

Quadrotor Control using Adaptive Fuzzy PD Technique

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Abstract - Quadrotors have a variety of applications in real time e.g. surveillance, inspection, search, rescue and reducing the human force in undesirable conditions. Quadrotor UAV is equipped with four rotors for the purpose of stability but this will make quadrotor more complex to model and control. In this paper, intelligent controller is designed to control attitude of quadrotor UAV. The paper presents a detailed simulation model for a Quadrotor UAV and Adaptive Fuzzy PD control strategy is designed to implemented for four basic motions; roll, pitch, yaw, and Z Height. The controller presented in this paper is very simple in structure and it is easy to implement. The main objective of this paper is to get the desired output with respect to the desired input. Simulink model and results are shown at the end of the paper

Key Words: Quadrotor, UAV, Adaptive Fuzzy PD, Dynamics, Roll, Pitch, Yaw

1. INTRODUCTION

A quadrotor or quadcopter can be defined as a “multi-rotor copter with four arms, each of which have a motor and a propeller at their ends [1].

UAVs are classified depending upon type of wings as shown in figure 1.

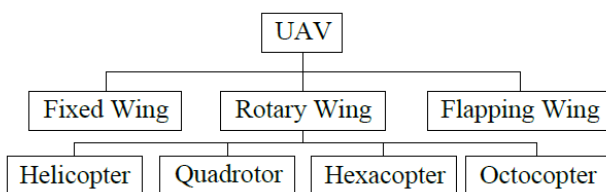


Figure -1: UAV Classification

Quadrotor lies in the category of Rotary wing class of UAVs they are usually used in the applications that required hovering flights such as search and rescue operations, security, journalism, emergency response and in military applications [2].

Quadrotors UAV are different from a helicopter for two main reasons

- a) The way they are controlled i.e. helicopters are not fully autonomous

- b) Second is helicopter can change their blades angle of attack while quadrotor lacks this functionality.

Quadrotors have many advantages over traditional helicopters such as

- a) Quadrotors have Small sizes
- b) They are safe to use for civilians because of small rotor.
- c) Less complex mechanical structure
- d) They are very easy to maintain
- e) Due to their maneuverability, they are safer in hazardous situations

This paper presents different classical and modern control strategies for the control of quadrotor. Simulations result and comparison of all control techniques are presented at the end of this paper.

2. Dynamic Modeling of Quadrotor

Quadrotor UAV flies with the assistance of four motors as shown in figure below. For the purpose of vertical flight two opposite motors rotates in the similar direction. The combination of opposite motors rotates in the similar direction for stabilization on the x-axis other combination of opposite motors keeps it stabilizes on the y-axis [3].

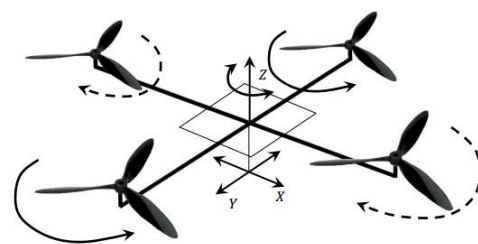


Figure -2: Quadrotor Motion

Quadrotor UAV is a 6 DOF aircraft, so there are 6 variables (x, y, z, ϕ , θ and ψ) that are used to express its orientation in space. ϕ , θ , and ψ are also known as Euler’s angles. Details of each variable are as follows [4]

- x and y: These variables are used to represent the position of Quadrotor in space.
- Z: Defines the altitude of quadrotor

- ϕ : ϕ or Roll angle it represent angle about the x-axis
- θ : θ or Pitch angle it represent angle about the y-axis
- φ : φ or Yaw angle it represent angle about the z-axis

In this Paper, Newton-Euler formalism is used to derive the dynamics of the quadrotor. Following are the assumptions made for the design [5]

- The Structure is rigid and symmetrical
- The propellers are rigid
- Thrust and drag are proportional to square of propellers speed

