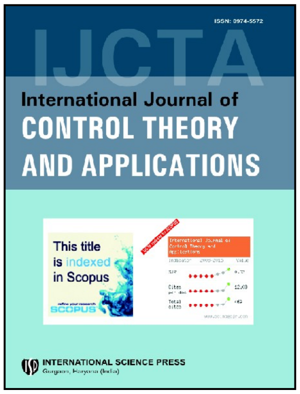

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Comparative Analysis of PID and Fuzzy-PID Controllers for Quadcopter Altitude Control

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Abstract: Unmanned Aerial Vehicles (UAVs) have been used for various applications in human life. A quadcopter is a specific type of UAV with vertical takeoff and landing capability in limited space. Dynamics of a quad copter is very complex and very difficult to control. In the present work, dynamics of a quadcopter is analyzed, and controllers are developed for its altitude control. The developed controllers include classical PID controller and Fuzzy-PID controller based on fuzzy logic for tuning of control gains. The two control methods are analyzed and compared through simulation results.

Keywords: Quadcopter, Modeling and Simulation, Fuzzy, PID control.

I. INTRODUCTION

Quadcopter is a type of UAV, which has four propellers, driven by four direct current (DC) motors. The motion of the quadcopter in 3-D space is governed by these motors by providing the different angular speed to them. Quadcopter is being wildly used by the researchers for their research because of its interesting flight dynamics and various applications in today's scenario. Currently, quadcopters have applications in military operations, rescue operations, and daily life applications. Quadcopter is famous because of the spy vision and photography.

For successful implementation of quadcopters, their control is very important. Many researchers have proposed various control methods for their altitude and attitude control. In this work, we focus on altitude control of a quacopter. Some control strategies for altitude control of a quadcopter include Fuzzy control [1], classical PID control [2, 3, 4], classical PD [5],Sliding Mode Control [6], LQG [7], LQR [8] Fuzzy-PID [9].

The main contribution in this paper is to analyze the mathematical model of a quadcopter, and consequently, to develop control strategies for its altitude control. Two control strategies are developed namely PID control and Fuzzy-PID control for quadcopter altitude. Finally, two control methods are analyzed and compared through simulation.

II. MODELING

2.1. Kinematics and Dynamics

Modeling of the quadcopter includes kinematics and dynamics. Figure 1 shows the schematic representation of the considered quadcopter. The figure shows two frames: frame {1} is the earth fixed frame, and frame {2} is the body fixed frame. The rotary motions of the four propellers generate the thrust forces (F_1, F_2, F_3 and F_4) in the z direction. The angular speeds of left, back, right and front propellers are denoted by ω_1, ω_2, ω_3, and ω_4, respectively. The translational and rotational motions of the quadcopter are obtained by the difference in angular speeds of four propellers, which change the roll ϕ, pitch θ, and yaw ψ angles.

The transformation between quadcopter's body fixed frame and the reference frame is described by three consecutive rotations roll ϕ, pitch θ, and yaw ψ (Euler's angle) about three principal axes. The transformation matrix is given below.

