these include optimal robust control approach [2], PID controller [3], fuzzy logic approach as in [4] and [5] or an integration of two approaches as in [6]. One of these approaches is fuzzy logic which is a method to systematically and imitates human reasoning and decision-making function. A fuzzy logic controller does not require a precise mathematical model for the controlled plant; as an alternative it utilizes previous experiences and knowledge in form of series of IF/THEN rules. In some cases the system might have a large number of inputs and outputs. Therefore, obtaining the rule base for the systems might be tedious, if not impossible. Some might think that the fuzzy logic controller is only a tool for converting linguistic data into a machine defined language. However, fuzzy controllers are able to make decisions and solve problems on the basis of imprecise linguistic information [7]. Recent developments in fuzzy theory offer a variety of effective methods for the design and tuning of fuzzy logic controllers, reflecting a deeper understanding of the nature of fuzzy control.

This paper is organized as follows: Section 2 discusses some literature reviews on aircraft pitch systems control using a number of methods. Section 3 describes the problem and explains the methodology used to achieve the aim of this analysis. Section 4 shows the obtained results and its analysis and finally the conclusion of this study is drawn in Section 5.

2. LITERATURE REVIEW

In relation to the passing air, an aircraft has three main ways of changing its orientation which are the pitch, roll and yaw. The pitch is the movement of the nose up and down with rotation around the transversal axis (climb and descend) while the roll is the rotation round the axis that runs along the length of the aircraft and the last one which is the yaw is responsible for the movement of the nose left or right and about the vertical axis. Control of the pitch largely depends on the rear part of the tail-plane’s horizontal stabilizer which is hinged to create an elevator. A lot of researches have been conducted on aircraft pitch control system using different approaches and some of the recent works are reviewed in this section.

The design of aircraft nowadays has completely relied on automatic control system in order to monitor and control majority of the aircraft subsystems. In a research conducted in [9], linear quadratic controller (LQR) and fuzzy logic controller (FLC) are developed to control the pitch angle of an aircraft system. The two types of controllers were comparatively measured and analysed based on time response specification performance and the LQR controller has delivered a better performance with respect to the pitch rate and pitch angle. Reference [10] uses linear quadratic controller and proportional integral derivative (PID) controller in the design of an aircraft pitch control system. Under this research, genetic algorithm (GA) is used in tuning the controller’s parameter automatically with the sole aim of reducing the rise time, settling time, peak overshoot and thus optimizing the fitness function because there is always uncertainty in tuning the controller manually due to human error. It starts by developing the mathematical model in order to report for the longitudinal motion of the aircraft used in designing the pitch angle controller of an aircraft but there is a low performance shown by the PID controller as the settling time is quite higher. The LQR tuned parameters has shown the capability of controlling the pitch angle of the aircraft system.

Authors in [2] use a fractional order controller PID (FOPID) to design a robust pitch control of a flight control system. The combined sensitivity formulation has been used as a multi objective optimization problem in order to obtain optimal values of the controller gain and for the system to offer robust response based on generate first choose later (GFCL) approach. At the end of their research, a comparative analysis has shown that the FOPID and the multi objective GA tuned FOPID controller has given a better robustness compared to the multi objective GA tuned PID controller.

Authors in [11] use a multi objective differential evolution (MODE) in the design of the FOPID controller for flight control system and the result of the research has shown that the multi objective tuned fractional PID controller gives a quite reasonable time domain performance than the multi objective tuned PID controller. As fuzzy logic aimed at drawing conclusions typically from properties defined in fuzzy set, in [6] uses three different types of controllers in the design of a nonlinear aircraft pitch control system. The aim of the research is to evaluate multiple aircraft pitch controllers that are in motion in air, the three types of controllers designed are fuzzy, PID and fuzzy-PID and have utilized the Mamdani fuzzy reasoning model in tuning parameters and design of fuzzy controller and fuzzy-PID respectively. It is started by modelling the controller plant through building a nonlinear time invariant mathematical model that reflects the overall parameters which affect the aircraft dynamics so as to describe the motion. With the conventional, intelligent and hybrid control systems, the hybrid controller has shown the best response as it combines the features of both PID and fuzzy controllers and its ability to adapt with fuzzy rules.