The model presented in this Paper is considering following equation of motion

$$\begin{aligned}
 \ddot{x} &= (\cos \phi \sin \theta \cos \psi + \sin \phi \sin \psi) \frac{1}{m} U_1 \\
 \ddot{y} &= (\cos \phi \sin \theta \sin \psi + \sin \phi \cos \psi) \frac{1}{m} U_1 \\
 \ddot{z} &= -g + (\cos \phi \cos \theta) \frac{1}{m} U_1 \\
 \ddot{\phi} &= \dot{\theta} \dot{\psi} \left(\frac{I_y - I_x}{I_x} \right) - \left(\frac{J_r}{I_x} \right) \dot{\theta} \dot{\Omega} + \frac{l}{I_x} U_2 \\
 \ddot{\theta} &= \dot{\phi} \dot{\psi} \left(\frac{I_z - I_x}{I_y} \right) - \left(\frac{J_r}{I_y} \right) \dot{\phi} \dot{\Omega} + \frac{l}{I_y} U_3 \\
 \ddot{\psi} &= \dot{\theta} \dot{\phi} \left(\frac{I_x - I_y}{I_z} \right) - \left(\frac{1}{I_z} \right) U_4
 \end{aligned} \tag{1}$$

In equation (1) m [kg] represent the mass of quadrotor helicopter whereas I_{xx} [Nms²], I_{yy} [Nms²], I_{zz} [Nms²] describes the factors of inertia matrix expressed in body system, J [Nms⁻¹] is the angular momentum and Ω [rads⁻¹] is the speed of propeller. U_1, U_2, U_3, U_4 are the inputs or translation vector factors. Basic motions and the speed of the propeller can be depicted by following equation 2 [6]

$$\begin{aligned}
 U_1 &= b(\Omega_1^2 + \Omega_2^2 + \Omega_3^2 + \Omega_4^2) \\
 U_2 &= lb(-\Omega_2^2 + \Omega_4^2) \\
 U_3 &= lb(-\Omega_1^2 + \Omega_3^2) \\
 U_4 &= d(-\Omega_1^2 + \Omega_2^2 - \Omega_3^2 + \Omega_4^2) \\
 \Omega &= (-\Omega_1^2 + \Omega_2^2 - \Omega_3^2 + \Omega_4^2)
 \end{aligned} \tag{2}$$

In equation (2) l [m], b [Ns²] and d [Nms²] describe the distance between propeller center and quadrotors center, lift and drag respectively. Ω_1 [rads⁻¹], Ω_2 [rads⁻¹], Ω_3 [rads⁻¹] and Ω_4 [rads⁻¹] are front, right, back and left propeller's velocity.

3. Adaptive Fuzzy PD Control

As the name suggests this control technique is a mixture of two control techniques which are fuzzy and PID control the block diagram is shown below

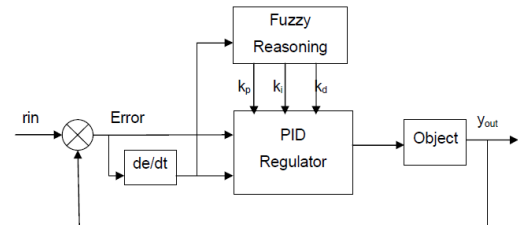


Figure -3: Fuzzy Adaptive PID Control

Adaptive control is basically a method which can tune and operate a system in a real time environment [7]. Conventional PD controllers are the most used controller in industrial applications but in robotic applications the biggest drawbacks of these controllers are overshoots and oscillation near settling points so this can be improved using a fuzzy logic control [8]. When we design an adaptive controller basic principle is to determine the relationship of fuzzy logic with the parameters of classical PD controller and also with the error and change of error. The error and change of error is supplied to the fuzzy logic controller and we get change in K_p and K_d as an output from the fuzzy logic controller [9]. In this control design fuzzy rules are defined as follows

