Design, Fabrication And Analysis Of Quadrotor

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Abstract
This paper aims at the design, fabrication and analysis of a quadrotor. It is a UAV that gets its thrust and lift by adjusting the relative speeds of four engines (motors). There are many notable works done in this section, currently Boeing and Bell are building a Quad Tilt Rotor (QTR) with a huge payload carrying capacity. So building a quadrotor will give an opportunity to study the dynamic behavior, governing control system, and sensor filtering techniques. Here in this paperwork a quadrotor is built out of aluminium with a take-off weight of around 1.6 kg and the model is capable of flying indoor or outdoor with an optimal wind speed. To make a stable flight it is equipped with an accelerometer, gyroscope, magnetometer and a barometer.

To give it a small amount of autonomy it is equipped with Obstacle Avoidance system which uses Infrared and Ultrasonic sensors. It is also equipped with ‘Fly Home’ technique that will fly the quad to its starting point in case of signal loss from the ground control system. A PI controller is used to control the stability and a Kalman filter to filter the errors bound by vibrations, noise etc. The final model will be tested by making it to fly in the outdoor. This quad can be used for surveillance, collecting test samples from hazardous environment, photography, vehicle traffic monitoring etc. In future, algorithms can be built with this base model using vision system to explore unknown surroundings, navigate full autonomously, target tracking etc.

KEYWORDS: Quad Tilt Rotor (QTR), Obstacle Avoidance system (OAS), Kalman Filter, Unmanned Aerial Vehicle (UAV), Inertial Measurement Unit (IMU),

I. INTRODUCTION
An Unmanned Aerial Vehicle (UAV), commonly known as a drone, is an aircraft without a human pilot on board. Its flight is either controlled autonomously by computers in the vehicle, or under the remote control of a navigator, or pilot (in military UAVs called a Combat Systems Officer on UCAVs on the ground or in another vehicle. A Micro Air Vehicle (MAV), or micro aerial vehicle, is a class of UAV that has a size restriction and may be autonomous usually operated from on-board battery[1-4]. Modern craft can be as small as 15 centimeters. The small craft allows remote observation of hazardous environments inaccessible to ground vehicles. MAVs have been built for hobby purposes, such as aerial robotics contests and aerial photography.

Miniature aerial vehicles (MAVs) have attracted major research interest during the last decade[5-9]. Recent advances in low power processors, miniature sensors and control theory have contributed to system miniaturization and creation of new application fields. „Quadrotor”, a vertical take-off and landing (VTOL) system is considered because of their challenging control problems, symmetrical airframe and their broad field of applications. A mathematical model is developed, with governing control system which processes the data from the sensors and fly the MAV autonomously. [10-12] Simple „Obstacle Avoidance System (OAS)” is deployed which ensures the safe operation of the Quadrotor.

This work focuses on the design of a Vertical Take-Off and Landing (VTOL) Miniature Aerial Vehicle (MAV). The proposed structure is a four propeller helicopter called quadrotor[13-16]. Since this model is highly stable and can fly at high altitude, which can be used for forest fire monitoring, aerial surveillance and photography, sample collection and analysis of hazardous environments and to understand and implement the concepts of Kalman filters, IMU, PID controller and Euler - angle methods which are the basic algorithms used in any UAV, aircrafts, missiles etc.
A. Limitations of The Paper

The main limitation is if one motor fails the total structure loses stability due to unbalanced torque and goes out of control. Weight plays a major factor here, so if weight increases, its flight time decreases. To increase the flight time more battery is needed which further increases the Quadrotor total weight making it further complicated [17-22]. Wireless transmission of data is used which is highly non reliable, if Quadrotor gets out of range it should be programmed to come back to initial home point from where flight is started initially.

B. Applications

Forest poachers monitoring, Forest fire monitoring, Aerial surveillance, Aerial photography, exploring unknown environment, sample collection in hazardous environment like volcanic eruption and so on [23-24].

