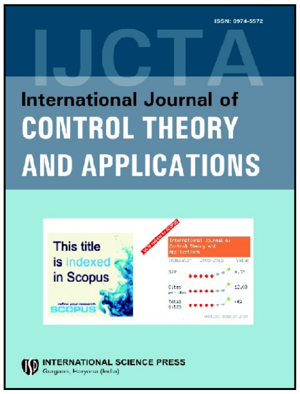

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Quadcopter Altitude Control using Classical PD and Fuzzy Control

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Abstract: Currently, Unmanned Aerial Vehicles (UAVs) are gaining popularity due to their applications in various fields such as rescue operations and transportation. A specific type of UAV is called quad copter which possesses the capability of vertical take-off and landing in limited space. Dynamics of quadcopter is very complex due to its nonlinearities; therefore control of quadcopter motion becomes difficult but important. In the present work, dynamics of a quad copter is analyzed for its altitude control. Two control strategies namely PD control and Fuzzy control have been developed to lock the height of the quad copter, i.e., altitude control. The developed control methods have been analyzed and compared through simulation results.

Keywords: Quadcopter, Control, PD, Modeling, Fuzzy.

I. INTRODUCTION

The quadcopter is a type of small UAV, whose motion is controlled by four D.C. motors. It has vertical take-off and landing ability in limited space. It has interesting applications in today's life like, spy vision, building inspection, photography and many more. There are four D.C. motors which provide the angular speed to four propellers of the quadcopter. Rotation of these propellers generates the upward thrust force, which moves the quadcopter in upward direction. The translational and rotational motions of the quadcopter depend on the difference in angular speeds of the four propellers. Therefore, control of the system becomes difficult as six degrees of freedom in space are controlled by four inputs (angular speeds of the propellers).

Many researchers proposed various modeling and controlling techniques to improve the flight dynamics of the quadcopter. Dynamic modeling equations of a quadcopter can be obtained using Newton- Euler or Lagrange-Euler formulations. These equations of motion can be used to develop some control on the quadcopter for its reliable performance in various applications. In present work, we focus on altitude control of a quadcopter. Some well known control strategies include Sliding Mode Control [1], LQG [2], LQR [3] Fuzzy-PID [4], Fuzzy control [5], classical PID control [6, 7, 8], classical PD [9].

In this paper the main contribution is to analyze the mathematical model of a quadcopter. Subsequently, control strategies are developed for its altitude control. The altitude of the quad copter is controlled using PD control and Fuzzy control methods. Finally the performance of these two controllers is analyzed and compared through simulation.

II. MODELING

2.1. Equations of Motion

Quadcopter mathematical model is obtained by the kinematic and dynamic analysis. Rotational dynamic model is obtained using Euler's equation. Furthermore, translational dynamic model is obtained by Newton's second law of motion. Figure 1 shows the schematic representation of the quadcopter and all of its parameters.

For modeling of the considered quad copter, two frames are used as shown in Figure 1, frame {1} is the reference frame, while frame {2} is body fixed frame. It is assumed that the three principal axes of the quadcopter are aligned with the axes of body fixed frame. The angular speeds of the propellers are denoted by ω_1, ω_2, ω_3, and ω_4; and these angular speeds generate the thrust forces F_1, F_2, F_3 and F_4, respectively.

