ISLAMIC UNIVERSITY OF TECHNOLOGY (IUT)

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DEPARTMENT OF MECHANICAL & CHEMICAL ENGINEERING (MCE)

FABRICATION OF A QUADROCOPTER

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ABSTRACT

This paper presents a quadrocopter helicopter as a prototype platform usable for research and education. Apart from the description fabrication hardware and controlling software, we discuss several issues regarding drone equipment, abilities and performance. We show, how to perform basic tasks of position stabilization, object following and autonomous navigation. Moreover, we demonstrate the drone ability to act as an external navigation system for a formation of mobile robots. To further demonstrate the drone utility for robotic research and using in daily basis, we describe experiments in which the drone has been used.

CONTENTS

CHAPTER 1

FOREWORD

1.1 INTRODUCTION

A quad rotor helicopter or quadrocopter is an aerial vehicle propelled by four rotors. The propellers have a fixed pitch, which makes the quadrocopter mechanically simpler than an ordinary helicopter. However, the quadrocopter is inherently unstable, and therefore, its control is rather difficult. The progress on the field of control engineering allowed dealing with inherent instability of the quad rotors, and therefore, they have started to appear in military, security and surveillance systems. Quadrocopters are with us almost one century. First experiments with it started at the beginning 20th century. The first functional quadrocopter was built in year 1920 by Etienne Oehmichen. Quadrocopters are compact rotor craft air vehicles with vertical takeoff and landing (VTOL) capability. Like a conventional helicopter they can hover, but have significant other advantages such as ease of piloting and mechanical simplicity — they have no swash-plate mechanism. The simplicity of the quadrocopter makes it easy and cheap to build and there are a number of low-cost radio-controlled toy quadrocopter.

1.2 What is Quadrocopter?

Quadrocopter it's a flying object, which flies with a help by four propellers placed on the end of a cross construction. Main features of this device are stability, small weight and maneuverability. At present it is popular for its advantages.

Early in the history of flight, quadrotor configurations were seen as a possible solution to some of the persistent problems in vertical flight; torque-induced control issues (as well as efficiency issues originating from the tail rotor, which generates no useful lift) can be eliminated by counter-rotation and the relatively short blades are much easier to construct. A number of manned designs appeared in the 1920s and 1930s. These vehicles were among the first successful heavier-than-air vertical takeoff and landing (VTOL) vehicles.[*] However, early prototypes suffered from poor performance,[*] and latter prototypes required too much pilot work load, due to poor stability augmentation[*] and limited control authority.

More recently quadrotor designs have become popular in unmanned aerial vehicle (UAV) research. These vehicles use an electronic control system and electronic sensors to stabilize the aircraft. With their small size and agile maneuverability, these quadrotors can be flown indoors as well as outdoors.[*]

There are several advantages to quadrocopter over comparably-scaled helicopters. First, quadrotors do not require mechanical linkages to vary the rotor blade pitch angle as they spin. This simplifies the design and maintenance of the vehicle.[*] Second, the use of four rotors allows each individual rotor to have a smaller diameter than the equivalent helicopter rotor, allowing them to possess less kinetic energy during flight. This reduces the damage caused should the rotors hit anything. For small-scale UAVs, this makes the vehicles safer for close interaction. Some small-scale quadrotors have frames that enclose the rotors, permitting flights through more challenging environments, with lower risk of damaging the vehicle or its surroundings.[*]

1.3 APPLICATIONS

- The real driving force behind the quadrotor design and the perfect job for them. Since these things almost fly themselves, hover like they are glued in the air, have superior lift efficiency, and don't take that much skill to pilot, they have become one of the most popular vertical lift and flying platforms for dozens of different aerial photo and video applications. Many of these FPV quadrotor RC helis are also called UAV’s (Unmanned Aerial Vehicles).

- One of the most common and recognizable high end radio controlled quadracopters is the Draganflyer X4 industrial vertical lift platform. These have been used in surveillance work, search & rescue operations, and law enforcement for example or in much higher demanding image quality aerial photography/video rolls such as professional photography, video brochures, and aerial real estate to name just a few of the applications.

- With more and more quadrotor RC helis hitting the marketplace, it is really hard to stay current, but here are a few links to companies that manufacture & carry radio controlled quadrotor helicopters from the hobby variety up to more industrial applications.

