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Designing Fuzzy PID Controller for Quadrotor

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Abstract

In this study we discuss quadrotor control based on linear models obtained in the laboratory of Ferdowsi University of Mashhad. First of all motion simulation of quadrotor is designed in simulink environment of MATLAB software. Then the linearization is done through Lagrange method and semi-automatic control of quadrotor. Since quadrotor is a low actuator system, controlling quadrotor is a multivariable control issue. So first the control strategy is discussed and the controller structure is designed. Then by using the idea of sequential closed loop multivariable control, quadrotor control will be studied. Quadrotor is controlled by using two types of controller: in one method by using 4 PID controllers and in the other by using the combined fuzzy PID controller, finally it is shown that the hybrid control is more resistant based on fuzzy control and is reliable in the presence of turbulences which always exist in real environments.

Key words

PID Control, Fuzzy Control, Quadrotor.

I. Introduction

Nowadays the design of control systems is an essential need. A new controlling technique for modeling of procedures is one of the major research areas of the era. Since the last decade there has been a considerable interest arisen from industry, government and academia to design unmanned vehicles capable of vertical flight [1] In this research, a quadrotor system is used. Quadrotor is an unmanned flying machine having four engines, which its thrust force is produced through power transmission of engine into the propellers. Control and stability of this flying vehicle is possible with the engine RPM. High maneuverability, short time needed for learning piloting which takes a few days, simplicity of construction, low maintenance costs and low noise are the advantages of this unique flying machine compared to the other similar unmanned flying machines. Since the advent of quadrotor its control also was also put into the consideration of researchers around the world, we can point out some of the most significant works:

In 2004 Huffman used LQR optimal control to stabilize angles, which gave good results at lower speeds, but because of large vibrations of motor controller this method provided a poor performance at higher speeds.

Castelo used the results of LQR simulation to reach a desirable control. He eventually by getting feedback from y, Φ could greatly reduce the fluctuation of output and control the flying machine with little fluctuations in hovering condition and also created a good trace route. The type and amount of turbulence and uncertainty taken into account in this study, is not reported by the writer, and this research is the first automatic control design of quadrotor.

In the years 2005 to 2006 because the use of LQR control method for controlling quadrotor, did not meet the desired control, researchers of Italian Heudiasyc laboratory sought to test the nested saturation control method on quadrotor. This method was developed in such a way that could maintain a series of integrations with bounded inputs. In the papers related to this field, this control method became more complete and was employed on a micro-controller. Experimental results show that this control system is low cost and has a desirable performance [14-11].

In the years 2004 to 2007, laboratory researchers in the (EPFL Boo Abdollah, et.) used the PID controller to control quadrotor, and compared the results with the LQR controller. The results showed that PID controller is appropriate for hovering state and if there is strong turbulence, it shows poor performance. Because of the lack of variation in output, PID in hovering condition presents a better and more effective performance than LQR. In these studies, PID controller is designed on a linear model and merely on the angle control in a floating state. [18-11]

In 2010, Jack Shepherd and his colleagues used neural control algorithm to maintain the angles and height control. In this study, the results of a PID which performed well in the absence of turbulence was used for training the network [19]

II. Quadrotor

As mentioned before, quadrotor is an unmanned flying machine that has four engines and its thrust is produced through power transfer of engines into the propellers. Control and stability of this flying machine is possible by changing the engine RPM. High maneuverability, short time needed for learning piloting which takes a few days, simplicity of construction, low maintenance costs and low noise are the advantages of this unique flying machine compared to the other similar unmanned flying machines. The only downside of this flying machine is the low flying endurance, because it consumes high electrical power due to the use of four engines. Interesting and unique characteristics of this unmanned flying machine, has made it as one of our dear country's recent research projects.

In the past few decades due to the wide application context provided for quadrotor, researchers have shown great interest in controlling this flying machine. In this section we will discuss the degree of freedom and how flying machines navigate.