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

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

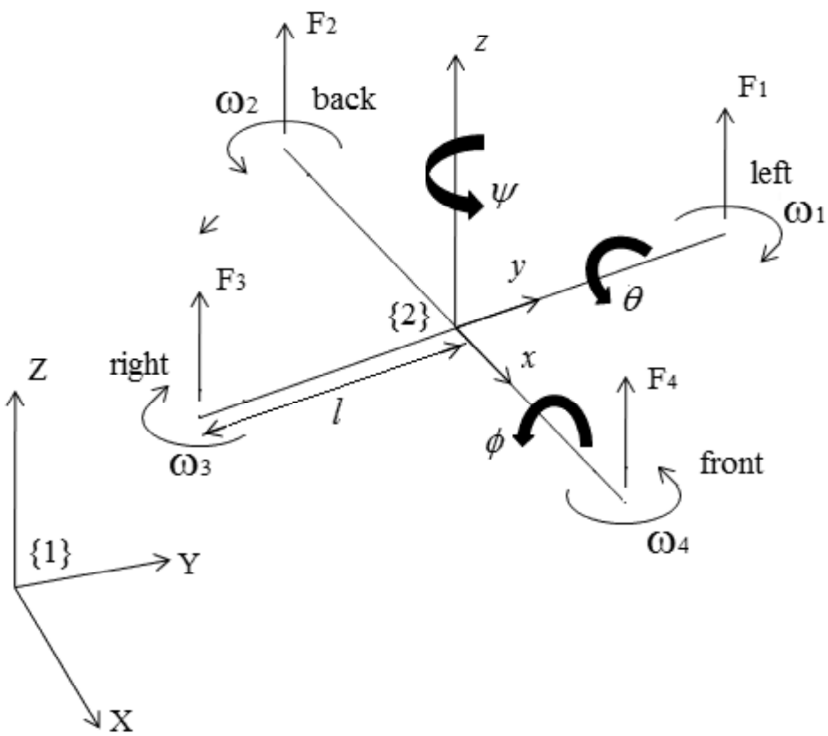

Figure 1: Schematic diagram of quadcopter

Dynamics of the quadcopter include the study of forces and torques acting on it. Newton-Euler formulation is used to obtain the dynamic model. The dynamic equations of motion for the quadcopter can be given as follows [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, $F = F_1 + F_2 + F_3 + F_4$.

The difference between angular speeds (ω_1 and ω_3) results in roll motion about x-axis. The torque developed about x-axis is given by T_x.

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

Where, l is the length from quadcopter's frame centre to propeller's centre.

Similarly, the difference between angular speeds (ω_2 and ω_4) results in pitch motion about y-axis. The torque developed about y-axis is given by T_y.

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

Finally, the yaw motion is obtained by the moments produced by four propellers. The torque developed about z-axis is given by T_z.

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

Where, M_1, M_2, M_3, and M_4 are the moments produced by the motion of four propellers.

Thrust and moment are the function of angular speed and can be calculated as follows.

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

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

Where, K_f and K_m are thrust and drag coefficients, respectively. The subscript i (i = 1, 2, 3 and 4) represents the propeller number.

III. ALTITUDE CONTROL

3.1. PID Control

In this section, the dynamic equations are exploited to control the quadcopter altitude. Classical proportional-integral-derivative (PID) control strategy is developed for altitude control. In this control, vertical height (z) of the quadcopter is controlled. If z_d is the desired height than the error e in altitude can be given as follows.

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

Figure 2 shows the PID control strategy for altitude control. The controlled input to the system is total thrust F, therefore, the PID control law can be written as:

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

Where, k_p, k_i and k_d are proportional, integral and derivative gain, respectively. The output of PID controller represents the total thrust force, which is to be applied on the quadcopter in upward direction to maintain the desired altitude.

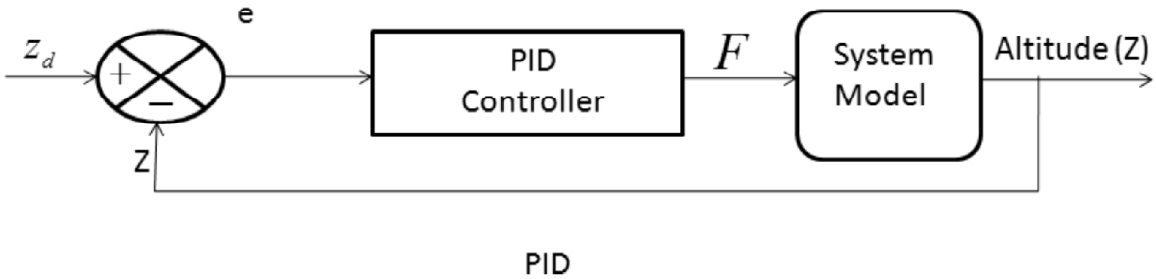

Figure 2: Block diagram of PID control strategy

3.2. Fuzzy-PID Control

In this section rule based mamdani type fuzzy system is used for PID gains scheduling. Figure 3 describes the Fuzzy control strategies, where, the error and the derivative of error are considered as the inputs and k_p, k_i and k_d are the outputs. The outputs from fuzzy system are used for tuning of gains in PID controller.

Figure 4 describes the fuzzy control structure in fuzzy inference system. In fuzzy inference system there are two inputs (*error* and derivative of error *Derror*) and three outputs (k_p, k_i and k_d). The range of inputs and the outputs have been determined by trial and error experience. So that range [-20 20] and [-2 2] have been chosen for error and Derror, respectively. Range [35 50], [5 15], and [3 11] have been chosen for k_p, k_i and k_d, respectively. The output membership function is same as the input membership function and combined by trapezoidal and triangular function curves. The membership functions for error and derivative of error are shown in Figure 5 and 6.