II. METHODOLOGY

In this section the working of the Quadrotor is involved. The four propellers are used to actuate the Quadrotor. Depends on the propeller speed variation the movement of Quadrotor is obtained. To fly the Quadrotor need to maintain the four propeller speed as constant with maximum speed. Once its flies the direction will be controlled by the speed variation in the different motor

A. Block Diagram

The main heart of this Quadrotor is controller (microchip). The orientation of the vehicle is sensed by inertial measurement unit (IMU). It will sent the gyro, X-tilt, Y-tilt to the controller. Depends on the feedback the controller will send the signal to the corresponding motor to balance the Quadrotor. The operator will give the input to the controller by remote transmitter to obtain the Thrust, Pitch, Roll and Yaw motions. Corresponding data is processed by the controller it will generate the PWM signal to control the motor speed[25-27]. The fig 2.1 represents how the control system interacts with the physical system for controlled quad-rotor flight.

Fig 2.1 Block Diagram

B. Control Flow Chart

The vehicle controls have the particular flow diagram that shown in fig 2.2 To obtain the result the important factor is Design of the Quadrotor in this paper we taken the (+) type design. This design is fully
depending upon the application definition. So the Quadrotor mass and size desire the propeller parameter. Depends on the propeller parameter the power requirement is identified. It provides the actuator data base [28-29]. The iterative algorithm used to maintain the stabilization of the vehicle with respect to the variation in the input.

III. DESIGN OF QUADROTOR

There are two types of configurations in Quadcopter which is (+) configuration and other is (×) configuration. Due to high stability and easy to control configuration, plus (+) configuration is chosen.

A. Material Selection of Frame

Due to low weight and high strength Aluminium square tube is chosen as the frame material which is also cheaper when compared to carbon fiber tubes.

B. Hollow Square Area Calculation

\[
\text{Hollow Square Area} = \text{outer } a^2 - \text{inner } a^2 \\
= [12.7^2 - (12.7-6)^2] \times 10^{-6}
\]
\[ = 1.164 \times 10^{-4} \text{m}^2 \]

![Fig 3.1 . Cross Sectional Area of Arm](image)

**Big arm (1 nos)**

Length  
= 780mm  
= 780 \times 10^{-3} \text{ m}  
Volume = A \times h  
= 1.164 \times 10^{-4} \times 780 \times 10^{-3}  
= 9.0792 \times 10^{-5} \text{ m}^3  
Density = \frac{\text{Mass}}{\text{Volume}}  
Density of Aluminium = 2720 \text{ kg/m}^3  
Mass = \text{Density} \times \text{volume}  
Mass = 2720 \times 9.0792 \times 10^{-5}  
Mass = 0.247 \text{ kg}  

**Small arm (2 nos)**

Length = (780-12.7)/2 = 383.63  
Length of each tube = 383.63 \times 10^{-3} \text{ m}  
Volume = A \times h  
= 1.164 \times 10^{-4} \times 780 \times 10^{-3}  
= 8.931 \times 10^{-5} \text{ m}^3  
Density = 2720 \text{ kg/m}^3  
Mass = 2720 \times 8.931 \times 10^{-5}  
Mass = 0.243 \text{ kg}  

Two base Plates, Square in size are used to hold the plus structure together, which has small openings inside to reduce the weight and for also connecting wires from battery. Weights of two base plates are around 0.12 kg
C. Weight Calculation
The weight of quadrotor is calculated, so that total thrust required can be calculated.
Total weight = Airframe weight + motor weight +
propeller weight + ESC weight +
Battery Weight + others
= [0.247 + 0.243 + 0.12] + 0.264 + 0.04 + 0.160 + 0.210
AUW = 1.284 kg (without Flight Controller, wires, Telemetry, Ultrasonic sensors etc.,)

D. Thrust Calculation

From weight, we can know how much minimum Thrust we need to have for Stable flight. The thrust is given by
Thrust = AUW * 2

= 1.284 * 2
= 2.57 kg i.e., minimum thrust needed

With 11” × 4.5” Propeller, 800 g of thrust is produced, so
AUW = (4 * 800 g) [for 4 motors]

AUW = 3200 g
At 72% throttle of motor

By increasing motor throttle to 88%, we can increase weight to 4400 g.

E. 3D Model of Quadrotor
The fig 3.4 shows the 3D model of the quadrotor. It having the (+) configuration frame to hold the motor. The BLDC motor are fixed on the end of the square hallow frame. The thrusters are fixed with motor. The flight controller module placed top side on centre of the frame. The battery fixed bottom side in the centre of the frame.

IV HARDWARE DESIGN

A. BLDC Motor

The motors are brushless, DC motors rated for 11 V, 18 amps is shown in Figure 4.1. The DC, brushless Motor configuration was desired for ease of control (ability to control via PWM). The motors use strong rare earth magnets and provide the best power to weight ratio of the hobby motors available for model aircraft.

