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Design, Fabrication and Testing of Quadrotor prototype

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***Abstract*-With the advancement of new technologies in robotics and aviation, there is currently a limited diversity of vehicles capable of Vertical Take-Off and Landing and shown a visible interest of Unmanned Aerial Vehicles, particularly an aircraft called quadrotor. The use of quadrotor has grown drastically to operate in dangerous situations where human can be safe at a distance. Our project has verified that it is possible to build a small-scale Quadrotor using simple physics that could achieve a tethered flight and can maintain a stable position when flying. Our prototype is equipped with gas leakage sensor and hence can be used as mobile gas leakage detector in chemical industry.**

***Index terms*– Quadrotor Control Strategy, Dynamics, Physics**

I. INTRODUCTION

UNMANNED AERIAL VEHICLE:

An Unmanned Aerial Vehicle (UAV), commonly known as drones, an aircraft without a human pilot aboard. Its flight is controlled either autonomously by on board computers or by the remote control of a pilot on the ground or in another vehicle[1].

QUADROTOR:

Quadrotor are unmanned aerial vehicle that produce thrust using 4 propellers similar to helicopter but doesn't require tail rotor for its stability.The Quadrotor's attitude (aircraft orientation relative to the vehicle's center of gravity) is completely controlled by four propellers.

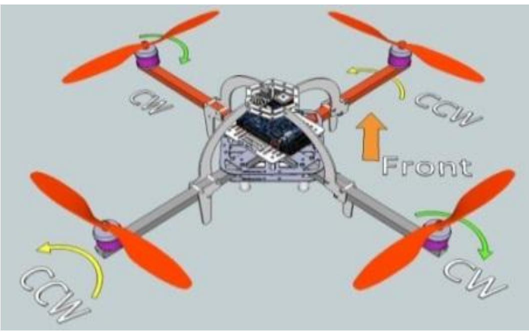

Fig 1. Quadrotor [2]

LITERATURE REVIEW

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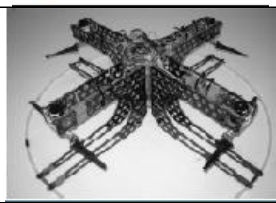
The table introduces some of the works presented in recent years.

Table 1.the works presented in recent years

PROJECT	UNIVERSITY	PICTURE
DRAGONFLY X4 [7]	COMMERCIAL	
MICHAEL J. STEPANIAK THESIS [8]	OHIO UNIVERSITY	
P. POUND'S THESIS [9]	AUSTRALIAN NATIONAL UNIVERSITY	
STARMAC [10]	STANDFORD UNIVERSITY	
2008 AUVSIUAS STUDENT COMPETITION [11]	OKALAND UNIVERSITY	

II. PROBLEM DEFINITION

Correct execution of any aerial vehicle stage provides the early determination of what the drawbacks in the design are and allows us to save not only money but also time. In this way, few changes need to be implement after building quadrotor.

The keypoints for building quadrotor are [1]:

- Overall mass should not be more than 1kg, because the heavier they are, the more expensive they are.
- Flight autonomy between 10 to 20 minutes. There is no point in using quadrotor for 2 minutes and then wait a couple of hours to recharge the batteries.
- Ability to control the movements of quadrotor wirelessly.

- To implement as flying gas leakage detector in chemical industry.

III. DESIGN, ANALYSIS AND COMPONENT SELECTION

STATIC THRUST CALCULATION:

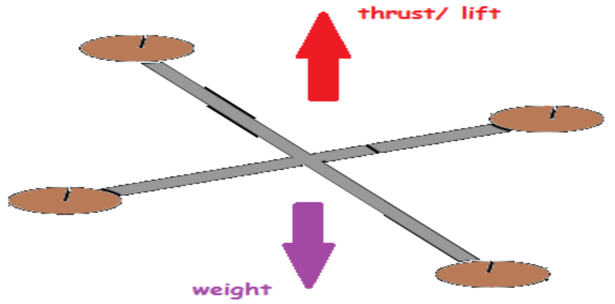


fig 2: Forces in Quadrotor

Assuming quadrotors maximum weight = 1kg
Therefore,
total thrust = 1* 9.81 = 9.81 N
and it is mandatory that each propeller is able to provide atleast = 9.81/4 = 2.45 N
From fig1-
Minimum rotational speed for lift-off ≈ 412 rad/s
= 3934 RPM
And propeller power = 26 watt.

