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Multivariable flight controller design for ultrastick-25e UAV

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Abstract. Ultrastick-25e is an Unmanned Aerial Vehicle (UAV) invented by university of Minnesota. Its controller was designed with conventional PI controller in both longitudinal and lateral channels. Throughout this paper, four control techniques are purposed for controlling the unmanned fixed-wing plane (Ultrastick-25e). These controllers are genetically tuned PI and PID, fuzzy like PI, and fuzzy like PD controllers. These controllers are utilized to control both longitudinal and lateral channels for the linear and nonlinear model of the Ultrastick-25e. The four controllers improve the system response of the UAV. Every controller passes the system robustness evaluation including the disturbance rejection and the noise attenuation capabilities. Furthermore, robustness is evaluated for model uncertainties using the nonlinear model. The essential contribution in this paper is utilizing the fuzzy logic controller for the unmanned fixed-wing Ultrastick-25e. The simulation results analysis assure the superiority of the two fuzzy logic controllers compared with the genetically tuned PI and PID controllers.

Keywords. Fixed-Wing UAV, Flight Controller, Genetic Algorithm, Fuzzy Logic Controller.

1. Introduction

The neoteric researches in advanced guidance, control, and navigation have been grown rapidly in the last decade [1 - 4]. The utilization of autonomous Unmanned Aerial Vehicles (UAV) opens the gate to a vast diversity of both military and civil applications [5 - 9]. The researchers' goals are flight robustness and acceptable performance for their control system design of the UAVs. Several control methods are utilized to control Ultrasticke-25e based on mathematical modeling [10 - 12]. Conventional PI controller is designed in 2015 to improve the performance of the PI controller designed by university of Minnesota [13].

Genetically tuned PI and PID, fuzzy like PI, fuzzy like PD controllers are utilized to enhance the control capabilities for regulating the Ultrastick-25e. Fuzzy Logic Controller (FLC) is utilized earlier in the autopilot of the Aerosonde UAV as a controller. It is also utilized for self-tuning of PID controller for Aerosonde UAV [14]. The autopilot controlled by FLC realizes an acceptable and an agreeable output response even the presence of disturbance and noise [15]. Utilizing FLC for the Ultrastick-25e is for the first time and can be considered as a contribution of this paper. A comparative study is derived and assures the superiority of the two FLC over the two genetically tuned PI and PID controllers.

This paper is outlined as follows:

Modeling of the Ultrasticke-25e is introduced in second section. The third section presents the control design of the two proposed FLC for the linear and nonlinear model. The fourth and the fifth sections show the simulation results and the comparative analysis of longitudinal and lateral channel for the linear and nonlinear models respectively. The simulation results and the comparative analysis of longitudinal and lateral channel considering the effect of disturbance and noise are configured as well. At last the sixth section summarizes the conclusion of the paper.

2. Ultrastick-25e mathematical representation

The equations of motion include the differential equations describing the aircraft dynamics [10, 11]. The equations of motion can be divided into two categories which are kinematic and dynamic equations. Kinematic equations describe the angular orientation and velocities of the body-axes platform regarded to the gravity vector. Dynamic equations consist of summation of acted forces and moments on the UAV using newton's law of motion. The equations (1) to (14) represent the Ultrastick-25e equations of motion. These are derived by taking into account the physical laws of motion. The transpose of the state vector X can be defined as follows:

$$X^T = [V_t\, \beta\ \ \alpha\, \phi\, \theta\, \psi\, p\, q\, r\, lat\ long\ h]$$

- Force equation

$$F_X = m\,(\dot{U} + q\,W - V\,r) \tag{1}$$
$$F_y = m\,(\dot{V} + P\,W - U\,r) \tag{2}$$
$$F_Z = m\,(\dot{W} + p\,V - U\,q) \tag{3}$$

- Moment equation

$$M = \frac{d(H)}{dt} + \omega \otimes H \tag{4}$$
$$H = I * \omega \tag{5}$$
$$M_X = I_{XX}\dot{p} - I_{Xz}(\dot{r} + p\,q) + \left(I_{zz} - I_{yy}\right) q\,r \tag{6}$$
$$M_y = I_{yy}\dot{q} - I_{Xz}(p^2 + r^2) + (I_{xx} - I_{zz})\,p\,r \tag{7}$$
$$M_z = I_{zz}\dot{r} - I_{Xz}\dot{p} + p\,q\left(I_{yy} - I_{xx}\right) + I_{Xz}q\,r \tag{8}$$

- Kinematic equation

$$\dot{\varphi} = p + tan\theta(q\ sin\varphi + r\ cos\varphi) \tag{9}$$
$$\dot{\theta} = q\ cos\varphi - r\ sin\varphi \tag{10}$$
$$\dot{\psi} = q\ sin\varphi \sec\theta + r\ cos\varphi \sec\theta \tag{11}$$

- Navigation equation

$$\dot{P}_n = U\ cos\theta\ cos\psi\ + V(-cos\varphi\ sin\psi + sin\varphi\ sin\theta cos\psi) + W\ (sin\varphi\ sin\psi + cos\varphi\ sin\theta cos\psi) \tag{12}$$
$$\dot{P}_e = U\ cos\theta\ sin\,\psi\ + V(cos\varphi\ cos\psi + sin\varphi\ sin\theta sin\psi) + W\ (-sin\varphi\ cos\psi + cos\varphi\ sin\theta sin\psi) \tag{13}$$
$$\dot{h} = U\ sin\theta - V(cos\varphi\ sin\psi + sin\varphi cos\theta) + W\ (cos\ \varphi\ cos\theta) \tag{14}$$

where: V_t A/C velocity vector, β side slip angle, α angle of attack, ϕ Roll angle, θ pitch angle, ψ heading angle, p roll rate, q pitch rate, r yaw rate, h altitude, m A/C mass. (U, V, W) velocities component, I Moment of Inertia, (F_X, F_y, F_z) force component, (M_X, M_y, M_z) moment component, $(\dot{P}_n, \dot{P}, \dot{h}\,)$ inertial position component, lat latitude, $long$ longitude.

The longitudinal dynamics branch mathematical model was figured out empirically by analyzing the Ultrasticke-25e nonlinear equation of motion. Linearization and validation of the Ultrasticke-25e model are conducted at definite flight situations [10, 11].

2.1. Longitudinal branch

From the derivation of the linearized model, the obtained transfer function of pitch angle is given in equation (15), and transfer function of pitch rate is given in equation (16). The two loops are shown in Figure 1.

$$G_1(z) = \frac{\theta}{\delta e} = \frac{-0.0539\,z}{z^2 - 1.573z + 0.5729} \tag{15}$$

$$G_2(Z) = \frac{q}{\delta e} = \frac{-2.655}{z - 0.5811} \tag{16}$$

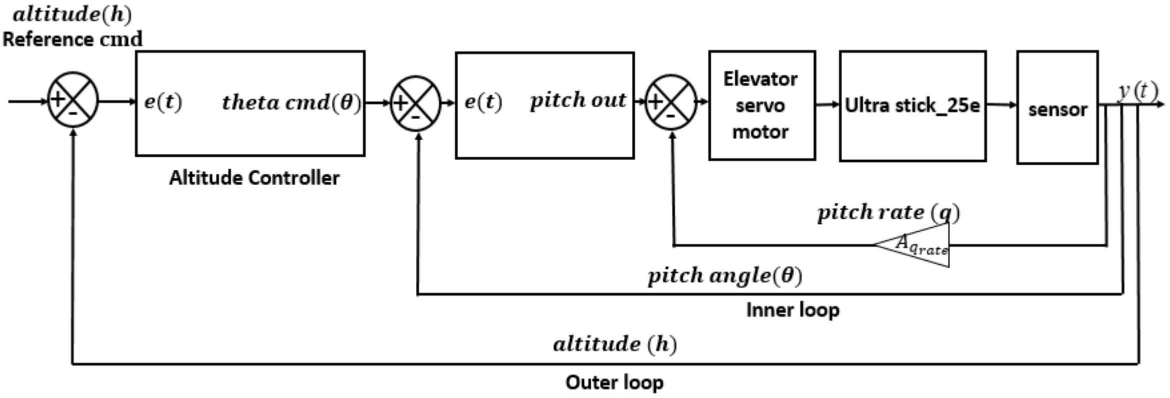


Figure 1. Longitudinal Autopilot

2.2. Lateral branch

From the derivation of the linearized model, the obtained transfer function of roll angle is given in equation (17), and transfer function of roll rate is given in equation (18). The two loops are shown in Figure 2.

