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POSITION CONTROL OF A QUADCOPTER WITH PID AND FUZZY-PID CONTROLLER

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Keywords
Drone, Quadcopter, PID, Fuzzy, Simulation.

Abstract
In this study, PID based efficient control systems are designed and compared for position control of a quadcopter in six degrees of freedom. The main goal is to get the quadcopter to the desired position in three-dimensional space. Firstly, the desired position for the quadcopter to reach is determined. Then, the physical model of the system is selected, and mathematical model is derived according to the physical model. Initially, all external disturbances like drag force and wind are neglected. However, various external disturbances are then applied to the system to measure robustness of the designed controllers. Firstly, PID controller is implemented to the quadcopter system. Secondly, Fuzzy-PID controller is used. Necessary pitch and roll angles are found and control forces are calculated by using both controllers. Also, angular velocities of the motors and current values which are needed to be supplied to each motor are calculated and compared to evaluate performance and applicability of the proposed controllers. According to the results, it is observed that both controllers worked successfully, quadcopter is able to reach the desired location in three-dimensional space. However, Fuzzy-PID controller gives faster response and smaller overshoot levels than basic PID controller. In addition, it is seen that the Fuzzy-PID controller is less affected by external disturbances, and it recovers faster against these changes.

BİR DÖRTPERVANELİNİN PID VE BULANIK MANTIK-PID KONTROLCÜ İLE POZİSYON KONTROLÜ

Anahtar Kelimeler
İnsansız Hava Aracı, Dörtpervaneli, PID, Bulanık Mantık, Benzetim.

Öz
Bu çalışmada, bir dörtpervanelinin altı serbestlik derecesinde pozisyon kontrolü için PID tabanlı verimli kontrol sistemleri tasarlanmış ve karşılaştırılmıştır. Asıl amaç, dörtpervaneliyi üç-boyutlu uzayda istenen konuma getirmektir. İlk olarak dörtpervanelinin ulaşması istenen pozisyon belirlenmiştir. Sonra sistemin fiziksel modeli seçilmiştir ve matematiksel model, fiziksel modele göre türetilmiştir. Başlangıçta sürükleme kuvveti ve rüzgar gibi tüm dış etkiler yoksayılmıştır. Fakat, tasarlanan kontrolcülerin sağlamlığını ölçmek için çeşitli dış etkiler sisteme daha sonra uygulanmıştır.İlk olarak PID kontrolcü dörtpervaneli sistemine uygulanmıştır, ikinci olarak Bulanık Mantık-PID kontolcü kullanılmıştır. Gerekli olan yunuslama ve yuvarlama açıları bulunmuş ve kontrol kuvvetleri her iki kontrolcü ile de hesaplanmıştır. Ayrıca motorların açısal hızı ve her bir motora sağlanması gereken akım değerleri, önerilen kontrolcülerin performansı ve uygulanabilirliğini ölçmek için, hesaplanmış ve karşılaştırılmıştır. Sonuçlara göre, her iki kontrolcünün de başarılı şekilde çalıştığı gözlemlenmiştir, dörtpervaneli üç-boyutlu uzayda istenen konuma ulaşabilmiştir. Fakat, Bulanık mantık-PID kontrolcü, temel PID kontrolcüden daha hızlı ve daha az seviyede aşımla cevap vermiştir. Ayrıca, Bulanık Mantık-PID kontrolcünün dış etkilerden daha az etkilendiği ve bu değişiklikler karşısında daha hızlı toparladığı görülmüştür.

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Highlights (At least 3 and maxium 4 sentences)

- Physical and mathematical model of the system were found,
- PID and Fuzzy PID controllers were designed for the quadcopters.
- Both controllers were implemented to the quadcopter system separately and simulated in the Simulink.
- Results for both controllers were obtained and compared. According to the results, controllers have highly satisfying results. However, Fuzzy logic increased the system's overall performance.

Purpose and Scope

The main purpose of this study is to design efficient control systems to get the quadcopter to the desired position in three-dimensional space. While doing this, it also compares two different control algorithms and shows the success of the controllers in complex 6-DOF system.

Design/methodology/approach

Physical model for the quadcopter was determined and then mathematical model of the system was derived acoording to free body diagram. Non-linear equations were linearized. DC Motor equations were used to find necessary current values for each motor. Disturbances were added to system to test robustness of the controllers. Both controllers were implemented to the system in Simulink and results were obtained.

Findings

According to the results, both control algorithm have successful results. PID controller can be used for such complex systems that have six degrees of freedom and it can be combined with Fuzzy logic to increase performance. Fuzzy-PID algorithm significantly increased the speed of the system and it has less overshoot than the regular PID. Disadvantage of the fuzzy method is that it will require more powerful motor and battery to reach higher speed and current.

Originality

This article presents simple and efficient way to control position of the quadcopters. The error founded in this study is very low. It is a comprehensive study not limited with just controller design in MATLAB-Simulink. DC motor, power consumption equations are also used to reach desired solution. Therefore, it can help readers for motor and battery selection for their own applications.

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1. Introduction

Drones or Unmanned Aerial Vehicles (UAV) are basically defined as aircraft without a human pilot which has been an increasingly preferred topic for academic researches and industrial applications. Although their popularity increased in recent years, researches about drones have started in the early 1900s. (Praveen and Pillai,2016). There are numerous applications of UAVs such as military applications, traffic and security, photography, shipping, mapping, health sector, agriculture and so forth. A quadcopter is one of the most commonly used type of drones driven by four electric motors. They have the ability to take off and land safely using the thrust force generated as a result of the rotation of their propellers (Bozkurt and Dandıl,2020).