Degrees of Freedom and Navigation of the Flying Machines

Quadrotor is a flying object which can move with 6 degrees of freedom: three straight-line motions and three rotational motions. The propellers 3 and 1 rotate counterclockwise and the propeller 2 and 4 rotate clockwise (Fig.1).

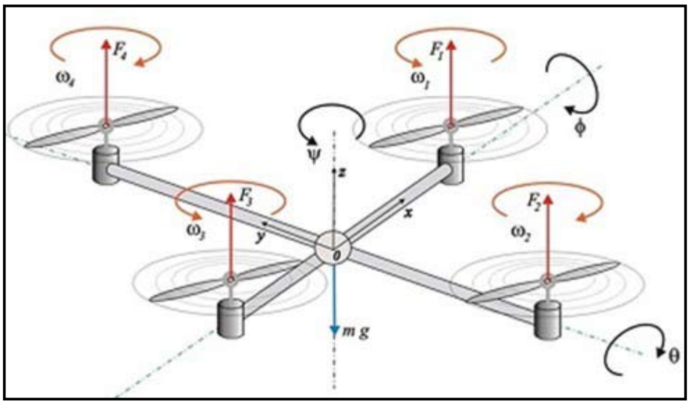

Fig. 1: A plot of the forces on quadrotor

By changing the RPM, the size of the lift force will change which results in the movement of the flying machine. We must simultaneously increase or decrease the RPM of the engines in order to increase or decrease the height. If the flying machine has rotated around one of its axes and the total lift force of the vertical component is equal to the weight, the flying machine will move along the horizontal component and in a straight line (Fig. 2).

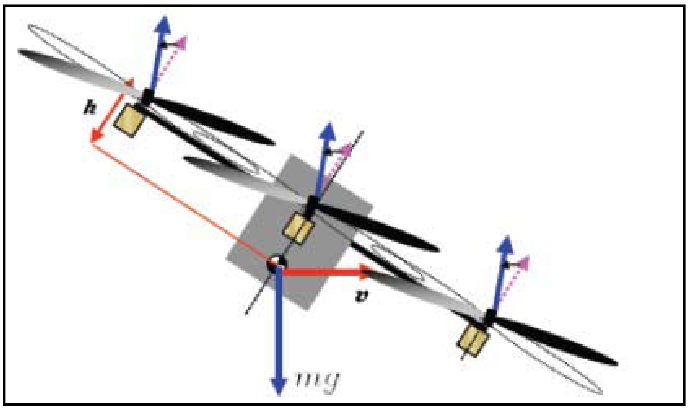

Fig. 2: The position of quadrotor in direct movement mode

The flying machine will rotate around the z axis in positive direction by balancing the facing RPMs and by increasing the torque series obtained from the motors 1 and 3. And in case the torqueses of the facing motors were not balanced against each other (1 and 3 or 2 and 4) the flying machine would rotate around its vertical axis (x, y).

III. PID controller

Proportional, integral and derivative Controller (PID), are the most common controllers in the control of industrial processes which despite the mathematical development of control theory in the last 50 years have still retained their position. The main reason is that they have a simple structure and are easily understandable for engineers and under practical conditions and compared to the more developed and sophisticated controllers; they have a more reliable performance. [15-17]

As it was mentioned, PID controller is composed of three parts, proportional, integral and derivative. A schematic of this controller is shown in Figure 3.

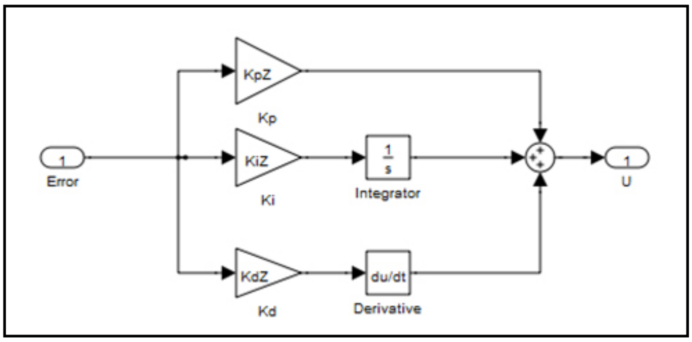

Fig. 3: Schematic of a PID controller

Proportional controller (P): The P proportional part of the PID controller has the task of reducing the rising time. If only a proportional controller is used to control the system, permanent fault occurs in the system.