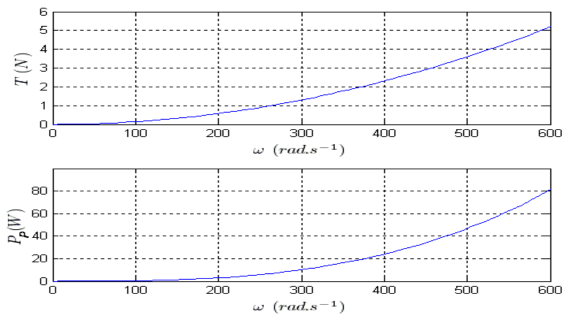


Fig.3: Theoretical thrust and power of a propeller [3].

DC MOTORS:

A method of selecting the appropriate motor is outlined below. Fig 4 shows a generalized torque vs. speed curve of a DC motor with a constant applied voltage.

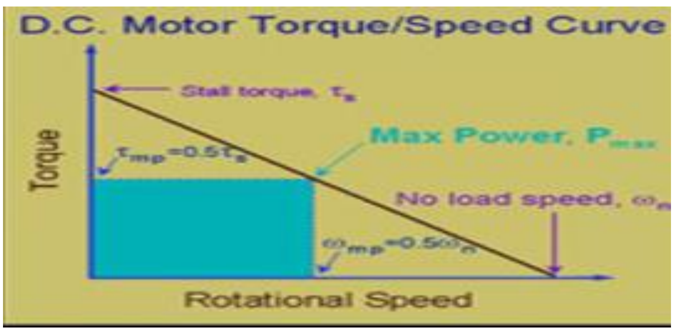


Fig. 4: Torque vs. Speed curve of a DC motor with constant applied voltage.

DC motors perform the best when they are producing the most mechanical power. Power is the product of torque and rotational speed which is given in Equation (i).

Power = Torque * Rotational speed…… (i)

In order to find the maximum power of a motor, all that is needed is to find the rotational speed at which the maximum power occurs. It is shown in Fig 4 that maximum power is achieved at a torque and rotational speed that is half of the motor's maximum capabilities given a constant voltage. Maximum power output is important because it is desirable to match a motor's best range of performance with the most common flight situations of the aircraft. In this case, the quadrotor helicopter's most common mode of flight is to hover. Hovering occurs when a propeller/motor set produces thrust (mass) that equals the weight of the aircraft. Hovering should occur at 50% of the motor's maximum capabilities which directly relates to the equivalent of half the battery's voltage.

Since DC motors are rated in Kv (rpm/v), the rotational speed at which maximum power is achieved is found by multiplying the motors Kv by half the battery voltage and dividing the results by 2. This process is illustrated in Equation(ii) below [4].

$$rpm_{max\ power} = \frac{Kv*0.5*battery\ volts}{2} \ldots..(ii)$$

The resulting desired rpm occurs at 1/4th the maximum rpm of the motor at full voltage. This desired rpm will be used in the Propeller and Motor Selection section of this paper. But before a proper propeller and motor can be selected, the mass of the aircraft must be estimated.

MASS ESTIMATION:

In order to determine which motor and propeller combination is needed to power the aircraft, the mass of the aircraft must be estimated. To do this estimation, all the different components that are needed to build the aircraft are found and an average weight of each component is calculated. Table 1 shows the components, their weights, and the accumulated total weight.

Table 2: Mass estimation

COMPONENT	MASS(G)	QUANTITY	TOTAL MASS(G)
PROPELLER	23	4	92
REMOTE RECEIVER	7	1	7
MOTORS	48	4	192
ESC	9	4	36
BATTERY	185	1	179
KK2 MICROCONTROLLER	35	1	35
FRAME	260	1	260
MACHINE SCREWS, WIRING, ETC.	50	1	50
TOTAL MASS			851

Table shows an estimated weight of about 851g which will now be used to acquire the appropriate motors and propellers.