$$G_1(z) = \frac{\varphi}{\delta a} = \frac{-0.04612\,z}{z^2 - 1.737\,z + 0.7366} \tag{17}$$

$$G_2(z) = \frac{p}{\delta a} = \frac{-2.297}{z - 0.7389} \tag{18}$$

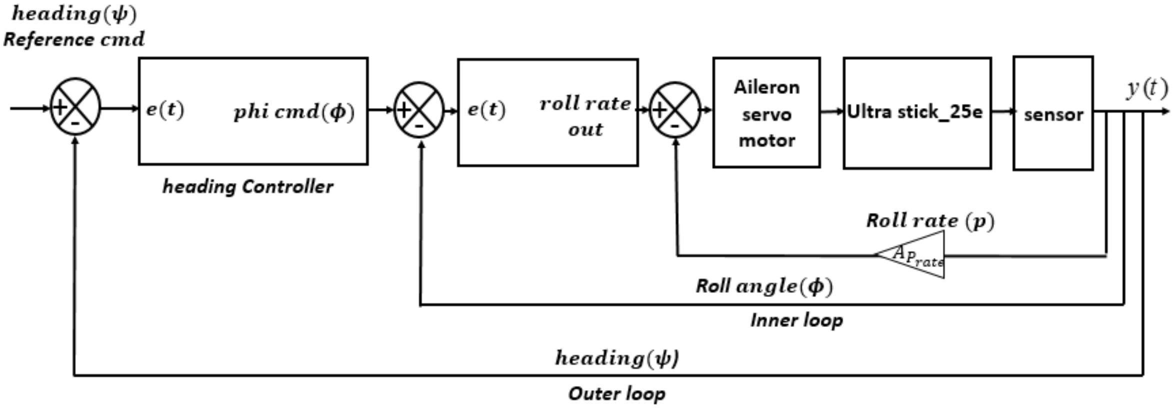


Figure 2. Lateral Autopilot

3. Flight control system design

Different controllers are designed to enhance the performance and robustness of the autopilot regarding to the PI controller designed by university of Minnesota.

3.1. Genetically tuned (PI and PID) controller

Conventional (PI and PID) controllers are utilized and their parameters are adjusted using genetic algorithm optimizer to minimize the objective function which is the mean squared error between the desired output and the actual output of the system [16 - 19].

3.2. FLC (fuzzy like PI and fuzzy like PD)

FLC (fuzzy like PI and fuzzy like PD) is utilized depending on seven triangular membership functions for every input and output. The if-then principle is established on expert realization. Equation (19) represents the conventional PD controller, where KP and KD are the proportional and the differential gain factors respectively. Also, e and Δe are the error and the change of error respectively [15], [21-24].

$$u(t) = K_P e(t) + K_D \Delta e(t) \tag{19}$$

The schematic block for the fuzzy like PD controller is presented in Figure 3.

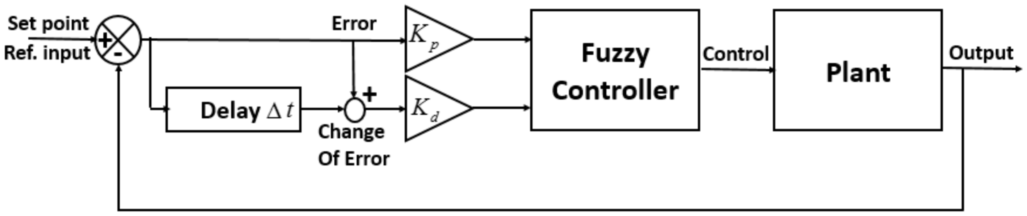


Figure 3. Fuzzy like PD controller

Equation (20) represents the conventional PI controller, where K_P, and K_I are the proportional and the integral gain factors respectively. Also, *e* and *∫e* are the error and the integration of error respectively [15], [21-24].

$$u(t) = K_P e(t) + K_I \int_0^t e(t)dt \tag{20}$$

The schematic block for the fuzzy like PI controller is presented in Figure. 4.

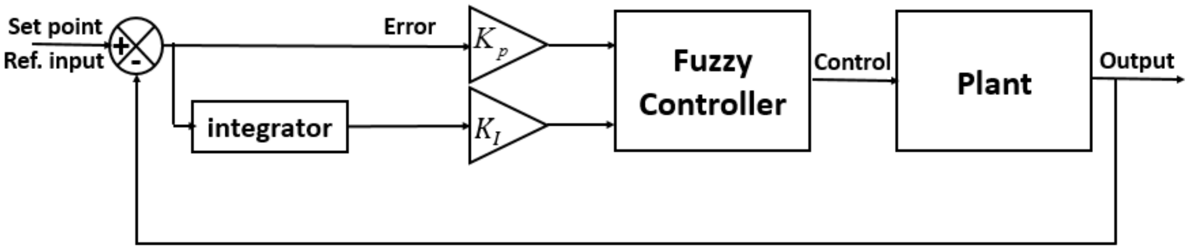


Figure 4. Fuzzy like PI controller

Figure 5 displays the Membership functions of inputs and outputs for fuzzy like PI and fuzzy like PD. The inputs and outputs range will always be from -3 to 3 (theoretically from 0 to 100%).