Moreover, reference [12] presents a self-tuning PID controller design for aircraft pitch control system. The adaptive controller employed in this research is designed based on the dynamic modelling of the system in order to improve performance for a pitch control of aircraft system. The design starts by deriving a mathematical model suitable for the description of the longitudinal motion of the aircraft. Fuzzy logic is used in tuning the PID controller's parameter via the use of an appropriate fuzzy rules and it has been proven that the effect of disturbance in the aircraft pitch control system can be controlled successfully by the hybrid method rather than using the conventional controller alone. Classical controllers such as PID have a wide range of application in industrial control processes due to their simple structure and robust performance under numerous environmental working conditions, a lot of numerical approaches such as evolutionary algorithm and fuzzy logic controller algorithm are used in order to optimize the design of the PID controller. In [4], Bees algorithm is used in tuning the parameters of the Mamdani-type fuzzy logic controller in optimization for pitch displacement of aircraft with integral time absolute error as the cost function. At the end of their research, result of their simulation has proven that the fuzzy logic controller tuned using the bees algorithm has better performance than the PID and fuzzy expert tuned by bees algorithm and Ziegler-Nichols for aircraft pitch control.

3. METHODOLOGY

This section presents the procedure of designing fuzzy logic controller using MATLAB/SIMULINK software.

3.1 Model of the System and the Design Requirements

By assuming that the aircraft is in steady-cruise at constant altitude and velocity; thus, the thrust, drag, weight and lift forces balance each other in the x- and y-directions. It is also assumed that a change in pitch angle will not change the speed of the aircraft under any circumstance. Under these assumptions, the longitudinal equations of motion for the aircraft can be written as in Equation (1) [13].

$$P(s) = \frac{\theta(s)}{\Delta(s)} = \frac{1.151s + 0.1774}{s^3 + 0.739s^2 + 0.921s} \tag{1}$$

where $\Delta(s)$ is the elevator deflection and $\theta(s)$ is pitch angle.

The criteria and requirements of the design are chosen. In this design, a feedback controller is designed so that in response to a customized set point as shown in Figure 3 of pitch angle the actual pitch angle overshoots less than 10%, has a rise time of less than 2 seconds, a settling time of less than 10 seconds, and a steady-state error of less than 2%. For example, if the reference is 0.2 radians (11 degrees) , then the pitch angle will not exceed approximately 0.22 rad, will rise from 0.02 rad to 0.18 rad within 2 seconds, will settle to within 2% of its steady-state value within 10 seconds, and will settle between 0.196 and 0.204 radians in steady-state.

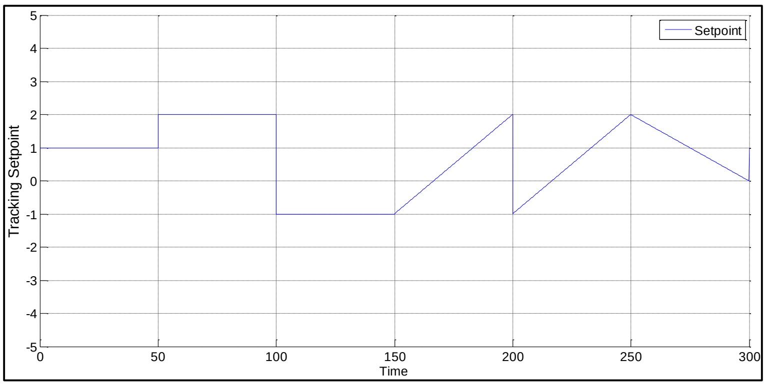

Figure 3. The tracking signal

3.2 Structure of Fuzzy Logic Controller

Fuzzy logic controller consists of four main parts as follows:

1. Fuzzifier: involves the conversion of the input/output signals into a number of fuzzy represented value (fuzzy sets) which comprise the selection of an appropriate membership function to represent each fuzzy set.
2. The knowledge base: consists of the rule base and the data base. The basic function of the rule base is to provide the necessary information for the proper functioning of the fuzzification module, the rule base and the defuzzification module.
3. Inference engine: provide the mechanism for invoking or referring to the rule base such that the appropriate rules are fired.
4. Defuzzification: is a mapping from a space of fuzzy control actions defined over an output universe of discourse into a space of non-fuzzy (crisp) control action [8].

