International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 04 Issue: 07 | July -2017 www.irjet.net p-ISSN: 2395-0072

Design and Development of a Quadrotor – A Didactic Approach

Sajid Shaikh[1], Ritesh Varpe[2], Vaibhav Adhalage[3], Akshay Virade[4]

[1, 2, 3,4]*Student, Department of Mechanical Engineering, Dr D Y Patil SOET, Pune, India*

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Abstract - *A quadcopter can be concisely categorized as an Unmanned Aerial Vehicle (UAV) that has an immense potential of performing complex tasks in dynamic environments that are often precarious. Development of an efficient, low-cost and robust multirotor being the primary objective of this project, a didactic approach is maintained. In considerations of an optimal design, the mechanical structure as well as the electronics are designed using a CAD modelling software and a suitable material is selected that is unequivocally the most synthetically efficient. After a comprehensive study of dynamics of a vertical flight and thrust calculations, desired specifications of propellers and brushless motors are set. Autonomous levelling of the system is achieved with a Flight Control Board having the functionality of P and I gains manipulation. These types of systems have a wide range of applications and have a controllable versatility. Using this project as a tool for integrating the knowledge of different disciplines as a mechatronic system, an inter-disciplinary method is predominantly emphasized.*

Key Words: Multirotor, Quadrotor, Quadcopter design, UAV

1. INTRODUCTION

The spectrum of developing an adroit UAV (Unmanned Aerial Vehicle) has been witnessing an incessant growth as new technology disembarks day by day. The development of quadrotors hasn't been untouched amidst this technological reform. While more and more quadrotors are being improvised and developed with distinctive purpose to enter the pool of wide range of applications including photography, defence, and delivery using GPS navigation, the mankind is certainly achieving automation [1].

A basic quadrotor comprises of mechanical hardware along with the electronic components making it an inter-disciplinary system. This mechatronics project is explicitly aimed at helping the students familiarize with the modern technologies that are being used in UAVs and understand the working principle. The system primarily consists of brushless DC motors, electronic speed controllers, electronic stabilization unit with 3-axis gyroscope and accelerometer, a radio receiver and transmitter.

The design process is carried out with the help of CAD modelling software with the selected frame size and aluminium is used as frame material because it is light in weight and strong as well. The motors are selected pertaining to the desired thrust requirements. Ascertaining a methodical approach, an orderly procedure is followed throughout the build.

2. FRAME DESIGN AND 3D MODELLING

2.1 Frame Size

Frame size, here in case of a quadrotor, is the proposed distance between the two vertical axes of diagonally opposite motors. The selection of frame size is the most fundamental and significant part of the build process. Most frequently used frame sizes for a quadcopter are 180 mm, 200 mm, 250 mm, 350 mm, 450 mm, 500 mm, etc.

The smaller frame sizes are to be used when the ultimate purpose of the quadrotor is predominantly concerned with high speed application and a compact system. The larger frame sizes, on the other hand, are relatively slower in speed and are suitable for high thrust applications. In case of this project, a moderate frame size of 450 mm is selected.

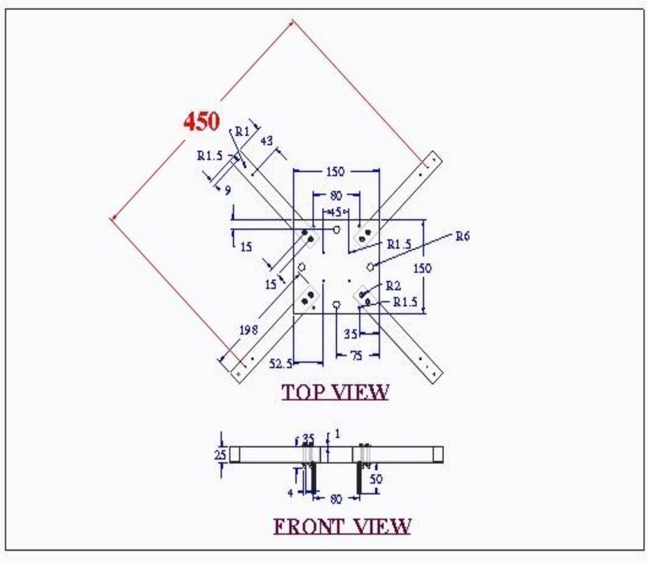

Fig -1: Drafted views of Frame

Figure 1 illustrates the drafted views of the frame that was modelled using CAD software, including the various dimensions.

Some of the major dimensions: (*All in mm*)

i. Length of each of the four arms(booms) = 198
ii. Cross-section of the arm = Square 25 x 25
iii. Base plate and Top plate (Square) = 150
iv. Holes = ϕ3, ϕ4, ϕ12

2.2 3-D MODELLING

A better perspective is achieved through 3D modelling of the design about the actual appearance of the quadcopter in reality. Figure 2 illustrates the assembled 3 dimensional view of the frame.

