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EXPERIMENTAL VALIDATION OF AN ALTITUDE CONTROL FOR QUADCOPTER

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ABSTRACT

This paper discusses on the experimental validation of an Altitude control for quadcopter. The paper describes the analysis of automated altitude control for quadcopter in real time. The controller was designed by considering all the physical parameter that required in the mathematical model. The autonomous altitude controller has been designed using Mat-lab Simulink. The paper examines PID controller in implementation of automated altitude control for quadcopter. 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 experiment showed the controller designs are implemented and tuned to the real system using Real Time Windows Target approach by Mat-Lab Simulink. The proximity sensor is required to detect the height in the control system, and it requires some filter to stabilize the signal and make it reliable for their maximum distance measurement. Therefore a low pass filter will be designed for this purpose. All the result will be discussed.

Keywords: quadcopter modelling, altitude control, helicopter test, PID controller, UAV multi rotor.

INTRODUCTION

The study of the UAV Drone has become a requirement for each developed country with technology. UAV is divided into two types, namely fixed wing and rotary wings. Quadcopter is one of the most popular UAV rotary wings today. There are a lot of advantages of this robot with its ability to take off and landing in a vertical condition. Moreover, it has the advantage of good mobility, simple mechanics, and ability on load capacity.

According to a study of quadcopter model, it has a non-linear system, where the acceleration quadcopter for take-off is not directly proportional to the speed of the rotating propeller. The speed rotating propeller will generate a lift force and torqueses are directly proportional, and this will determine the behavior quadcopter.

Study on autonomous UAV has been drastically growing because of the nowadays technology demand. The autonomous UAV Quadcopter itself has a lot of advantages in surveillance. Three important criteria to ensure the UAV Quadcopter can run in autonomous, i.e. are automatically take-off system, automatic landing system, and the automatic navigation system. The paper scope to develop an automatic controller for vertical take-off and landing of quadcopter.

Automatic vertical take-off system is used to enable the quadcopter begin to fly from the ground. The system also must to ensure the height of quadcopter controlled consistently. Quadcopter operate by each 4 motor will produce a lift force to enable the system lift up the Quadcopter body. The performance of the controller is indicated on the period taken to achieve the target height. The better performance also measured on how smooth the controller maintains in stationary during fly.

Previous researchers have been studied on how to use the fuzzy controller for tuning the PID gains in simulation. When the system in flight, the reference height always changes. Therefore, the value of gains needs to adjust using fuzzy logic to get better response in target change (E. Abbasi, 2012).

The autonomous quadcopter system must have a good auto landing system to ensure ability to landing in safe. Drastic decrement of motor speed will be affect the quadcopter height drop faster and caused to unsafe landing.

This paper will be presented a method for experimental validation of an Altitude control for quadcopter. The controller and filter will be designed using simulation base on the quadcopter model derived in previous work. As in previous work, a mathematic model of quadcopter was explained and tested to simulate the behavior of the quadcopter. A mathematic model of quadcopter was explained and tested to simulate the behavior of the quadcopter. The result parameters of the work were used in this paper for designing the altitude controller A. (Bousbaine *et al*., 2012). In previous work, a mathematic model of quadcopter was explained and tested to simulate the behavior of the quadcopter. The result parameters of the work were used in this paper for designing the altitude controller (S. Bouabdallah and R. Siegwart, 2007). Equation 1 is about the mathematical model that used to represent the quadcopter system. The first 3 equations are contributing to linear vector and the next 3 contribute to angular velocity vector for the quadcopter rigid body system.

Equation 2 represents all the input variables in producing the movement of the system. Each vector represents the thrust, rolling, pitching, and yawing rotation respectively.

All the physical parameter will be defined to insert into simulation model. Then these controllers are applied into real time model.