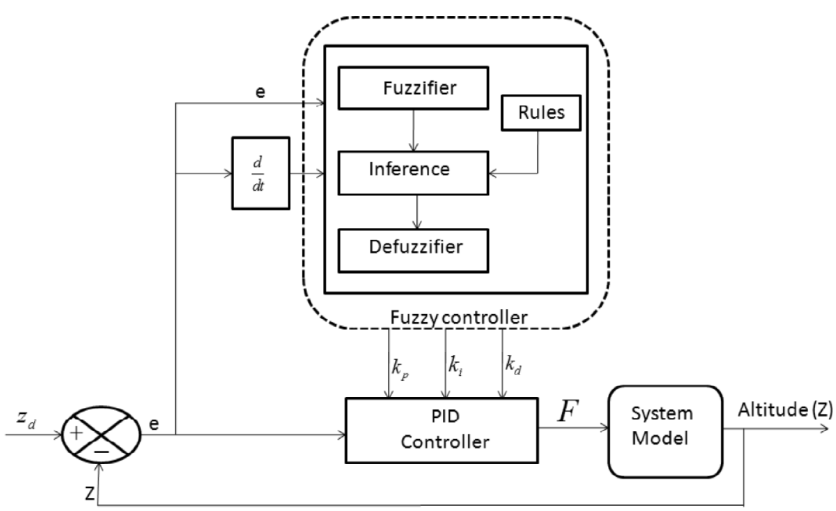

Figure 3: Block diagram of fuzzy based PID controller

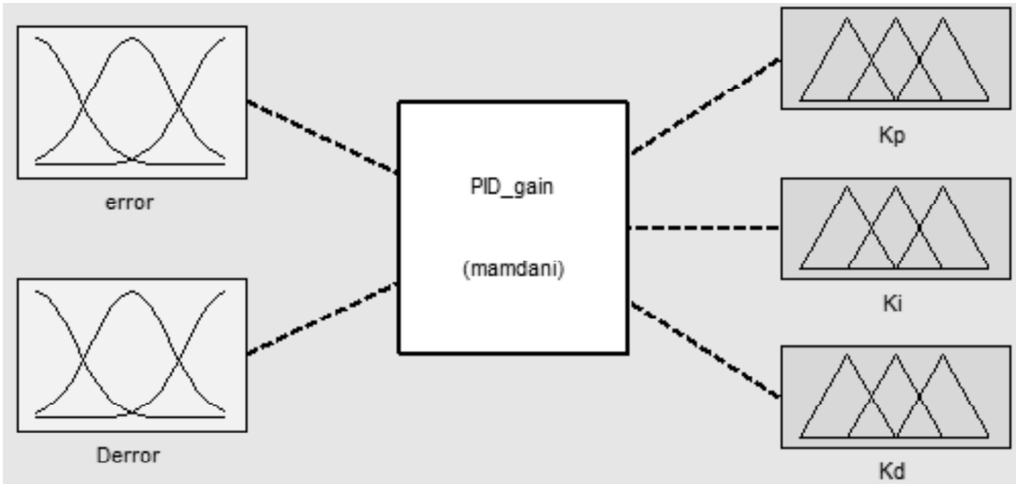

Figure 4: Fuzzy control structure in MATLAB environment

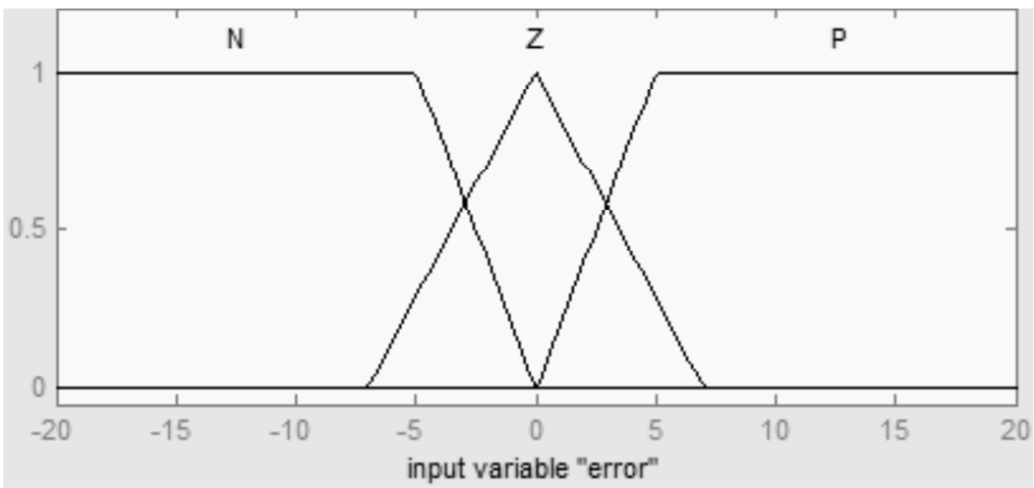

Figure 5: Error input membership function

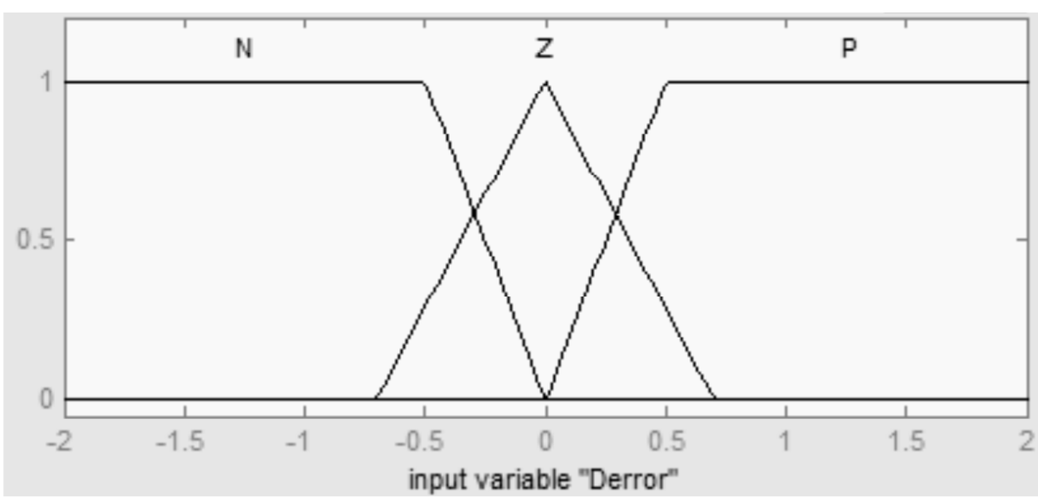

Figure 6: Derror input membership function

IV. SIMULATION

The aim of simulation is to analyze the performance of two controllers. The results are compared to analyze that how well the controller can achieve the desired value of altitude. The dynamic equations of the quadcopter are solved using Runga-Kutta method in MATLAB 13. Data used in simulation is given in Table 1 [10]. The present section is divided into two parts, i) open loop simulation and ii) closed loop simulation.

Table 1
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

4.1. Open Loop Results

In this section, the dynamic model is simulated without any control on its motion. We provide the equal angular speed (905 rad/s) to each motor. It can be seen in Figure 7 that the altitude (z) of the quadcopter is increasing with time. It travels 3.5 meters in 20 seconds.