Table -1: Fuzzy Rules

Height					
$\frac{dE}{dt}$	NB	N	Z	P	PB
E					
N	GDM	GD	GD	S	GU
Z	GUM	GD	S	GU	GUM
P	GD	S	GU	GUM	GUM

Where

N: Negative

P: Positive

GU: Go Up

GDM: Go Down Much

NB: Negative Big

Z: Zero

GUM: Go Up Much

S: Stand

GD: Go Down

PB: Positive Big

For quadrotor control triangular, trapezoid and Gaussian membership functions are used. Input range is from [-2, 2] whereas output variable lies in the range of [-15, 15]. Following are the membership defined for each controller.

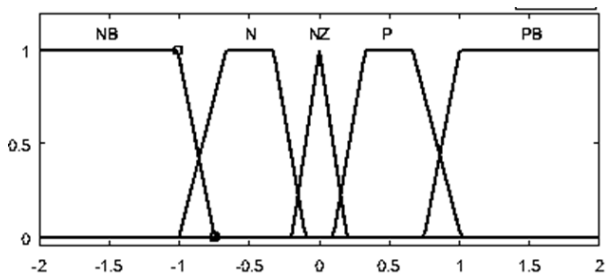


Figure -4: Error Input Membership Function

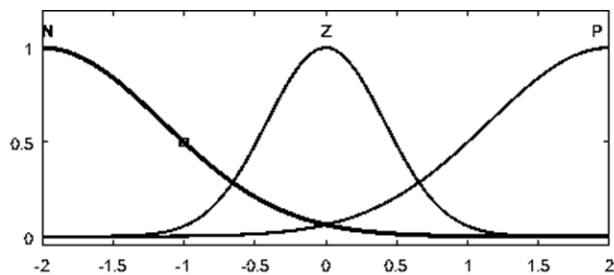


Figure -5: Derivative of Error Input Membership Function

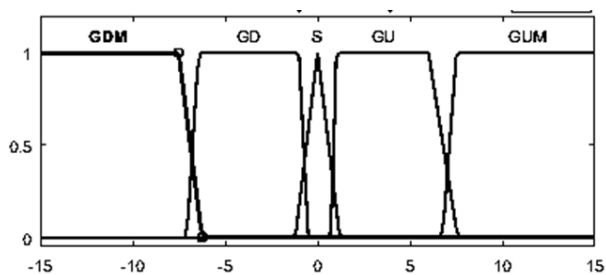


Figure -6: Output Membership Function

The simulation in this paper is using the parameters as mentioned in **Bouabdallah** PHD thesis as shown in table below [5].

Table -2: Quadrotor Parameters

I_{xx}	0.0075
I_{yy}	0.0075
I_{zz}	0.0130
J_r	6.50×10^{-5}
B	3.13×10^{-5}
D	7.50×10^{-5}
L	0.23
M	0.65

Simulink is used to develop the controller. For the control of quadrotor four Adaptive Fuzzy PD type controllers are used in order to achieve the desired output. In this paper we are only going to discuss the Roll Controller and rest remains similar.

For the control input we are using equation 3. The total k_p and k_d can be described by the following equation [10]

$$U_2 = K_p \cdot (\phi_d - \phi) + K_d \cdot (\dot{\phi}_d - \dot{\phi}) \quad (3)$$

