

Altitude Controller Design for Quadcopter UAV

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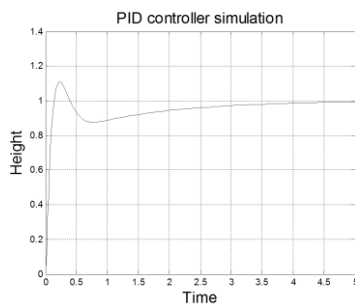
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Graphical abstract



Abstract

This paper discusses on attitude control of a quadcopter unmanned aerial vehicle (UAV) in real time application. Newton-Euler equation is used to derive the model of system and the model characteristic is analyzed. The paper describes the controller design method for the hovering control of UAV automatic vertical take-off system. In order to take-off the quadcopter and stable the altitude, PID controller has been designed. The scope of study is to develop an altitude controller of the vertical take-off as realistic as possible. The quadcopter flight system has nonlinear characteristics. A simulation is conducted to test and analyze the control performance of the quadcopter model. The simulation was conducted by using Mat-lab Simulink. On the other hand, for the real time application, the PCI-1711 data acquisition card is used as an interface for controller design which routes from Simulink to hardware. This study showed the controller designs are implemented and tuned to the real system using Real Time Windows Target approach by Mat-Lab Simulink.

Keywords: Quadcopter modelling; altitude control; helicopter test; PID controller; UAV multi rotor

Abstrak

Kertas ini membincangkan berkaitan kawalan ketinggian bagi Quadcopter UAV dalam aplikasi masa sebenar. Persamaan Newton-Eular digunakan untuk mendapatkan matematik model bagi sistem quadcopter dan ciri-ciri model dianalisis. Kertas ini menghuraikan kaedah rekaan kawalan terbang bagi automatik UAV berlepas dan mendarat secara menegak. Untuk memastikan sistem quadcopter berlepas dalam keadaan stabil, kawalan PID direka. Skop kajian merangkumi pembinaan kawalan ketinggian sistem berlepas menegak yang sesuai bagi quadcopter. Sistem penerbangan quadcopter adalah tidak linear. Satu simulasi dilakukan untuk menguji dan menganalisis prestasi kawalan bagi model quadcopter. Simulasi tersebut dilakukan dengan menggunakan Mat-Lab Simulink. Selain daripada itu, untuk aplikasi masa sebenar, PCI-1711 DAQ digunakan sebagai perantara untuk kawalan di mana menghubungkan antara Simulink kepada peranti luar. Kajian ini menunjukkan rekaan kawalan diimplimentasi dan ditala supaya sesuai kepada aplikasi RTWT dari Mat-Lab Simulink.

Kata kunci: Memodel quadcopter; kawalan ketinggian; ujian helicopter; pengawal PID, UAV quadcopter

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1.0 INTRODUCTION

The Unmanned Aerial Vehicle (UAV) robot has gained demand on the worldwide markets. There are two types of UAV which is fixed wing and rotary wings. Nowadays, one of the most popular rotary wings UAV is quadcopter. It has more advantages in term of their capability to take off and landing in vertical condition. In addition, it has good mobility, simple mechanics, and ability on load capacity.¹⁻³

The studies in quadcopter UAV modeling and control have been increasing rapidly recently. A number of examples of these studies can be summarized as follows; A. Bourbon modeled using the force moment balance and simulate a small quadcopter model using Mat-lab Simulink.⁴ Bora Erginer et al. also done the quadcopter modeling and simulate PD control of a quadcopter

using vision to estimate relative position.⁵ Tommaso Bresciani modeled a quadcopter using Newton -Euler method and PID control algorithms were compared in 3D graphic simulation.⁶

Development of autonomous UAV has been growing fast as it is more reliable in applications. The system can be categorized into three types, i.e. automatic landing system, automatically take off system, and the automatic navigation system.

An automatic landing system requires landing the quadcopter safely. Safe landing is much more critical which is the uncontrolled decrease of motor speed which affects the body drop drastically and leads to unsafe landing.

The automatic take-off system used to initiate the UAV begin to fly from the ground autonomously. The system should ensure the height of quadcopter in a consistent condition. In this case, each four motor propeller must produce a force against the

gravitational force and able to lift the quadcopter. The better performance of automatic vertical take off system indicates how fast the quadcopter achieves its desired altitude in steady state. The performance of the system also signifies how smooth it maintains the height of quadcopter.