Proportional-integral controller (PI): By adding the L Integrator section to the controller P, Permanent fault of the system is deleted. It could also lead to the creation of fluctuations in the system, these fluctuations may be mortal or immortal. So to correct the controller, derivative part is added to it.

Proportional-integral-derivative controller (PID): Addition of the derivative section enables the controller to predict a kind of system behavior, and before the error rate is increased highly, it corrects the control input.

Designing the PID Controller is in fact the correct adjustment of the three proportional, integral, and derivative coefficients. So far, several algorithms have been proposed to adjust the three factors, such as Ziegler-Nichols algorithm and lambda's targeted trial and error (which is usually the method used in the industry). In this study the trial and error is used to adjust the parameters. The algorithm of this method is as follows:

1. Gain the step response of the system.
2. For reducing the rising time (tr) add the Kp coefficient to the system.
3. If necessary, add the Kd to the system to reduce the maximum overshoot (Mp).
4. In case the permanent fault is remained (ess), add the Integrator to the system
5. Adjust the values until achieving the desired responses by using the previous sections.

In table 1 it's attempted to briefly investigate the effect of each of the proportional, integral, and derivative sections on the system response. This table can be very useful when adjusting the PID coefficient.

Table 1: more information about the coefficients of the PID

Coefficient	Role	Large initialization	Small initialization
Proportional (Kp)	Acceleration, stability	Stability reduction	permanent fault, slower response
Integrator (Ki)	Reduction of permanent fault	Stability reduction, Prolongation of the oscillatory response	Slower return to permanent response

Derivative (Kd)	Increase of the stability, Reduction in oscillation range	Increase of the stability, Turbulence amplification	Failure to gaining advantages

IV. Implementation of PID controller on the system

In order to evaluate the efficacy and accuracy of stated control rules, it is used to control the stability of quadrotor in hovering flight conditions. The quadrotor is considered at a height of 1 meter to the ground and is abandoned in the initial conditions of φ = θ = 0.5 rad. It's expected that at an optimum time quadrotor can reach to an equilibrium state φ = θ = Ψ = 0 rad, after applying the controller the system is as follows:

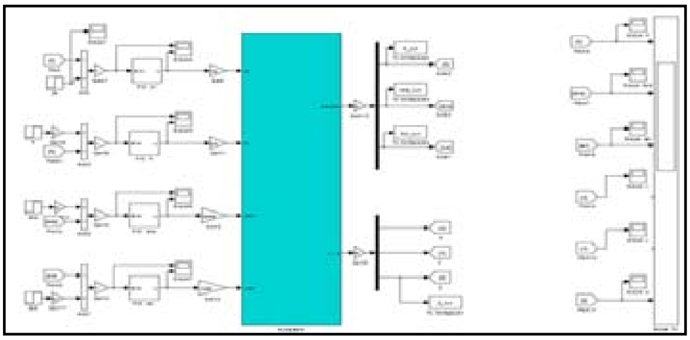

Fig.4: System with PID controller

Obtained results for the height Z is shown in Figure 5, for fi angle in Figure 6, for Theta angle in Figure 7 and for Ψ angle in Figure 8.