PROPELLER AND MOTOR SELECTION:
The ideal rpm of each motor is located in Table 3.
The next step is to determine the ideal rpm of the propeller. Ideal rpm for a propeller is found by combining Equations1 and 6 and solving for rpm. Equation 9 shows the result of this mathematical manipulation [5].

$$(rpm)ideal = \left(\frac{x}{y}\right)^{\frac{1}{2\omega}}\left(\frac{g^{3}/2 \cdot m^{3}/2}{\alpha D\sqrt{\rho}}\right)^{3/2} \quad \text{.............(iii)}$$

ω=Power factor from aircraft world.com

α=Power coefficient from aircraft world.com

D= Diameter [m]
ρ=Air density [1.225 kg/m^3]

M= mass [kg]
G= gravity [9.81 m/s^2]

The mass that is entered into Equation (iii) is the estimated mass of 851g divided by 4 because there are four motor/propeller sets that contribute to lift.Table 4 shows the results of Equation (iii) for a range of different APC E propellers.

Ideal thrust (mass kg) = 0.4462 (each propeller)
Air density [kg/m^3] = 1.225
Gravity [m/s^2] = 9.81

Table3: List of motors

Table 4: ideal motor rpm for different propellers

PROPELLER	DIAMETER (M)	PC	P F	IDEAL RPM
8*8	0.2032	0.148	3.2	3721
9*4.5	0.2286	0.09	3.2	4189
9*6	0.2286	0.129	3.2	3744
9*7.5	0.2286	0.352	2.9	3036
9*9	0.2286	0.448	2.9	2794
10*5	0.254	0.144	3.2	3500

From Tables 3 and 4, it is clear that the APC E 10 * 5 propeller is the best match to the given set of motors. To be more specific, the 10 * 5 propeller has an ideal rpm that would support hovering for the given estimated mass of the aircraft, and the ideal rpm of the propeller closely matches the ideal rpm of the motors listed in Table 3.3.

In addition to the analysis performed above, there are other

Motor	Kv(rpm/v)	Max rpm	Ideal rpm
THS3628 Brushless Outrunner	890	2893	723
Turnigy L2215J-900 Brushless Motor (200w)	900	9990	2498
A28L brushless Outrunner 920kv	920	10212	2553

considerations in choosing a motor, like price and availability. Ultimate the THS3628 Brushless Outrunner and APC E 10*5 propellers where chosen for this project.

BATTERY AND FLIGHT TIME:

The most commonly used type of battery is Lithium Polymer (Lipo), and this type was chosen for this project. The popularity of Lipo batteries is due to their large capacity, light weight, and excellent discharge capabilities.

- Flight time, which is directly proportional to battery capacity, can be found by dividing battery capacity by the amount of amps being drawn from the battery. Flight time is given in Equation 10 below [4] .

flight time = Battery capacity/amps ....(iv)
Therefore, theatrical flight time =

$$2200mAh\left(\frac{60 \cdot 1 \cdot A}{hour \cdot 8A \cdot 1000mA}\right) = 16.5 \text{ min}$$

The THS3628 Brushless Outrunner has a maximum amp rating of 25 amps. Since there are a total of 4 motors, the total maximum drain of the battery will be 100 amps. Table 5 lists a variety of batteries with different capacities and their corresponding flight times at full and half discharge rates.

Table 5:Flight time with respect to battery capacity and discharge rate

CAPACITY (MAH)	FLIGHT TIME AT 100% DISCHARGE RATE (MIN)	FLIGHT TIME AT 50% DISCHARGE RATE (MIN)
1000	1.5	3
1200	1.8	3.6
1400	2.1	4.2
2000	3	6
2200	3.3	6.6
2400	3.6	7.2

After researching the many different batteries available on the market, a Blue LiPo 2200 mAh 20C battery was chosen. This battery is approximately the same weight of the battery in the weight estimation performed earlier and has a capacity that will maintain flight for about 6.6 min at a 50% discharge rate.