In regards to hovering control of quadcopter UAV, several results can be found in previous research work. For example, in E. Abbasi, the fuzzy PID had been proposed to adjust the PID gains automatically when the prescribed altitude is changed.⁸ However, the proposed method cannot be possible to be implemented practically as the method assumed zero delay every time the PID is tuned. Meanwhile, the authors in Anil Guclu (2012) presented the PID control for altitude control experimentally. The xPC Target is used to link between Matlab/Simulink and quadcopter. The PID controller is tuned as $K_p=0.06$, $K_i=0.5$, $K_d=1.6$ with the payload of quadcopter is 2kg, the system takes 7second to reach a 30cm reference altitude.

This paper described a method to design Quadcopter altitude control system for 100cm from the ground. Detailed model of the quadcopter is given. The PID controller designed will be implemented in real time model by using real time windows target approach.

Contents of this paper are as follows: In section 2, the basic theory of the quadcopter is explained. The mathematical model derivation is explained in section 3 and it is continue to 6 degree of freedom equations using Newton-Euler equation in section 4. The physical parameter determination are presented in section 5.

2.0 PROBLEM STATEMENT

2.0 BASIC THEORY

Quadcopter can be modeled as a 4 motor thruster on a crossed rigid body. Each motor has the same specification of the propeller to make the air flow that produces the pressure downward until the lift force on body created. The body frame is designed in symmetry to simplify the model of quadcopter. In a quadcopter system, only the speed of the motor is controlled. The trajectory that is produced by the system only based on the speed of motor propeller.¹⁰ Based on Figure 1, each motor produces a force (F) and torque (τ). Each motor speed varies to determine the movement of roll, pitch or yaw.¹¹

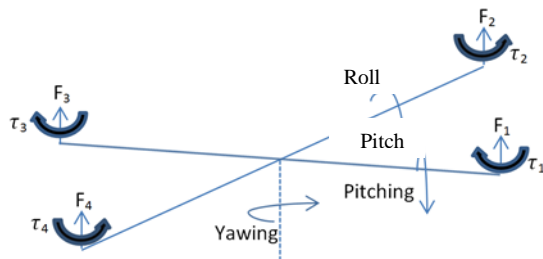


Figure 1 Quadcopter system

Table 1 shows the move Yaw racteristic that is produced by the change of motor speed. The minimum speed of hover (Ω_H) is used as reference. The increment ($+\Delta\Omega$) or decrement ($-\Delta\Omega$) of the speed is same to produce the balance thrust of the moment.

Table 1 Movement characteristic

Moment	Direction	M ₁	M ₂	M ₃	M ₄
Thrusting	Up	$\Omega_H+\Delta\Omega$	$\Omega_H+\Delta\Omega$	$\Omega_H+\Delta\Omega$	$\Omega_H+\Delta\Omega$
	Down	$\Omega_H-\Delta\Omega$	$\Omega_H-\Delta\Omega$	$\Omega_H-\Delta\Omega$	$\Omega_H-\Delta\Omega$
Roll	Right	Ω_H	$\Omega_H+\Delta\Omega$	Ω_H	$\Omega_H+\Delta\Omega$
	Left	Ω_H	$\Omega_H+\Delta\Omega$	Ω_H	$\Omega_H-\Delta\Omega$
Pitch	Forward	$\Omega_H-\Delta\Omega$	Ω_H	$\Omega_H+\Delta\Omega$	Ω_H
	Backward	$\Omega_H+\Delta\Omega$	Ω_H	$\Omega_H-\Delta\Omega$	Ω_H
Yaw	Clockwise	$\Omega_H-\Delta\Omega$	$\Omega_H+\Delta\Omega$	$\Omega_H-\Delta\Omega$	$\Omega_H+\Delta\Omega$
	Counter clockwise	$\Omega_H+\Delta\Omega$	$\Omega_H-\Delta\Omega$	$\Omega_H+\Delta\Omega$	$\Omega_H-\Delta\Omega$

3.0 QUADCOPTER FRAMES AND MATHEMATICAL MODEL

The physical model of quadcopter can be derived easily by assuming several physical conditions of quadcopter. This simplifies the system generated from the quadcopter dynamics. Some assumptions made in this model to consider the system in ideal cases:

- a. The body structure is rigid,
- b. The body frame structure is symmetrical,
- c. The propeller structure is a rigid,
- d. Thrust force and drag force is proportional to the speed of the propeller.

