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Viswanadhapalli Praveen* and Anju S. Pillai

ABSTRACT

Quadcopter also called as quadrotor helicopter, is popular in Unmanned Aerial Vehicles (UAV). They are widely used for variety of applications due to its small size and high stability. In this paper design and development of remote controlled quadcopter using PID (Proportional Integral Derivtive) controller implemented with Ardupilot Mega board is presented. The system consists of IMU (Inertial Measurement Unit) which consists of accelerometer and gyro sensors to determine the system orientation and speed control of four BLDC motors to enable the quadcopter fly in six directions. Simulations analysis of quadcopter is carried out using MATLAB Simulink. Pitch, roll and yaw responses of quadcopter is obtained and PID controller is used to stabilize the system response. Finally the prototype of quadcopter is build PID logic is embedded on it. The working and performance of quadcopter is tested and desired outputs were obtained.

Keywords: Quadcopter, PID controller, Pitch, Roll, Yaw, MATLAB Simulation.

1. INTRODUCTION

One of the popular area of research is UAV. In the mid 1800s, researches started in UAV and Drones (small sized UAV) started in the early 1900s and it became more popular in World War-I. Most popular UAV is Quad Copter (QC) and is preferred due to small size and high stability. It can vertically take off and land (VTOL). It can change the direction immediately to reach the unreachable areas. Mostly quadcopter is used in military applications: to identify the unknown objects, enemies, boarder patrolling etc. Recently, quadcopters are used in small goods transportation.

Many researches are carried out about quadcopter and a wealthy literature support can be found in the field. In [1], Quadcopter pitch and roll moments are simulated using PID and PD controller. PID and PD results of pitch and roll moments responses are compared to choose the proper controller for pitch and roll moments. In [2], PID controller is used to control the quadcopter and Extended Kalman Filter (EKF) is used to reject the noise from IMU sensor. In [3], author proposes three algorithms: PID, PD and Back stepping algorithms to get the stabilized response of quadcopter dynamic motions and all the results are compared using three algorithms. In [4], PD auto tuner is designed to achieve stable and robust performance of quadrotor. In [5], in presence of disturbances, an adaptive controller is used to improve the tracking position and trajectory following of the quadcopter. In [6], adaptive neuro PID controller is used for stabilizing quadcopter motions. Using this algorithm, there is no need for different mathematical analysis for defining the proper coefficients. In [7], details regarding how to build own quadcopter and use PID controller for stabilized operation of quadcopter is presented. In [8], [9] UAV provides wide range of visual information to UGV (Unmanned Ground Vehicle) through cameras and inertial sensors. Phenox, a fully automated palm sized robot's software and hardware design and development details are presented in [10].

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In the current work, a quadcopter prototype is designed and developed using PID controller. IMU is used to determine the system orientation. In this work, mathematical modeling of qudcopter is done using MATLAB Simulink model using PID controller for stabilized operation of quadcopter. Pitch, roll and yaw movement of quadcopter responses are obtained through MATLAB Simulink.

The rest of the paper is organized as follows. Section 2 explains the system overview. Section 3 explains the modeling of the quadcopter. Sect4 explains the control strategy of the quadcopter is presented. Results are explained in section 5 and the paper is concluded in section 6.

2. SYSTEM OVERVIEW

In this section, the overview of quadcopter is explained. There are four motors in quadcopter (M_1, M_2, M_3 & M_4). M_1 and M_3 are rotated in clockwise direction. M_2 and M_4 are rotated in anticlockwise direction in order to stabilize the quadcopter. The quadcopter is controlled using a radio controller which communicates with the copter wirelessly through a transceiver. Radio controller sends PWM signals to quadcopter. The receiver in quadcopter receive the PWM signal and is fed to controller. Ardupilot Mega board is used which consists of ATMEGA 2560 controller. The controller sends the PWM signal to motor. According to PWM signal, the four motors will be rotated and the quadcopter hover in air. To stabilize the quadcopter, PID controller is used. A detailed system description is shown in Figure 1.