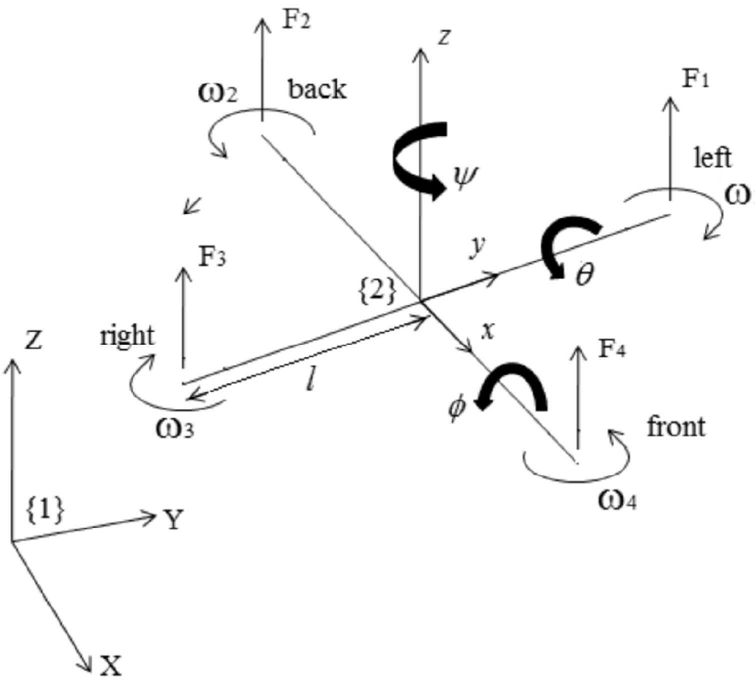

Figure 1: Schematic of the considered quadcopter

The differences in the angular speeds change the quadcopter orientations which are given by Euler angles (roll ϕ , pitch θ , and yaw ψ). These three Euler angles provide the translational motion in *x*, *y* and *z* directions. The transformation between the two frames (frame {1} and {2}) is given by the rotation matrix *R*.

$$[R] = \begin{bmatrix} c\theta c\psi & s\phi s\theta c\psi - c\phi s\psi & c\phi s\theta c\psi + s\phi s\psi \\ c\theta s\psi & s\phi s\theta s\psi - c\phi c\psi & c\phi s\theta s\psi - s\phi c\psi \\ -s\theta & s\phi c\theta & c\phi c\theta \end{bmatrix} \quad (1)$$

Where, $c\theta = cos\theta$, $s\theta = sin\theta$, $c\varphi = cos\varphi$, $s\varphi = sin\varphi$, $c\psi = cos\psi$, and $s\psi = sin\psi$

The dynamic equations of motion for quadcopter are obtained by the Newton- Euler formulation, as given below [10].

$$m\ddot{X} = F(c\phi s\theta c\psi + s\phi s\psi) \tag{2}$$

$$m\ddot{Y} = F(c\phi s\theta s\psi + s\phi c\psi) \tag{3}$$

$$m\ddot{Z} = Fc\phi c\theta - mg \tag{4}$$

$$I_x\ddot{\phi} = T_x + \dot{\theta}\dot{\psi}(I_y - I_z) \tag{5}$$

$$I_y\ddot{\theta} = T_y + \dot{\psi}\dot{\phi}(I_z - I_x) \tag{6}$$

$$I_z\ddot{\psi} = T_z + \dot{\phi}\dot{\theta}(I_x - I_y) \tag{7}$$

Where F is total thrust produced by four propellers, $F = F_1 + F_2 + F_3 + F_4$. While, T_x, T_y and T_z are the torques produced about x, y and z axis, which results in roll, pitch and yaw motions, respectively. These torques are produced due to difference in the angular speeds of four propellers. Mathematically, it can be given as follows.

$$T_x = (F_1 - F_3)l \tag{8}$$

$$T_y = (F_2 - F_4)l \tag{9}$$

$$T_z = (M_2 + M_4 - M_1 - M_3) \tag{10}$$

$$F_i = K_f\omega_i^2 \tag{11}$$

$$M_i = K_m\omega_i^2 \tag{12}$$

Where, i denotes the number of propeller (i = 1, 2, 3 and 4). While, M_1, M_2, M_3, and M_4 are the moments produced by the motion of four propellers, l is the length from quadcopter's centre to the propeller's centre, and K_f and K_m are thrust and drag coefficients, respectively.

III. ALTITUDE CONTROL

3.1. PD Control

The present section deals with the control of quadcopter altitude by classical PD control method. The error in the quadcopter altitude is calculated by the difference in the actual height (z) and the desired height (z_d) as given below.

$$e = z_d - z \tag{13}$$

Figure 2 shows the block diagram of PD control strategy for altitude control. The quadcopter move in the vertical z direction if every propeller rotates with same angular speed and generate the equal thrust force.

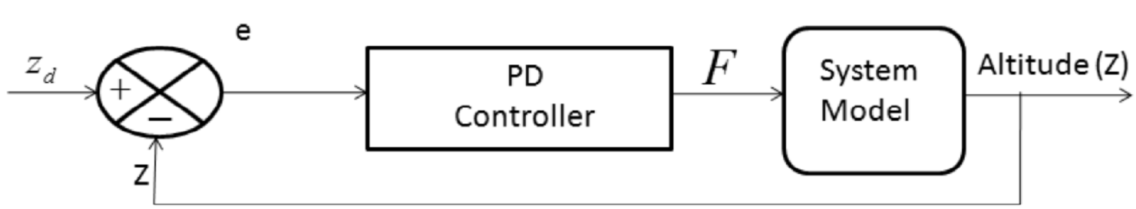

Figure 2: Block diagram of PD control strategy

Therefore, the control input for the system is the total thrust force F, and represented by the following equation.

$$F = k_p e + k_d \frac{de}{dt} \tag{14}$$

Where, k_p and k_d are proportional and derivative gain, respectively.