1.4 OBJECTIVE

- To fabricate a quadrocopter

1.5 THE WHOLE APPEARANCE

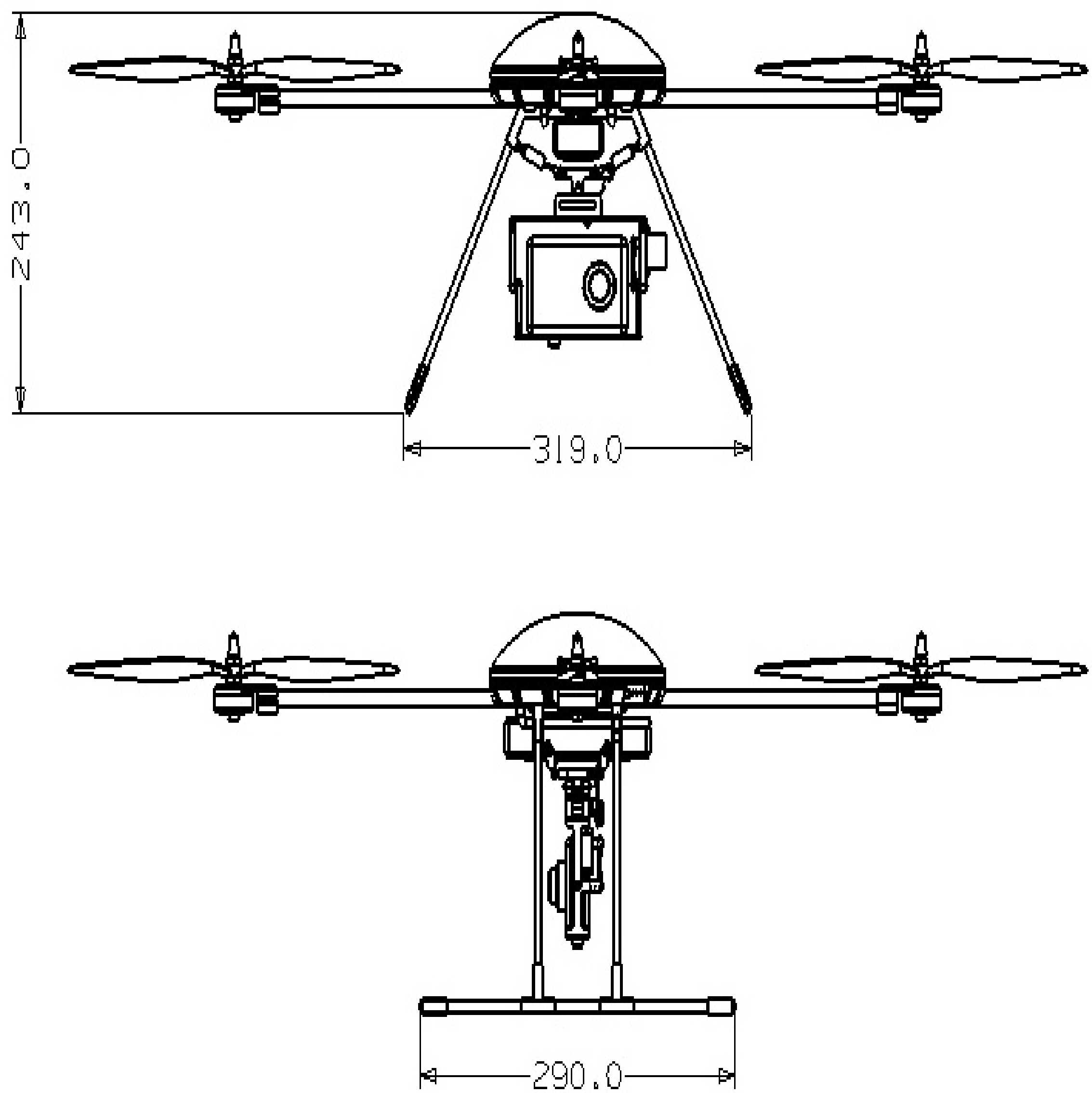


Fig 1.1: The outline size

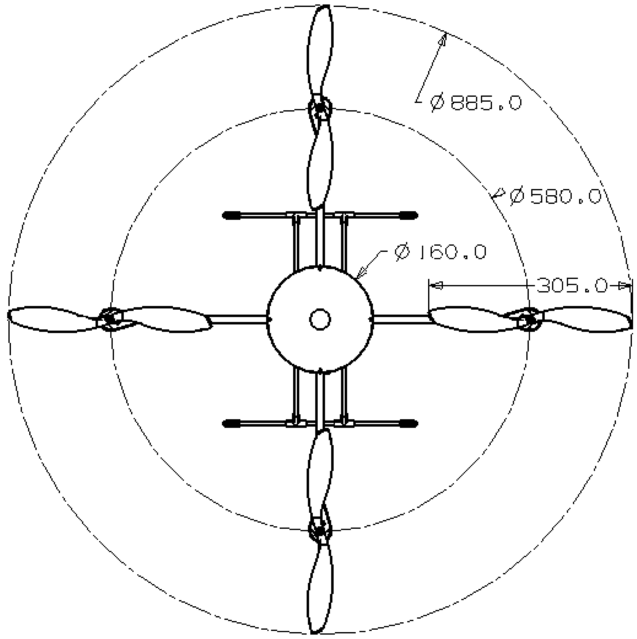


Fig 1.2: The stretching size

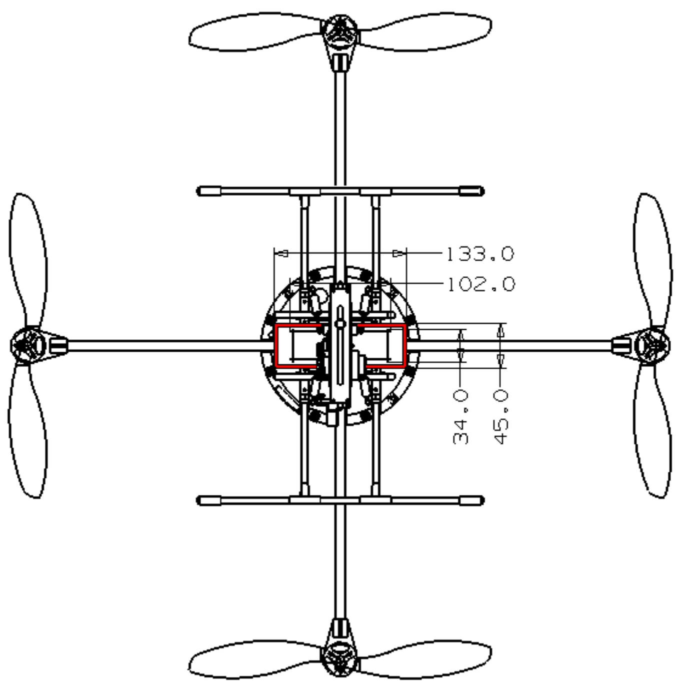


Fig 1.3: Battery installation location

CHAPTER 2

ASSEMBLY UNIT

2.1 BODY PARTS

Table 2.1: Parts with specifications

Part	Specifications
Main shell	ABS composite material
Arm	Fiberglass / carbon fiber
Tripod	Fiberglass, rubber, aluminum
Motor	C2806 KV600 Efficient brushless motor
Propeller	1260,1260 R Nylon composite slow paddle
PTZ	Fiberglass / carbon fiber two-dimensional equilibrium
Head hangers	Elastic damping, shock absorber suspension
Steering head	High Speed Digital Servo Metal
ESC	2-3S 18A high-speed electronic transfer

2.1.1 FRAME

The quadrocopter has an aluminum centre frame with carbon fiber-foam sandwich arms. Regularly spaced mounting points allow the Cogs to be shifted easily. Motors and batteries are mounted as far from the central axis as possible. The arms angle down slightly to provide more clearance between the bottom of the arms and flapping rotor tips. The rotor mounts are teetering hubs, a freely pivoting joint between the drive shafts and rotor blades, machined from aluminum. The blades are screw-clamped between the rotor mount top and bottom plates.

- Center plate: Aluminum
- Tube arm:
  They are (9" x 5/8" x 5/8") or (12" x 5/8" x 5/8") and weigh about 1oz each. They are low cost, sturdy and are directly compatible with the AeroFPV frame.
- Battery mount
- Motor mounts:
  It is easy to install motor mounts that work perfectly with 5/8" frame arms and fit all of motors. They are available as single mounts to allow building desired quadrocopter configuration.
- Protective dome
- Landing gear