Where,

M_1 & M_3 – anticlockwise rotating motors

M_2 & M_4 – clockwise rotating motors

ESC – Electronic Speed Controller

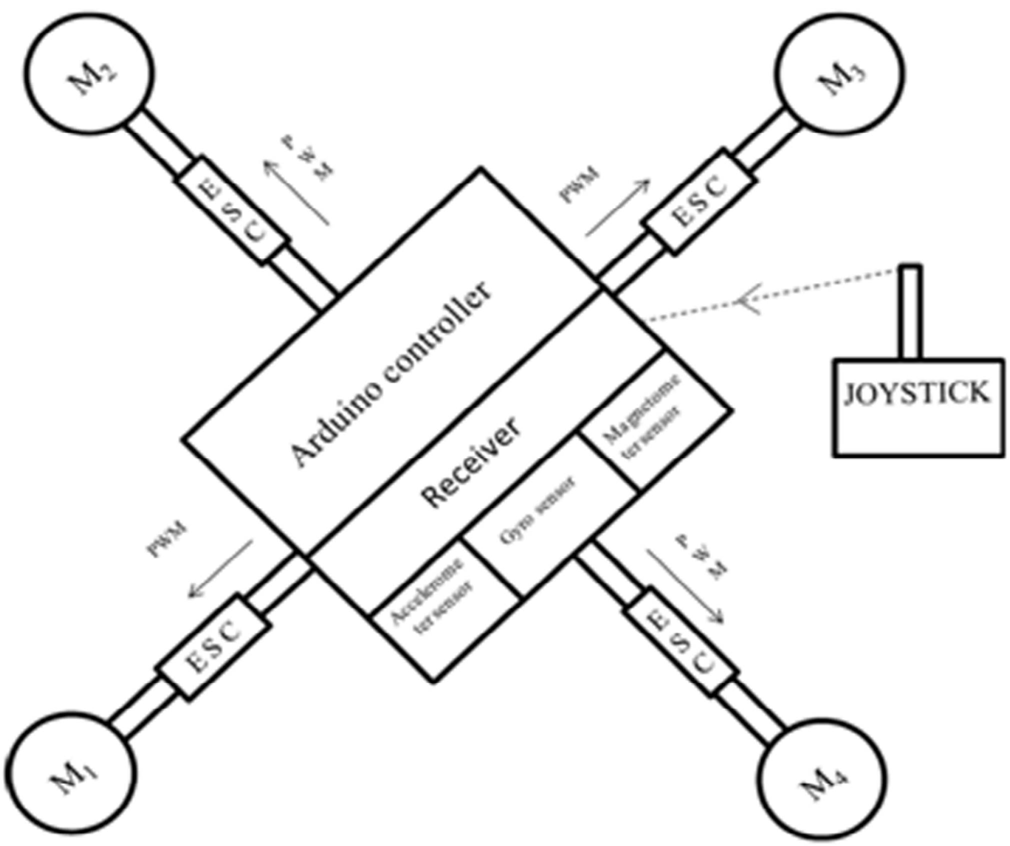


Figure 1: System Block Diagram

2.1. System Design

The hardware model consists of flight controller board, Electronic Speed Controller (ESC), BLDC motors and propellers.

(i) Mechanical Components:

- Quadcopter Frame: Frame is made from the plastic material. Its width is 450mm, height is 55mm and weight is 280g.
- Motors: Four BLDC motors are used with rating of 12V and 1000 rpm/voltage.
- Propeller: Four propellers are used. Two propellers rotate clockwise and other two in anticlockwise direction.

(ii) Electrical Components:

- ESC: Four ESCs are used to control the speeds of the four BLDC motors.
- Flight Controller Board: Ardupilot Mega board is used to control the quadcopter.
- 2.4 GHz radio controller: Radio controller sends input signals to quadcopter
- Battery: 2300mAh battery is used to give power to ardupilot mega board and motors.