The motors used are limited to hobby motors due to design budget. As a result, the rest of the structural
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design revolves around these motors and the allowable weight of the craft based on the lift provided by these motors.

B. **Electronic Speed Control**

An electronic speed control or ESC shown in Figure 4.2. It is an electronic circuit with the purpose to vary an electric motor's speed, its direction and possibly also to act as a dynamic brake.

![Electronic Speed Control](image)

Fig 4.2 Electronic Speed Control

ESCs are often used on electrically powered radio controlled models, with the variety most often used for brushless motors essentially providing an electronically generated three phase electric power low voltage source of energy for the motor[38-39].

C. **Propellers**

The propellers are 11” from tip to tip. Two are of the tractor style, for clockwise rotation, and the other two are of the pusher style, for counter clockwise rotation. For our design, a propeller with a shallow angle of attack as shown in Figure above was necessary as it provides the vertical lift for stable hovering. The propellers used here is steeper than the ideal design because of limited availability of propellers that are produced in both the Tractor and Pusher styles.

D. **Flight Controller**

A Flight controller shown in Figure above is an electronic circuit board has sensors, microcontrollers, interfacing units that fly the Quadcopter by getting values from sensors and computing them. The selected controller has accelerometer, gyroscope and a ATMega 8 bit processor. Its shown in Fig 4.3
E. **Radio Transmitter/Receiver**

Radio signal is used to control the Quadrotor from the ground. The RC model we opted is FLYSKY with 6 channels but 4 channels would be enough[33-37]. This is shown in Figure 4.4. This transmitter used to send the command from the user to controller.

F. **Wires**

As the motors can use current up to 25A, there is need for special wires that can handle high current without failure. Normal wires fail due to overheating. So special wires like Silicone wires are used, which can withstand 200°C and also they are very Flexible so that they can be bent and used.

G. **Connectors**

Since we are dealing with current around 80A, it is mandatory to use special connectors that can withstand high current. Motors use Bullet connectors, battery use Deans T connector; we can also use XT60 Nylon made connector which is easy to handle.
V. CONTROLLER DESIGN

Two PI loops are used independently to control Pitch, Roll and Yaw. Since Pitch and Roll are same here due to symmetry structure one PI loop for controlling this and other for Yaw movement. This PI values are tuned accordingly to reduce/increase the settling Time.

A. Digital Filter Design

To get error free value from the sensors, there is need for Filters which identifies noise and eliminates them. Kalman Filter would be the filter of priority but due to its complexity and need of huge processing power, we just adopt Complementary Filter which just averages the value from the accelerometer and gyroscope at some rate called Timing constants. This constant defines how for the weightage given to each sensor. Accelerometer drifts initially, as time passes it works fine. On the other case Gyroscope works fine in a short run as it measure only rate of change. So accelerometer can be trusted here. So we have timing constant so that accelerometer value has more weightage than gyroscope

\[
\text{Filtered gyro} = A \times \text{filtered gyro} + (1-A) \times \text{gyro rate} \\
\text{Filtered acc} = A \times \text{filtered acc} + (1-A) \times \text{acc angle} \\
\text{Filtered angle} = \theta \times \text{filtered gyro} + \text{filtered acc} \\
\text{Where} \quad \theta = A / (1-A) \times dt \\
\text{dt - loop time} \\
A - \text{constant} \\
\theta - \text{Timing constant}
\]

B. Auto Stabilization

To fly stable, there is need to keep the platform horizontal always. To stabilize we use sensors to measure the tilt in the platform and compensating them by adjusting the motor speed. A 3-axis Accelerometer, 2-axis gyroscope and a 1-axis gyroscope is used. Z-axis yaw is measured with the single axis gyroscope as Z-axis drifts very easily. fig 5.1 shows block diagram of auto stabilization

VI. CONCLUSION AND RESULT

This paper proposes Design, Fabrication and Analysis of Quadrotor UAV. A final test has been done by flying the model and its behavior is analyzed and accordingly some parameters are adjusted. This UAV is designed for working in extra-terrestrial applications and aerial photography. The final Designed and tested
Quadrotor is shown in fig 6.1

Fig 6.1 final Designed and tested Quadrotor

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