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$$\begin{bmatrix} \ddot{X} = (\sin\psi\sin\phi + \cos\psi\sin\theta\cos\phi)\frac{U_1}{m} \\ \ddot{Y} = (-\cos\psi\sin\phi + \sin\psi\sin\theta\cos\phi)\frac{U_1}{m} \\ \ddot{Z} = -g + (\cos\phi\cos\theta)\frac{U_1}{m} \\ \dot{p} = \frac{U_2}{I_x} \\ \dot{q} = \frac{U_3}{I_y} \\ \dot{r} = \frac{U_3}{I_z} \end{bmatrix} \tag{1}$$

Equation 1 is about the mathematical model that used to represent the quadcopter system. The first 3 equations are contributing to linear vector and the next 3 contribute to angular velocity vector for the quadcopter rigid body system.

$$\begin{bmatrix} U_1 = b(\Omega_1^2 + \Omega_2^2 + \Omega_3^2 + \Omega_4^2) \\ U_2 = bl(-\Omega_2^2 + \Omega_4^2) \\ U_3 = bl(-\Omega_1^2 + \Omega_3^2) \\ U_4 = d(-\Omega_1^2 + \Omega_2^2 - \Omega_3^2 + \Omega_4^2) \end{bmatrix} \tag{2}$$

Equation 2 represents all the input variables in producing the movement of the system. Each vector represents the thrust, rolling, pitching, and yawing rotation respectively.

PHYSICAL PARAMETER DETERMINATION

Introduction

After deriving quadcopter model equations, its practical parameters have to be identified. The parameters to be identified are constant value in the model equations. The parameter is, the acceleration of gravity (g), mass (m) of quadcopter body, and inertial (I) parameters; aerodynamic parameters of constant thrust factor (b), drag factor (d), and the distance between the motor and the quad Copter centers (O. A. Bauchau *et al.*, 2009). 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

Moment of inertia

There are 2 methods to determine inertia parameter which was a moment of inertia calculation and by bifilar pendulum experiment. This paper focused of the bifilar pendulum experimental method. Figure-1 shows the bifilar pendulum system for measuring the value of inertia.

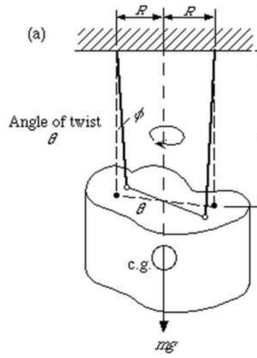

Figure-1. Bifilar pendulum test.

In bifilar experiment, two ropes are used to string up the quadcopter body, next the quad copter 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 (Keun Uk Lee *et al.*, 2011).

$$I = \frac{mgT^2b^2}{4\pi^2L} \tag{3}$$

Where:-
m = mass of quad copter body, (kg)
g = acceleration due to gravity, (m/s2)
T = period of swing in the 1 cycle (s) from IMU data.
b = radius between the rope point (m)
L = the rope length (m)

The Quad copter design is symmetrical. The inertia for rolling is the same as that for pitching movement. Table-1 shows the value of each constant parameter in bifilar test.

Table-1. Constant parameter.

Parameter	*Value*
m (kg)	0.80
g (m/s^2)	9.81
b (m)	0.20
L (m)	1.50

Table-2 shows the result for the moment of inertia. It consists of three rotation movements, i.e. rolling, pitching and yawing rotation. They will be used in control system design.

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Table-2. 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

Thrust force factor

The 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 situations, hence the parameter can be much more reliable (I. Maybe *et al.,* 2011). Figure-2 shows the method to measure the relationship of force produced by the speed of the propeller.

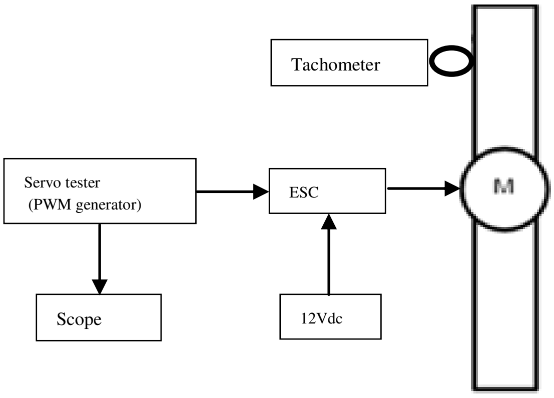

Figure-2. Lift test method for Brushless motor.