The inertial frame (E- frame) is a frame with coordinating base on fix earth coordinates, which refers to the center of gravity (linear quadcopter). The body fixed frame (B- frame) is based on the body frame of quadcopter. These frames are pointing at the center of mass of the quadcopter body (angular velocity quadcopter). These two frames are used as references for 6 degrees of freedom (DOF) rigid body equations. The equations express the dynamic of the system with respect to a composed linear quadcopter based on E-frame and angular quadcopter based on B-frame.¹² Figure 2 shows the rotation about each axis to produce three basic attitudes of roll(ϕ), pitch(θ), and yaw(ψ) movement of quadcopter.

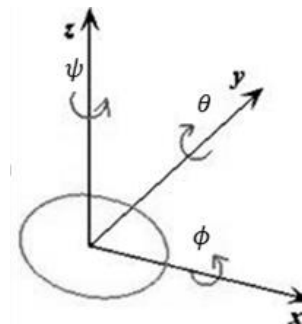


Figure 2 Roll, pitch, and yaw rotation

The roll equation is given about the rotation of the x axis:

$${}^0_0(\phi) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix} \quad (1)$$

The pitch equation is given about the rotation of the y axis:

$${}^0_1(\theta) = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \quad (2)$$

The yaw equation is given about the rotation of the z axis:

$${}^0_2(\) = \begin{bmatrix} \cos & \sin & 0 \\ -\sin & \cos & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (3)$$

To find the Euler angles from translation of ϕ , θ , and ψ , the transformation from the inertial frame to the body frame is made. The rotation matrix matrix as follows:

$$\begin{pmatrix} \phi \\ \theta \\ \psi \end{pmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos & \sin \\ 0 & -\sin & \cos \end{bmatrix} \begin{bmatrix} \cos & 0 & -\sin \\ 0 & 1 & 0 \\ \sin & 0 & \cos \end{bmatrix} \begin{bmatrix} \cos & \sin & 0 \\ -\sin & \cos & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (4)$$

is the transpose of , hence the transformation matrix is as follows:

$$= \begin{bmatrix} - & + \\ + & - \end{bmatrix}$$

4.0 6 DOF EQUATIONS WITH NEWTON-EULER EQUATION.

6 degrees of freedom rigid body are required to represent the quadcopter movement system. Newton-Euler formalism is used to derive the quadcopter rigid body system. The general Newton-Euler equation used is as follows:

$$[\begin{smallmatrix} 3 \times 3 \\ 0_{3 \times 3} \end{smallmatrix}] [\] + [\begin{smallmatrix} \times () \\ \times () \end{smallmatrix}] = [\]. \quad (5)$$

Where m is mass, i inertia matrix, is linear acceleration, is angular acceleration, is angular velocity, is linear velocity, is force on quadcopter body frame, and is torque on quadcopter body. Hence, (3×3) is Mass identity matrix that can be written is as follows:

$${}_{3 \times 3} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix};$$

and ($\)$ is 3 dimension inertia matrixes (x, y and z). Since the quadcopter designed in symmetric, inertia matrix can be written by assume = = = 0, therefore:

$$= [\begin{smallmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{smallmatrix}] = [\begin{smallmatrix} 0 & 0 \\ 0 & 0 \end{smallmatrix}]. \quad (6)$$

The second group matrix in general Newton-Euler equation is about Coriolis-Centripetal matrix. The Coriolis only affect from the angular velocity vector ($\)$ for the body fix frame only. Thus, value of linear velocity quadcopter (V) in body fix frame is equal to zero. Hence, we have:

$$[\begin{smallmatrix} \times () \\ \times () \end{smallmatrix}] = [\begin{smallmatrix} 0_{3 \times 3} & 0_{3 \times 3} \\ 0_{3 \times 3} & - () \end{smallmatrix}]. \quad (7)$$

Angular velocity vector ($\)$, in view of angular velocity components of the quadrotor can be written as:

$$= [\] = [\]. \quad (8)$$

Then, to derive 3D angular velocity vector, skew-symmetric technique is applied. The result is as follows:

$$[\begin{smallmatrix} \times () \\ \times () \end{smallmatrix}] = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad (9)$$