Quadcopters have important advantages such as the ability of vertical landing (VTOL), small size and maneuverability. Also, they have important mechanical design flexibilities and they are easier to manufacture. Therefore, it is possible to generate more productive and efficient models than the other types of UAVs. Despite the positive aspects of quadcopters, they are highly unstable systems and they have complex non-linear dynamics which make them difficult to analyze (Suiçmez and Kutay,2014).

Development in technology and control theory have become a strong factor in increasing the number of researches about the control of quadcopters. Different control strategies have been applied to the quadcopters to solve different problems like position control, velocity control, autopilot, path planning, object tracking, etc.

In this study, PID Controller and Fuzzy-PID controller were designed to control position of a quadcopter in three dimensional space. The main aim of this study is to compare the robustness and success of PID and Fuzzy-PID controllers on the quadcopter system. To achieve that, system model was designed on the Simulink and the success of both controllers in position control was compared. Also, some disturbances were added to the system to evaluate robustness of the controllers. Additionally, angular velocities of the motors and current values which are needed to reach these velocities were found. Motor selection can be done by using the approach that will be presented in this article. Mathematical model of the quadcopter was derived according to the chosen physical model. Then, MATLAB/Simulink model of the system was created and controllers were implemented to the system. Finally, performance of both controllers and simulation results were discussed. Results showed that an easy PID control algorithm became successful to control complicated system which has six degrees of freedom without error compared to some other similar studies. However, Fuzzy-PID controller improved the performance of the system with higher speed and less overshoot. In addition, Fuzzy-PID controller was less affected by the disturbances like mass increase and external forces, it had faster response and recovered faster than PID controller against external disturbances.

2. Literature Survey

Praveen and Pillai (2016) designed a remote-controlled quadcopter using PID, implemented PID with Ardupilot Mega board and tested quadcopter performance in MATLAB/Simulink. Romero, Pozo and Rosales (2014) used PID controller to arrange four movements of a quadcopter which are row, pitch, yaw and altitude. They used necessary sensors to implement PID to their system and wireless interface to observe data during flight. According to the result of the study, PID became successful but disturbances affected its behavior and performance in a bad way. Zouaoui, Mohamed and Kouider (2018) used PID controller for tracking of UAVs and they suggested that PID is effective for trajectory guiding as a result of their MATLAB simulation. Cedro and Wieczorkovski (2019) worked on quadcopter dynamics and created a model to tune the PID controller gains. He and Zhao (2014) designed PD controller for simple attitude control of the quadcopter by using Ziegler-Nichols method to tune the PD parameters which provided highly robust control system. As a similar perspective research, Sabo and Cohen (2012) implemented Fuzzy Logic for motion planning problem in 2D and obtained a %3 failure rate which highlighted one of the advantages of the fuzzy method with maintaining low control effort. Prayitno, Indrawati and Trusulaw (2017) made a comparison of PID and fuzzy controller for position control of drones and emphasized that PID control gave better performance despite the overshoot. Rahimi, Hajighasemi and Sanaei (2014) made comprehensive research about vertical position control of UAVs by using three different control methods which are LQR, Fuzzy and PID. According to their MATLAB and Simulink models, using Fuzzy PID controller significantly improved the performance of control. Another study about trajectory and position control was made by Reizenstein (2017) by implementing LQ and PID controllers. Also, GPS and LIDAR were added to the system to measure position. As a result, both controllers became successful at controlling the quadcopter's position in all three dimensions . Li (2020) applied Fuzzy control algorithm to control the attitude of the quadcopter and to solve problems about slow response and poor robustness. PID, Cascaded PID and Fuzzy-PID controllers were designed in this research with step signal. Li's simulation results also showed that Fuzzy PID have the better result.

3. Material and Method

3.1. Mathematical Model

Dynamic model of the quadcopter was derived according to the physical model which can be seen in figure 1. In this model, two uniform rods having equal mass and length were attached perpendicular and symmetrical from their centers.

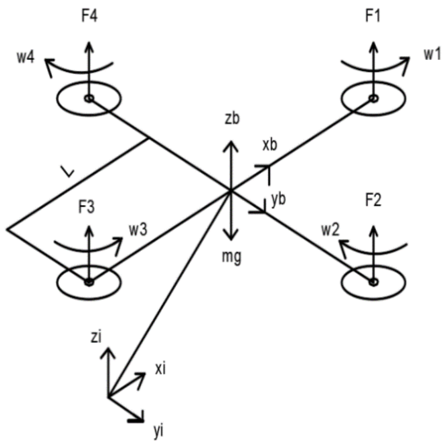

Figure 1. Physical Model

Quadcopters have six degrees of freedom (3 translational, 3 rotational). By changing the rotational speed of the motors, all these six motions can be achieved. Since there is no force in the x and y directions, quadcopters have to rotate to move in these directions because when it rotates, thrust force components will form in the x and y-axis. Two different coordinate systems were defined in the dynamic model, the body frame which is fixed to the center of gravity of the quadcopter and the ground (inertial) frame. These two coordinate systems were used to find the equations of motion of the model.

Gravity force must be balanced for quadcopters to stay in air. This balancing force comes from the thrust generated by the rotation of the motors. Motors 1 and 3 turn counterclockwise, while motors 2 and 4 turn clockwise as can be seen from the dynamic model of the system (Figure 1). Rotational speed difference between motors 2 and 4 causes rotation about x-axis. This maneuver is known as roll motion which is represented by angle ϕ. Similarly, speed difference between motors 1 and 3 causes rotation about y-axis known as pitch motion and θ represents the pitch angle. Finally, there is rotation about vertical axis z represented by yaw angle ψ.