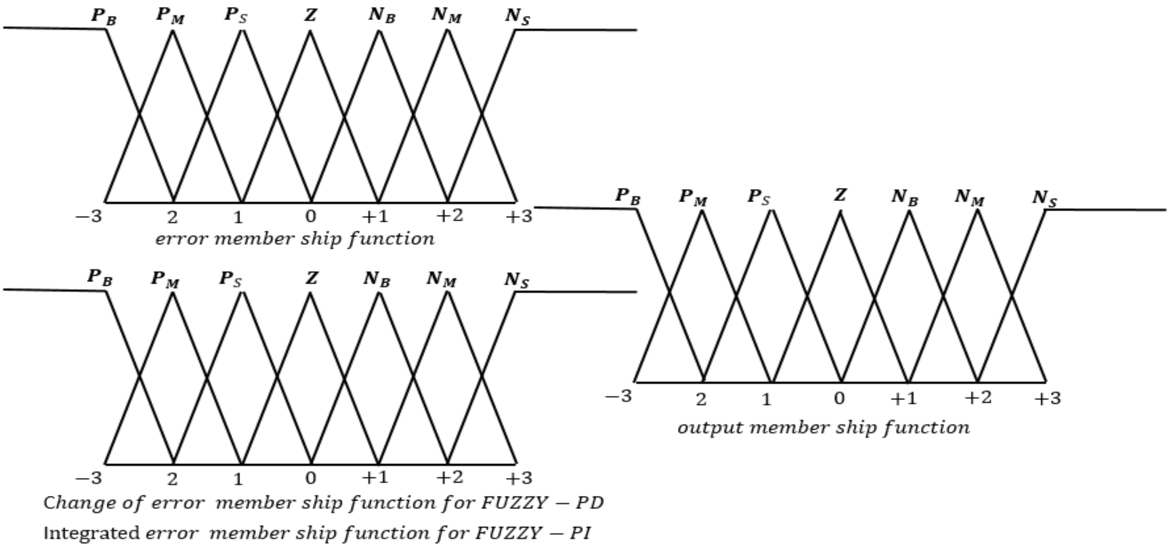


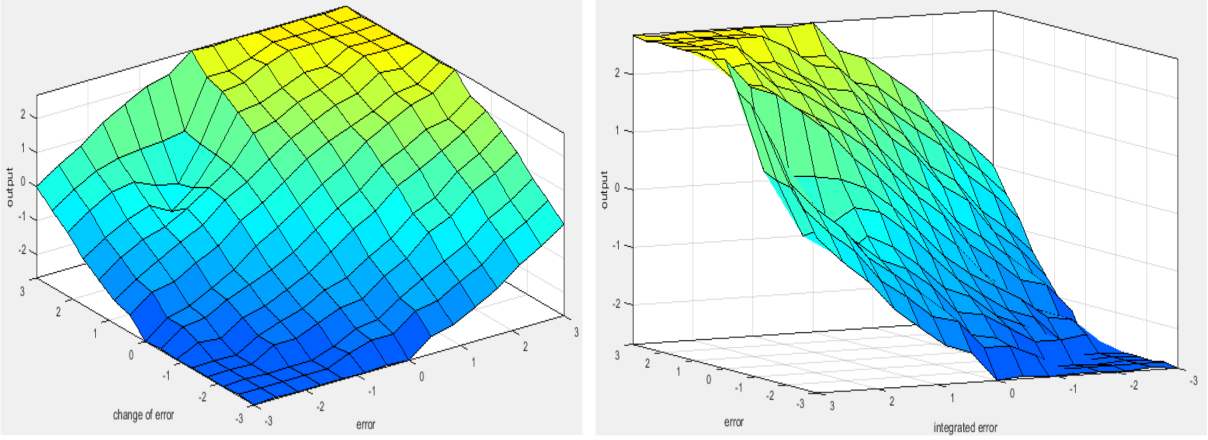
Figure 5. Membership functions.

Table 1. Rule table of the FLC like PD

Δe e	PB	PM	PS	Z	NS	NM	NB
PB	PB	PB	PB	PB	PM	PS	Z
PM	PB	PB	PB	PM	PS	Z	NS
PS	PB	PB	PM	PS	Z	NS	NM
Z	PB	PM	PS	Z	NS	NM	NB
NS	PM	PS	Z	NS	NM	NB	NB
NM	PS	Z	NS	NM	NB	NB	NB
NB	Z	NS	NM	NB	NB	NB	NB

Table 2. Rule table of the FLC like PI

∫e e	PB	PM	PS	Z	NS	NM	NB
PB	PB	PB	PB	PM	PM	PS	Z
PM	PB	PB	PB	PM	PS	Z	NS
PS	PB	PB	PM	PS	Z	NS	NM
Z	PB	PM	PM	PS	NS	NM	NB
NS	PM	PS	PS	NS	NM	NB	NB
NM	PS	Z	NS	NM	NM	NB	NB
NB	Z	NS	NM	NM	NB	NB	NB



a Rules of the error, error change, and output

b Rules of the error, integrated error, and output

Figure 6. Surface Rules for fuzzy like PI and Fuzzy like PD

The parameters of designed classical (PID, PI) controllers and FLC (fuzzy like PI, fuzzy like PD) for longitudinal channel are represented in Table 3. The Conventional PI designed by university of Minnesota is also represented in Table 3 to be compared with the different designed controllers.

Table 3. Controller parameters for longitudinal channel

controller	Conventional PI		Genetically tuned PID		Genetically tuned PI		Fuzzy like PI		Fuzzy like PD	
Theta θ	$A_{q_{rate}}$	-0.1	$A_{q_{rate}}$	-0.1	$A_{q_{rate}}$	-0.1	$A_{q_{rate}}$	-0.08	$A_{q_{rate}}$	-0.09
	Kp	-0.751	Kp	-0.901	Kp	-0.905	Kp	-0.84	Kp	-0.83
	Ki	-0.23	Ki	-0.31	Ki	-0.3020	Ki	-0.23	Kd	-0.24
			Kd	0.001						
Altitude h	Kp	0.023	Kp	0.0196	Kp	0.0191	Kp	0.01	Kp	0.02
	Ki	0.01	Ki	0.099	Ki	0.099	Ki	0.001	Kd	0.001
			Kd	0.01						

The parameters of designed classical (PID, PI) controllers and FLC (fuzzy like PI, fuzzy like PD) for lateral channel are represented in Table 4. The Conventional PI designed by university of Minnesota is also represented in Table 4 to be compared with the different designed controllers.

Table 4. Controller parameters for lateral channel

Controller	Conventional PI		Genetically tuned PID		Genetically tuned PI		Fuzzy like PI		Fuzzy like PD	
Phi φ	$A_{p_{rate}}$	-0.07	$A_{p_{rat}}$	-0.07	$A_{p_{rate}}$	-0.09	$A_{p_{rate}}$	-0.065	$A_{p_{rate}}$	-0.07
	Kp	-0.52	Kp	-0.52	Kp	-0.482	Kp	-0.5632	Kp	-0.52
	Ki	-0.20	Ki	-0.20	Ki	-0.187	Ki	-0.20	Kd	-0.197
	Kd	0.001	Kd	0.001						
heading ψ	Kp	1.2	Kp	1.6	Kp	0.95	Kp	0.8	Kp	0.079
	Ki	0.01	Ki	0.023	Ki	0.001	Ki	0.01	Kd	0.09

4. Simulation results and comparative study for linear model

The performance of the controlled system is analyzed for both longitudinal and lateral channels. The wind disturbance rejection and noise attenuation are considered as items for comparison beside the system performance.

4.1. Longitudinal channel

The designed classical (PID, PI) controllers and FLC (fuzzy like PI, fuzzy like PD) for longitudinal channel are compared with the conventional PI controller designed by university of Minnesota. The performance comparison of various control systems is set up by specifying particular test input signals and by comparing the various systems responses to these input signals for linear model. The commonly used test input signals are doublet response function for pitch angle, unit step function for altitude as illustrated in the Figure 7 and Figure 8 respectively.

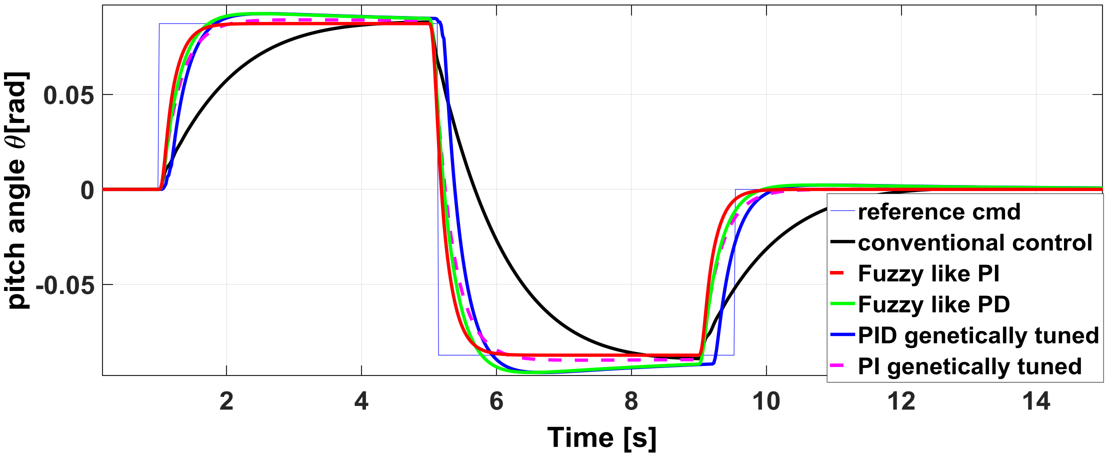


Figure 7. Degree doublet signal response for pitch tracker (linear model)

Figure 7 illustrates the performance of the designed PID, PI, fuzzy like PI, and fuzzy like PD controllers for linear model. The input doublet signal is shown in that figure. The reference Pitch angle changes from zero degree to +5 degree, then to -5 degree, and finally to zero degree. The system output response controlled by fuzzy like PI is the best response followed by system controlled using genetically tuned PI, fuzzy like PD, and genetically tuned PID. The worst response is the conventional PI controller designed by university of Minnesota. The rise time, the settling time, and the steady state error of fuzzy like PI controller are better than the corresponding ones of the four other controllers compared.