On a body of quadcopter, force ($\)$ and torque ($\)$ vector affected by gravitational, gyroscopic and main input vector.¹³ First contribution is the gravity force (G) where it is only changing to the quadcopter linear only. The gravity force is effected of the vertical (z) vector. The gravity force being opposite to the thrust force. So the gravitational vector can write as shown below:-

$$= \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \quad (10)$$

Second contribution is the gyroscopic effects which come from the torque generated by each of the motor propeller's rotation. To avoid the gyroscopic effects, speed of the 4 motors must be balanced algebraic sum which is the two of the motors rotates clocwise and another two motor rotate counter clockwise. However the gyroscopic effects are used to produce yawing movement. In another case, when the motor speed is varied for others movement, such as rolling and pitching, an undesirable gyroscopic effect also produced. In that case, only the angular velocity part is involved is as the expression below:-

$$= \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad (11)$$

Where;

$$= [\ 1 \ 2 \ 3 \ 4] .$$

The third contribution of the force and torque vector is a main input vector of the system. The aerodynamic theories determine that both force and torques change linearly to the squared propeller velocity. Hence, the mathematic model of the motor propeller required. There are two aerodynamic parameters included in this system which is the thrust vector and drag factor that produced by each propeller. For quadcopter movement system, only has 4 basic movement vector, where is U_1 is the total force produced by 4 motor propellers. U_2 represents the rolling torque produced by the velocity of motor 4 and motor 2. U_3 refers to the pitching torque produced by the velocity of motor 3 and motor 1. U_4 is about the yawing torque.

$$\begin{aligned}
 & \begin{bmatrix} 1 \\ 1 \\ 1 \\ 2 \\ 3 \\ 4 \end{bmatrix} = \begin{bmatrix} (\frac{2}{1} + \frac{2}{2} + \frac{2}{3} + \frac{2}{4}) \\ (\frac{2}{1} + \frac{2}{2} + \frac{2}{3} + \frac{2}{4}) \\ (\frac{2}{1} + \frac{2}{2} + \frac{2}{3} + \frac{2}{4}) \\ (\frac{2}{4} - \frac{2}{2}) \\ (\frac{2}{3} - \frac{2}{1}) \\ [(\frac{2}{2} + \frac{2}{4} - \frac{2}{1} - \frac{2}{3})] \end{bmatrix} \quad (12)
 \end{aligned}$$

The input τ_1 affects will be transformed into three linear vectors through the transformation matrix T . The product of main input can be derived in matrix form. The input τ_2 is used to generate rolling movement, while τ_3 and τ_4 is used to generate pitching and yawing movement. τ_1 In this system, in term of thrust force, while τ_2, τ_3, τ_4 represent of torque to produce the movement.

$$\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}_{3 \times 3} \begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \\ \tau_4 \end{bmatrix} = \begin{bmatrix} (s i n \beta i n + c o s \beta i n o s) \tau_1 \\ (- \tau_2 + \tau_3) \tau_1 \\ \tau_2 \\ \tau_3 \\ \tau_4 \end{bmatrix} \quad (13)$$

Thus the generalized acceleration vector can be summarized as following:-

$$\begin{bmatrix} \ddot{\alpha} \\ \ddot{\beta} \\ \ddot{\gamma} \end{bmatrix} = \begin{bmatrix} 0_{3 \times 3} & 0_{3 \times 3} \\ 0_{3 \times 3} & 0_{3 \times 3} \end{bmatrix}^{-1} \left(\begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \\ \tau_4 \end{bmatrix} + \begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \\ \tau_4 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \\ \tau_4 \end{bmatrix} - \begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \\ \tau_4 \end{bmatrix} \times \begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \\ \tau_4 \end{bmatrix} \right) \quad (14)$$

The quadcopter model can be simplified to make the system easy to analyze. Since the change of roll and pitch angle is too small compared to the hovering angle, the change of angular velocity value can be assumed as zero. Hence, quadcopter angular velocity of E-frame equal to the angular velocity for B-frame. Another term to be simplified is Coriolis effect, because it is too small to obtain. Thus the model will be simplified as follows:-

$$\begin{aligned}
 & = (s i n \beta i n + c o s \beta i n o s) \tau_1 \\
 & = (- \tau_2 + \tau_3) \tau_1 \\
 & = - \tau_2 + (\tau_3) \tau_1 \\
 & = \tau_2 \\
 & = \tau_3 \\
 & = \tau_4
 \end{aligned} \quad (15)$$

Where;

$$\begin{aligned}
 \tau_1 & = (\frac{2}{1} + \frac{2}{2} + \frac{2}{3} + \frac{2}{4}) \\
 \tau_2 & = (- \frac{2}{2} + \frac{2}{4}) \\
 \tau_3 & = (- \frac{2}{1} + \frac{2}{3}) \\
 \tau_4 & = (- \frac{2}{1} + \frac{2}{2} - \frac{2}{3} + \frac{2}{4})
 \end{aligned} \quad (16)$$

5.0 PHYSICAL PARAMETER DETERMINATION

After deriving quadcopter model equations, its practical parameters have to be identified. The parameter are; the acceleration of gravity (g); mass (m) of quadcopter body and; inertial (I) parameters.¹⁴ There are three inertia parameters of

movements i.e. rolling due to x-axis, pitching due to y-axis and yawing due to z-axis.