The transformation matrix between the body frame and the ground frame can be defined by multiplying the three rotation matrices which result from the rotation of the body frame. By ignoring drag forces, there are only thrust forces on the body frame. These thrust forces were transferred to the ground frame by using rotation matrix resulting from equation 1. (Long and He ,2014)

$$F_G = RF_B$$
$$\begin{bmatrix} c_\theta c_\psi & s_\phi s_\theta c_\psi - c_\phi s_\psi & c_\phi s_\theta c_\psi + s_\phi s_\psi \\ c_\theta s_\psi & s_\phi s_\theta c_\psi + c_\phi s_\psi & c_\phi s_\theta s_\psi - s_\phi c_\psi \\ -s_\theta & s_\phi c_\theta & c_\phi c_\theta \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ F_z \end{bmatrix} - \begin{bmatrix} 0 \\ 0 \\ mg \end{bmatrix} \quad (1)$$

Result of Equation 1 defines the quadcopter’s linear dynamics in x, y and z positions.

$$\ddot{x} = \frac{(cos\phi sin\theta cos\psi + sin\phi sin\psi) * F_z}{m} \quad (2)$$

$$\ddot{y} = \frac{(cos\phi sin\theta sin\psi - sin\phi cos\psi) * F_z}{m} \quad (3)$$

$$\ddot{z} = \frac{(cos\phi cos\theta) * F_z}{m} - g \quad (4)$$

Forces that are generated by the rotation of the propellers can be assumed as proportional to the square of the rotational speed.

$$Thrust = F = b * \omega^2 \quad (5)$$

where b is the thrust coefficient and ω is the rotational speed of the motors. Finally total thrust force can be written as below:

$$F_z = F_1 + F_2 + F_3 + F_4 = b(w_1^2 + w_2^2 + w_3^2 + w_4^2) \quad (6)$$

Rotational dynamics of the quadcopter can be analyzed in the body frame. Gyrosopic effect caused by the rigid body rotation and drag forces were neglected for simplicity. Also, velocities at the body frame and ground frame were considered as equal. Therefore, only thrust forces can produce torque on the quadcopter. Torque generated in the different axes can be found by taking moments according to the center of gravity of the quadcopter.

$$\tau_x = L(F_4 - F_2) = Lb(w_4^2 - w_2^2) \quad (7)$$

$$\tau_y = L(F_1 - F_3) = Lb(w_1^2 - w_3^2) \quad (8)$$

F_4 and F_1create positive moment about x and y axis, respectively and F_2 and F_3create negative moment about these axes. L is the distance between the center of gravity of the quadcopter and the motors. Moment in the z-direction is the net moment of the motors which is positive at counterclockwise and negative at clockwise directions.

$$\tau_z = d(w_1^2 - w_2^2 + w_3^2 - w_4^2) \quad (9)$$

At equation 9, d is a new constant known as drag factor (Jiinec,2011). After finding moments from equations 7,8 and 9 angular accelerations can be written by Newton's laws of motion:

$$\ddot{\phi} = \frac{\tau_x}{I_x} \quad (10)$$

$$\ddot{\theta} = \frac{\tau_y}{I_y} \quad (11)$$

$$\ddot{\psi} = \frac{\tau_z}{I_z} \quad (12)$$

Generally, brushless DC motors are used for drone applications. Needed current values to reach desired angular velocities can be found theoretically by using brushless DC motor equations. Torque generated by each motor is defined by the equation below (Gibiansky):

$$\tau = K_t * (I - I_o) \quad (13)$$

where, τ is the torque generated by each motor, K_t is the torque constant, I is the current and I_o is the no load current. I_o has a small value, therefore it can be taken as zero. With no motor resistance, voltage of the motors can be written as:

$$V = K_v * \omega \quad (14)$$

where K_v is the electromotive force constant and ω is the angular velocity of the motor.

By using conservation of the energy, power of the motors can be calculated by multiplying thrust force and air velocity. Also, V_h (air velocity while hovering) can be found from momentum theory (Gibiansky).

$$P = T * V_h \quad (15)$$

$$V_h = \sqrt{\frac{F}{2\rho A}} \quad (16)$$

$$P = \frac{F^{3/2}}{\sqrt{2\rho A}} = \frac{(b * w^2)^{3/2}}{\sqrt{2\rho A}} \quad (17)$$

where ρ is the air density and A is the area swept out by the motor.

Finally, current values needed for each motor can be found by equation:

$$I = \frac{P}{V} = \frac{P}{K_v * \omega} \quad (18)$$

3.2. PID Controller Design

PID controller is the most common control mechanism that can be used in many different systems. In this study, PID control was implemented to the system to get the quadcopter to desired position. Since there are four inputs to quadcopter, system is underactuated because there are six degrees of freedom to be controlled. Thrust force F_z and moments τ_x, τ_y and τ_z can be taken as control inputs and controlled by PID to solve this problem.