3.2. Fuzzy Control

In this section, a fuzzy rule based controlled is developed for altitude control of the quadcopter using the mamdani type fuzzy controller. Now, the controlled input (total thrust force F) for the system is controlled by the fuzzy inference system. Figure 3 shows the block diagram of fuzzy controller.

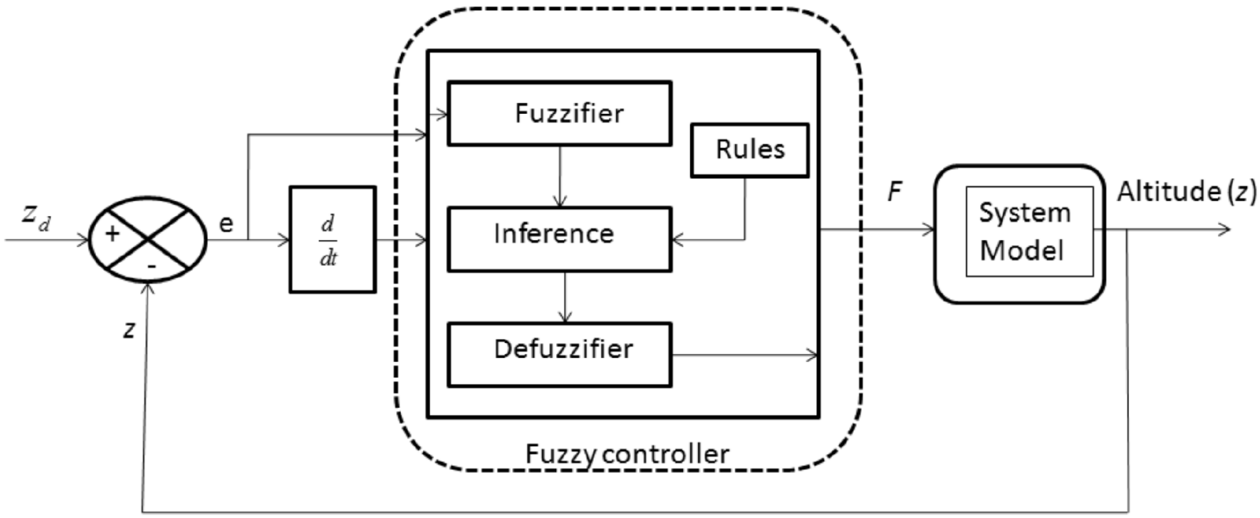

Figure 3: Block diagram of fuzzy controller

Figure 4 describes the fuzzy inference system, where error and derivative of error (derror) are considered as inputs and the total thrust force F is output. The range of the input and output has been determined by trial and error experience. Therefore, range [-30 30], [-3 3] and [-12 30] have been chosen for error, derror and output thrust, respectively. The input membership function is same for error and derror, combined by trapezoidal and triangular function curve as shown in Figure 5 and 6.