Figure 8 illustrates the output of each controller for altitude step input of 100 m. This Figure illustrates that, the fuzzy like PI and fuzzy like PD are better than classical PI, PID controllers, and conventional PI controller designed by University of Minnesota. They have the smallest overshoot, fastest settling time, and no steady state error.

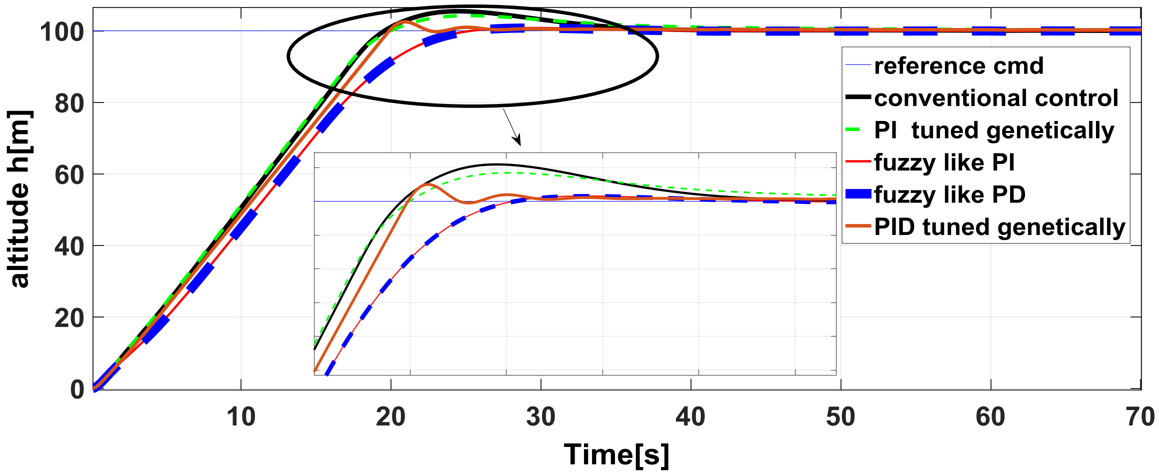


Figure 8. Level climbs scenario100m altitude from pitch (linear model)

The evaluation of the disturbance rejection is carried out in the step response when reaching steady state. Three controlled systems are compared. The fuzzy like PI is chosen as the first controller to be compared because its response is better than the fuzzy like PD. The genetically tuned PI is chosen as the second controller to be compared because its response is better than the genetically tuned PID. The third controller to be compared is the conventional PI controller designed by University of Minnesota. In Figure 9 the wind disturbance is applied after 20 seconds. The response of the system at this time is at steady state for each controller. From this figure, it is assessed that the wind disturbance rejection of the system that controlled by fuzzy like PI is better than the genetically tuned PI. The worst wind disturbance rejection is for the conventional PI designed by University of Minnesota.

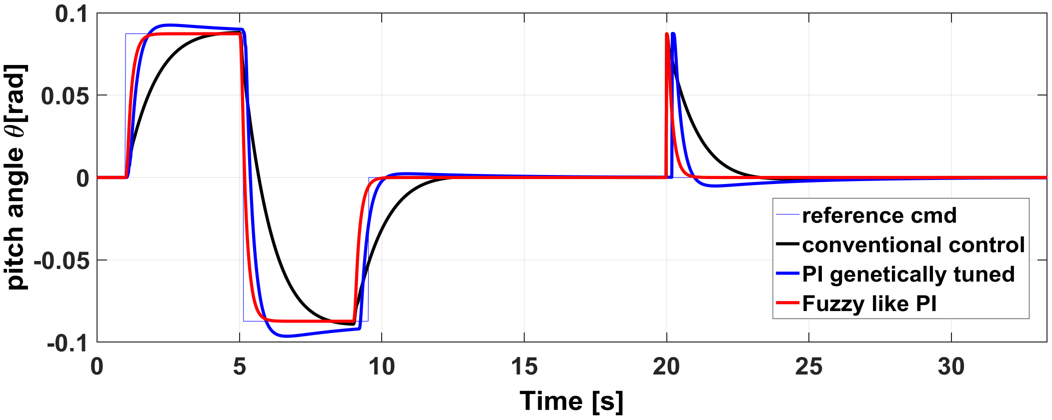


Figure 9. Wind disturbance rejection in pitch channel.

The sensors noise effect with $\frac{N}{S} = 10\%$ can be considered for the pitch tracker and altitude hold controller as seen from Figure 10 and Figure 11 respectively. Figure 10 shows that the best noise attenuation for pitch tracker is obtained using fuzzy like PI followed by the genetically tuned PI. Figure 11 illustrates the best attenuation of noise for altitude hold is obtained using fuzzy like PI followed by the genetically tuned PI.