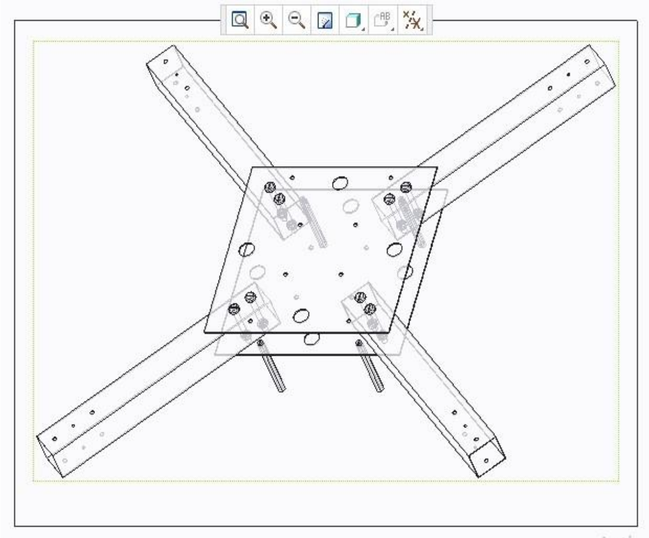

Fig -2: 3D Model of Frame

Figure 3 illustrates the final 3 dimensional view of the model with all of the components assembled.

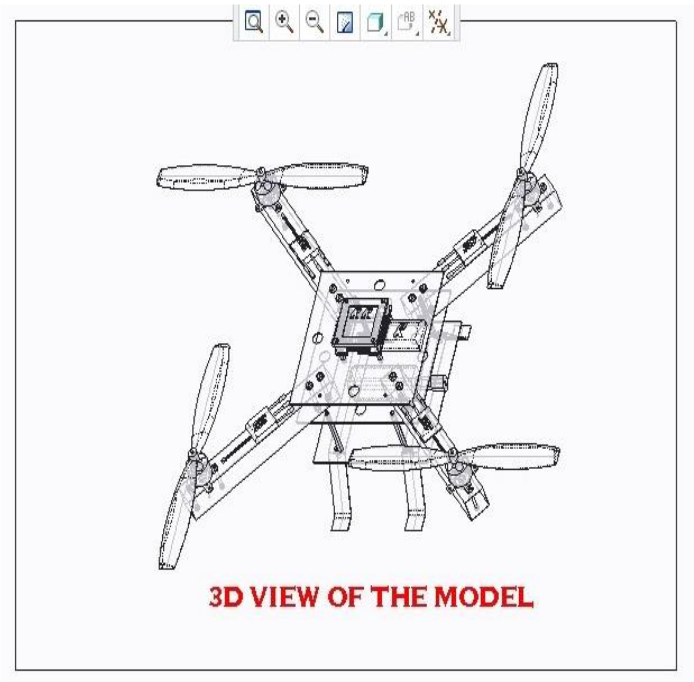

Fig -3: Final 3D CAD Model

3. MOTOR SELECTION

3.1 BRUSHLESS DC MOTOR THEORY

The use of brushes, present in the normal DC shunt motors, is eliminated in the BLDC motors, thereby reducing maintenance costs. The operation of BLDC motors comprises of stationary current-carrying coils and rotating permanent magnets [2]. Figure 4 illustrates the two types of physical BLDC motor configurations.

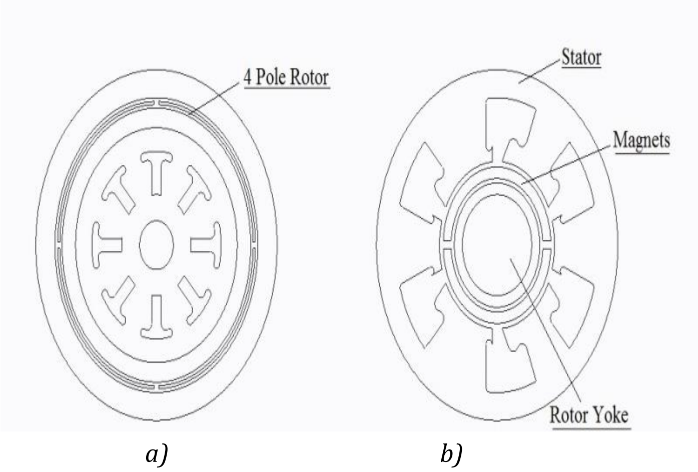

Fig -4: a) Outer-rotor BLDC motor and b) Inner-rotor BL DC motor [2]

The inner-rotor has coil windings along the outer periphery surrounding the magnets at the center. The outer-rotor has coil windings at the center being stationary enclosed by permanent magnets which rotates along with outer casing. This type of physical configuration is favored over the inner-rotor configuration for a multirotor system due to the need for lower energy magnets, reduced copper losses, reduced production costs, and greater rotor inertia [2].

3.2 KV RATING OF MOTOR

Theoretically, KV rating of motor is defined as increase in rotations per minute per 1V increase in the voltage without any load on the motor i.e. without propellers [3]. KV rating and torque generated by motor are inversely proportional to each other. Lower KV rating motor coupled with larger size propeller tend to produce higher torque whereas higher KV rating motor coupled with smaller size propeller tend to produce less torque. The former combination is best suited for slow and high thrust applications and the latter is best suited for high speed applications. Considering our moderate thrust application 1000 KV rating motors are selected and used.