3. MODELING

Modeling of quadcopter will be beneficial to comprehend the copter dynamics to control and stabilize the quadcopter accurately. The mathematical modeling of the quadcopter is studied from [2]. Quadcopter can move in six directions: forward, backward, right, left, up and down by varying the speeds of four motors. Equations 4, 5 & 6 models the quadcopter pitch, roll and yaw dynamic motions.

Applying Newtons-Euler formulation to Figure 2, equations 1, 2 & 3 are derived which describes the roll, pitch and yaw movement of quadcopter as in [2].

$$\ddot{\phi} = \frac{I_{yy} I_{zz}}{I_{xx}} \theta\psi - \frac{J_{tp}}{I_{xx}} \theta\omega + l \frac{U_2}{I_{xx}} \quad (1)$$

$$\ddot{\theta} = \frac{I_{xx} I_{zz}}{I_{yy}} \theta\psi - \frac{J_{tp}}{I_{yy}} \theta\omega + l \frac{U_3}{I_{yy}} \quad (2)$$

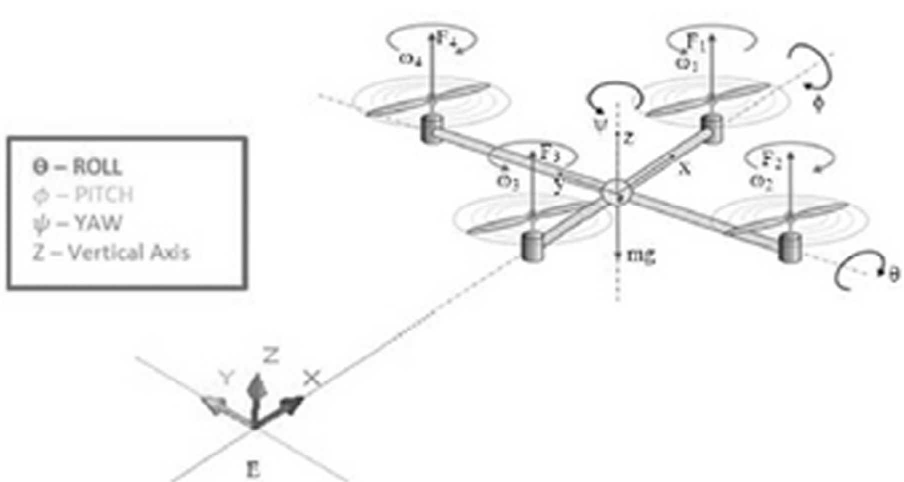


Figure 2: Free body force, Source [1]

$$\ddot{\Psi} = \frac{I_{xx} I_{yy}}{I_{zz}} \theta \psi - l \frac{U_4}{I_{zz}} \tag{3}$$

Where,

$$U_2 = b(\omega_2^2 - \omega_4^2)$$
$$U_3 = b(\omega_1^2 - \omega_3^2)$$
$$U_4 = d(\omega_1^2 - \omega_2^2 + \omega_3^2 - \omega_4^2)$$

4. CONTROL STRATEGY

PID controller is used to control the roll, pitch and yaw movement of quadcopter. Gyroscopic torque and coriolis – centripetal terms are neglected to reduce the complexity copter modeling while hovering at run time. After reducing terms, the quadcopter dynamic equations are:

$$\ddot{\phi} = l \frac{U_2}{I_{xx}} \tag{4}$$

$$\ddot{\theta} = l \frac{U_3}{I_{yy}} \tag{5}$$

$$\ddot{\Psi} = l \frac{U_4}{I_{zz}} \tag{6}$$

Apply the Laplace transform to equations 4, 5 & 6,

$$\frac{\phi(s)}{U_2(s)} = \frac{lb}{I_{xx} S^2} \tag{7}$$

$$\frac{\theta(s)}{U_3(s)} = \frac{lb}{I_{yy} S^2} \tag{8}$$

$$\frac{\psi(s)}{U_4(s)} = \frac{ld}{I_{zz} S^2} \tag{9}$$

Where,

l	=	Arm length
b	=	Thrust coeffient
d	=	Drag coeffient
I_{xx}	=	Moment of inertia along x-axis
I_{yy}	=	Moment of inertia along y-axis
I_{zz}	=	Moment of inertia along z-axis
ω	=	Angular velocity