All components of the controller are shown in a feedback system as in Figure 4.

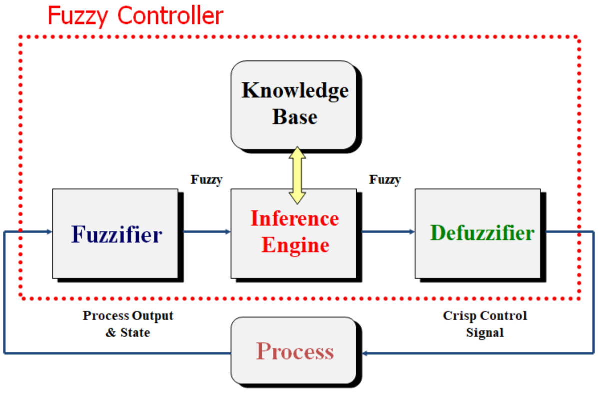

Figure 4. Basic fuzzy logic control architecture

3.3 Designing Fuzzy Logic Controller

Fuzzy logic controller is designed by using MATLAB toolbox which provides the development of fuzzy logic systems using graphical user interface (GUI) tools. There are five primary GUI tools which are fuzzy interference system (FIS) editor, membership function editor, rule editor, rule viewer and surface viewer.

3.3.1 FIS Editor

The fuzzy logic controller can be designed by using FIS editor before running in the simulation in MATLAB / SIMULINK. First of all, the member function was chosen first before is created to design the fuzzy logic controller. In fuzzy logic controller, the set of linguistic rules is the most important part. In this study, we choose the Mamdani type as shown in Figure 5, where two inputs which are the deflection angle error and the change in error, and one output which is the change in controlled signal which will be added into the past controlled signal value after defuzzification to form the actual controlled signal. Each input and output of the method consists of five membership functions, they are Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS) and Positive Medium (PM).

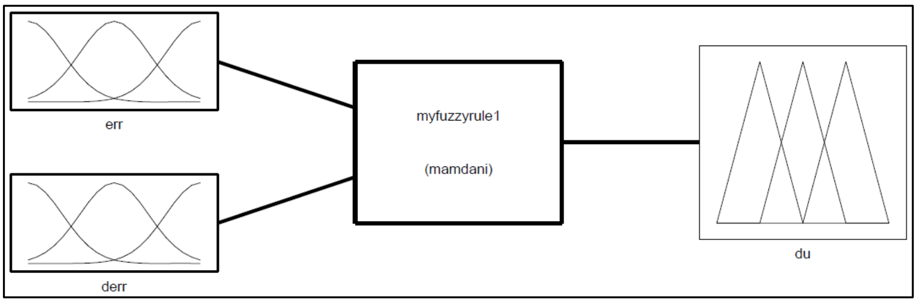

Figure 5. Mamdani type fuzzy controller

3.3.2 Membership Function Editor

Membership functions editor is a tool to display and edit all the membership functions associated with all the inputs and outputs variables for the entire fuzzy interference system. The membership functions for input and output shown in Figure 6, Figure 7 and Figure 8. The range is chosen to be from -2 to 2 for the error, -0.3 to 0.2 for the change of error and -5 to 5 for the output.