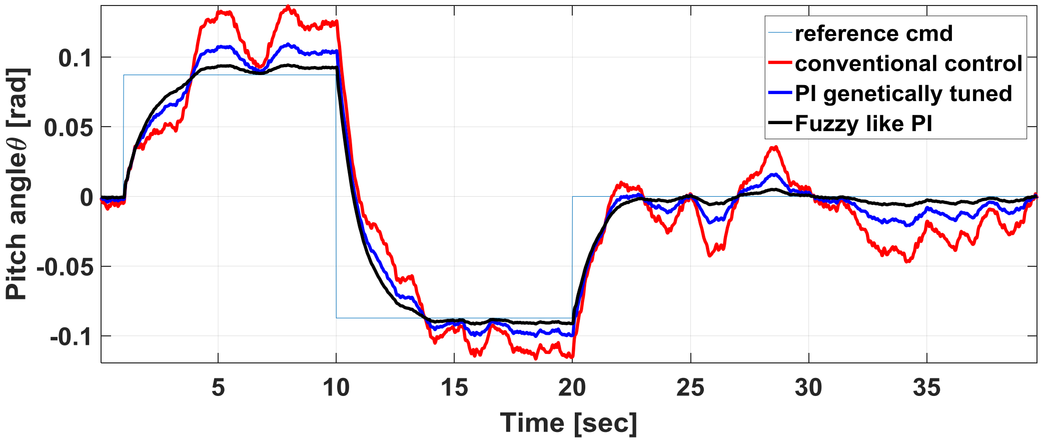


Figure 10. The noise effect in the doublet signal response

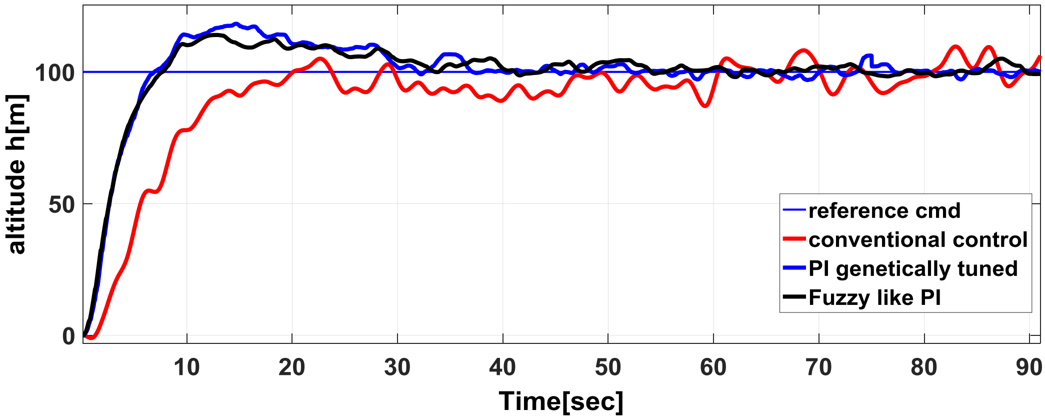


Figure 11. The noise effect in the altitude step response

4.2. Lateral channel comparative synthesis of PID and FLC in linear model

The designed classical (PID, PI) controllers and FLC (fuzzy like PI, fuzzy like PD) for lateral channel are compared with the conventional PI controller designed by university of Minnesota. The performance comparison of various control systems is set up by specifying particular test input signals and by comparing the various systems responses to these input signals for linear model. The commonly used test input signals are doublet response function for roll angle, multistep function for heading angle as presented in the Figure 12 and Figure 13 respectively. Figure 12 illustrates the performance of the designed PID, PI, fuzzy like PI, and fuzzy like PD controllers for linear model. The input doublet signal is shown in figure. The reference roll angle changes from zero degree to +5 degree, then to -5 degrees, and finally to zero degree. The output responses of the system controlled by fuzzy like PI and fuzzy like PD are better than genetically tuned PI, PID controllers. The worst response is the conventional PI controller designed by university of Minnesota. The rise time, the settling time, and the steady state error of fuzzy like PI controller are better than the corresponding ones of the four other controllers compared.

Figure 13 shows the output response of each controlled system for multistep heading angle. This Figure illustrates that, the fuzzy like PI is the best controller followed by fuzzy like PD, genetically tuned PI, PID, and conventional PI controller designed by University of Minnesota.

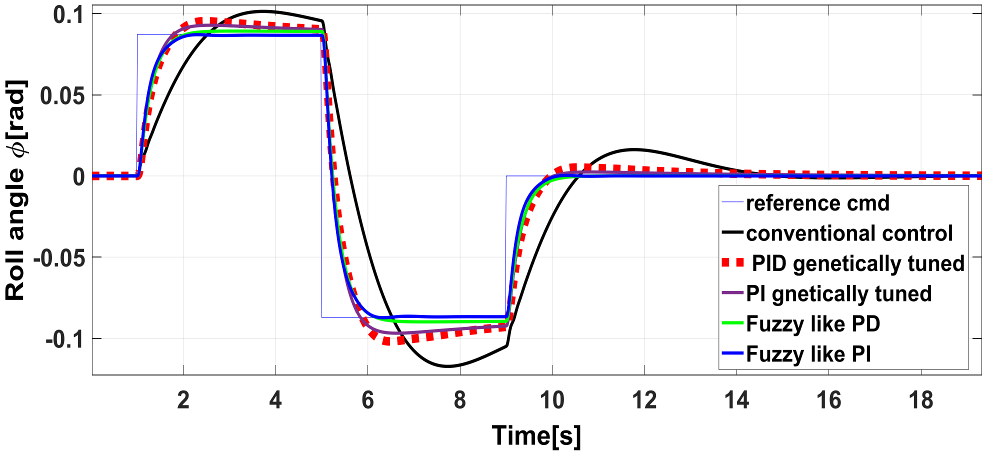


Figure 12. Doublet signal response for roll tracker (linear model)

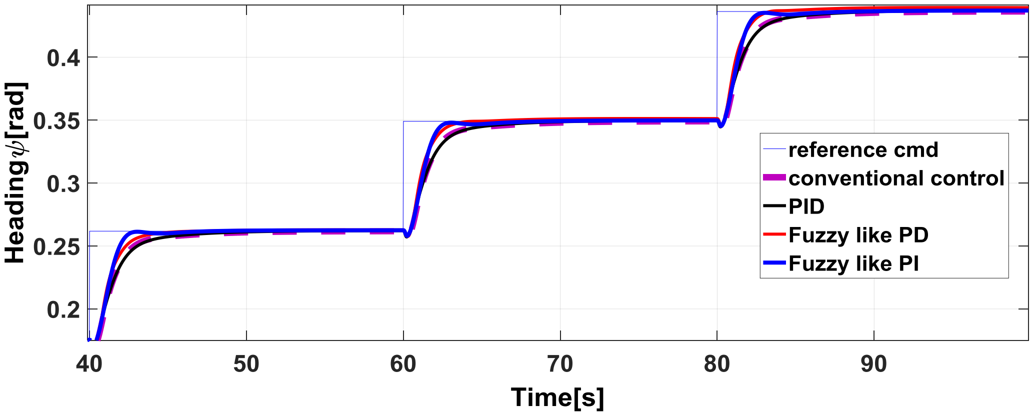


Figure 13. Multistep signal response for heading tracker (linear model)

The rejection of the wind disturbance is evaluated in the step response when reaching the steady state condition. Three controlled systems are compared. The fuzzy like PI is chosen as the first controller to be compared because its response is better than the fuzzy like PD. The genetically tuned PI is chosen as the second controller to be compared because its response is better than the genetically tuned PID. The third controller to be compared is the conventional PI controller designed by University of Minnesota. In Figure 14 the wind disturbance is applied after 20 seconds. The response of the system at this time is at steady state for each controller. From this figure, it is assessed that the wind disturbance rejection of the system controlled by fuzzy like PI is better than the genetically tuned PI. The worst wind disturbance rejection is for the conventional PI designed by University of Minnesota.

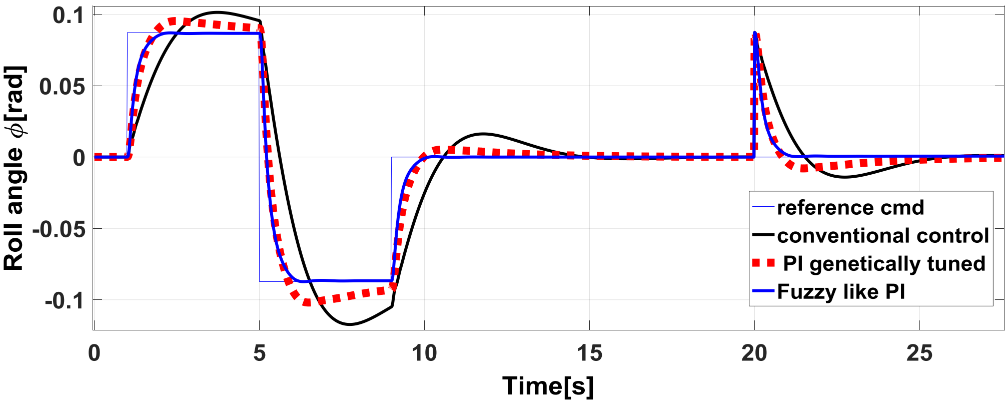


Figure 14. The ability of roll tracker to disturbance rejection

The sensors noise effect with $\frac{\mathrm{N}}{\mathrm{S}} = 10\%$ can be considered for the roll tracker and heading angle controller as seen from Figure 15 and Figure 16 respectively. Figure 15 shows that the better noise mitigation for roll tracker is obtained using fuzzy like PI followed by the genetically tuned PI. Figure 16 shows that the better noise mitigation for heading angle is obtained using fuzzy like PI followed by the genetically tuned PI.