According to the equations 2, 3 and 4, linear position of the quadcopter is only controlled by the force F_z and rotational degrees of freedom are controlled by moments τ_x, τ_y and τ_z, respectively. Therefore, control inputs can be written as:

$$U_1 = F_1 + F_2 + F_3 + F_4 = b(w_1^2 + w_2^2 + w_3^2 + w_4^2) \quad (19)$$

$$U_2 = L(F_4 - F_2) = Lb(w_4^2 - w_2^2) \quad (20)$$

$$U_3 = L(F_1 - F_3) = Lb(w_1^2 - w_3^2) \quad (21)$$

$$U_4 = d(w_1^2 - w_2^2 + w_3^2 - w_4^2) \quad (22)$$

Output of the PID controller calculates the necessary force inputs, and then from equations 19, 20, 21 and 22 angular velocities of each motor can be found.

$$\omega_1 = \sqrt{\frac{U_1}{3b} + \frac{U_3}{2Lb} + \frac{U_4}{4d}} \quad (23)$$

$$\omega_2 = \sqrt{\frac{U_1}{4b} - \frac{U_2}{2Lb} - \frac{U_4}{4d}} \quad (24)$$

$$\omega_3 = \sqrt{\frac{U_1}{4b} - \frac{U_3}{2Lb} + \frac{U_4}{4d}} \quad (25)$$

$$\omega_4 = \sqrt{\frac{U_1}{4b} + \frac{U_2}{2Lb} - \frac{U_4}{4d}} \quad (26)$$

Simulation model of the system was created in MATLAB-Simulink. Rotational dynamics were modeled based on equations 10, 11 and 12 and linear dynamics were modeled after nonlinear equations of motions were linearized by assuming roll, pitch and yaw angles are small. Linear equations of motion can be seen below:

$$\ddot{x} = \frac{\theta * U_1}{m} \quad (27)$$

$$\ddot{y} = \frac{\phi * U_1}{m} \quad (28)$$

$$\ddot{z} = \frac{U_1}{m} - g \quad (29)$$

Assuming no external disturbances, if all motors turn with the same speed, quadcopter can only move up (in the z-direction) when the generated thrust force become higher than the weight of the quadcopter. Higher than the critical speed, quadcopter overcomes gravity force and starts moving upward. Also, quadcopters have thrust forces only in z-direction. Therefore, for quadcopter to move in x and y directions, pitch or roll movement (rotations) are needed. Pitch and roll angles must be calculated to find necessary control inputs. After finding desired angles, PID controller can be designed to calculate control inputs U_1 , U_2 U_3 and U_4.

Simulink model of the system can be seen at appendix (Figure 16). Desired positions were defined in 'Reference Path' subsystem. Both desired roll and pitch angles to move x and y directions were calculated from 'Angle Control' subsystem with PID controllers. Control inputs U_1 , U_2, U_3 and U_4 were also calculated by PID controllers inside the 'Position Control' subsytem. 'Quadcopter Plant' subsystem consists of linear and rotational dynamics of quadcopter based on mathematical model. Finally, angular velocity and current values were calculated from simulation.

3.3. Fuzzy-PID Controller Design

Fuzzy logic is one of the most preferred intelligent control methods. Rather than traditional boolean logic which has 0 and 1 only, fuzzy logic design can have many values between 0 and 1. In this study, fuzzy logic was used to find PID controller gains, Kp, Ki and Kd. In this way, a hybrid controller was designed with PID as the main controller and fuzzy logic to tune the PID parameters.
The PID design presented in section 3.1 is still same and valid, but for controlling the roll, pitch, yaw angles and also altitude, PID gains were found by Fuzzy-logic for each degree of freedom. Error and its derivative were provided to fuzzy logic controller as inputs. Then, inputs were analyzed in the Fuzzy system with if-then logic and as a result, Kp, Ki and Kd were outputted from the controllers. With this approach, system will automatically tune the PID controller, gains will change according to time and an adaptive control will be provided to the system.
Designed Fuzzy-logic controllers have two inputs and one output. Inputs are error and its derivative and they have five membership functions namely Negative Large (NL), Negative Small (NS), Zero (Z), Positive Small (PS) and Positive Large (PL). Outputs also have five membership functions which are Very Small (VS), Small (S), Medium (M), Large (L) and Very Large (VL). In this study, Mamdani type Fuzzy system was used with centroid defuzzification method. Range of the outputs and inputs were determined separately for each degree of freedom and each gain for all Fuzzy systems. One example system can be seen in the figures below.

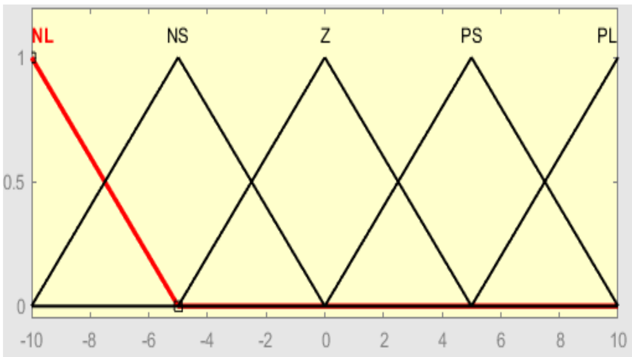

Figure 2a. Error Input

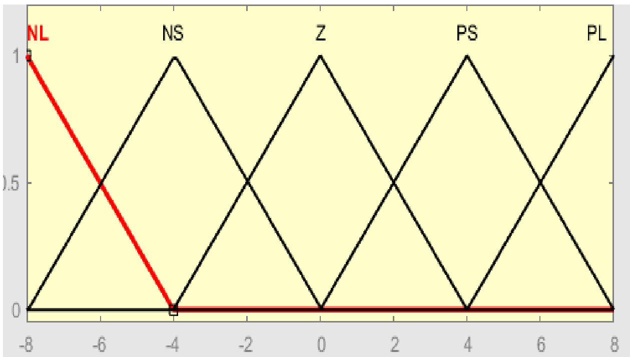

Figure 2b. Error Derivative Input

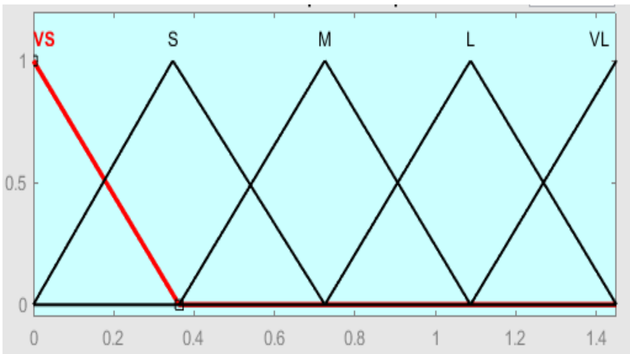

Figure 3. Kp Fuzzy Output

After defining inputs, outputs and their ranges, fuzzy control rules were defined based on if-then logic. Resulting rule table can be seen below.