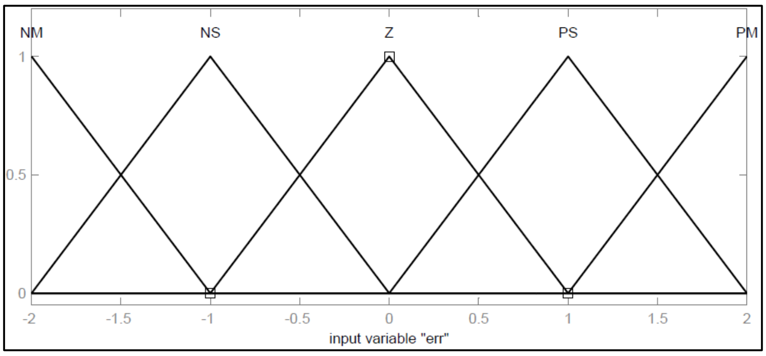

Figure 6. Fuzzy sets of input 1 (Error)

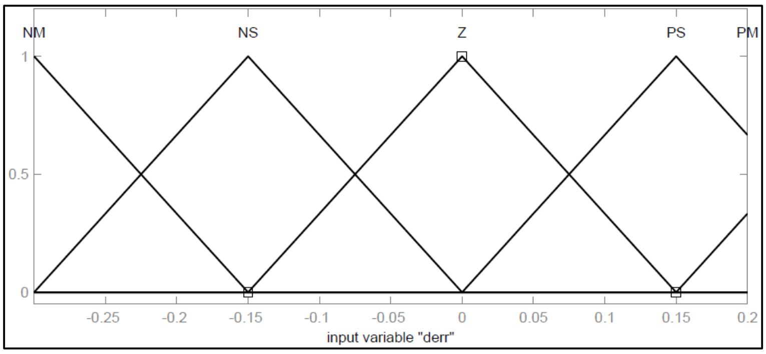

Figure 7. Fuzzy sets of input 2 (change of error)

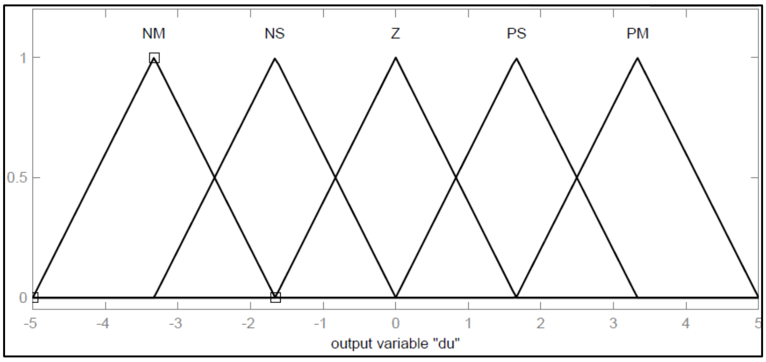

Figure 8. Fuzzy sets of the output

3.3.3 Rule Editor

To develop the fuzzy logic control, we have used 17 rules to obtain the best result. Table 1 shows the rule base for the fuzzy logic controller design.

Table 1. The rule matrix of the design

Δe\e	NM	NS	Z	PS	PM
NM	NM	NS	NS	PM	PM
NS	NM	NM	NS	PM	PM
Z	NM	NM	Z	PM	PM
PS	NM	NM	PS	PM	PM
PM	NM	NM	PM	PS	PM

4. SIMULATION RESULTS AND ANALYSIS

4.1 Simulation of PID Controller for Aircraft Pitch Control

The PID controller is designed with these gain values; K_i = 4.45, K_p = 2, and K_d = 4.90, where the parameters were tuned by using the Ziegler-Nichols method which available in the Matlab Toolbox. The feedback system with PID controller is as shown in the block diagram in Figure 9, while the result of the PID approach is shown in Figure 10.