FRAME DESIGN:

The frame of a quadrotor helicopter has to be rugged while being light enough to take flight. When all of the available materials are taken into consideration, Aluminum proves to be the most effective material for a frame due to its low density and extremely high strength. The minimum size of frame is 0.254m*0.254m in cross configuration. But there is high probability that propeller in this case will interfere with each other during operation. This interference will continue to happen in range 0.254m*0.254m to 0.360m*0.360m and will damage the propellers as shown in fig 5 and 6

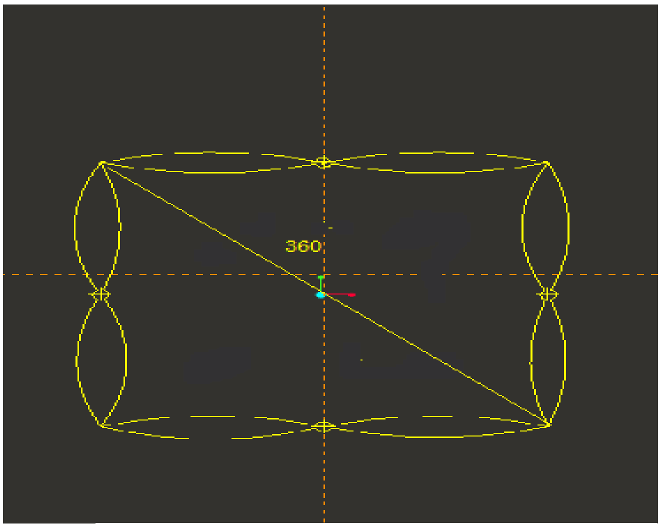


Fig. 5

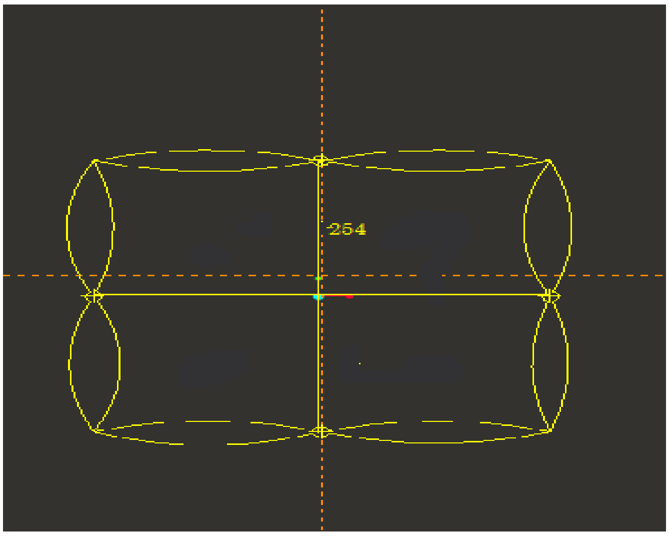


Fig. 6

Fig 5 & 6 interference in frame

Therefore, frame should be between size 0.4m*0.4m to 0.46m*0.46m for proper balancing and stability of frame during flight.

Alternatively, the cross configuration of frame can be assumed as four cantilever beams fixed at center of frame. The deflection of cantilever beam of length *L* is acted upon by point load of W, is given by formula---- ,

$$y = \frac{WL^3}{3EI} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(v)$$

whereEI= flexural rigidity of material.

For a quadrotor, W = thrust = 1.2 kg = constant

EI = constant

Implies y α L ^ 3

Therefore,

200 mm < y < 230 mm

If y < 200 mm then, there will be clash of rotor blades during flight and if y> 230 mm then deflection increases.

The ProE model of frame of size 0.45m*0.45m is shown in Fig. 7.

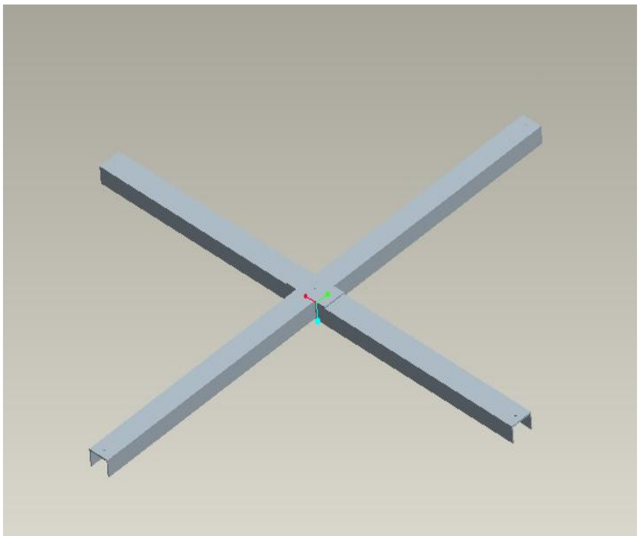


Fig.7 ProE model of Frame

Analysis of the same model is done using ANSYS V11 in workbench. Fig.12 shows meshing of the frame. And fig. 9 shows the loads applied on the frame for the analysis.