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.

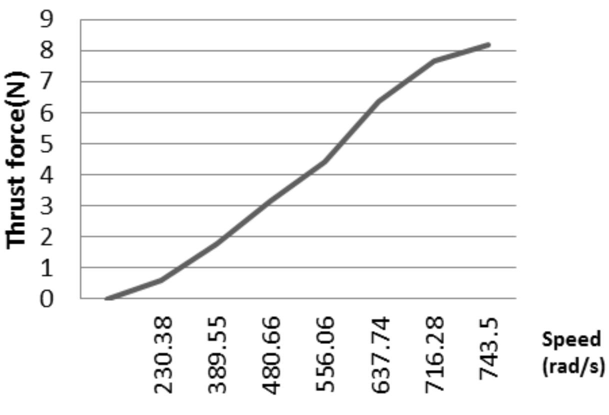

Figure-3. Force vs speed of propeller.

Figure-3 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, the equation below is applied.

$$b = \frac{f}{\Omega^2} \quad \text{Thus;} \quad b = 1.50 \times 10^{-5} \tag{4}$$

According to aerodynamic theory, drag factor depends on lift factor by a ratio $\frac{d}{b} = \tan\alpha$, where α is attack angle of propeller (Andrew Neff, 2007). The value of α equal to 15°, and drag factor is equal to $d = 4.02 \times 10^{-6}$.

SIMULATION

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 Mat-lab. 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 quad copter at certain propeller speed. The simulation setup is shown in Figure-4.

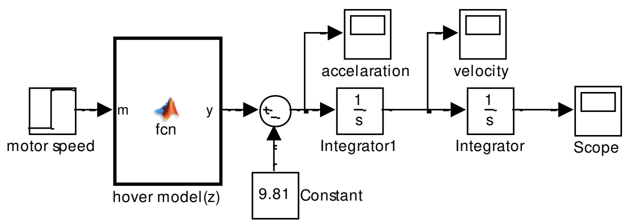

Figure-4. The altitude system simulates in Simulink.

Each physical parameter in the model is involved as shown in Table-3.

Table-3. Physical parameter.

Parameter	Value
Mass (*kg*)	0.9
Gravity (m/s^2)	9.81
Lift factor (N/s^2)	1.5×10^{-5}

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RESULTS

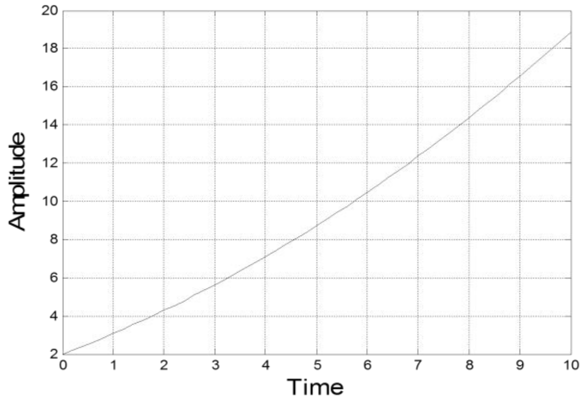

Figure-5 (a). The position change when Ω=400rad/s.

Figure-5 (a) shows quadcopter system has flown up when the speed of each propeller at 400rad/s.