$$K_p = K_{p1} + \Delta K_{p2} \quad (4)$$

$$K_d = K_{d2} + \Delta K_{d2} \quad (5)$$

Where

U_2 : Control Input

K_d : Derivative Gain

ϕ : Actual Roll

K_p : Proportional Gain

ϕ_d : Roll Desired

K_{p1} : Designed Proportional Gain

K_{p2} : Adjustable Proportional Gain from Fuzzy Controller

K_{d1} : Designed Derivative Gain

K_{d2} : Adjustable Derivative Gain from Fuzzy Controller

Figure 7 shows the roll controller based of AFPD technique

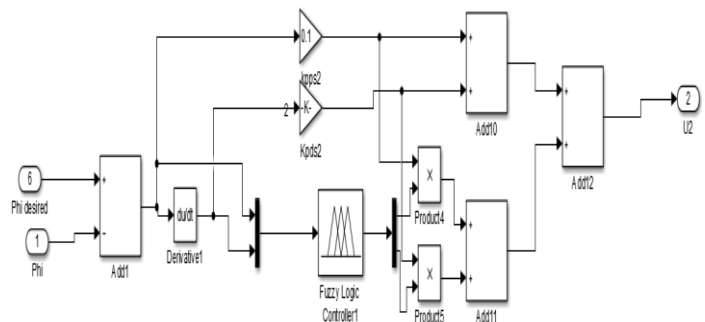


Figure -7: Adaptive Fuzzy PD Roll Controller

Fuzzy rules surface can be seen in the figure below

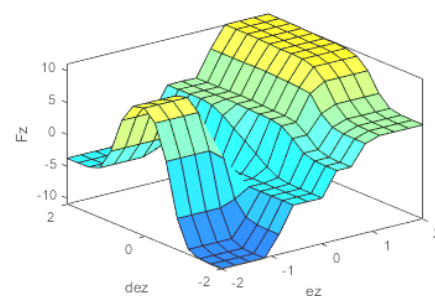


Figure -8: Fuzzy rules surface

4. Simulation and Results

Block diagram of whole system in Matlab is shown in the figure below

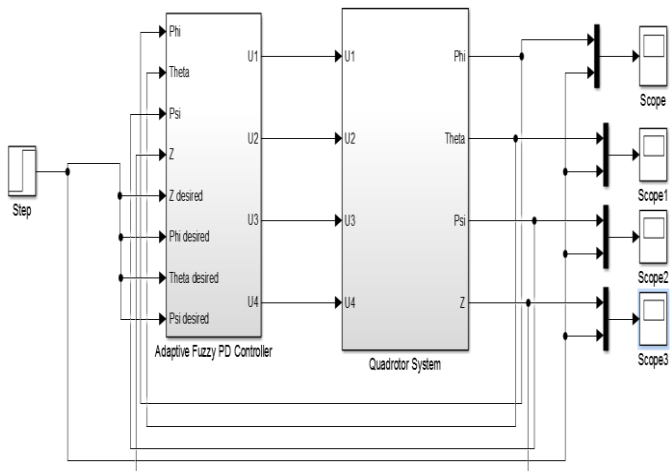


Figure-9: System Block Diagram

Here in this case the desired input is unit step and desired output is also unit step. Simulation results with respect to the desired input is shown in the figures below