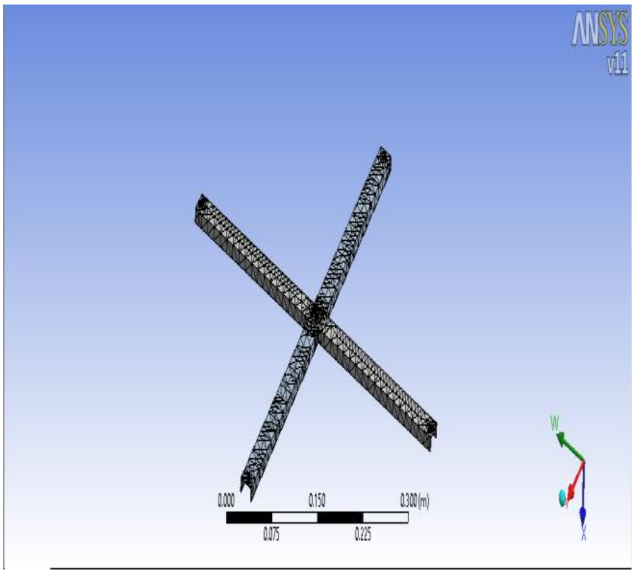


Fig. 8 Meshing of frame

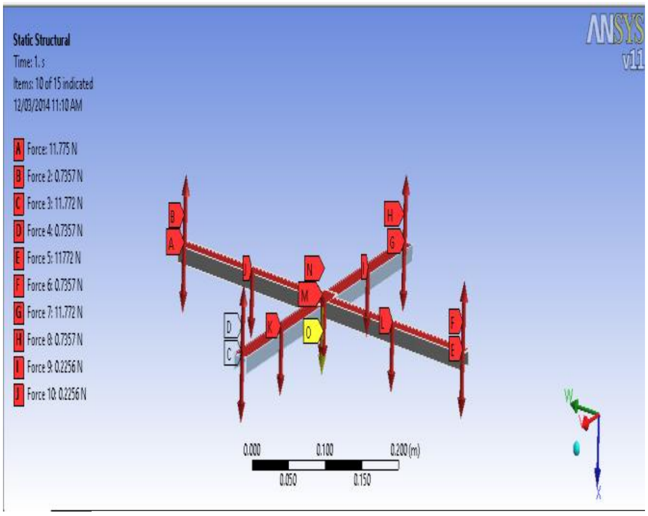


Fig. 9 Static load applied on frame

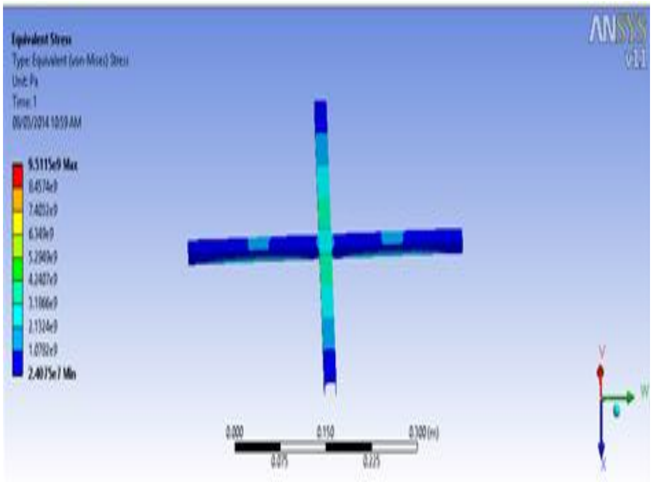


Fig. 10 Stress distribution on frame

Von Mises stress distribution in frame is shown in fig. 10 Maximum stress ($9.5115*10^9$ Pa) is observed at the center of the frame. Blue and shades of green in stress distribution shows that the frame is absolutely safe.