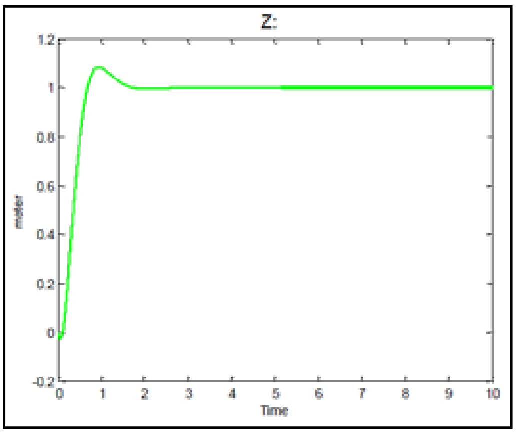

Fig. 5: Height changes for initial conditions of one meter height φ = θ = 0.5 rad

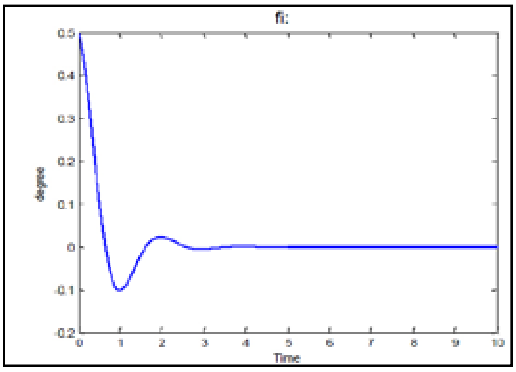

Fig. 6: Angle changes for initial conditions of one meter height φ = θ = 0.5 rad

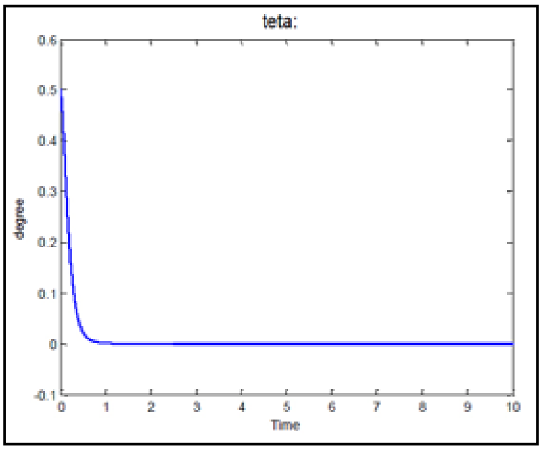

Fig. 7: Theta angle changes for initial conditions of one meter height φ = θ = 0.5 rad

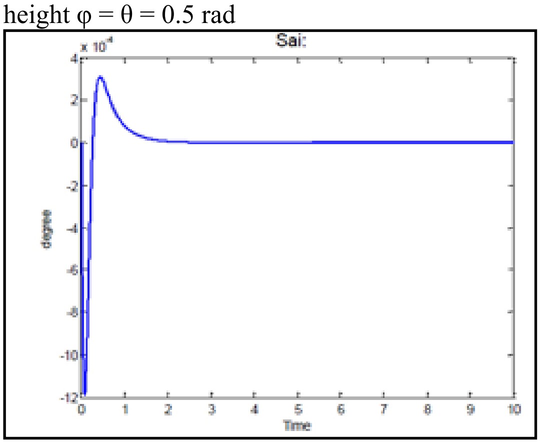

Fig. 8: Ψ angle changes for initial conditions of one meter height φ = θ = 0.5 rad

Now we address the performance of the controllers in the presence of turbulence. For this purpose, a cumulative turbulence is added to the roll angle feedback. The physical meaning of this type of turbulence is the noise of the sensor. The entered turbulence of a signal is defined as the random numbers in the range of -2 to 2 which simulates the range of 2 to -2 degrees of sensor error.

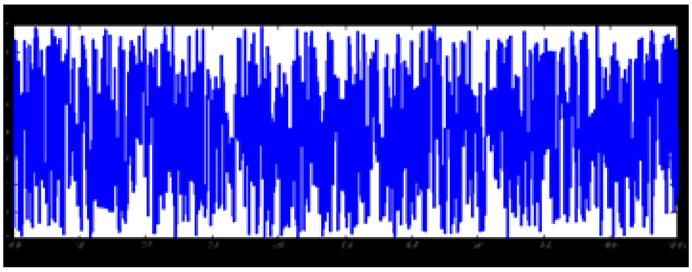

Fig.9: The defined signal of turbulence in random in the range of 2 to -2

Response time of the system after applying the turbulence to the system to the desired input $\varphi = 5^0$ to the system is shown in Fig. 10.