Table 1. Fuzzy Rules

	NL	**NS**	**Z**	**PS**	**PL**
NL	M	L	VL	L	M
NS	S	M	L	M	S
Z	VS	S	M	S	VS
PS	S	M	L	M	S
PL	M	L	VL	L	M

4. Simulation Results

Main goal of the control systems is getting the quadcopter to desired position. This position was defined in three dimensional space as x = 10, y=5 and z=20. Error between these values and actual positions calculated by the model were given to PID controllers as an input. For Fuzzy-PID controllers, error and its derivative were given to Fuzzy system as an input.
After performing position control, angular velocities can be found from the simulation. Angular velocities are also necessary to find currents which are needed to supply to each motor. After simulation model was created, necessary outputs were sent to MATLAB workspace from Simulink and results were obtained for both controllers. Parameters used in this study can be seen from Table 4 at the appendix section (Lin et.al., 2016)

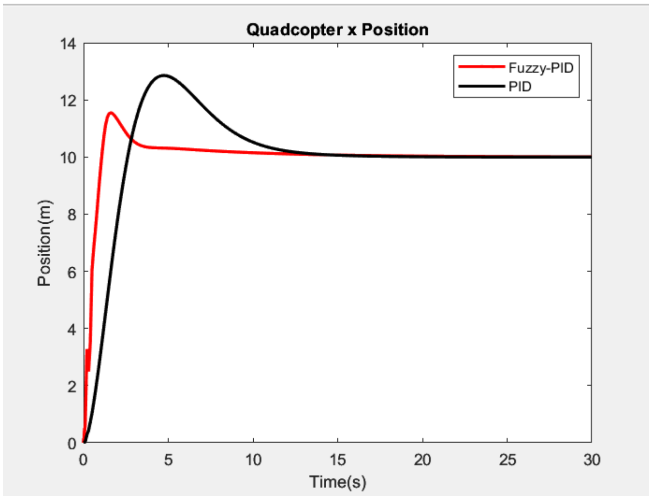

Figure 4. Quadcopter x Position

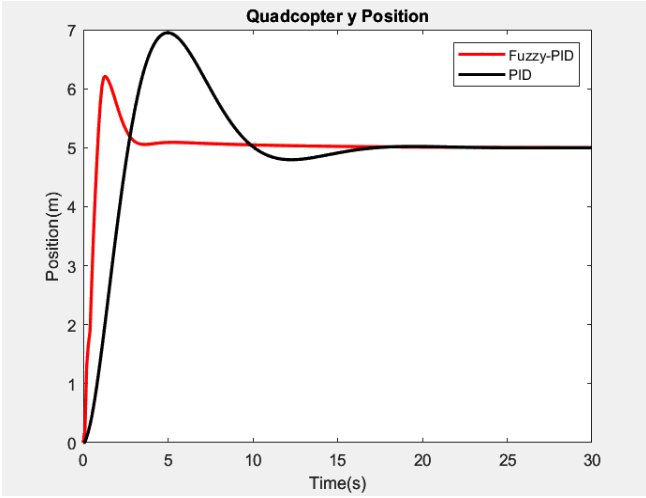

Figure 5. Quadcopter y Position

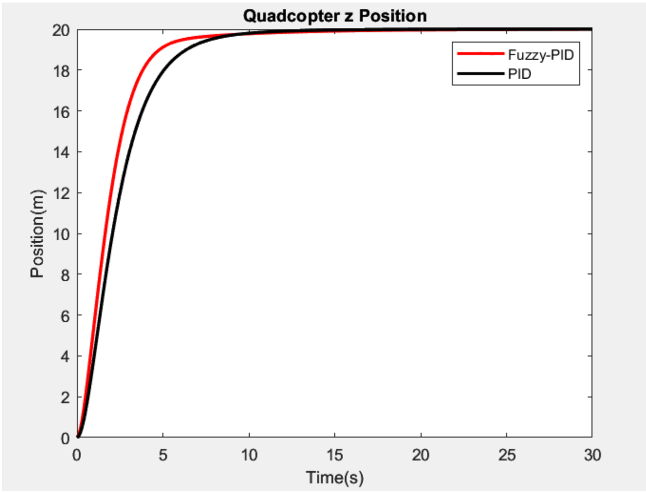

Figure 6. Quadcopter z Position

Figure 4 is the quadcopter's position at x axis. U_2 controls the quadcopter's position at this axis. Quadcopter's position at y-axis is controlled with U_3 which can be seen in figure 5 above. Figure 6 shows the quadcopter altitude control. Both desired roll and pitch angles were calculated from the simulation before finding U_2 and U_3. As can be seen from the figures 4,5 and 6, calculating PID gains with Fuzzy logic increased the system's speed. Also, it had less overshoot than PID controllers. Actually, adaptive control is provided by Fuzzy logic with the time-dependent variation of the PID controller gains Kp, Ki and Kd.

Equations 23, 24, 25 and 26 were used to find angular velocities. Then, current values which are needed to supply to each motor were found by brushless DC motor equations.