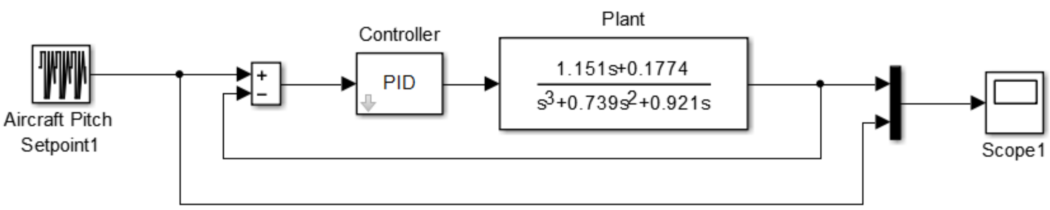

Figure 9. PID controller for aircraft pitch control system

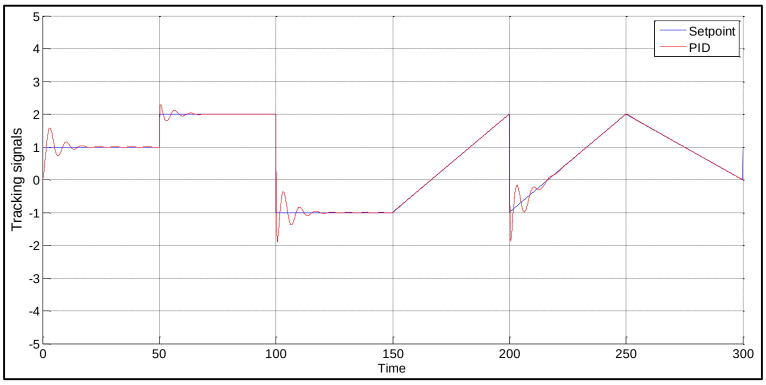

Figure 10. The PID tracking results for aircraft pitch control system

4.2 Simulation of FLC for Aircraft Pitch Control

By using the same transfer function of the plant in the previous section (i.e. Equation (1)), the block diagram of FLC feedback control system is shown in Figure 11. One of the results of the fuzzy controller is shown in Figure 12 and some other results with some drawbacks are shown in the Appendix section. The fuzzy inference rules and the surface output are illustrated in Figure 13 and Figure 14, respectively.