Assembly block diagram for quadrotor

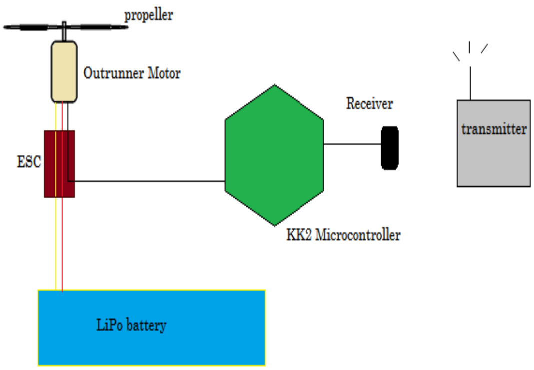


Fig. 11 assembly

ELECTRONIC COMPONENTS:

i. Microcontroller

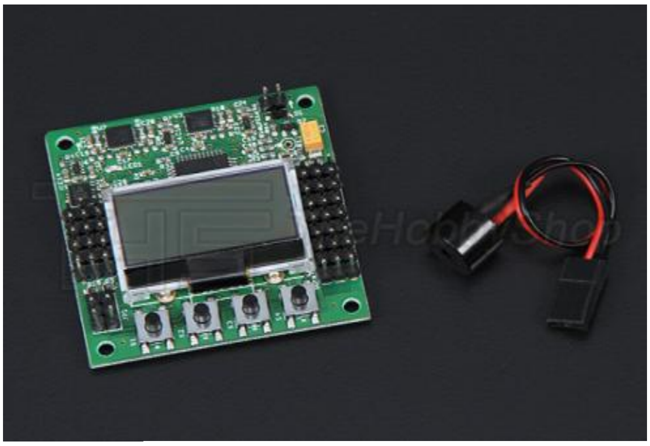


Fig. 12 Microcontroller

Designed by the Grand father of the KK revolution, Rolf R Bakke, exclusively for HobbyKing, the KK2.0 is the evolution of the first generation KK flight control boards. The KK2.0 was engineered from the ground up to bring multi-rotor flight to everyone, not just the experts. A host of multi-rotor craft types are pre-installed. Simply select the craft type, check motor layout/propeller direction, calibrate the ESCs and radio and it is ready to go. All of which can be done with the help of the on screen prompts [6] [8].

ii. Electronic Speed Controller

An electronic speed control or ESC 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. ESCs are often used on electrically powered radio controlled model , with the variety most often used for brushless motor essentially providing an electronically-generated three phase electric power low voltage source of energy for the motor. Brushless ESC systems basically drive tri-phase brushless motors by sending sequence of signals for rotation. Brushless motors, otherwise called out runners or in runners, have become very popular with radio controlled airplane hobbyists because of their efficiency, power, longevity and light weight in comparison to traditional brushed motors. However, brushless AC motor controllers are much more complicated than brushed motor controllers. Most modern ESCs incorporate a battery eliminator circuit (or BEC) to regulate voltage for the receiver, removing the need for receiver batteries [6] [8].

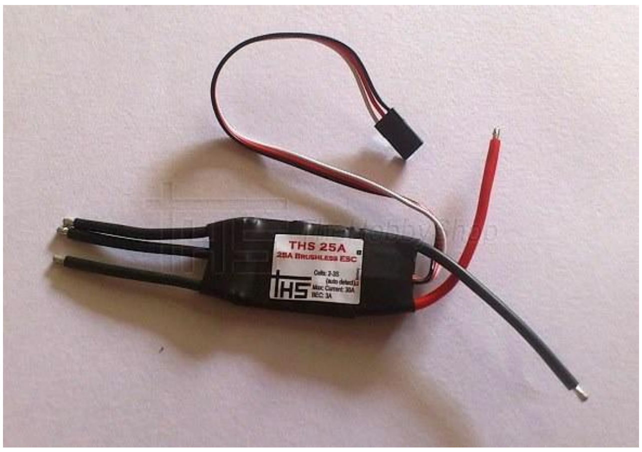


Fig. 13 ESC

(iii) Transmitter and Receiver

An RF Module (Radio Frequency Module) is a usually small electronic circuit used to transmit and/or receive radio signals on one of a number of carrier frequencies. RF Modules are widely used in electronic design owing to the difficulty of designing radio circuitry. Good electronic radio design is notoriously complex because of the sensitivity of radio circuits and the accuracy of components and layouts required to achieve operation on a specific frequency. Here we are using fly sky (fs) ct6b transmitter and receiver [6] [8].