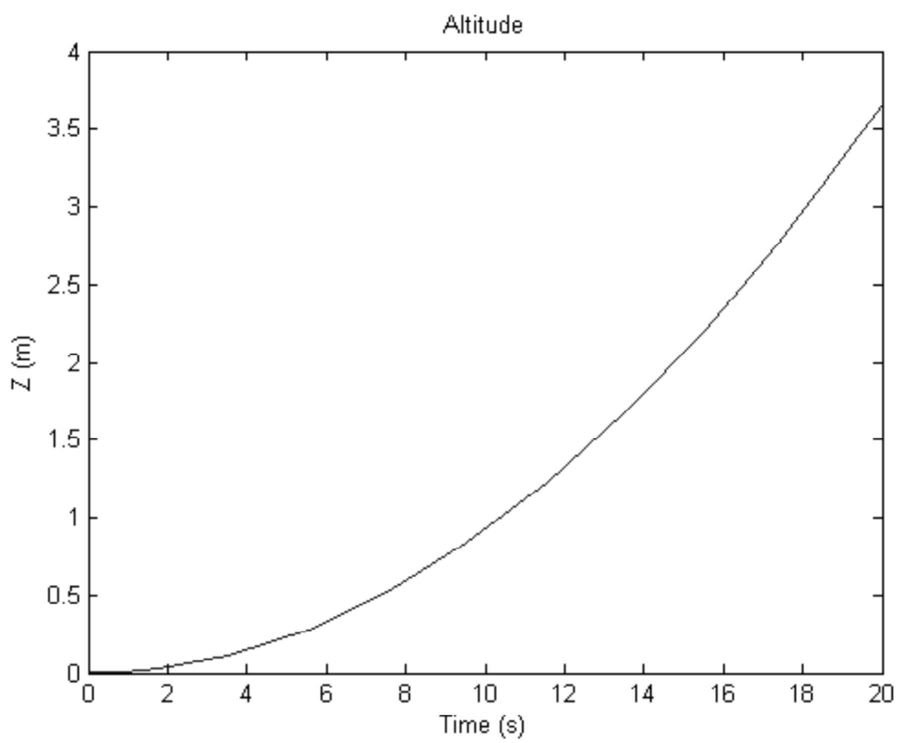

Figure 7: Quadcopter altitude (open loop)

4.2. Closed Loop Results

In the previous section, it can be seen that the altitude of the quadcopter is increasing continuously. Therefore, it requires a controller to lock the altitude (vertical height). Two controllers PID and Fuzzy-PID developed in the previous section are used to control the quadcopter altitude. The simulation results are shown in Figure 8.

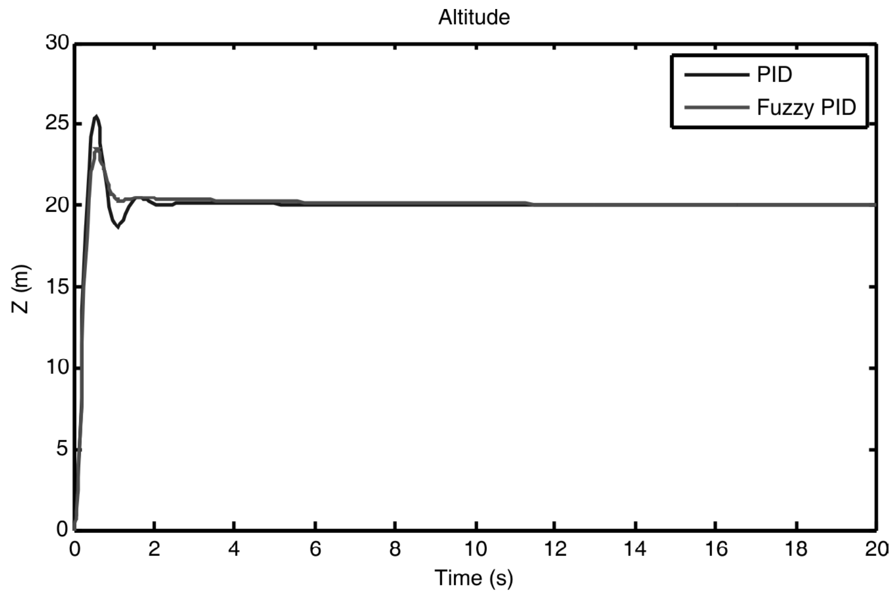

Figure 8: Altitude control (closed loop)

The values of control gains k_p, k_i and k_d for PID controller are tuned based on trial and error method and the selected values are 40, 5, and 5, respectively. In case of Fuzzy-PID controller, the values of PID gains are tuned by the fuzzy system.

The desired altitude for both the controller is set to 20 m. In Figure 8, it can be observed that the both controllers achieve the desired value of altitude, but Fuzzy-PID controller shows less overshoot and settling time as compared with PID controller. Therefore, performance of Fuzzy-PID controller is better than classical PID controller. has higher overshoot and more settling time as compare to Fuzzy based PID controller.

IV. CONCLUSION

The present paper analyzes the dynamics of a quadcopter UAV and develops control strategies for its altitude control. The height of the quadcopter is locked using two control algorithms, namely, PID and Fuzzy-PID controllers. The developed control methods are compared through simulation. From simulation results it has been observed that performance of altitude control using Fuzzy-PID is better than classical PID control. For future work, more complex dynamics can be analyzed by adding effect of wind disturbances during quadcopter flight. In addition, the proposed controller will be validated through experiment on real quadcopter.

IV. ACKNOWLEDGEMENT

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