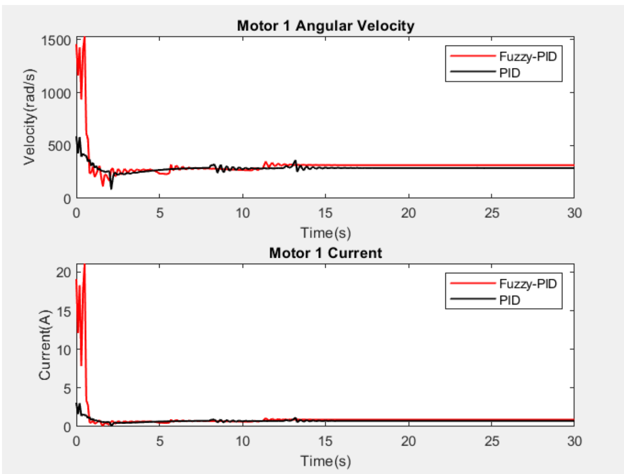

Figure 7. Motor 1 Velocity and Current

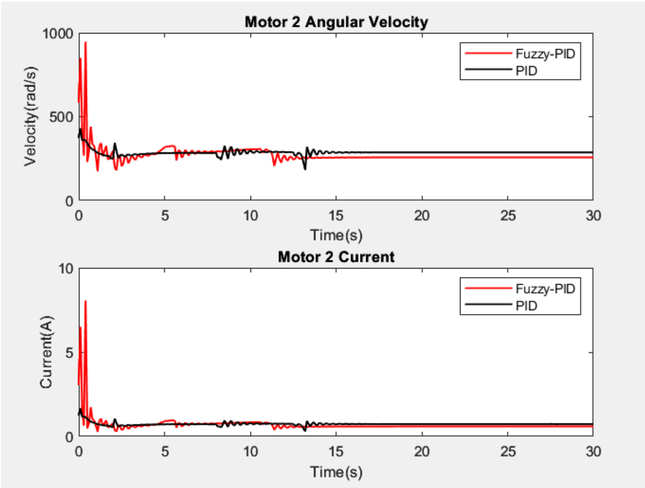

Figure 8. Motor 2 Velocity and Current

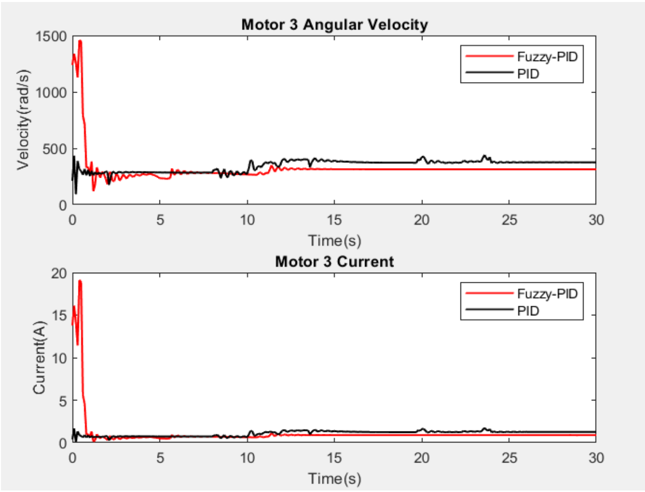

Figure 9. Motor 3 Velocity and Current

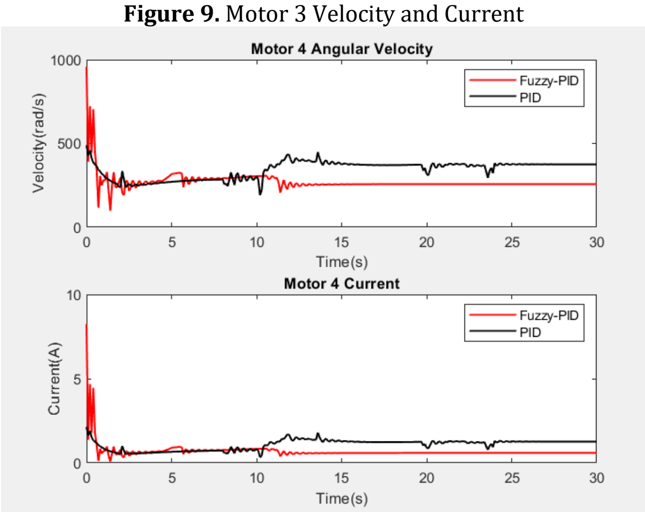

Figure 10. Motor 4 Velocity and Current

As a next step, some disturbances were applied to system to measure robustness of the proposed controllers. To compare the robustness of PID and Fuzzy-PID controllers, we added some effects for each direction. Firstly, in x and y directions 10 N extra force was applied to the system for 1.5 seconds. Applied disturbance can be seen below:

Figure 11. External Force

New results with disturbances can be seen below for both controllers in x and y directions.