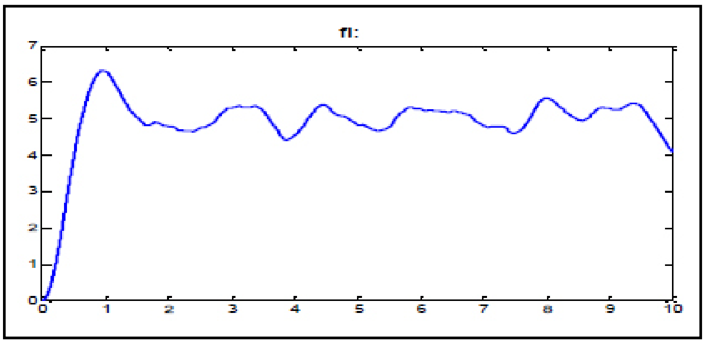

Fig.10: The response time of the system after applying the turbulence

VI. Modeling fuzzy controller

In classical logic, an element either belongs to a category or not. In other words the degree of membership of each element in a given category is either zero or one, but in the fuzzy logic the degree of membership of each element is a number between zero and one. It should be noted that this type of control is used in cases where mathematical models of system are not available or are highly nonlinear. [20-54]

The fuzzy controller used in this study was Sugeno fuzzy controller.

The structure of the fuzzy controller is composed of two inputs (including error and derivative error), and three outputs (including proportional gain, integral gain and derivative gain) which are shown in figure 11 and figure 12. And for each input variable an error, and a derivative error, from 7 triangular membership function for the outputs of the proportional gain, integral gain of two member functions, the constant type and for the derivative gain of three membership functions of constant type is considered. Max – Min method is used for fuzzy making. Three-dimensional shapes of chosen fuzzy rules for the PID controller design are shown in figures (7, 8, 9).

Fuzzy PID controller is made of "if .... Then ...." fuzzy rules and these selected rules for the quadrotor control process are as tables (2 and 3)

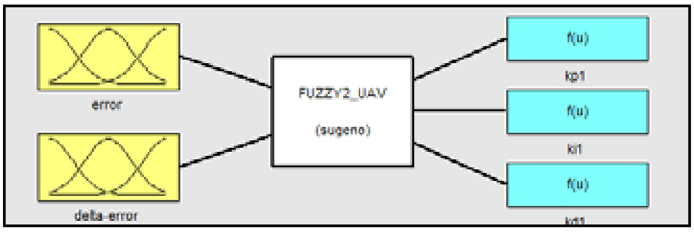

Fig. 11: Graphical structure of fuzzy controller

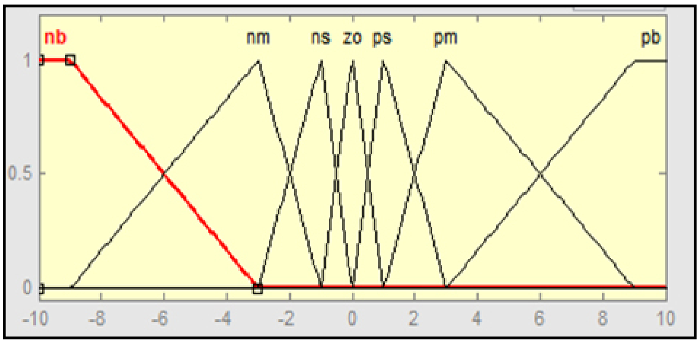

Fig.12: The triangular membership functions designed for input

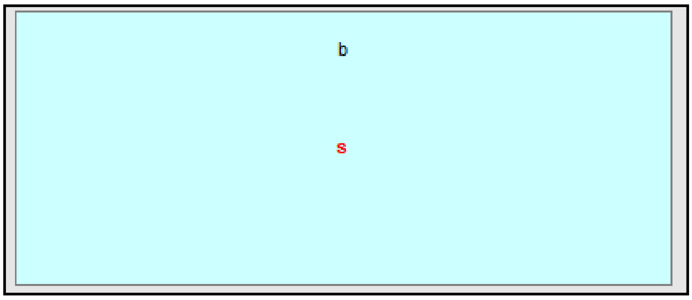

Fig. 13: Membership functions are designed for proportional gain, integral gain, in which:
b = 0.9, s = 0.1