5.1 Moment of Inertia

There are 2 methods to determine inertia parameter which use moment of inertia calculation and by bifilar pendulum experiment. This paper focuses on the bifilar pendulum experimental method. Figure 3 shows the bifilar pendulum system for measuring the value of inertia.

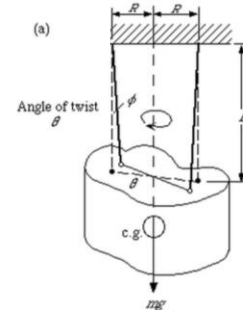


Figure 3 Bifilar pendulum test¹⁵

In bifilar experiment, two ropes are used to string up the quadcopter body, next the quadcopter body is held at a certain degree by hand, and then it is released. Due to the tension of the rope, the system is swung about the vertical axis of the system. The inertia can then be calculated with bifilar equation.¹⁵

$$I = \frac{2 L^2}{4 T^2} \quad (17)$$

Where m is the mass of quadcopter body in kilogram, g is the acceleration due to gravity in m/s², T is period of swing in 1 cycle (s) from inertia measurement unit (IMU) data, b is the radius between the rope point in meter and L is the rope length in meter. In this work the quadcopter design is symmetrical. Hence the inertia for rolling is the same as that for pitching movement. Table 2 is about the value of each constant parameter in bifilar test.

Table 2 Constant parameter

Parameter	Value	Unit
	0.80	kg
	9.81	m/s ²
	0.20	m
	1.50	m

Table 3 shows the results for the moment of inertia. It consists of three rotation i.e. rolling, pitching and yawing rotation. All of them will be used in the control system design later.

Table 3 Moment of inertia value

Moment of inertia	Period per cycle (s)	Value (kgm ²)
I _x	1.40	0.0398
I _y	1.40	0.0398
I _z	1.85	0.0421

5.2 Thrust Force Factor

Thrust force factor can be determined using different 2 methods, one is by blade element theoretical calculation, and another is by force lift test experiment. In this paper, force lift test method is chosen, because the blade element analysis requires a lot of environmental and blade specification variables, and the experiment deals with real situation, hence the parameter can be much more reliable.¹⁶ Figure 4 shows the method to measure the relationship of force produced by the speed of propeller.

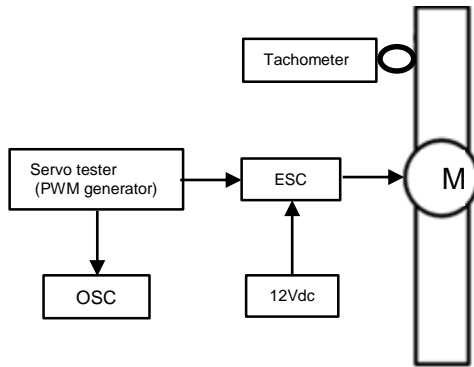


Figure 4 Lift test method for brushless motor

Electronic speed controller is used and triggered by PWM generator. Propeller speed will be determined with micro tachometer. The thrust force is recorded by changing the propeller speed.

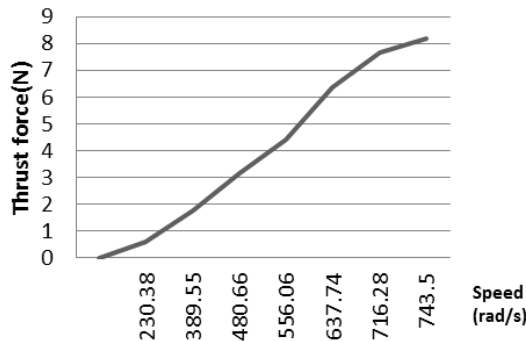


Figure 5 Force VS speed of propeller

Figure 5 shows the relationship between thrust forces produced by propeller speed. Theoretical aerodynamic has already proved that thrust force varies proportionally with squaring velocity. To define the constant values of the relationship, equation below is applied.

$$F = \frac{1}{2} \rho v^2 C_L A \quad \text{Thus; } C_L = 1.5 \times 10^{-5} \quad (18)$$

According to aerodynamic theory, drag factor depends on lift factor by a ratio $C_D = C_L \tan^2 \alpha$ where α is attack angle of propeller.¹³ The value of α equal to 15° , and drag factor is equal to $C_D = 4.0 \times 10^{-6}$.