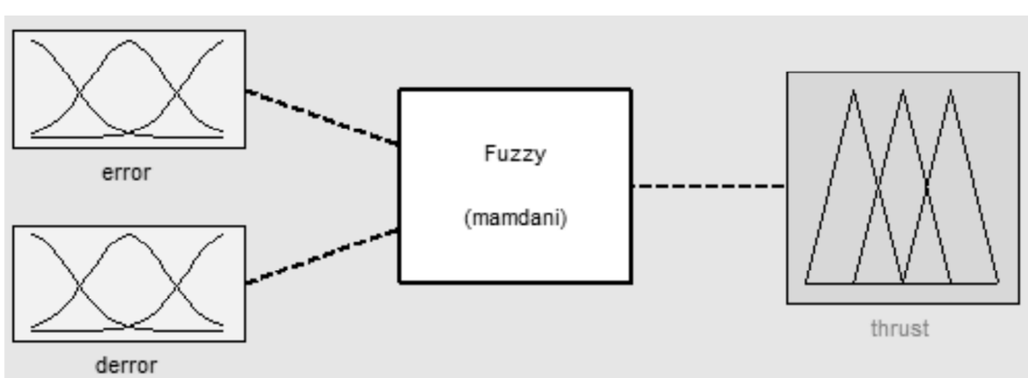

Figure 4: Fuzzy control structure in MATLAB environment

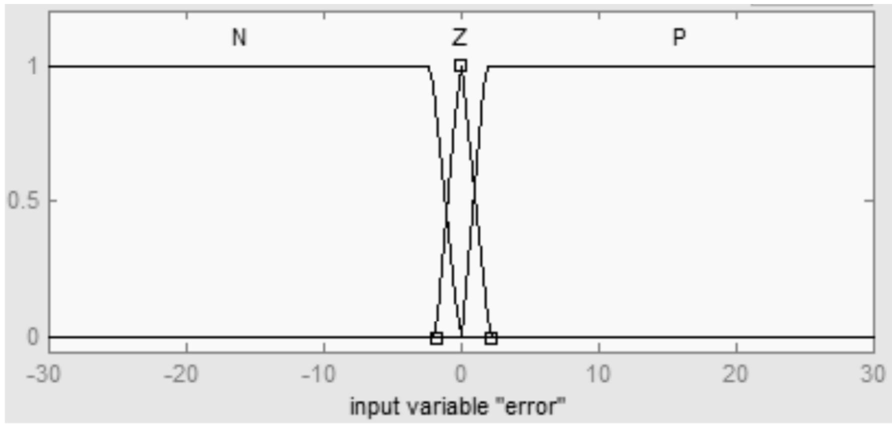

Figure 5: Error input membership function

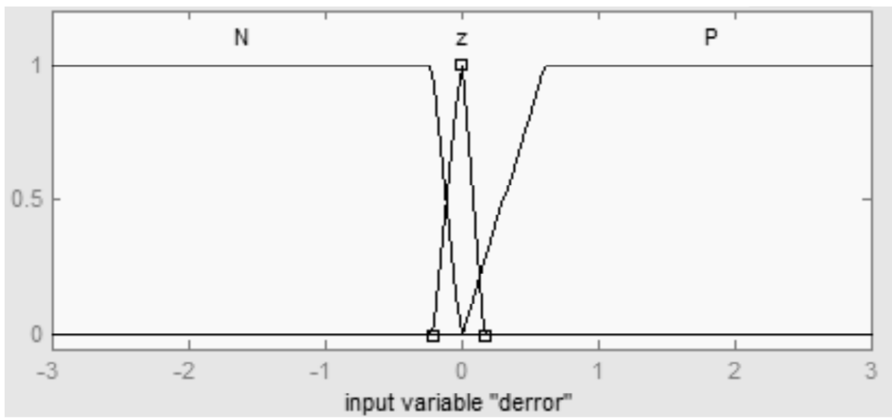

Figure 6: Derror input membership function.

Three fuzzy rule sets are used for inputs (N, Z, and P) and three fuzzy rule sets are used for output (Td, Tz, and Tup). The output membership function is also combined by trapezoidal and triangular function curves as shown in Figure 7. The mapping between error and derror using fuzzy rules are given in Table 1.