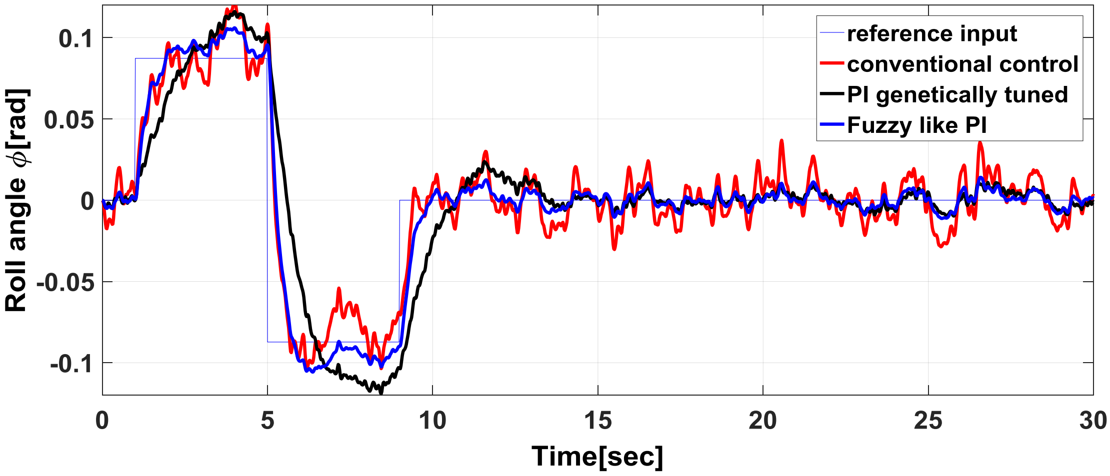


Figure 15. sensors noise effect in the doublet response for roll tracker

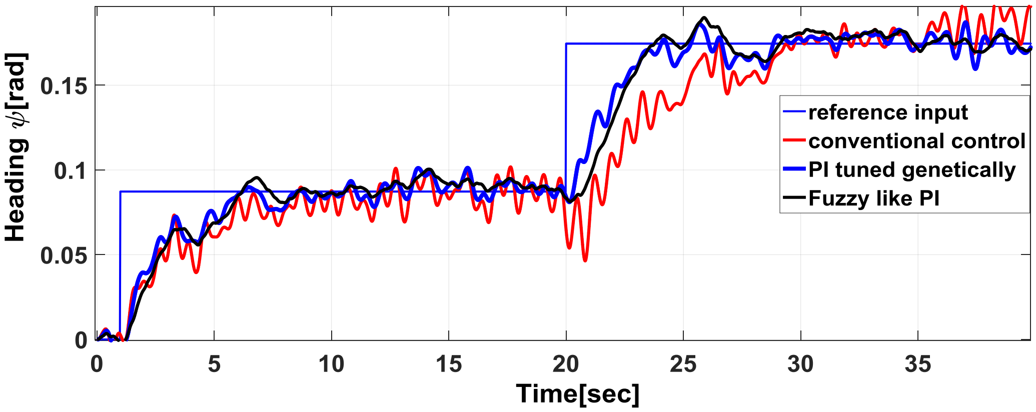


Figure 16. Sensors noise effect in the multistep response for heading angle

5. Simulation results and comparative study for nonlinear model

After obtaining acceptable control response for linear model, the designed controllers are applied for nonlinear model. A comparative study is held between the four designed controllers. This is can be considered as robustness evaluation to model uncertainties. This is because the controllers are designed for the linear model and tested for the nonlinear model.

5.1. Longitudinal channel

The designed genetically tuned (PID, PI) controllers and FLC (fuzzy like PI, fuzzy like PD) for longitudinal channel of the nonlinear model of the system are compared with the conventional PI controller designed by university of Minnesota. Fig. 17 illustrates the performance of the designed PID, PI, fuzzy like PI, and fuzzy like PD controllers for nonlinear model of pitch tracker. The input doublet signal is shown in figure. The output response of the system controlled by fuzzy like PI is the best response followed by system controlled using genetically tuned PI, fuzzy like PD, and genetically tuned PID. The worst response is the conventional PI controller designed by university of Minnesota. The rise time, settling time, and steady state error of fuzzy like PI controller are better than the corresponding ones of the four other controllers compared.

Fig. 18 illustrates the performance of the designed PID, PI, fuzzy like PI, and fuzzy like PD controllers for nonlinear model of velocity. The input unit step signal for velocity as shown in figure. The output response of the system controlled by fuzzy like PI is the best response followed by system controlled using genetically tuned PI.

Fig. 19 shows the output response of each controlled system for altitude step input of 100 m. This Figure illustrates that, the fuzzy like PI and fuzzy like PD are better than classical PI, PID controllers, and conventional PI controller designed by University of Minnesota. They have the smallest overshoot, fastest settling time, and no steady state error.

The output time response parameters for pitch angle and altitude for each controller are summarized in Table 5 and Table 6 respectively.

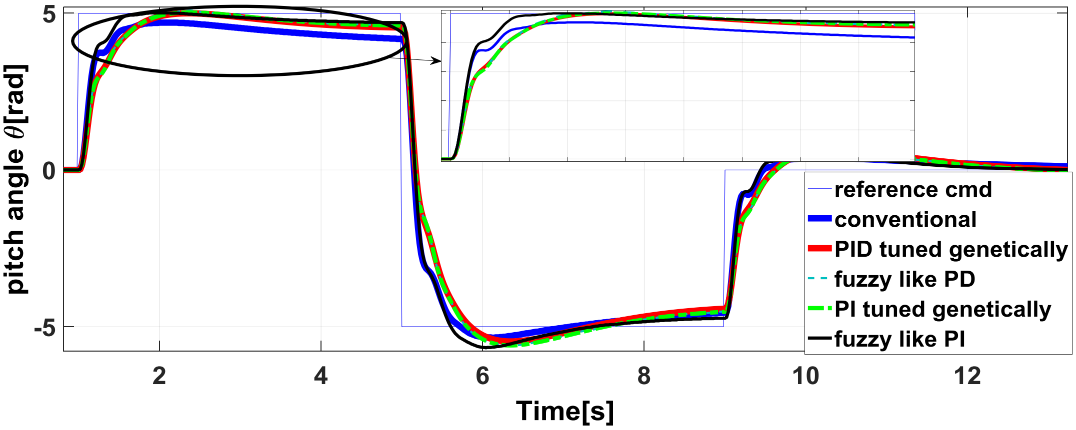


Figure 17. Doublet signal response for pitch tracker (nonlinear model)

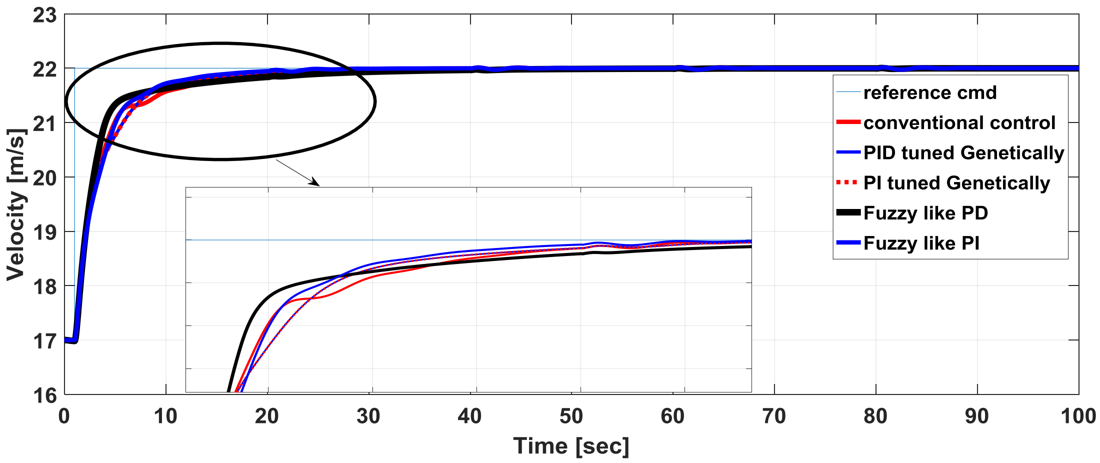


Figure 18. Step response for aircraft velocity (nonlinear model)

