



Dynamic Modeling, Assembly and implementing Quadrotor UAV Using PID Controller

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(Manuscript Received --- 05 Jan. 2018; Revised --- 04 Apr. 2018; Accepted --- 16 Jul. 2018)

Abstract

In the past decade, paying attention to the vertical fliers has been noted by most of the scientist and researchers, because of their exclusive features. The special capabilities of these, reducing radar identifier, low risk for human life, no restrictions on size and uses such as photography, survey, press coverage, checking, power lines, meteorological analysis, traffic, monitoring, in urban areas, crops and poison, spraying products, controlling country boundaries, controlling illegal imports and exports, fire detection and control, search and rescue operations for missing people and natural disasters can be mentioned, which leads to the plenty of motives for researchers. Contains wide researchers and putting various topics in front of researchers. One of these fields is using various algorithms with the ability to use in their control system. Mainly, the PID controllers are reported by the researchers, but although the PID controller as a classic model has some restrictions, it has shown a good performance. In this research, with the aim of design and implement of extracted value from the Dynamic system to controller point of view first, the history of vertical fliers and quadrotor are discussed, in the following, the result of PID controller is implemented on a real robot and its sustainability is investigated then, through applying the route to the quadrotor, the controller performance of stability and chasing the path is evaluated in practice

Keywords: Robot, Quadrotor, PID Controller, Unmanned Flier, UAV (Unmanned Aerial Vehicle).

1-Introduction

In recent years, using quadrotor to do different things is increasing quickly. Height maneuverability low cost, reducing radar identifier, being ineffective, low risk for human life, and no restriction on size are the same factors which lead to being bold [1]. The quadrotor is an unmanned flyer with the frame designing in “X” and “H” shape. It is the subset of the multirotor group with 4 fans for propeller force, as a

quad (4), named “quadrotor” and with due attention to the frame and equipment’s, it is changeable. It is equipment has 4 operators or rotor at the end of each arm, with the symmetrical arms, same distance, and size in the structure. Turning even rotors on the contrary to each other are clockwise and counterclockwise [2].

Generally, quadrotor movement controlling is done by adjusting engine

velocity to control robot movement, 3 angles of “Roll”, “Pitch” and “Yaw” should be adjusted. And moving up is done but using speed adjustment in each rotor through pulse width modulation to access desired output.[3]. By using four rotors and propeller and also pairwise turn in opposite direction, quadrotors make neutral torque and it causes result force.[4][5]. Generally, the flier in the space can be considered as a free object with 6 degrees of freedom, which by using that, the position and situation consist of 3 linear and 3 rotational motions. Linear motions are included motion in the line of X-axis, motion in the line of Y-axis and motion in the line of Z-axis and also swift motions consists of rotating around X-axis(Roll), around Y-axis(pitch) and around Z-axis(Yaw).[4]

This paper described the system modeling and equation along with real parameter of Quadrotor extracted by the CATIA V5R21 software In Section II, and discuss the PID controller as the basic model to control the UAV in section III. Section IV included the Quadrotor assembly part and Hardware structure with controller extracted parameter extracted from Matlab implementation on quadrotor result .the paper ended with the result and discussion In Section IV,

2- System modeling

system modeling is containing cinematic and dynamic quadrotor, which is derived from Newton Euler equations. Checking the movement of quadrotor in space is required two coordinate systems. Inertia coordinate system (N E D) and frame coordinate system (X Y Z) [6].

Euler angles: to have the situation of quadrotor in the space, frame coordinate

system should be placed toward the ground coordinate system, the quadrotors position in the space can be described by its location vector, but for describing its orientation in the space, required to introduce Euler angles. These angles of rotation defined in the following:

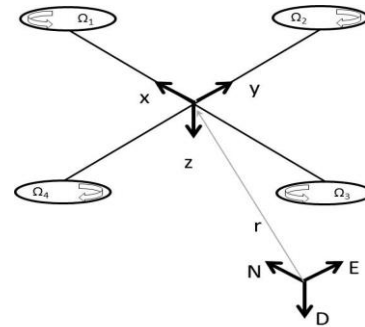


Figure 1 cinematic Model of the Quadrotor body

Φ : Roll angle (rotating around X-axis)

Θ : Pitch angle (rotating around Y-axis)

Ψ : Yaw angle (rotating around Z-axis)

In order to get system dynamic model, in the form of state space model, the state variable is considered as $\dot{X} = f(X,U)$ which is U is an indicator of input vectors system and X is stated variables vector. (According to the equations 1)

$$X = [\phi \ \dot{\phi} \ \theta \ \dot{\theta} \ \psi \ \dot{\psi} \ z \ \dot{z} \ x \ \dot{x} \ y \ \dot{y}]^T \quad (1)$$

$$U = [U_1 \ U_2 \ U_3 \ U_4] \quad (2)$$

2-1 State space model: Finding state space model system is a great help to make the easy design of controller and it is required of defining x state variable and corresponding elements

$$X = [x_1 \ x_2 \ x_3 \ x_4 \ x_5 \ x_6 \ x_7 \ x_8 \ x_9 \ x_{10} \ x_{11} \ x_{12}]^T \quad (3)$$

2-1-1 X variable state: state vector variable is defined in the form of the equation 3.[6]

Which robot degree of freedom is defined respectively in the form of the equation 4 [6].

$$X = [\phi \ \dot{\phi} \ \theta \ \dot{\theta} \ \psi \ \dot{\psi} \ z \ \dot{z} \ x \ \dot{x} \ y \ \dot{y}]^T \quad (4)$$

In equation 4, $x \ y \ z$ is the position of ϕ, θ, ψ Euler angles and their derivation which presenting the velocity of the component. State space vector is notable because of it is the ability to show position, angle and the linear velocity of the quadrotor.