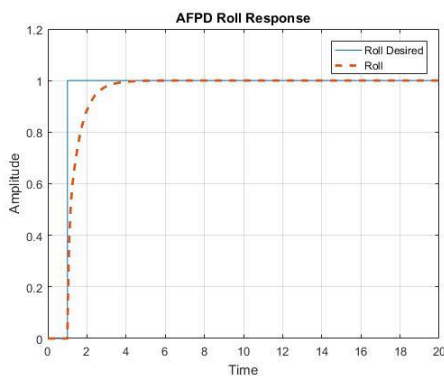


Figure -10: Roll Response

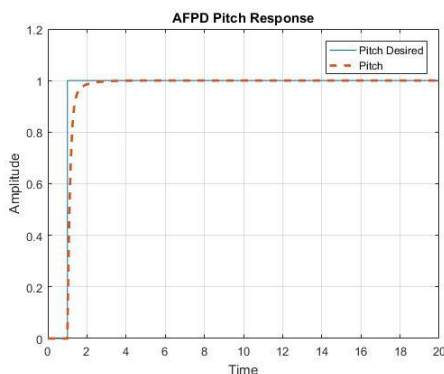


Figure -11: Pitch Response

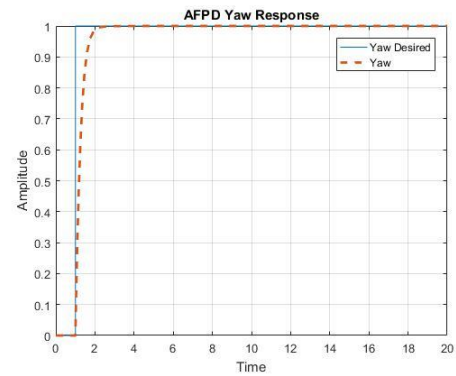


Figure -12: YAW Response

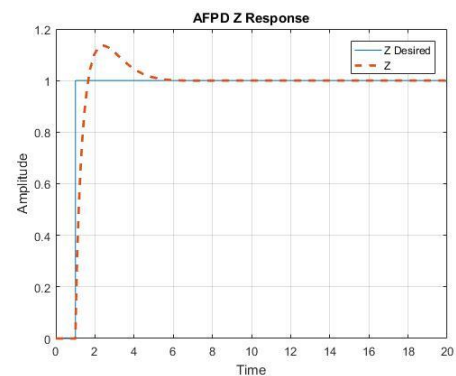


Figure -12: Z/Altitude Response

5. CONCLUSIONS

In this paper a nonlinear mathematical model of quadrotor is presented and implementation of the presented model is done through Matlab/Simulink. The presented model also considered rotor dynamics and aerodynamic effects which in most of the literatures are not considered during modeling. By looking at the responses shown in figures above we can observe that the behavior of Roll, Pitch, Yaw and Z are almost the same as the provided input. Further investigation can be made by using the same controller design and implement it on hardware.

REFERENCES

- [1] Quadrotor HQ. (2013, August) QUADCOPTER HQ. [Online]. HYPERLINK "http://quadcopterhq.com/what-is-a-quadcopter/" http://quadcopterhq.com/what-is-a-quadcopter/
- [2] Y. Aghli, M. Alimohammadi, A. A. Akbari S. Norouzi Ghazbi, "Quadrotors unmanned aerial vehicles : A review," vol. 9, no. 1, 2016.
- [3] Pavel Chmelař, "BUILDING AND CONTROLLING THE QUADROPTER," vol. VI, 2011.
- [4] Heba talla Mohamed Nabil ElKholy, "Dynamic

Modeling and Control of a Quadrotor Using Linear and non linear approach," Cairo, 2014.

- [5] Samir BOUABDALLAH, "Design and Control of quadrotors with application to autonomous flying," Lausanne, 2007.
- [6] Mohammad Bagher Menhaj, Roland Siegwart Fardin Fakurian, "FUZZY CONTROLLER DESIGN FOR QUADROTOR UAVS USING MINIMAL CONTROL INPUT," , Tehran, 2014.
- [7] R. Rinkevičienė S. Lisauskas, "Fuzzy adaptive PID control Design," Department of Automation, Vilnius Gediminas Technical University, Vilnius, Paper.
- [8] Yibin Huang Congying Qiu, "The Design of Fuzzy Adaptive PID Controller of Two-Wheeled Self-Balancing Robot," International Journal of Information and Electronics Engineering, vol. 5, pp. 1-5, May 2015.
- [9] Guo Qing Zhang , Huan Xin Cheng ,Li Cheng Jing Li, "Applications of Fuzzy adaptive PID control in the thermal power plant denitration liquid ammonia evaporation," in MATEC Web of Conferences, Xinjiang,China, 2016, pp. 1-3.
- [10] Abdel-Razzak MERHEB and Hassan NOURA, "Novel Bioinspired Stochastic Tuning of a Quadrotor PD Controller," , Sydney, 2012 Australian Control Conference.

BIOGRAPHIES



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