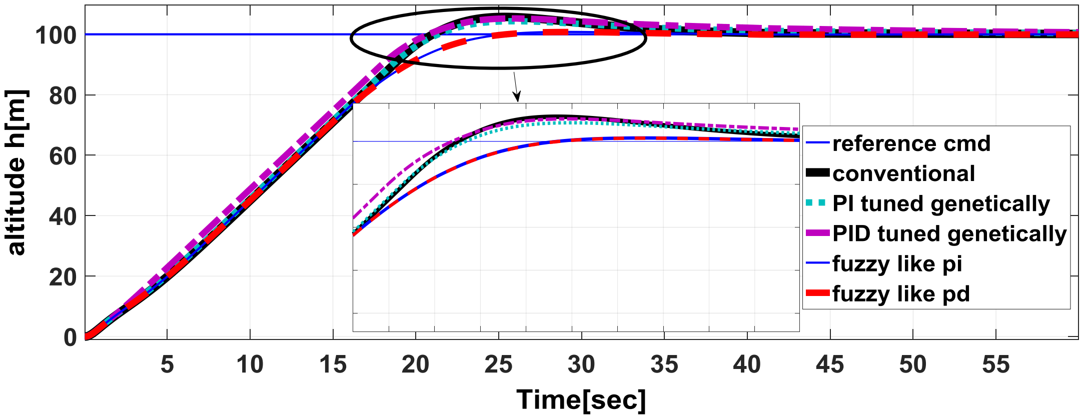


Figure 19. Level climbing scenario100 m altitude from pitch (nonlinear model)

Table 5. Time analysis of longitudinal channel controllers (inner loop-pitch tracker)

	Conventional control	Fuzzy like PD control	Fuzzy like PI control	PID Control	PI control
Rise time(sec)	0.683	0.42	0.37	0.614	0.668
Settling time(sec)	15.3	14.9	14.9	13.9	14.5
Max O.S %	0	0	0	0	0
Undershoot %	0	0	0	0	0
Peak	0.0854	0.0865	0.0869	0.0860	0.0855
Peak time(sec)	1.31	0.0920	0.0905	1.26	1.35

Table 6. Time analysis of longitudinal channel controllers (outer loop-altitude)

The property	Conventional control	Fuzzy like PD control	Fuzzy like PI control	PID Control	PI control
Rise time(sec)	15.95	16.81	16.81	15.64	16
Settling time(sec)	31	22.9	22.9	29.95	30.3
Max O.S %	5.7	0.82	0.82	5.1	4.4
Undershoot %	0	0	0		0
Peak	104.9	0.82	0.82	104.1	104.5
Peak time(sec)	27	29.25	29.25	26	26

A flight path Climbing Turn Scenario is illustrated in Fig.20. The altitude command is from 100 meter to reach 200m, the simulation time is 100 s. The scenario for level climbing and then straight and leveling flight evaluate the performance of the longitudinal motion controller. The flight paths for fuzzy like PI and genetically tuned PI controllers are shown in Fig. 20. It is clear that, the fuzzy like PI has the best performance. The climb and level from (0:23) sec ascending and then straight and level after above 23 sec at Altitude command 200 m.

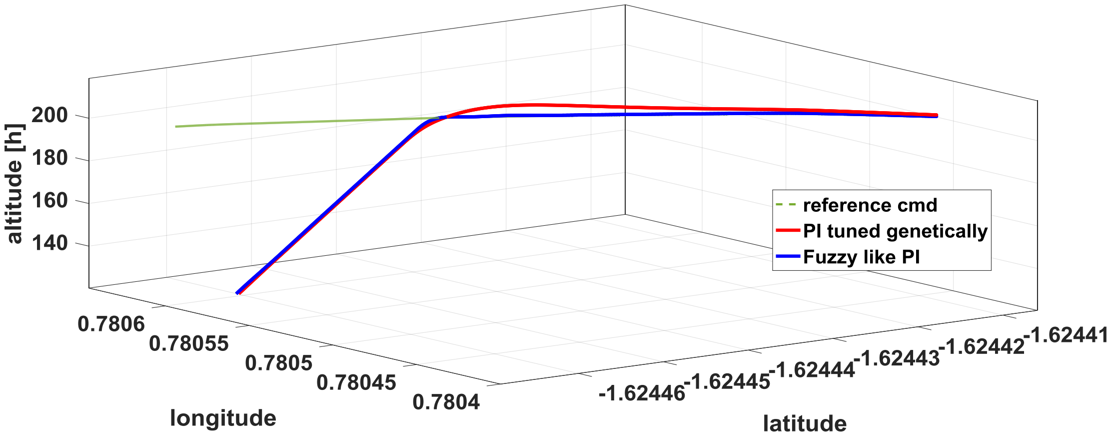


Figure 20. Climbing and level trajectory of the aircraft

5.2. Lateral channel

The designed genetically tuned (PID, PI) controllers and FLC (fuzzy like PI, fuzzy like PD) for lateral channel of the nonlinear model of the system are compared with the conventional PI controller designed by university of Minnesota. Figure 21 illustrates the performance of the designed PID, PI, fuzzy like PI, and fuzzy like PD controllers for nonlinear model of roll tracker. The input doublet signal is presented in the figure. The output response of the system controlled by fuzzy like PD is the best response followed by the system controlled using fuzzy like PI, system controlled using genetically tuned PI, and genetically tuned PID. The rise time, settling time, and steady state error of fuzzy like PD controller are better than the corresponding ones of the four other controllers compared. Figure 22 shows the output response of each controlled system for heading angle multistep input. This Figure illustrates that, the fuzzy like PD and fuzzy like PI are better than classical PI, PID controllers, and conventional PI controller designed by University of Minnesota. The output time response parameters for roll angle and heading for each controller are summarized in Table 7 and 8 respectively.

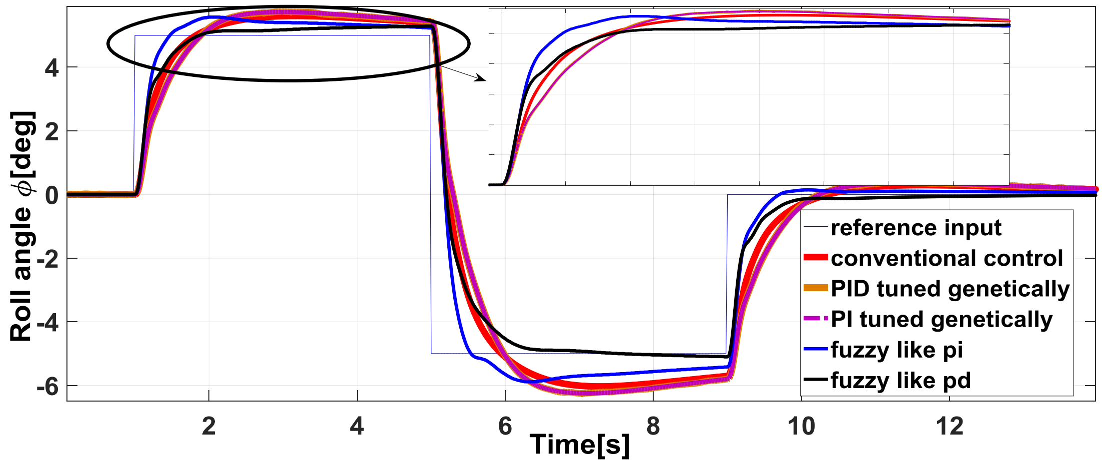


Figure 21. Doublet signal response for roll tracker (nonlinear model)