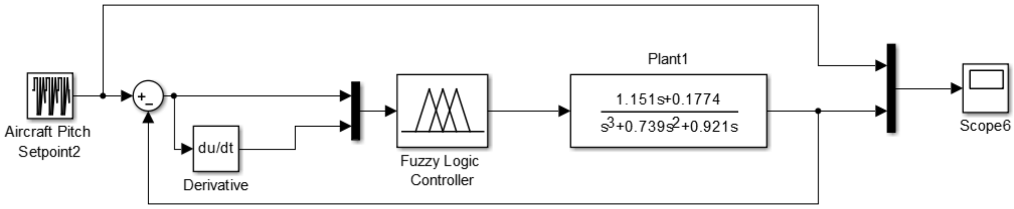

Figure 11. Fuzzy logic controller for aircraft pitch control

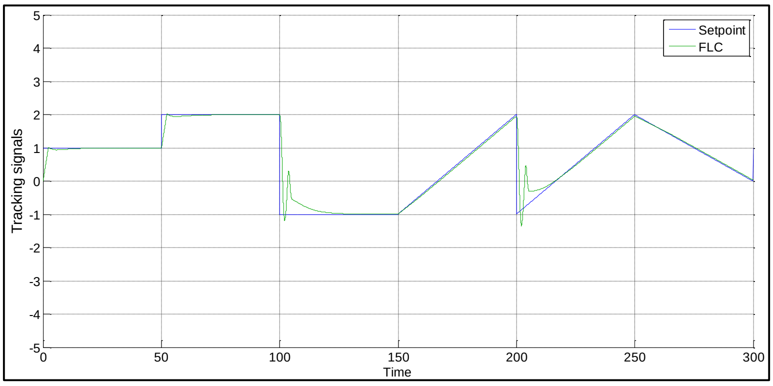

Figure 12. The PID tracking results for aircraft pitch control system

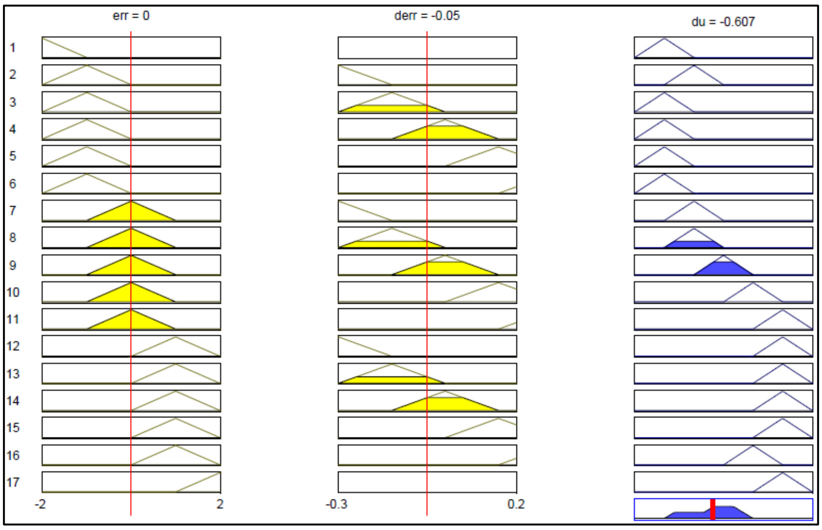

Figure 13. Fuzzy inference rules designed for aircraft pitch control

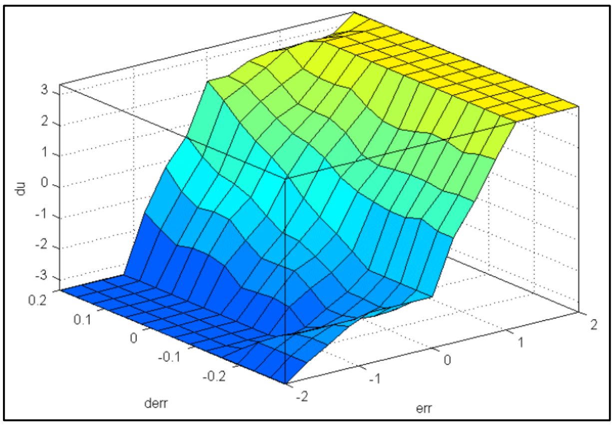

Figure 14. The output surface of the designed FLC

4.3 Discussion

The best set of the fuzzy rules has been set using the fuzzy control rules selection method proposed by [7]. The result of the FLC design which is shown in Figure 15 outperforms the result of PID control in all three tracking points (i.e. point A, B and C as shown in the figure) in terms of having less overshoot and steady state error and also better in terms of settling time at the first tracking point. The results met design requirements mentioned in the previous section except for settling time which was slightly more than the requirement. It is also observed that the PID settling time exceeds the requirement.

As observed from the figures in the Appendix, the result of FLC varies by altering the base set rules. In those graphs, some requirements are met, however it penalized by having unsatisfying results in terms of the other requirements either overshoot or rise time or settling time.

Table 2 shows the comparative results of using the best tuned PID and FLC controller. The result of the FLC design has insignificant overshoot compared to PID controller. The controller was tuned by adjusting the range of the inputs; error and change of error until the desired performance was achieved.