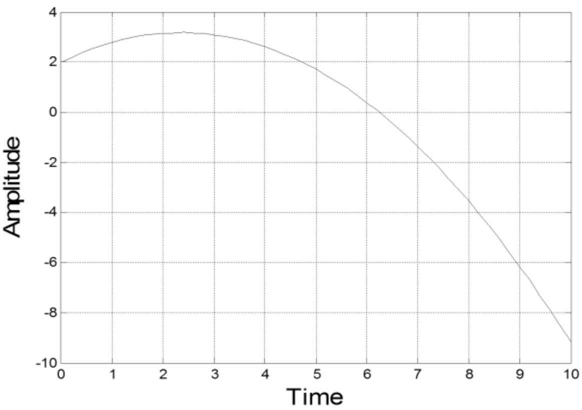

Figure 5(b). The position change when Ω=390 rad/s.

Figure-5(b) shows quadcopter system has flown down when the speed of each propeller at 390rad/s.

Based on the result, reference of motor speed (ω_H) to fly up the quad copter body could be determined. The analysis shows the minimum motor speed to fly up for the payload 0.9kg is Ω≥400rad/s. The reference motor speed is used to define the behavior of quadcopter systems.

Close loop with PID controller simulation

The close loop system is about the altitude controller designed appropriate the quadcopter system. The controller has been tested by simulation using Simulink. Hence, close-loop PID block set up in Simulink as shown in Figure-6.

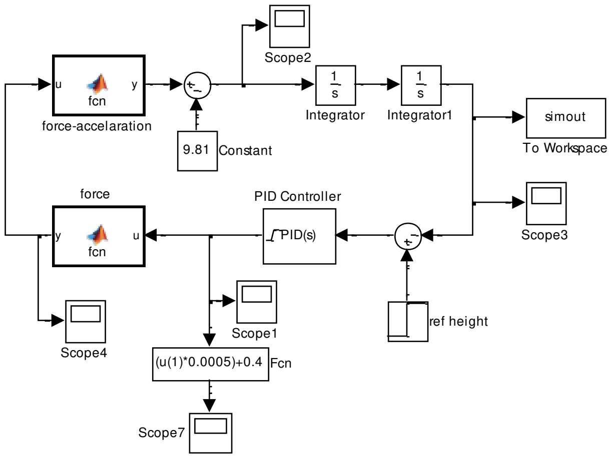

Figure-6. The altitude system with PID controller simulation.

The upper saturation is set on a PID controller to consider the limitation of the specification of hardware. Hence, the analysis of controller will be compatible to apply to the hardware.

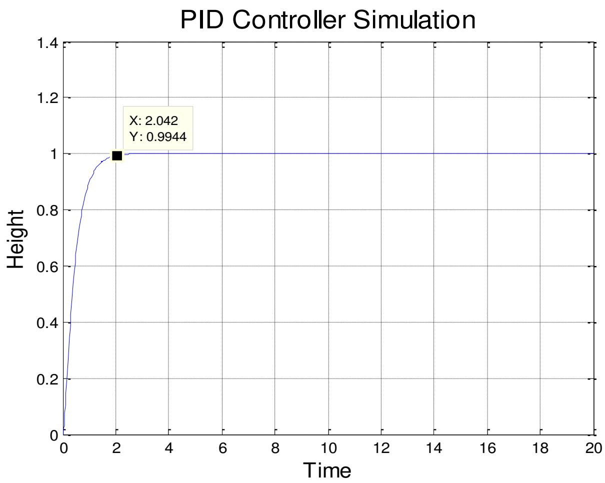

Figure-7. PID controller response.

Controller parameters for PID; proportional = 800, integral = 1, derivative = 0.3 and filter coefficient = 100. The response shows the controller system takes 2 second to reach the target height of 1 meter.

ALTITUDE ANALYSIS

Input

For real time applications, proximity sensor required to respond for the height in the control system. Proximity sensor suitable for this experiment is infrared proximity sensors. Infrared proximity sensor (Sharp GP2Y0A02YK0F) is capable to measure the distance between 15cm to 150cm. The signal produced is in analog form. However, the analog signal produced is proportional

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to non-linear response. Therefore, analog voltage signal from the sensor response must convert to distance scale in meters. Figure-8 shows the Simulink block set up for the proximity infrared sensor.