PID controller design is shown is below Figure 3. Reference signal is pitch or roll or yaw to PID controller and its output is given to quadcopter. Quadcopter output signal is given as negative feedback to adder block. According to error, K_p , K_i and K_d are chosen.

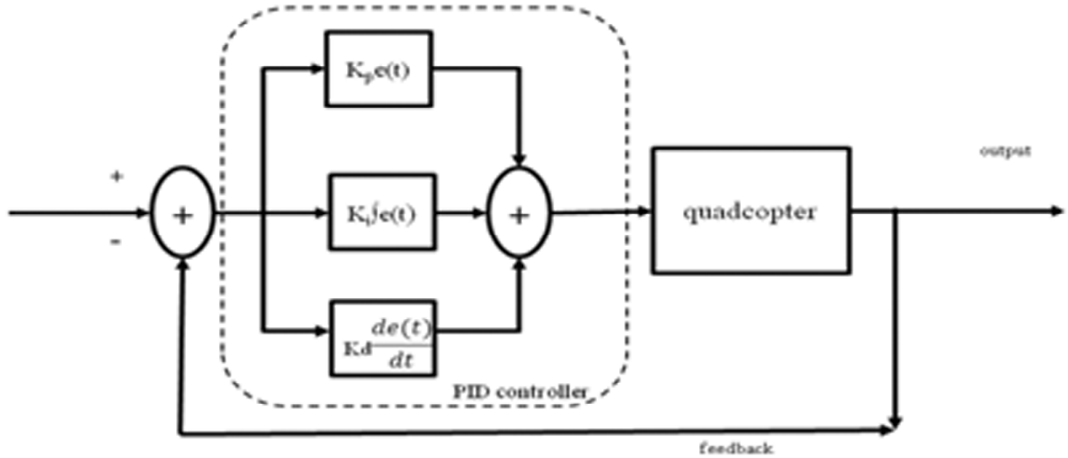


Figure 3: Quadcopter model using PID controller

K_p = Proportional gain

K_i = Integral gain

K_d = Derivative gain

e(t) = Error signal

u(t) = PID controller output

Quadcopter pitch, roll and yaw simulation block diagram is given in Figure 4. Step signal is given as input signal controlling quadcopter dynamic motions using PID controller. It consists of three PID controllers for pitch, roll and yaw given to three transfer function blocks (pitch, roll and yaw transfer functions). A multiport switch helps to get the output individually, by choosing constant as 1 or 2 or 3, pitch, roll and yaw responses are obtained at output scope.

5. RESULT ANALYSIS

5.1. Software Simulation Results

The quadcopter dynamic motions are simulated by using MATLAB software using PID controller. The MATLAB results are shown in Figures 5, 6 and 7 which are pitch, roll and yaw responses of quadcopter respectively. Figures 5 & 6 responses are same because of moment of inertias I_{xx} and I_{yy} are equal and thrust