4. WEIGHT AND THRUST CALCULATIONS

Table -1: Weight of components

SR. NO.	COMPONENT	WEIGHT (in grams)	QUANTITY
1	Motor	50	4
2	ESC	40	4
3	Flight Control Board	40	1
4	Receiver	30	1
5	Lipo Battery	150	1
6	Connecting wires	50	1
7	Propeller	14	4
8	Frame	300	1
9	Miscellaneous	50	1
	TOTAL	1036	

Let *W* be the total weight of the system and *T* be the thrust generated.

$$W = 1.036\ kg$$

Thrust of each motor is 0.7 kg. (Provided by manufacturer)

$$T = 4 \times 0.7\ kg$$

$$T = 2.8\ kg$$

Therefore, available thrust to weight ratio is

$$\frac{T}{W} = \frac{2.8}{1.036}$$

$$T : W = 2.7 : 1$$

Now, considering thrust to weight ratio 2 : 1

$$\frac{2}{1} = \frac{2.8}{Wm}$$

$$Wm = 1.4\ kg$$

Where, *Wm* is the maximum weight of the system.
Therefore, available mission pod (*M*) is

$$M = Wm - W$$

$$M = 1.4 - 1.036$$

$$\boldsymbol{M = 0.364\ kg}$$

5. CONTROL SYSTEM

The control system of a quadrotor primarily consists of various electronic components including different types of sensors like accelerometer and gyroscope. The main flight controller, that is equipped with PID control, works as a brain and controls the system in order to achieve a stable flight.

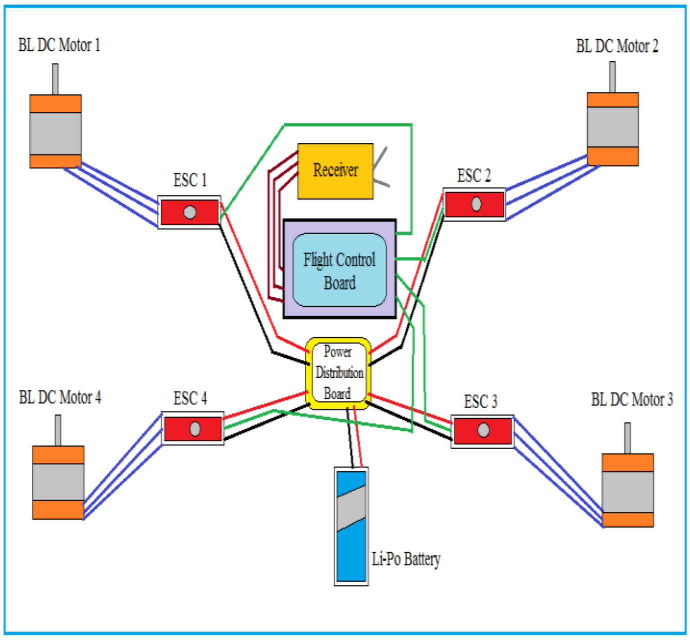

Fig -5: Schematic of the system

Off the shelf (OTS) components are used as integrated parts of the control system.

Table -2: Control system details

Flight Control Board	KK 2.1.5 3 axis gyroscope 3 axis accelerometer PI control
ESC	30 A SimonK
Battery	3S LiPo (12.6 V)
Transmitter and Receiver	2.4 GHz 6 Channel

The KK 2.1.5 flight controller board which is based on an 8 bit microcontroller is used to function as brain of the quadrotor system.

Throttle, aileron, elevator and rudder maneuvering movements are controlled by the flight control board according to the signals received from the transmitter. Additionally, the FCB has an integrated PI (Proportional-Integral) control system for self-leveling of the quadrotor. The P and I gain values are tuned for optimal self-leveling.

Fig -6: Realization of project

6. RESULTS AND CONCLUSION

This research work has resulted in successful design and development of a quadrotor. The hardware and electronic components used are entirely off the shelf which augments cost effectiveness.

Table -3: P and I gain values

CHANNEL	P GAIN	P LIMIT	I GAIN	I LIMIT
Aileron	38	23	5	20
Elevator	38	23	5	20
Rudder	25	20	5	10

According to the control board response and its self-level functioning, all the P and I gain settings are calibrated for the Roll/Pitch and Yaw/Rudder.

This type of developed system can be a convincing alternative to expensive quadrotor systems. Moreover, a didactic approach towards designing and developing of such a system will facilitate students to indulge and learn more about quadrotors.

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BIOGRAPHIES

Mr. Sajid Shaikh
Final year student - Mechanical Engineering (Savitribai Phule Pune University, Pune).

Mr. Ritesh Varpe
Final year student - Mechanical Engineering (Savitribai Phule Pune University, Pune).

Mr. Vaibhav Adhalage
Final year student - Mechanical Engineering (Savitribai Phule Pune University, Pune).

Mr. Akshay Virade
Final year student - Mechanical Engineering (Savitribai Phule Pune University, Pune).