6.0 ANALYSIS RESULTS

6.1 Open Loop Simulation

After obtaining each physical parameter from experiments, their values will be inserted into the model's equation. The system can be analyzed in simulation using Matlab. The behavior of altitude can also be observed in simulation. Base on the mathematical modeling, Figure 4 explains the altitude system which is used to analyze the behavior of quadcopter at certain propeller speed. The simulation setup is shown below.

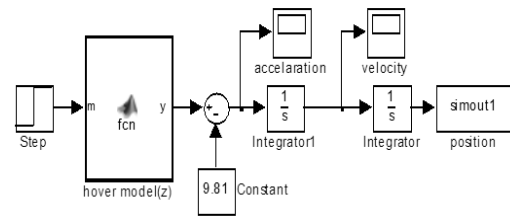


Figure 6 The altitude system simulates in Simulink

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

$$\dot{z} = \left(\frac{2}{1} + \frac{2}{2} + \frac{2}{3} + \frac{2}{4} \right) \quad (18)$$

The constants of quadcopter system which include the mass of the quadcopter (m) is 0.8 kg, the thrust factor (b) is 1.5×10^{-5} and the gravity acceleration (g) is 9.81. In this ideal case, roll and pitch angles are approximated to be zero. Figure 7.1 shows the positive changing of position for the speed of propeller at 400rad/s.

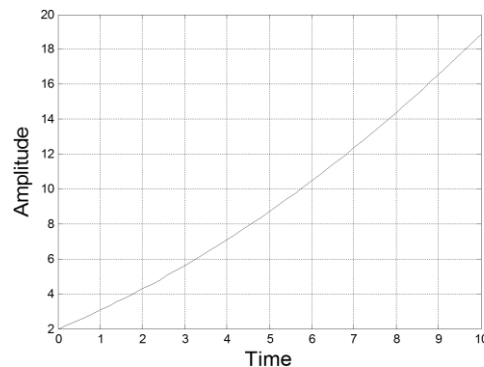


Figure 7.1 The position change when $\Omega=400\text{rad/s}$

Figure 7.2 shows the negative changing of position for the speed of propeller at 390rad/s.

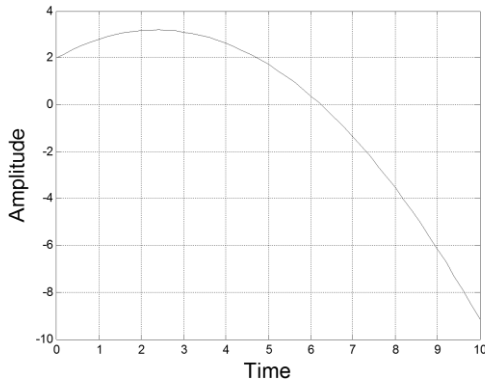


Figure 7.2 The position change when $\Omega=390$ rad/s

From basic movement concept, the speed is used to be the reference speed of each altitude control. The result shows the minimum speed of each motor to thrust the load of quadcopter body is $400 \text{ / } \text{,}$ for the payload of 0.8kg, and the thrust factor $1.5 \cdot 10^5$.

6.2 Closed Loop with PID Controller Simulation

The next step deals with designing the control system. The control system design will be tested in simulation using Simulink. The weakness and strength from each single proportional, integral and differential can be overcome by combining them together in parallel (PID). The parameters of the control system can be tested. Figure 8 shows the close loop PID controller setup for the testing.

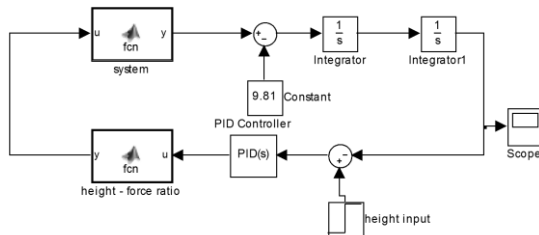


Figure 8 The altitude system with PID controller simulation

The simulation does not take hardware limitation into account. Saturation block can be used to declare output and input limitation in the system. Hence, simulation result can be more reliable to be implemented in real time application.

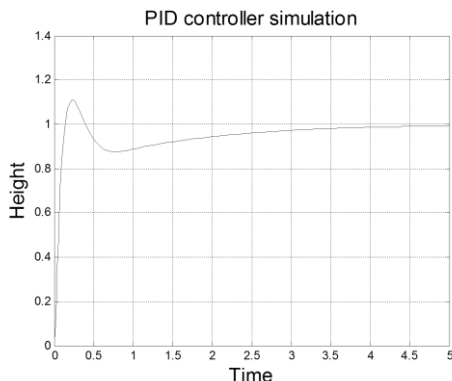


Figure 9 PID controller response

Controller parameters for PID; proportional = 50, integral = 30, derivative = 10 and filter coefficient = 100. The response shows the controller system takes 2 second to reach the target height of 1 meter.