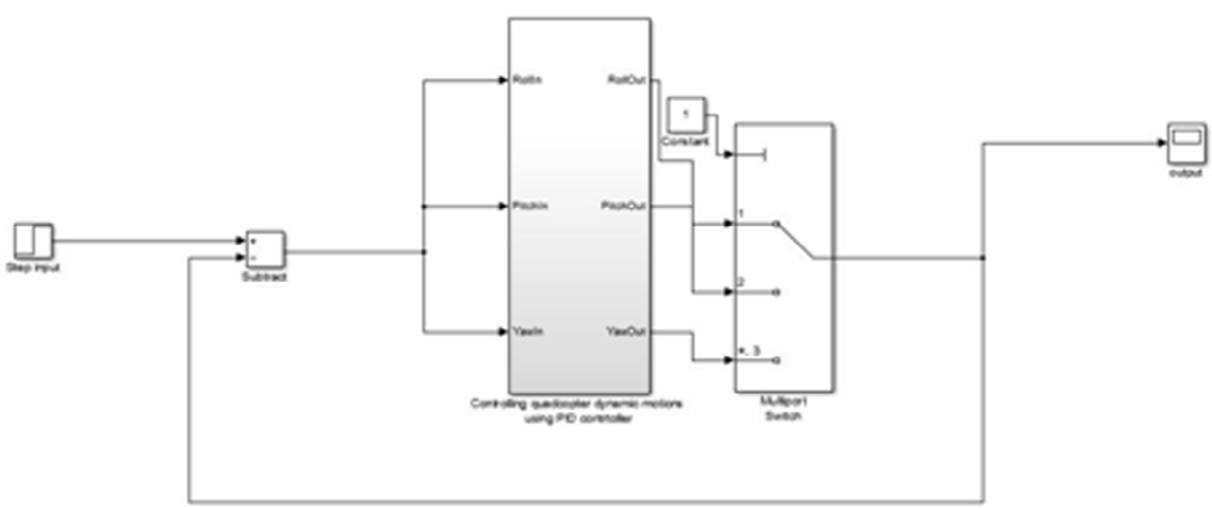
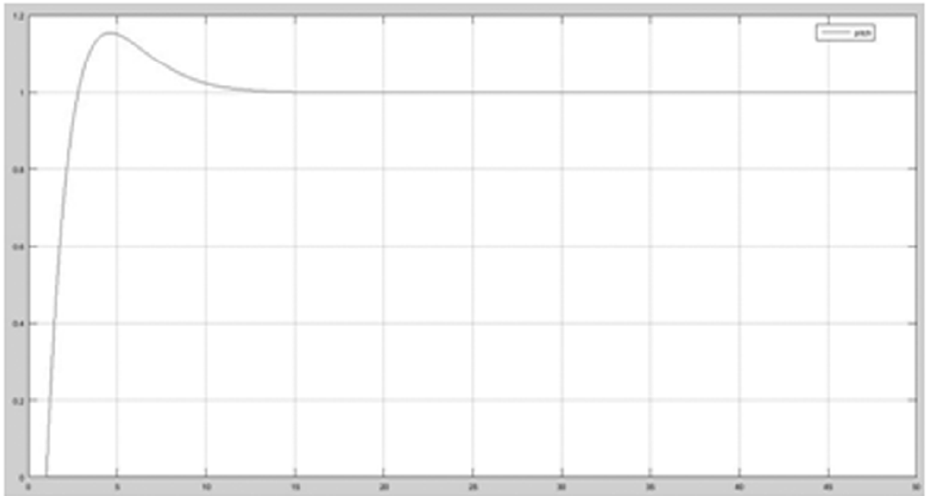