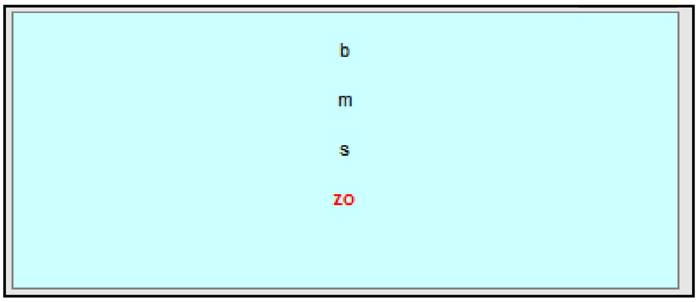

Fig. 14: Membership functions designed for derivative gain in which
b = 1, m = 0.7, s = 0.3, zo = 0

Table 2: Fuzzy rules for fuzzy PID controllers for KI, KP

		$\Delta e(k)$						
		NB	NM	NS	ZO	PS	PM	PB
$e(k)$	NB	S	S	S	S	S	S	S
	NM	B	B	S	S	S	B	B
	NS	B	B	B	S	B	B	B
	ZO	B	B	B	B	B	B	B
	PS	B	B	B	S	B	B	B
	PM	B	B	S	S	S	B	B
	PB	S	S	S	S	S	S	S

Table 3: Fuzzy Rules for Fuzzy PID Controller for KD

		$\Delta e(k)$						
		NB	NM	NS	ZO	PS	PM	PB
$e(k)$	NB	B	B	B	B	B	B	B
	NM	S	B	B	B	B	B	S
	NS	S	S	B	B	B	S	S
	ZO	S	S	S	B	S	S	S
	PS	S	S	B	B	B	S	S
	PM	S	B	B	B	B	B	S
	PB	B	B	B	B	B	B	B