Receiver specification :

- Channel: 6
- Frequency band: 2.4GHz
- Power source: 1.5V*4''AA''battery
- Modulation type: FM
- Static current: ≤85mA
- Size: 45*23*13.5mm
- Weight: 12g

Fig. 14: Receiver

Transmitter specification:

- Channels: 6
- Frequency band: 2.4GHz
- Power resource: 1.5V*8"AA"battery
- Modulation type: FM
- Static current: ≤250Ma

Fig. 15 Transmitter

IV. RESULTS

1st test flight:

Our 1st test flight was taken on 3rd Sept. 2013, and which was taken in the mechatronics lab of mechanical department. Following are the problems faced during the flight:

1. Loosening of screws,
2. Unbalancing of Quadrotor,
3. Quadrotor control was not so good,
4. Propeller slipped from shaft, and
5. Damage to the propeller

Even after so many problems Quadrotor was able to hover up to 2feet and there was no damage to frame which shows the capacity of frame to absorb sudden vibration was very good. The following suggestions were given for eliminating the problems:

1. Brazing
2. Welding
3. Araldite

Fig. 16 First test flight

2nd test flight:

We used araldite to fix the screws and other components which were losing its contact during the flight. And second test flight was taken on 15th Jan. 2014, which gave the following results:

1. Hovered up to 40 ft.,
2. Controlled successfully,
3. Time of flight more than 10 min,
4. No damage to the propeller and ESC,

The only problem occurred was landing of quadrotor, may be due lack of practice.

Fig. 17 test flight 2

V. PROPOSED APPLICATION

Quadrotor when equipped with gas leakage detector sensor can be used as flying leakage detector in chemical industries. When leaked gas is unknown and we want to know whether it is harmful to human life or not, Quadrotor in such situation will be very helpful if it is equipped with the gas detector sensor, since it can communicate wirelessly.

Gas detector basically consists of SnO_2 as sensing material. When the sensor is in clean air, oxygen from surrounding gets adsorbed and forms barrier and provides high resistance in circuit and very low current is given to the alarm. This current is not sufficient to turn on the buzzer which has preset value. When the gas is leaked in clean atmosphere oxygen level decreases and consequently the amount of adsorbed oxygen, due to this resistance to flow of current also lowers and as soon as value of current reaches preset value of buzzer, it turns on. Fig 1 shows the gas detector sensor kit and fig 2 shows the circuit of it [7].

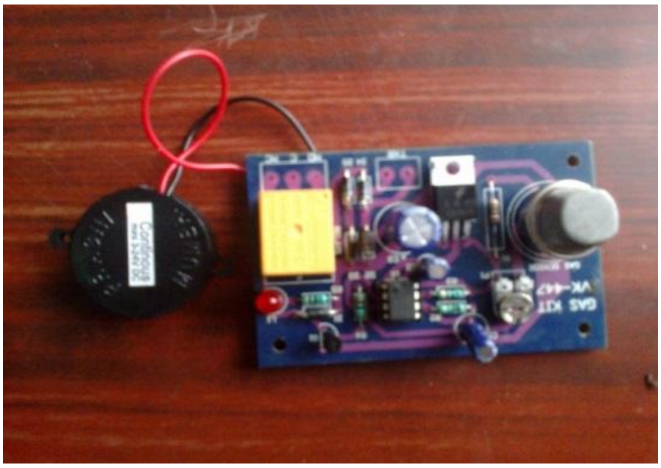


Fig. 18 Gas Detector Sensor kit.

VI. CONCLUSION

The main objective of this project was to design, fabricate and test the quadrotor prototype. In the first phase of this project, objectives were defined for the quadrotor design, and based on them a study was carried. This analysis resulted in the construction of a quadrotor capable of achieving Take-Off without using the motors at full throttle.

REFERENCES

[1] Jorge Miguel BritoDomingues, Quadrotor prototype, (2009).
[2] ShrikanthBabalu, RakeshMallem, Radiocontrolled quadrotor.
[3] http://www.aviastar.org/helicopters_eng/lomonosov.php
[4] Antonio DiCeare, Kyle Gustafson, Design optimization of a quadrotor capable of autonomous flight.
[5] http://aircraft-world.com/prod_datasheete/hp/emeter/ hp-propconstants.htm
[6] HoverflySPORT™ User's Guide.
[7] MQ6 Gas Sensor Brick -Arduino Compatible - emartee.com
[8] www.thehobbyshop.in

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