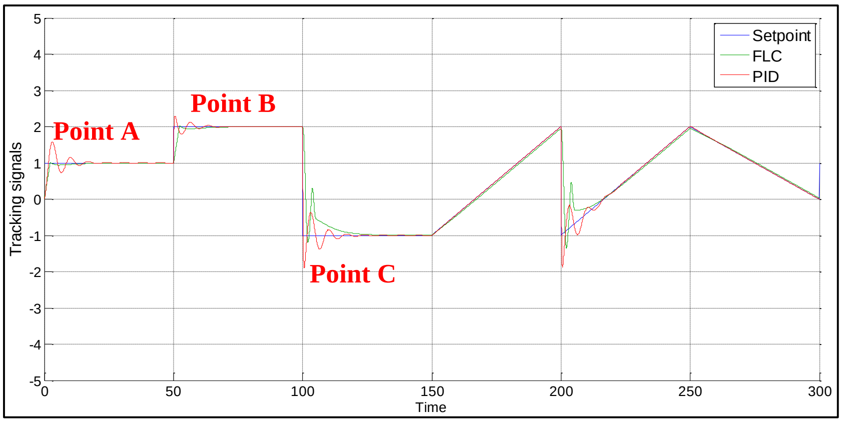

Figure 15. Comparison between PID and FLC with respect to the set point

Table 2. Comparison between PID and FLC based on the design parameters

Requirements	PID	FLC
First tracking point		
Rise time (2 sec)	1.16 sec	1.8 sec
Settling time (10 sec)	18.36 sec	16.1 sec
Overshoot (10%)	58.1 %	1.4%
Steady state error (2%)	0.01	0.0003
Second tracking point		
Rise time (2 sec)	0.16 sec	1.8 sec
Settling time (10 sec)	14.71 sec	15.9 sec
Overshoot (10%)	30.2 %	2.2%
Steady state error (2%)	0	0
Third tracking point		
Rise time (2 sec)	0.2 sec	1.1 sec
Settling time (10 sec)	21.4 sec	26.9 sec
Overshoot (10%)	30.2%	6.53%
Steady state error (2%)	0	0.0012

5. CONCLUSION

This paper has presented a comparative study of two types of control approach for aircraft pitch control system; PID and fuzzy logic controller. The PID parameters were tuned by using Ziegler Nichols method by using Matlab Toolbox. FLC was designed using Mamdani type fuzzy controller with five membership function and 17 rules. Max-min was chosen as the inferencing mechanism and the defuzzifier used centroid of gravity method. The result showed that, the response of FLC outperformed PID in most of the design parameters, however, the rise time of PID exhibited slightly better result. In short, fuzzy logic technique is a powerful controller in achieving the desired control performance. It does not require a mathematical model in order to design the controller, hence the underlying physics of the system is not necessarily to be known at first.

ACKNOWLEDGMENT

The authors would like to acknowledge the UTM-GUP Grant from Universiti Teknologi Malaysia (UTM) and Malaysian Government with vote number 17H40 for supporting this work.

REFERENCES

[1] Axes / Control Surfaces - Principles of flight, *Aeronautics Research Mission Directorate, National Aeronautics and Space Administration (NASA)*, 2010.
[2] P. Kumar and S. Narayan, Optimal design of robust FOPID for the aircraft pitch control system using multi-objective GA, *2016 IEEE Students' Conference on Electrical, Electronics and Computer Science*, Bhopal, India, 2016, pp. 1–6.
[3] Vishal and J. Ohri, GA tuned LQR and PID controller for aircraft pitch control, *2014 IEEE 6th India International Conference on Power Electronics*, Kurukshetra, India, 2014, pp. 1–6.
[4] R. Zaeri, A. Ghanbarzadeh, B. Attaran and Z. Zaeri, Fuzzy logic controller based pitch control of aircraft tuned with bees algorithm, *The 2nd International Conference on Control, Instrumentation and Automation*, Shiraz, Iran, 2011, pp. 705–710.
[5] D. We, H. Xiong and J. Fu, Aircraft autopilot pitch control based on fuzzy active disturbance rejection control, *2015 International Conference on Industrial Informatics - Computing Technology, Intelligent Technology, Industrial Information Integration*, Wuhan, China, 2015, pp. 144–147.
[6] I. N. Ibrahim and M. A. Al Akkad, Exploiting an intelligent fuzzy-PID system in nonlinear aircraft pitch control, *2016 International Siberian Conference on Control and Communications*, Moscow, Russia, 2016, pp. 1–7.
[7] C. C. Lee, Fuzzy logic in control systems: fuzzy logic controller, *IEEE Transactions on Systems, Man, and Cybernetics*, 20(2), 404-418, 1990.
[8] E. H. Mamdani, Application of fuzzy logic to approximate reasoning using linguistic synthesis, *IEEE Transactions on Computers*, 26(20), 1182–1191, 1977.
[9] N. Wahid and M. F. Rahmat, Pitch control system using LQR and fuzzy logic controller, *2010 IEEE Symposium on Industrial Electronics and Applications*, Penang, Malaysia, 2010, pp. 389–394.
[10] Vishal and J. Ohri, GA tuned LQR and PID controller for aircraft pitch control, *2014 IEEE 6th India International Conference on Power Electronics*, Kurukshetra, India, 2014, pp. 1–6.
[11] P. Kumar and J. Raheja, Optimal design of robust FOPID for the flight control system using multi-objective differential evolution, *2015 2nd International Conference on Recent Advances in Engineering & Computational Sciences*, Chandigarh, India, 2015, pp. 1–4.
[12] N. Wahid and N. Hassan, Self-tuning fuzzy PID controller design for aircraft pitch control, *2012 Third International Conference on Intelligent Systems Modelling and Simulation*, Kota Kinabalu, Malaysia, 2012, pp. 19–24.
[13] University of Michigan, Aircraft pitch: system modeling, *Control Tutorials for Matlab Simulink*, 2018. Available online at: http://ctms.engin.umich.edu/CTMS/index.php.