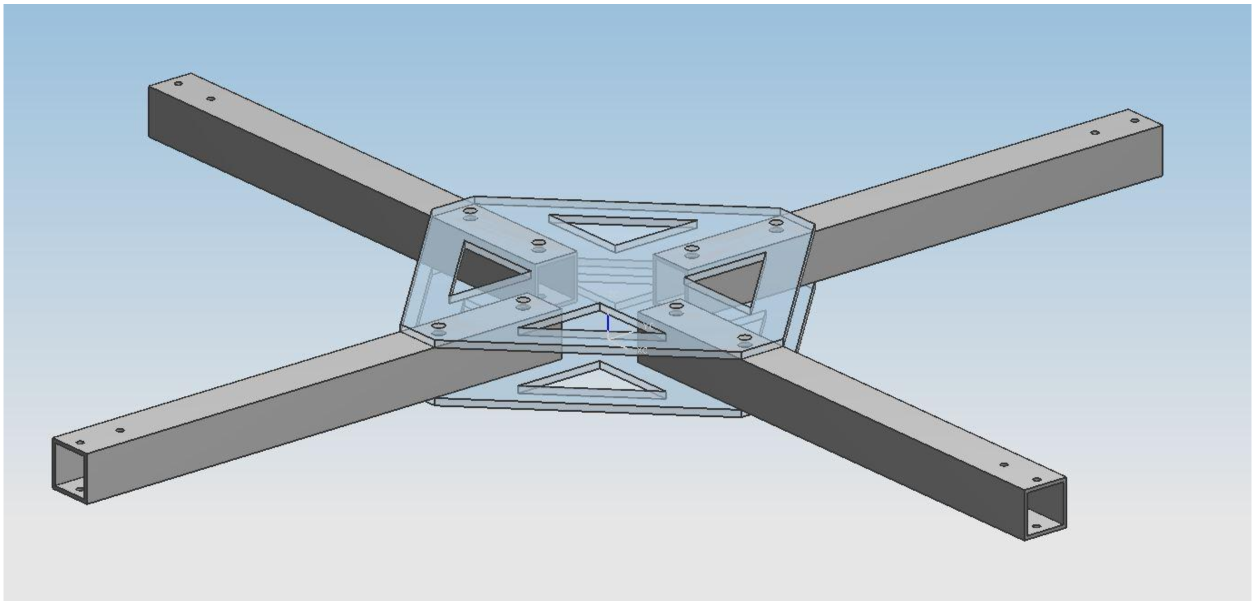


Fig 2.1: Main frame with center plate

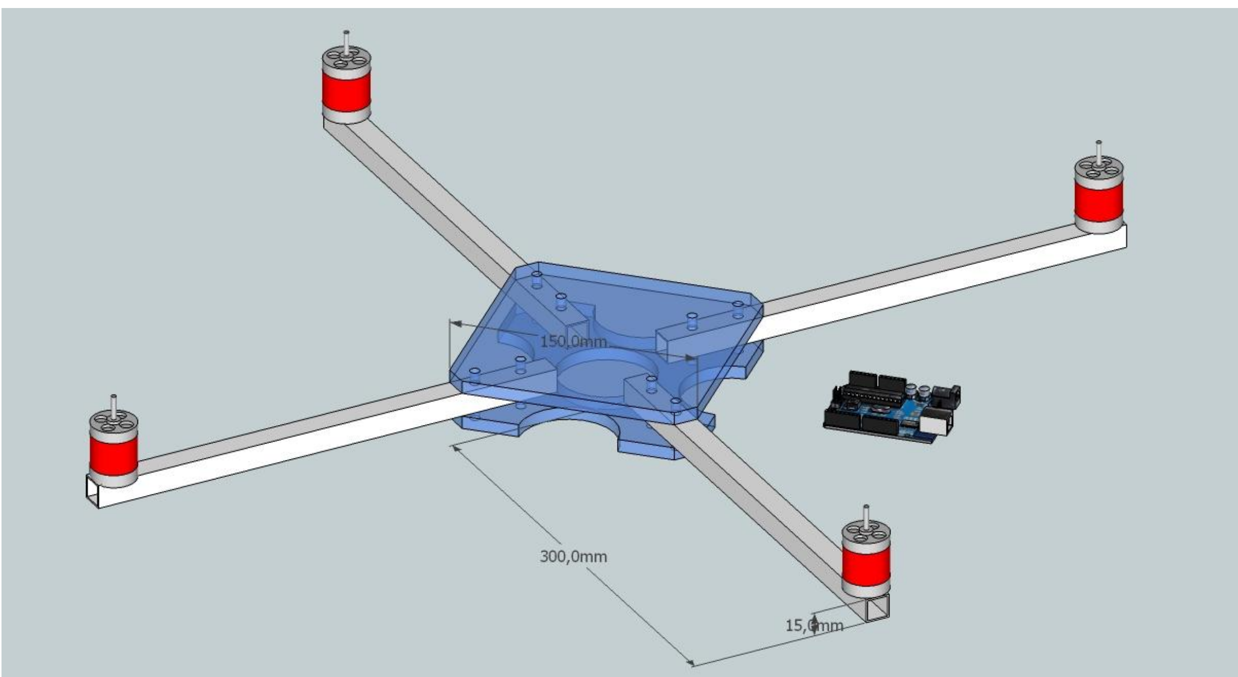