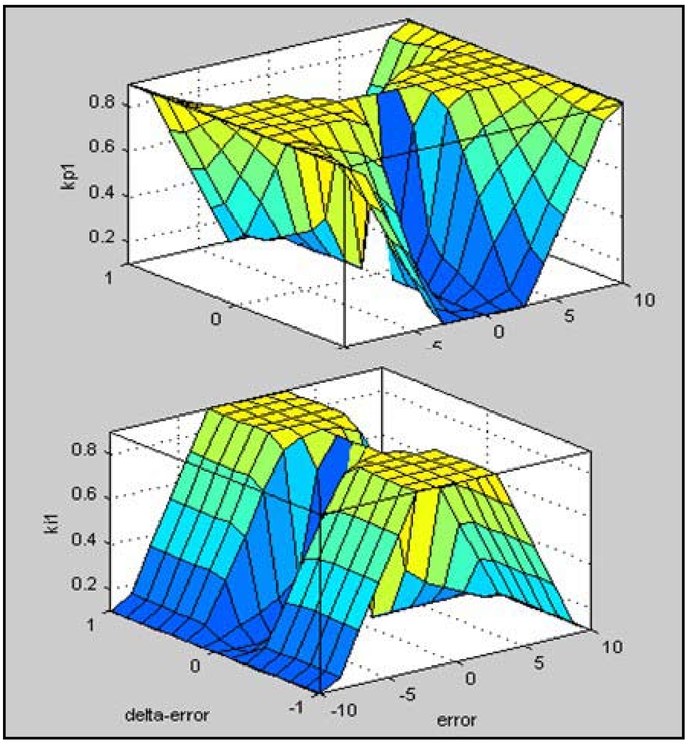

Fig.15: The error and derivative error for the output KI

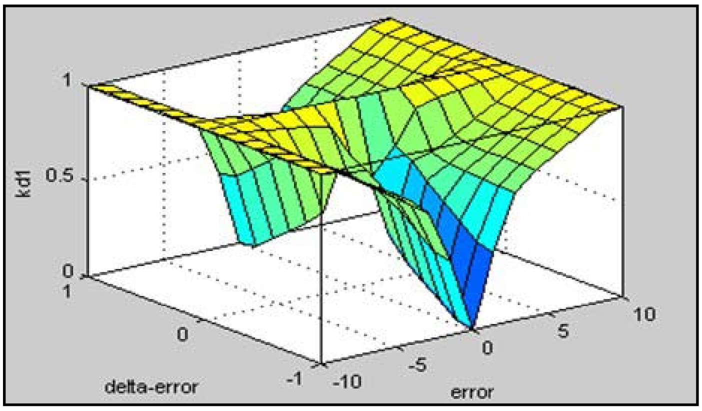

Fig.16: The error and derivative error for the output KD

VI. Applying Fuzzy PID Control on System

After applying fuzzy PID controller the system is as follows in which the left subsystems are applied fuzzy controllers model.

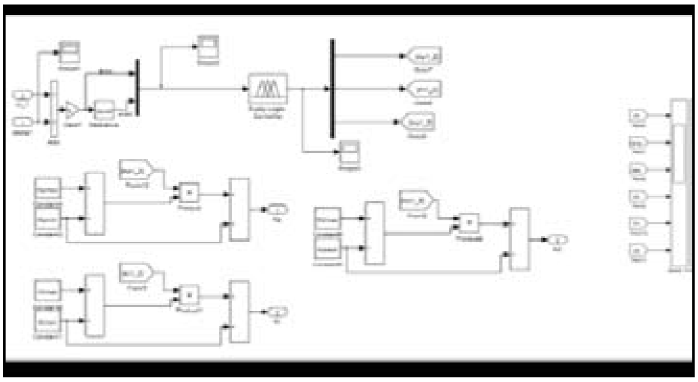

Fig. 17: Block controller used for one of the angles

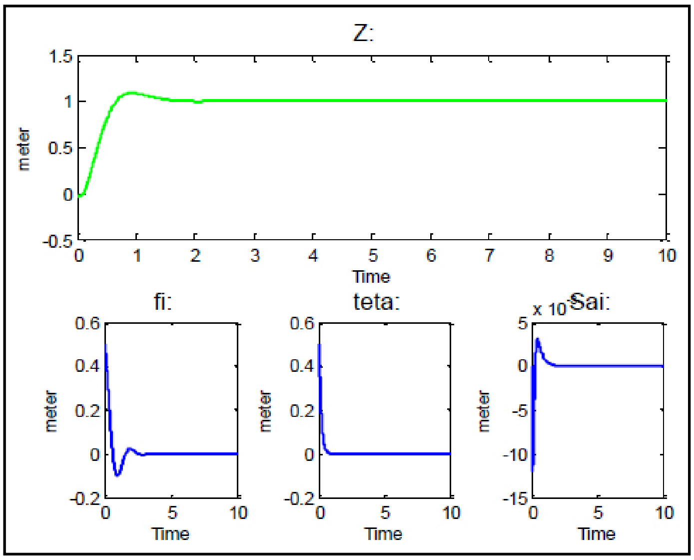

Fig. 18: system response with fuzzy PID controller to initial conditions on one meter height
φ = θ = 0.5 rad

VII. Experiments to test the fuzzy PID controller

In order to evaluate the efficacy and accuracy of the stated control rules and to compare with the designed PID controller in the previous step, we use for the height control.

In this study, the quadrotor is ordered to move 1 meter. The time response of z position in figure 19: System response with fuzzy PID control to the applied input is shown for one meter height. As it is shown in the figure, quadrotor has reached the desired height in 2/3 s, without equal overshoot and with or without oscillating motion which is slightly slower in reaching to the desired point compared to the PID controller system. Now we deal with the system in the presence of the turbulence, the general overview of the system is shown in figure 20: Block diagram of the fuzzy PID controller is associated with the application of the turbulence. The turbulence under study is the considered turbulence in figure 9: The defined signal of turbulence is in random in the range of 2 to -2.