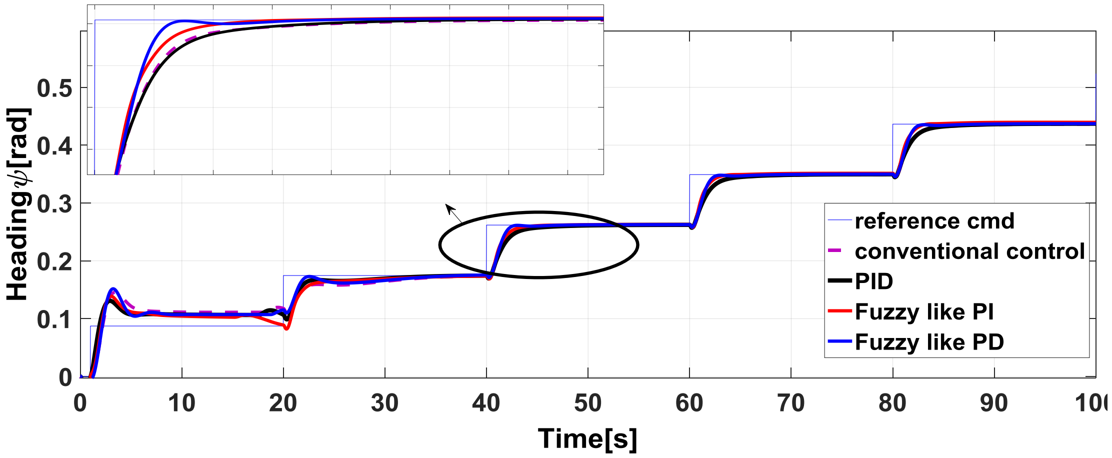


Figure 22. Multistep signal response for heading tracker (nonlinear model)

A flight path climbing turn scenario is illustrated in Figure 23 this scenario evaluates all autopilot performance for lateral and longitudinal branches in case of the climbing turn plan. The altitude level is about 100 m and the heading simulated results are presented in Figure 23 and Figure 24. The simulation time is 100 s, the turn consists of 4 procedures heading direction from 0 to 90 and altitude command 100 m ascending. This flight path is simulated for fuzzy like PI because it is the best controller for both lateral and longitudinal channels.

(a) Table 7. Time analysis of lateral channel controllers (inner loop-roll tracker)

The property	Conventional control	Fuzzy like PD control	Fuzzy like PI control	PID Control	PI control
Rise time(sec)	0.63	0.35	0.3	0.59	0.62
Settling time(sec)	7.425	5.9	5.7	7.13	7.44
Max O.S %	15.15	10.5	10.9	13.25	15.80
Undershoot %	0	0	0	0	0
Peak	0.0987	0.0915	0.0967	1.05	1.11
Peak time(sec)	2.132	1.15	1.06	1.8	1.9

Table 8. Time analysis of lateral channel controllers (outer loop-heading)

The property	Conventional control	Fuzzy like PD control	Fuzzy like PI control	PID Control	PI control
Rise time(sec)	0.7	0.58	0.54	0.62	0.66
Settling time(sec)	34.5	25.4	23.08	33.9	34.2
Max O.S %	65.4	54.5	53.3	61.53	64.79
Undershoot %	14	9.1	9.4	11.3	12.4
Peak	0.1444	0.1380	0.1338	0.1430	0.1466
Peak time(sec)	2.7	2.86	2.84	2.95	3.1

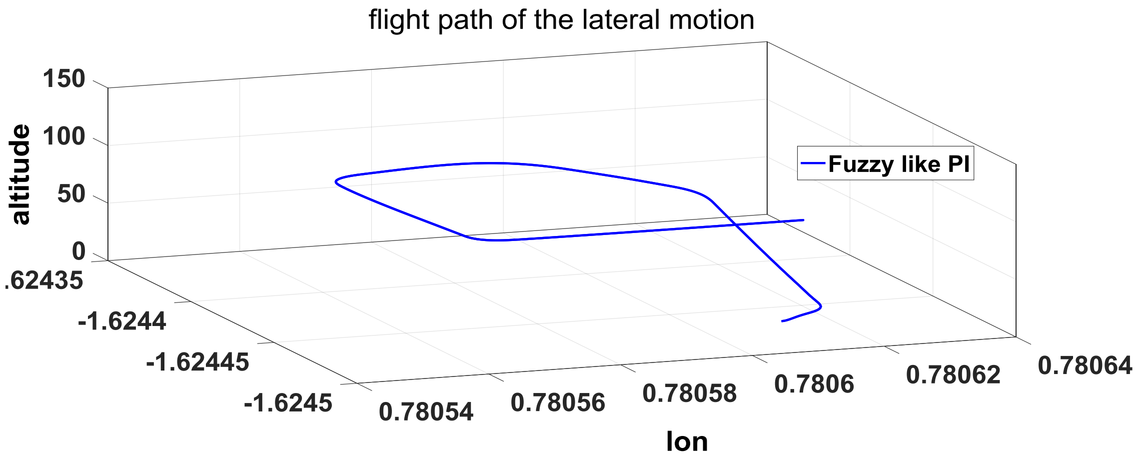


Figure23. Elevation view of flight path lateral motion

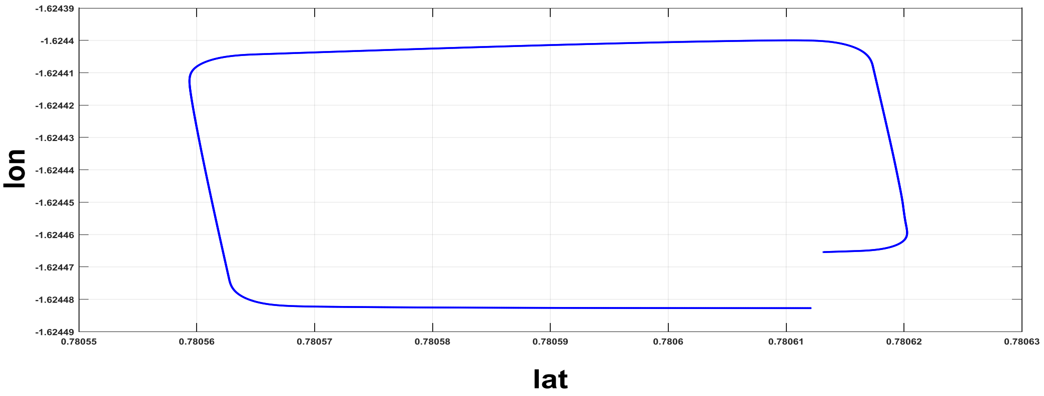


Figure 24. Plane view of flight path lateral motion

6. Conclusion

Four controllers were implemented for Ultrastick-25e model in both longitudinal and lateral branches in this paper. Two classical controllers which are genetically tuned PI, PID and two fuzzy logic controllers which are fuzzy like PI and fuzzy like PD. These controllers are compared with the conventional PI designed by university of Minnesota. The comparison is based on the system performance, robustness to model uncertainties, wind disturbance rejection, and measured noise attenuation. To evaluate the robustness to model uncertainties, the controllers are designed for the linear model and then applied for the nonlinear model. The comparative simulation results and flight path scenarios confirm the effectiveness of fuzzy like PI and fuzzy like PD over the genetically tuned PI and PID controllers for both lateral and longitudinal channels of linear and nonlinear models. Fuzzy like PI has the best output performance for both lateral and longitudinal channels of linear and nonlinear models. It also has the best wind disturbance rejection and measurement noise attenuation. Finally, it shows the best robustness to model uncertainties when dealing with the nonlinear model.

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