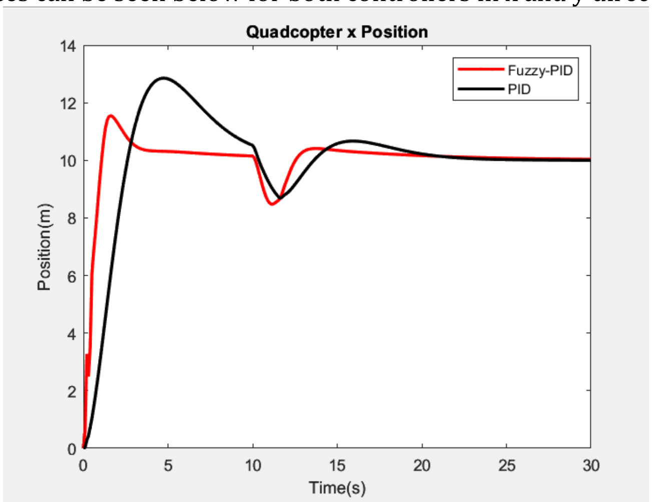

Figure 12. Quadcopter x Position with Disturbance

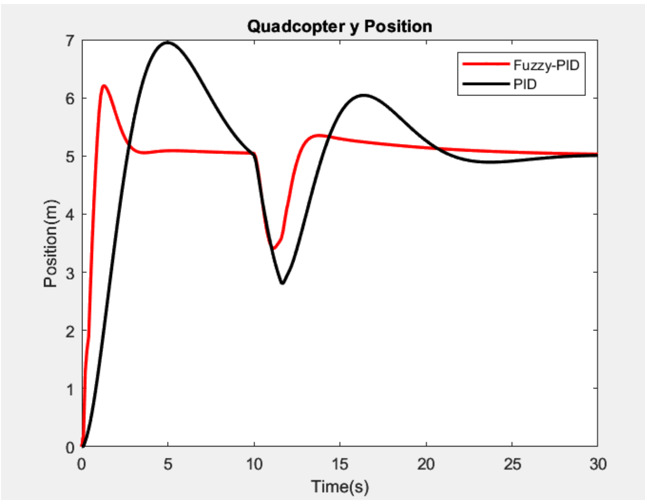

Figure 13. Quadcopter y Position with Disturbance

Figures 12 and 13 show the reaction of the controllers after external force application at 10th seconds. As can be seen, Fuzzy-PID controller was less affected by external disturbances. It also had faster response and recovered faster than PID controller. Fuzzy PID gave faster response since it is more robust than PID controller. It recovered faster with less overshoot and turned back to reference.

Secondly, to measure the performance of the controllers in z direction, mass of the quadcopter was increased from 1.05 kg to 1.8 kg at the 10th seconds. Mass increase did not create any effect on x and y directions.

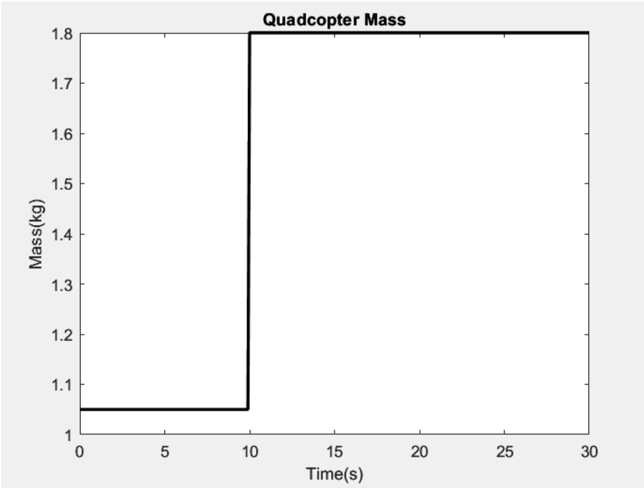

Figure 14. Mass Increase

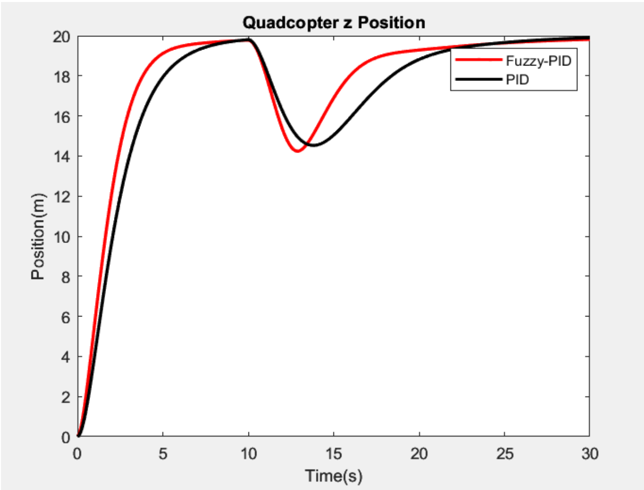

Figure 15. Quadcopter z Position with Disturbance

Similar behavior about the performance of the controllers can be seen also in figure 15. At 10th seconds, mass of the quadcopter was increased from 1.05 to 1.8 kg, Fuzzy-PID again adapted itself faster and tried to turn reference earlier than PID controller.

5. Conclusion and Discussion

In this study, PID and Fuzzy-PID control algorithms were developed to control position of the quadcopter in three-dimensional space. Firstly, simplified model for the quadcopter was selected and then free body diagram (FBD) of the model was obtained to find mathematical model of the quadcopter. Non-linear equations of motion were linearized before designing controller. Additionally, current values which must be supplied to each motor were calculated. DC motor can be selected by using this approach. Finally, some disturbances were added to model and robustness of the controllers was analyzed.

MATLAB and Simulink were used to simulate the system and obtain the results. Both controllers were implemented to the system in Simulink. PID parameters were found by trial and error method. In each trial, the model response was examined and the PID parameters were adjusted according to the system response. Increasing Kp caused more overshoot but less steady-state error. Kd was increased to control overshoot, also it helped system to adapt changes quicker, but increasing it too much caused unstability problem. Ki value was used to reduce steady-state error. With Fuzzy-PID, gains were automatically adjusted according to the system response and adaptive control of the system was achieved.

According to the results, quadcopter can reach the desired altitude without error but with some overshoot for both controllers. However, fuzzy-PID algorithm significantly increased the speed of the system, also this approach has less overshoot than traditional PID method. Position error table with respect to time can be seen in table 2 for both controllers.