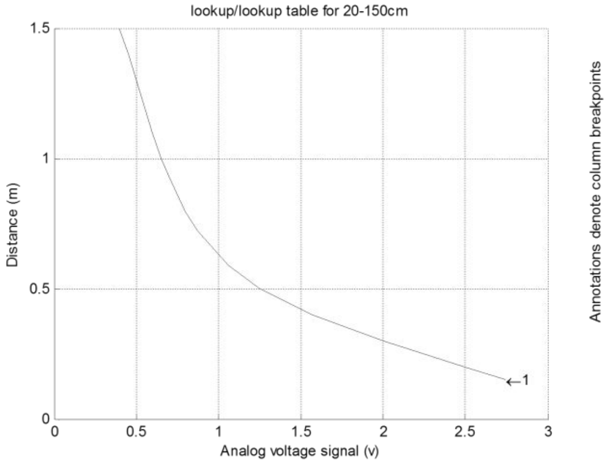

Figure-8. The look up table block data for infrared sensor.

Filter

The input signal in the form of analog voltage will be interrupted by several noise that exist by vibration, less efficiency of the sensor at their long distance, and disturbance from the environment. Therefore, filter required to remove some noise that may effect to controller system. The low pass filter approach will be applied to remove the high frequency noise. Hence, the transfer function for the low pass filter is shown as below.

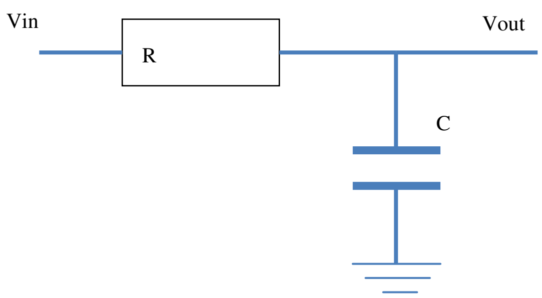

Figure-9. Low pass filter.

$$Vout = \frac{C}{C+R} Vin \tag{5}$$

Let:- $\omega_C = \frac{1}{CR} = 2\pi f_C$

$$Vout = \frac{1}{S*\frac{1}{2\pi f_C+1}} Vin \tag{6}$$

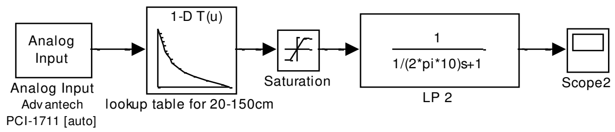

Figure-10. The input section with low-pass filter.

Figure-10 shows the low pass filter block has been included in the input. The first order low pass filter frequency is set to 10Hz. Therefore, the filter will reduce the amplitude of noise which the frequency over than 10Hz.

Output section

The output of the system is a brushless DC motor (BLDC). Brushless DC motor speed is controlled using an electronic speed controller (ESC). The ESC is functioning as motor driver. ESC is used to produce 3 phase DC supply to brushless DC motor. It is working with PWM signal input as a triggering the speed of the motor. To implement the ESC in Simulink, PWM signal generator block need to design. The design is shown in Figure-10. The frequency of the signal is fixing to 50Hz and the duty cycle varies with term of analog number.

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 the simulations performed in the previous session.

Figure-11 is about 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 the minimum signal value for the 2s in period.