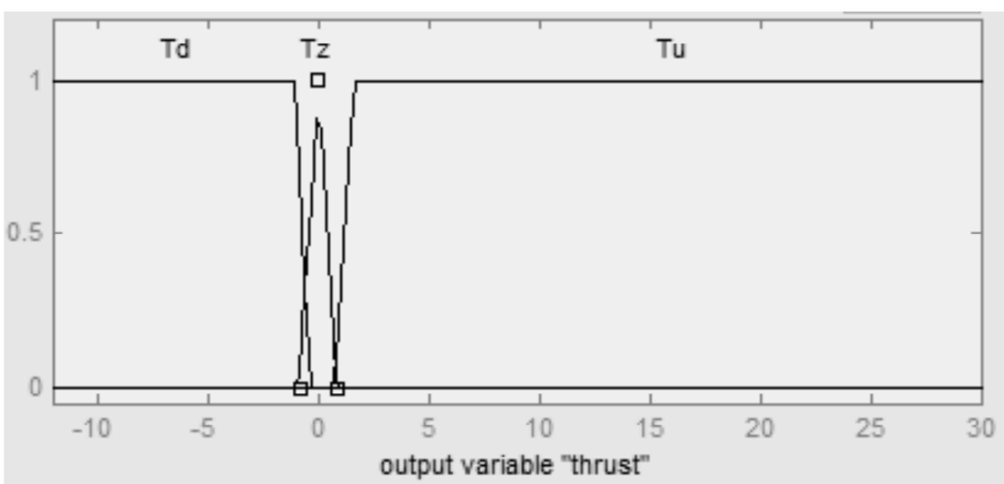

Figure 7: Output membership function

Table 1
Parameters for simulation

error	*derror* N	Z	P
N	Td	Td	Td
Z	Td	Z	Tup
P	Tup	Tup	Tup

IV. SIMULATION AND RESULTS

In this section, the dynamic equations of motion are simulated in MATLAB 13 to analyze and compare the performance of two controllers. The dynamic model is solved by Runga-Kutta method. All the parameter and their values which are used in the simulation are given in Table 2.

Table 2
Parameters for simulation

Parameter	*Symbol*	*Numerical value*
Distance between the center of quadcopter to the center of propeller (m)	l	0.2
Gravitational acceleration (m/s^2)	g	9.81
Mass of the quadcopter (Kg)	m	1
Thrust coefficient	K_f	3×10^{-6}
Drag coefficient	K_m	4×10^{-9}
Body moment of inertia about the x-axis (Kg-m^2)	I_x	0.11
Body moment of inertia about the y-axis (Kg-m^2)	I_y	0.11
Body moment of inertia about the z-axis (Kg-m^2)	I_z	0.04
Proportional gain	k_p	40
Derivative gain	k_d	5

Figure 7 shows the comparison between PD and Fuzzy controllers for same desired altitude of 20 m. From the results, it can be seen that the altitude response for the PD is having high overshoot as compare to Fuzzy control response. But, fuzzy controller has big settling time as compare to PD controller. PD and Fuzzy controllers have a steady state error of 1.226 % and 0.0355 %, respectively. Therefore, it can be observed that the fuzzy controller gives better response with considerable settling time. PD control settles to the desired height in 3 seconds whereas fuzzy control takes 14 seconds.

IV. CONCLUSION

In this work, dynamic equations of motion for a quadcopter are analyzed for its altitude control. Two control strategies PD and Fuzzy rule based control are developed to lock the height of the quad copter, i.e., altitude control. Simulation results conclude that fuzzy controller gives better performance with very low steady state error as compared to PD control. However, fuzzy control requires more settling time. For future work, it is interesting to add effect of wind dynamics in the model. In addition, the proposed controller will be validated through experiment on real quadcopter.

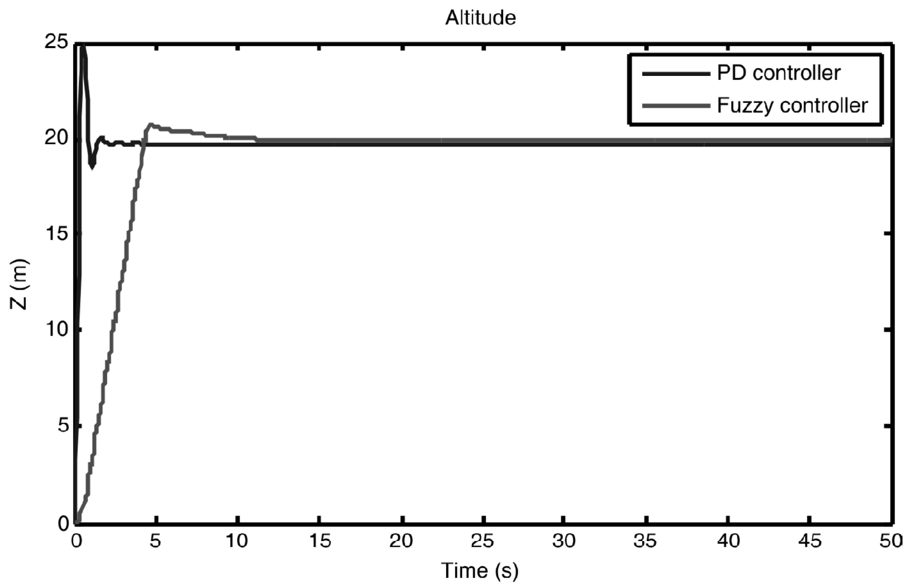

Figure 7: Quadcopter altitude control

IV. ACKNOWLEDGEMENT

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