7.0 REAL TIME WINDOWS TARGET

7.1 Real Time Execution

Creating a real-time application and using Simulink External mode, real-time workshop code generation software, real-time windows target software, and the open Watcom C/C++ compiler, to produce an executable file the kernel can run in real-time. This real-time application uses the initial parameters available for Simulink model at the time of code generation. Based on your selected sample rate, real-time windows target software uses interrupts to setup your application in real time at the proper rate. With each new interrupt, the executable file computes the entire block outputs from your model.

7.2 Input Section

For real time applications, the proximity sensor is required to detect the height in the control system. Infrared proximity sensors are suitable for this experiment. The sensors (Sharp GP2Y0A02YK0F) are capable of measuring the distance between 15cm to 150cm. The signal produced is in analog form. However, it is proportional to non-linear response. Therefore, analog voltage signal from the sensor response must be converted to distance scale in meters. Figure 9 shows the Simulink block set up for the proximity infrared sensor.

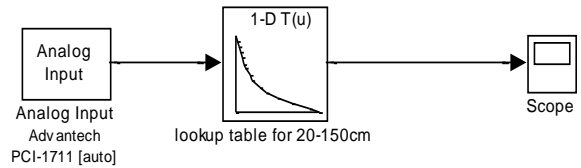


Figure 10 The infrared proximity sensor signal converter block

The lookup table block is used to convert the signal in term of voltage into height variable in meter. The configuration of the lookup table is same to the infrared proximity sensor signal specification. Figure 11 shows the lookup table block configuration.

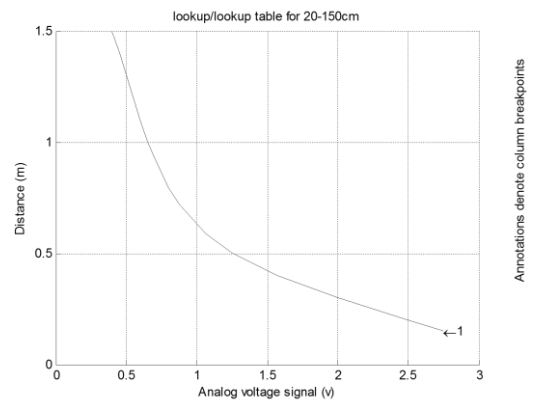


Figure 11 The look up table block data for infrared sensor

7.3 Output Section

The output of the system is a brushless DC motor (BLDC). Its rotation speed is controlled using an electronic speed controller (ESC) and it functions as motor driver. It is used to produce 3 phase DC supply for brushless DC motor. It is controlled by PWM signal for motor speed.

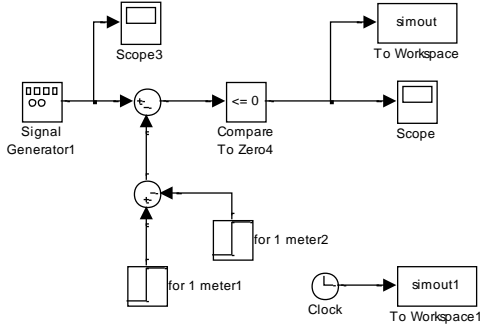


Figure 12 PWM signal generator block in Simulink

The frequency of the signal is fixed to 50 hz and the duty cycle varies in analog number. To test ESC in Simulink, PWM signal generator block need to be designed. The design is shown as figure 12. The signal frequency is fixed at 50 Hz and the duty cycle varies in term of analog number.

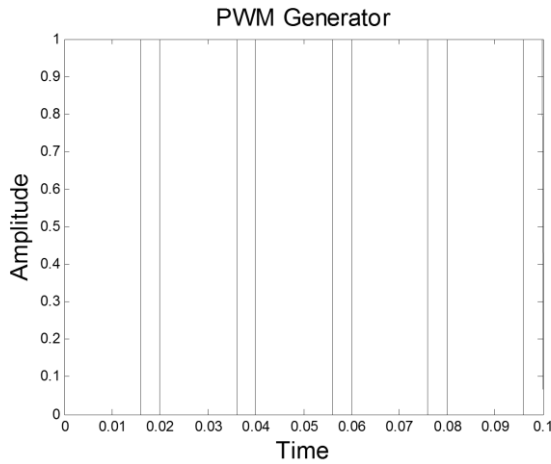


Figure 13 PWM signal. 50Hz duty cycle

ESC has to be calibrate first before to setting up the minimum and maximum PWM duty cycle for operation.