2-1-2 Input variable of state vector:

Input variable of state vectors are included 4 input from u_1 to u_4 and it has shown in equation 5 [6].

$$U = [U_1 \ U_2 \ U_3 \ U_4] \quad (5)$$

According to equation 5, for each of the inputs, Equations 6 to 9 can be written:

$$U_1 = K_f(\Omega_1^2 - \Omega_2^2 + \Omega_3^2 - \Omega_4^2) \quad (6)$$

$$U_2 = K_f(\Omega_2^2 + \Omega_4^2) \quad (7)$$

$$U_3 = K_f(\Omega_1^2 - \Omega_3^2) \quad (8)$$

$$U_4 = K_M(\Omega_1^2 - \Omega_2^2 + \Omega_3^2 - \Omega_4^2) \quad (9)$$

In the above equation, K_f is the aerodynamic power, K_M is fixed torque and Ω is the angular velocity of rotors. At the end. Dynamic equation of system is defined as following such as equation 10 to 15 [6].

$$\ddot{\phi} = \frac{1}{I_{xx}} U_2 - \frac{J_r}{I_{xx}} \dot{\theta} \Omega_r + \frac{I_{yy}}{I_{xx}} \dot{\psi} \dot{\theta} U_2 - \frac{I_{zz}}{I_{xx}} \dot{\theta} \dot{\psi} \quad (10)$$

$$\ddot{\theta} = \frac{1}{I_{yy}} U_3 - \frac{J_r}{I_{yy}} \dot{\phi} \Omega_r + \frac{I_{zz}}{I_{yy}} \dot{\phi} \dot{\psi} - \frac{I_{xx}}{I_{yy}} \dot{\psi} \dot{\phi} \quad (11)$$

$$\ddot{\psi} = \frac{1}{I_{zz}} U_4 - \frac{I_{xx}}{I_{zz}} \dot{\theta} \dot{\phi} + \frac{I_{yy}}{I_{zz}} \dot{\phi} \dot{\theta} \quad (12)$$

$$\ddot{x} = \frac{-U_1}{m} (\sin \phi \sin \psi + \cos \phi \cos \psi \sin \theta) \quad (13)$$

$$\ddot{y} = \frac{-U_1}{m} (\cos \phi \sin \psi \sin \theta - \cos \psi \sin \phi) \quad (14)$$

$$\ddot{z} = g - \frac{-U_1}{m} (\cos \phi \cos \theta) \quad (15)$$

Which is mentioned equations, J_r is rotor torque, I_{xx}, I_{yy}, I_{zz} are the torque region of inertia in the major pivot of the frame, $\dot{\phi} \ \dot{\theta} \ \dot{\psi}$ velocity and $\ddot{\psi} \ \ddot{\phi} \ \ddot{\theta}$ is the instant momentum of Euler angles [6]. With attention to required parameters by physical simulation of quadrotor in CATIA software, some of the quadrotor parameters are calculated and rest of parameters are estimated from comparing and evaluating other articles with similar articles, which has shown at TABLE 1.

TABLE 1 Quadrature parameters tested

NO	Parameters	Content	Unit
1	I_{xx}	5.49×10^{-4}	$kg \ m^2$
2	I_{yy}	5.49×10^{-4}	$kg \ m^2$
3	I_{zz}	8.28×10^{-4}	$kg \ m^2$
4	I_{rotor}	5.51×10^{-5}	$kg \ m^2$
5	m	0.620	kg
6	b	2.9×10^{-5}	$N \ s^2$
7	l	0.14	m
8	d	1.1×10^{-6}	$N \ m \ s^2$
9	g	9.81	$M \ s^{-2}$

As is shown in TABLE 1 I_{XX} is the moment of inertia around the X-axis, I_{YY} is the moment of inertia around the Y-axis, I_{ZZ} is the moment of inertia around the Z-axis, I_{rotor} is the moment of inertia around the motor axis, m is the weight of motor, b is the propeller result force index, d is the propeller counterpoise index, g is the earth gravitational force, to control the above parameters PID controller has used.

3- PID controller

PID controller belongs to the group of that controller based on the feedback, which considering the simple structure and resistant performance of this kind of controller, it is design and implementation is very common.[7]one of the big challenges of pilots in the flier robots, is finding the proper PID index with the physical condition of the quadrotor. Most of the pilots use the false and true method to the robot. So, finding the PID index is important.[8].