APPENDIX

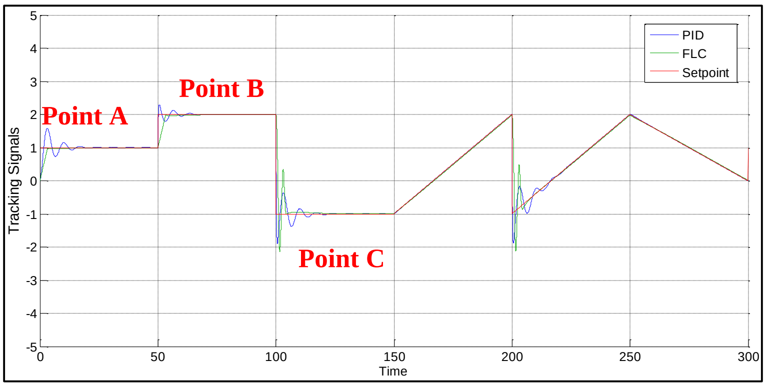

Figure A1. FLC design with better rise time but more overshoot at point 3

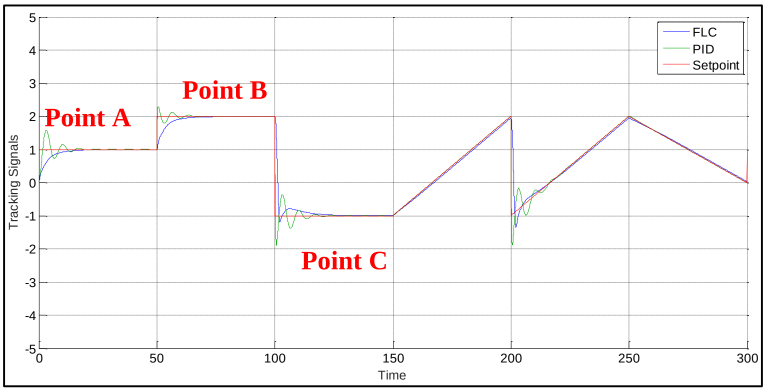

Figure A2. Another result with less overshoot but with slower rise time and settling time

Table A1. The rule matrix of Figure A1

Δe\e	NM	NS	Z	PS	PM
NM	NM	NS	NS	PM	PM
NS	NM	NM	NS	PM	PM
Z	NM	NM	Z	PM	PM
PS	NM	NM	PS	PM	PM
PM	NM	NM	PM	PS	PM

Table A2. The rule matrix of Figure A2

Δe\e	NM	NS	Z	PS	PM
NM	NM	NM	NM	PS	PM
NS	NM	NM	NS	PS	PM
Z	NM	NM	Z	PM	PM
PS	NM	NS	PS	PM	PM
PM	NM	NS	PM	PM	PM