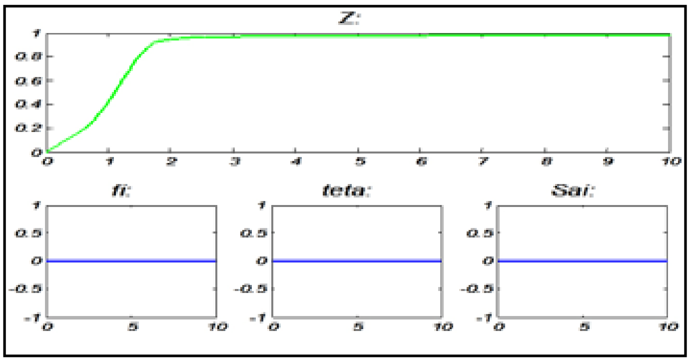

Fig.19: System response with fuzzy PID control to the applied input for a height of 1 m.

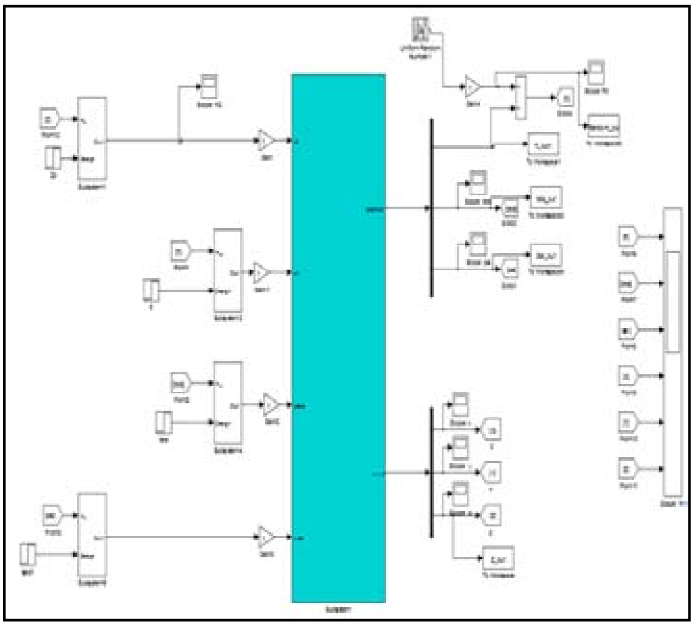

Fig. 20: Block diagram of fuzzy PID controller with applying the turbulence

Time responses of the system after applying the turbulence to the optimal input φ = 5^0 to the system in figure 21: System response with fuzzy PID controller is shown in the presence of turbulence for the angle φ = 5.

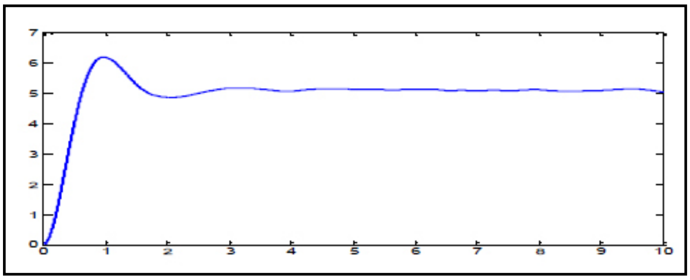

Fig. 21: System response with fuzzy PID controller in the presence of turbulence for the angle φ = 5

As it is observed the system is very resistant to the entered turbulence and it shows the advantage of using a fuzzy controller.

VIII. Conclusion

We can conclude that a quadrotor system is controlled well with PID controller when it is in a fixed route and away from turbulence, but when the system is exposed to turbulence and noise the system response alone is not suitable with PID control and needs to change relative to the different moments of control coefficients which can do it well in the presence of fuzzy control along with the PID control.

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