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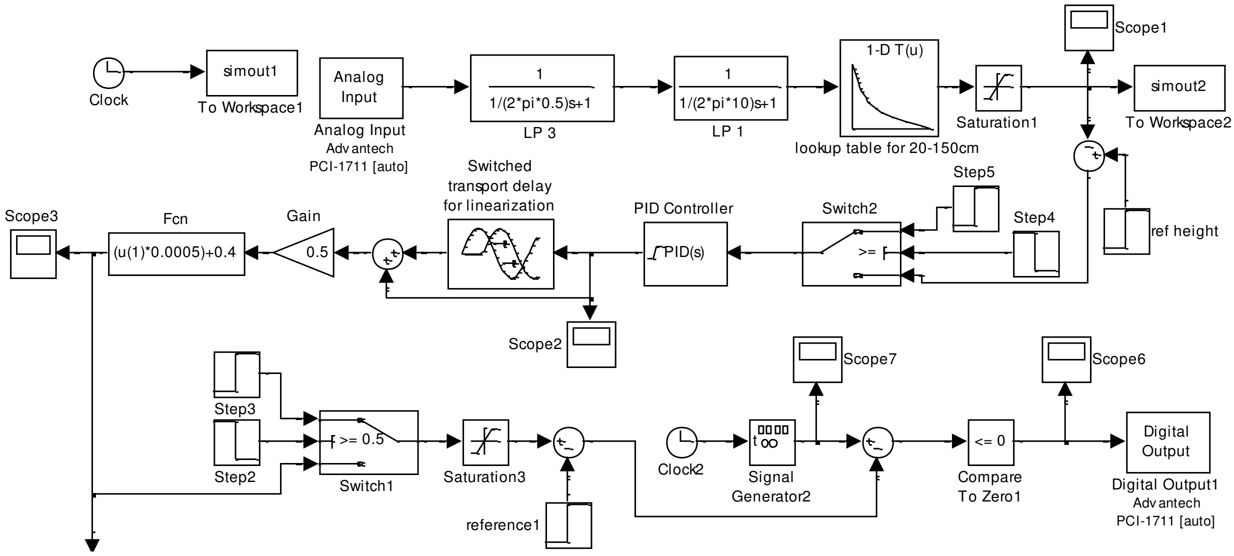

Figure-11. Altitude controls RTWT Simulink block.

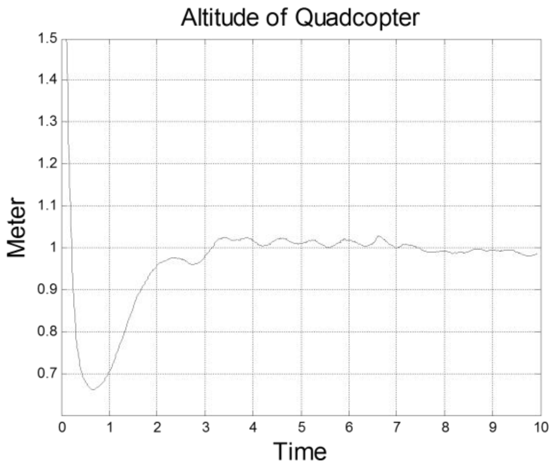

Figure-12. Altitude of Quadcopter in meter.

Figure-12 shows the result about high of quadcopter in meter due to time in second. Based on the result, the system is able to take off and control the altitude.

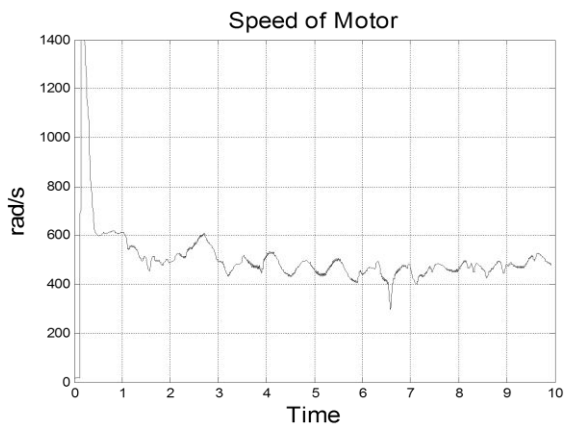

Figure-13. Speed of motor propeller in rad/s.

Figure-13 shows the graph of speed of each motor propeller. The results show that the speed of the motor when the system achieves 1 meter is more than 400rad/s.

CONCLUSIONS

The analysis of the altitude quadcopter control 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 specification. 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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