Equation 16 is the general equation of PID controller which K_p is proportional gain, K_d is derivative gain and K_i is integrator gain.[9]

$$U(t) = K_p e(t) + K_i \int e(t) dt + K_d \frac{de(t)}{dt} \quad (16)$$

TABLE 2 SPECIFICATIONS OF QUADROTOR COMPONENTS

NO	Components quadrotor	Model
1	Airframe	Tarot TL280H[14]
2	Motor	Air 2205 2000KV
3	Propeller	10 * 4.5 mm
4	Control board	ArduPilot APM 2.8[15]
5	GPS	Ublox NEO-7M[16]
6	telemetry	433 HZ[17]
7	Speed control	T-Motor Air 15A[18]
8	Radio transmitter	TX: NET-Q118G[19]
9	Radio receiver	RG831B, 8ch 2.4GHz[19]
10	battery	PULSE 2250mAh 3S LiPo Battery[20]

According to the equation 5, control input, the quadrotor PID controller, is defined as equation 17 to 20.[10][11]

$$U_1 = \frac{m(g + K_{pz}E_z + K_{dz}(\dot{E}_z) + K_{iz} \int E_z)}{\cos \phi \cos \theta} \quad (17)$$

$$U_2 = (K_{p\phi}E_\phi + K_{d\phi}(\dot{E}_\phi) + K_{i\phi} \int E_\phi) \quad (18)$$

$$U_3 = (K_{p\theta}E_\theta + K_{d\theta}(\dot{E}_\theta) + K_{i\theta} \int E_\theta) \quad (19)$$

$$U_4 = (K_{p\psi}E_\psi + K_{d\psi}(\dot{E}_\psi) + K_{i\psi} \int E_\psi) \quad (20)$$

In the above equations, parameters K_p , K_{dz} , K_{iz} respectively are controlled proportional, integrator and derivated gain, in height control. the indexes of $K_{p\phi}$, $K_{d\phi}$, $K_{i\phi}$ are control gains

to control ‘Roll’, $K_{p\theta}$, $K_{d\theta}$, $K_{i\theta}$ is controlled gains to control ‘Pitch’, $K_{p\psi}$, $K_{d\psi}$, $K_{i\psi}$ are control gains to control ‘Yaw’[12][13].in this research, the PID parameters are extracted with the help of Matlab simulation and shown in TABLE 3.

TABLE 3: PID parameters tested

NO	Parameters	K_I	K_D	K_P
1	Pitch	0.8	1.5	97
2	Roll	0.2	3.7	63
3	Yaw	0.1	4.8	43

4- Structure Assembly:

Making a quadrotor is required for the frame, motor, control system and energy resource and usually designing a quadrotor depends on it is an application, and each mentioned components are considered according to it. For example, for carrying weight from high watt power, motors and more energy consuming as well, a battery with high watt power is considered and for speed racing, the light H frame model with the small size is used. So based on the application, the physical designing is different. In this research, a sample of quadrotor, containing components of TABLE 2 have considered.



Figure 2: Quadrotor Model made

In order to the implementation of data, software ‘mission planner’ is an open source software, use the windows os, which is installed on the computer system in the ground station to set flight control and select the route, by this software.[21][22]. Setting states of the software mission planner are describing in the following:

- 1) Selecting kind of robot frame
- 2) Accelerometer calibration.
- 3) Compass calibration.
- 4) Board and power supply selection
- 5) Radio calibration
- 6) Reference route selection

4-1 Reference route selection for quadrotor:

4-1-1 first stage: Setting the start point position: the start point position, is a location, where the robot is ready to fight it means if ‘RTL’(Return To Launch)has been considered, the robot will return to start point.

4-1-2) second stage: setting route point: to set the route point in drop down menu of flight plan window, the desired command(point, height) can be set the PID indexes in mission planner software, challenging routes such as circle and spline has designed and tested in real, which results of real tests, can be observed in Figure 3 and 4 .



Figure 3 Circle path



Figure 4 spline path

The result of experiments in a circular (figure 3) and spline (figure 4) shows that in spite of some problems such as GPS module error about 4 meters, disconnection of the signal from telemetry module and system disturbance through wind, the robot has a good function to follow the route. In these, according to the weather station site, the wind speed was almost 7 km/h and robot moved up with the maximum height of 15 m. The error of tracking path in practical test eighth the use of mission planner software has shown in TABLE 4

TABLE 4 Tracking error in test outdoor

NO	Path Name	Error
1	circle	14.74%
2	spline	11.30%

5-Conclusion

In the research, by using Newton Euler method, the dynamic of quadrotor and system state equation described. For quadrotor controlling, a PID controller model has designed. The simulation of the designed model has done in Matlab software and quadrotor stability parameters have tested. Then the real quadrotor has made and robot operation in circular and spline path has studied at the end, the robot operation has less mistake which this

variance can be because of sending data (telemetry) and GPS. In general, we can say considering the PID index of the system has a proper operation instability and resource route chase. Even the PID controller has the complete response and results on the Quadrotor platform but it seems using the meta-heuristic algorithms may make the PID parameter Tuning better which will use in the future work of this research.

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