Figure 4: MATLAB Simulink model for quadcopter using PID controller

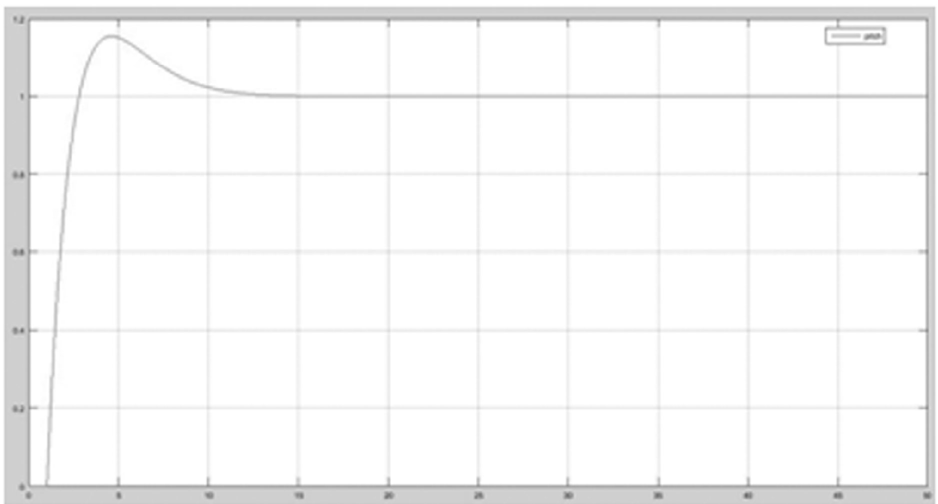
Angle



Time (seconds)

Figure 5: Pitch movement of the qudcopter

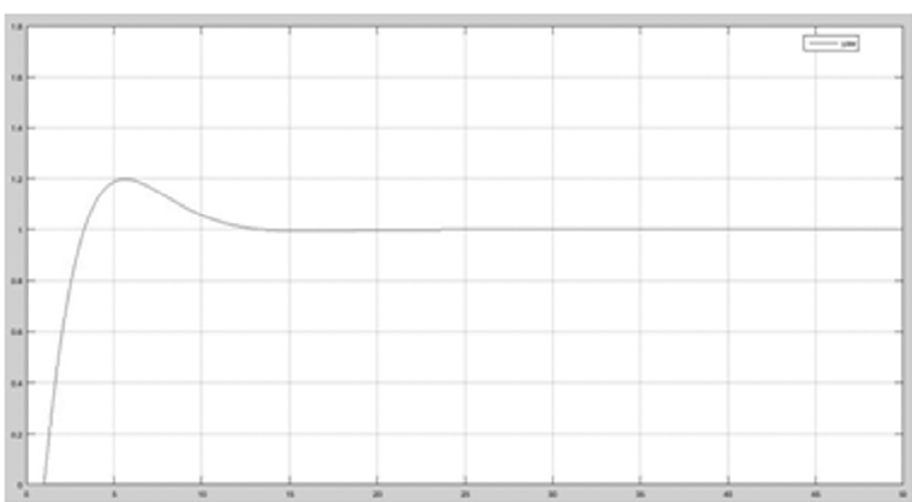
Angle



Time (seconds)

Figure 6: Roll movement of the qudcopter

Angle



Time (seconds)

Figure 7: Yaw movement of the quadcopter

coefficients are also same. Yaw response in Figure 7 is different from that of roll and pitch responses due to change in moment of inertia (I_{zz}) and drag coefficient(d) as shown in equations 7, 8 & 9. The Proportional, Integral and Derivative gains are chosen as 25, 0.2 and 80, to stabilize the quadcopter motions.

5.2. Hardware Implementation Results

After implementing the PID controller in software, quadcopter prototype is developed as in Figure 8. PID logic is dumped into Ardupilot Mega board. The P, I & D gains are to be again tuned for getting a stabilized motion of the quadcopter with the hardware.

Figure 8: Hardware Implementation of quadcopter

6. CONCLUSIONS AND FUTURESCOPE

In this paper, the working and implementation of pitch, roll and yaw movement of quadcopter based on PID logic controller is presented. Mathematical modeling of quadcopter is done using MATLAB Simulink model. For stabilization of quadcopter, PID logic controller was chosen. PID logic was implemented successfully in MATLAB. A prototype of quadcopter is build using PID logic controller embedded on it. The working and performance of quadcopter is tested and desired outputs were obtained using PID controller. Still there are opportunities for more effective controlling of quadcopter, by Ziegler-Nichols tuning method.

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