Table 2. Position-Error Table

Time (s)	PID X Error (m)	Fuzzy - PID X Error (m)	PID Y Error (m)	Fuzzy - PID Y Error (m)	PID Z Error (m)	Fuzzy - PID Z Error (m)
0	10.00	10.00	5.00	5.00	20.00	20.00
1	6.89	0.45	3.62	-0.73	16.01	14.43
2	2.23	-1.31	1.32	-0.70	10.34	7.90
3	-1.09	-0.53	-0.58	-0.11	6.17	3.79
4	-2.60	-0.33	-1.65	-0.06	3.58	1.76
5	-2.83	-0.31	-1.95	-0.09	2.07	0.88
6	-2.42	-0.28	-1.73	-0.09	1.21	0.54
7	-1.81	-0.24	-1.25	-0.07	0.73	0.40
8	-1.25	-0.20	-0.74	-0.06	0.45	0.32
9	-0.82	-0.17	-0.31	-0.06	0.29	0.27
10	-0.52	-0.15	-0.02	-0.05	0.19	0.22
11	-0.33	-0.13	0.14	-0.04	0.13	0.18
12	-0.21	-0.11	0.20	-0.04	0.09	0.15
13	-0.14	-0.09	0.19	-0.03	0.07	0.13
14	-0.09	-0.08	0.14	-0.03	0.05	0.11
15	-0.06	-0.07	0.09	-0.02	0.04	0.09

Detailed investigation of angular velocities and current values of motor 1 can be seen in table 3 below for both controllers. They are also in acceptable level and also relationship between them seemed true, for higher speeds more current is needed. According to table 3, disadvantage of the fuzzy method is that it requires higher speed and current to reach desired position. Therefore, more powerful motor and battery is required to apply this method.

Table 3. Current-Angular Velocity Relation

Time (s)	PID Current (A)	PID- Angular Velocity(rad/s)	Fuzzy-PID Current (A)	Fuzzy- PID Angular Velocity(rad/s)
0	3.09	586.54	19.08	1457.22
1	1.03	337.82	0.81	299.39
2	0.58	254.74	0.25	165.36
3	0.50	236.44	0.62	262.55
4	0.56	249.65	0.67	273.55
5	0.65	268.39	0.49	234.39
6	0.70	278.99	0.87	310.51
7	0.73	285.00	0.68	275.68
8	0.73	285.97	0.71	281.96
9	0.80	298.72	0.68	274.58
10	0.67	272.34	0.64	267.80
11	0.73	284.43	0.66	271.68
12	0.73	284.65	0.82	302.58
13	0.83	304.61	0.91	317.42
14	0.70	278.23	0.90	316.70
15	0.77	291.88	0.89	314.21

Finally, results showed that both control algorithms have highly satisfying results. Simple PID controller can be used for such complex systems that have six degrees of freedom and it can be combined with Fuzzy logic to increase performance. Today, quadcopters are very popular, and definitely their popularity will increase in the future. Therefore researches about controlling them will increase, too. This paper presents two simple and efficient ways to control quadcopter's position and to find necessary motor capacity. This method is easy to understand and also apply to real systems. It can be combined with other control algorithms like Sliding Mode Controller (SMC), convolutional neural networks (CNN) etc. In summary, it shows the power of the PID controller and its efficiency even in complex systems.

Conflict of Interest

No conflict of interest was declared by the authors.

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Appendix

Table 4. Parameters

Parameter	Value
I_x	0.0175 kgm^2
I_y	0.0165 kgm^2
I_z	0.0035 kgm^2
L	0.72 m
b	3.13*10^{-5} Ns^2
d	3.13*10^{-5} Ns^2
g	9.81 m/s^2
m	1.05 kg
ρ	1.225 kg/m^3
A	1.55 m^2
K_v	0.01 V/rad/sec
K_t	0.01 Nm/A

Table 5. PID Parameters

	Altitude	**x**	**y**	**Roll**	**Pitch**
P	1.2	1.5	1.5	0.3	0.45
I	0.2	0.02	0.02	0.1	0.1
D	2	0.6	0.6	0.5	0.6

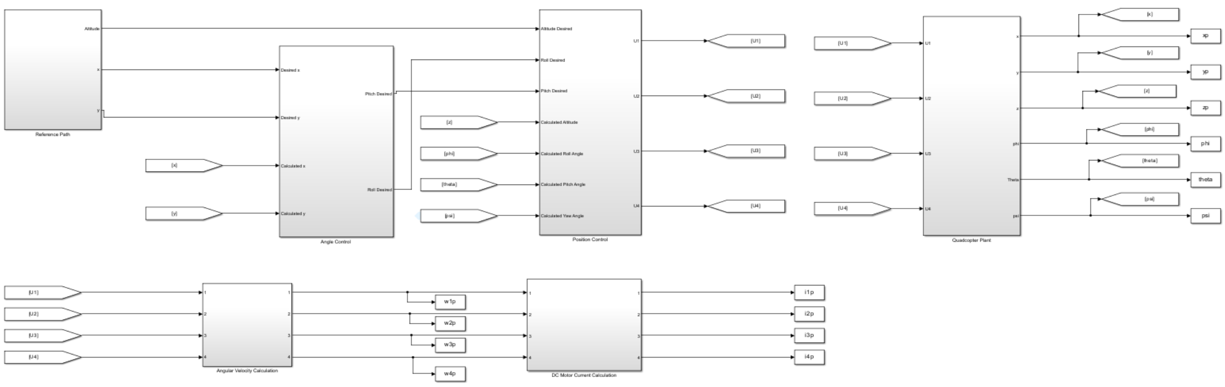

Figure 16. Simulink Model of the System