7.4 Altitude Control

The Altitude control system consists of three sections: the first one is the input, second is output and the third is control. PID control system parameters are taken from simulations performed in the previous session. Figure 13 shows the combined block to perform the controller in real-time application. This figure describes single output motor control. After the PID block, function block is used to convert the parameter of force that produced by the PID controller into motor speed variation in analog number. Switch block is used to initiate the ESC by providing a minimum signal value of 2s.

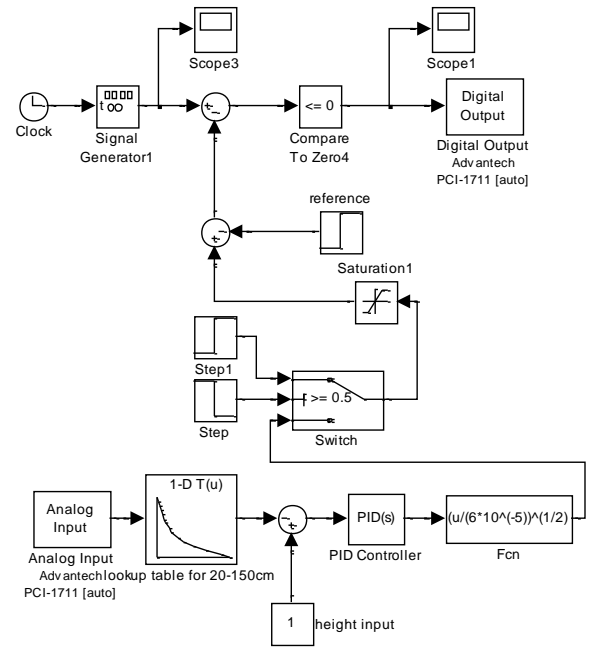


Figure 14 Altitude controls RTWT Simulink block

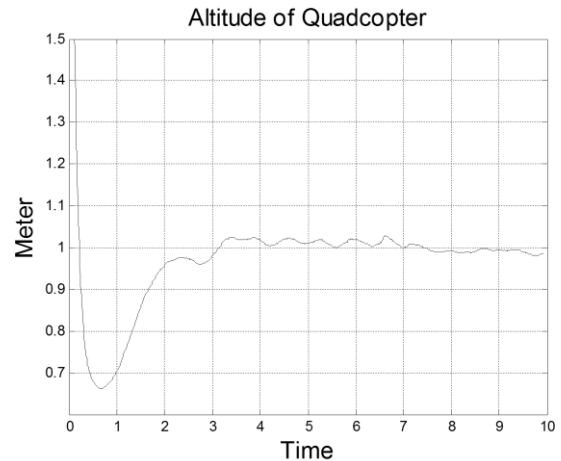


Figure 15 Altitude of quadcopter in meter

Figure 15 shows the result about high of quadcopter in meter due to time in second. Based on the result, the system are able to take off and control the altitude.

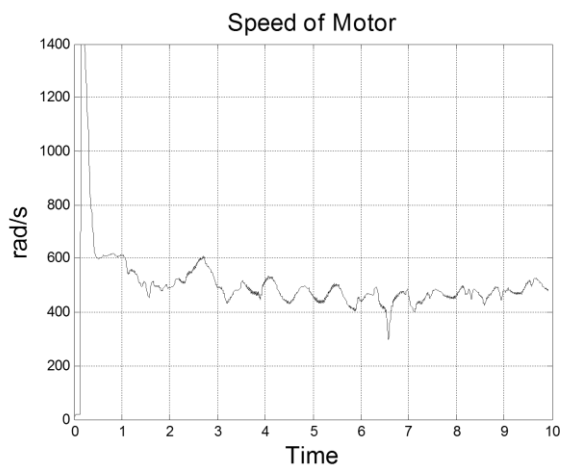


Figure 16 Speed of motor propeller in rad/s

Figure 16 shows the graph of speed of each motor propeller. The results show that speed of the motor when the system achieves 1 meter is more than 400rad/s.

8.0 CONCLUSION

The analysis of the altitude quadcopter system can be realized using relevant model description. The result of analysis helps others to start designing a controller that is compatible with the quadcopter system. Each model needs to be analyzed by undergoing simulation to understand the behavior of a system. The systematic procedure for the controller design of quadcopter design has been presented.

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