Fig 2.2: Motor and controller

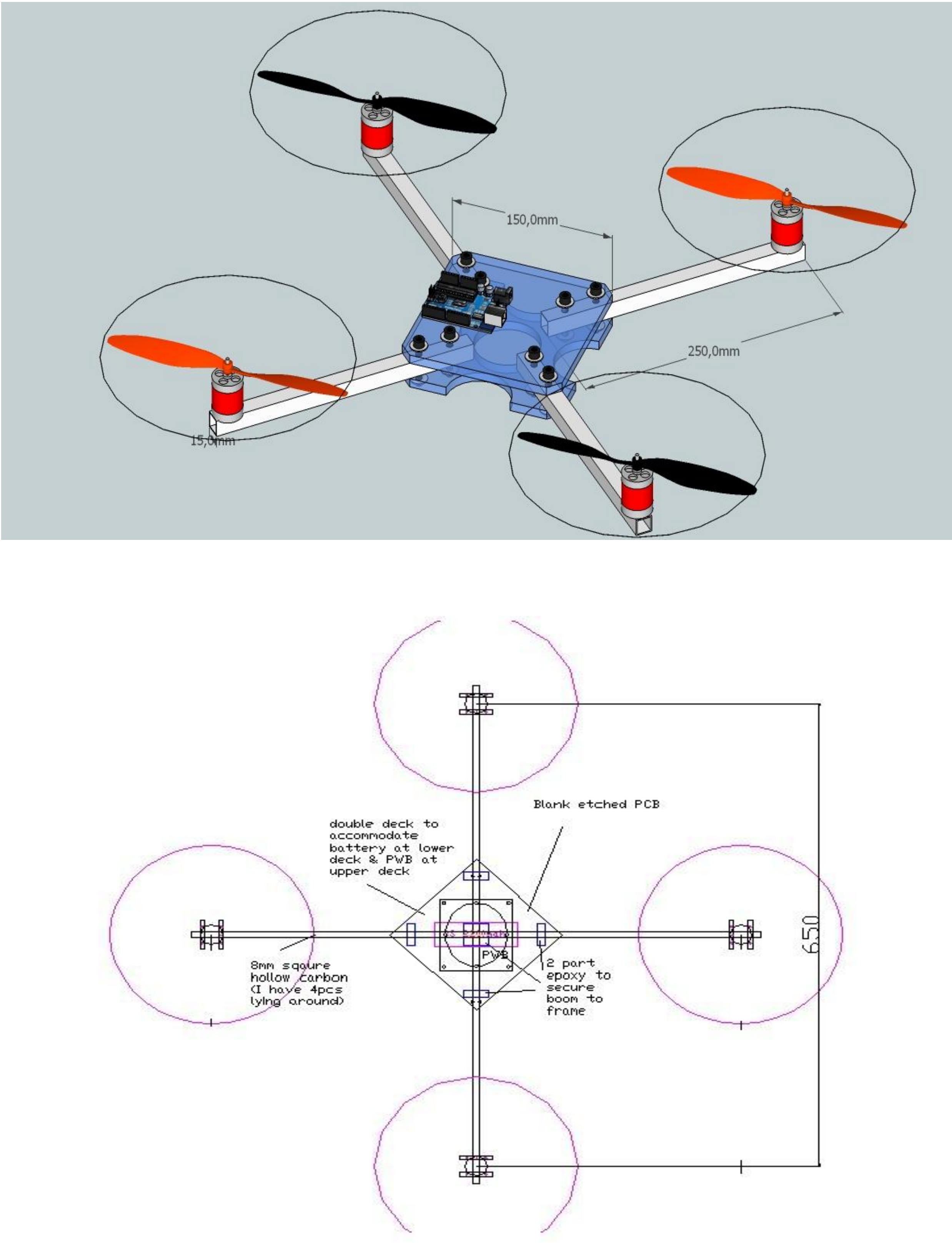


Fig 2.3: Propeller and whole unit

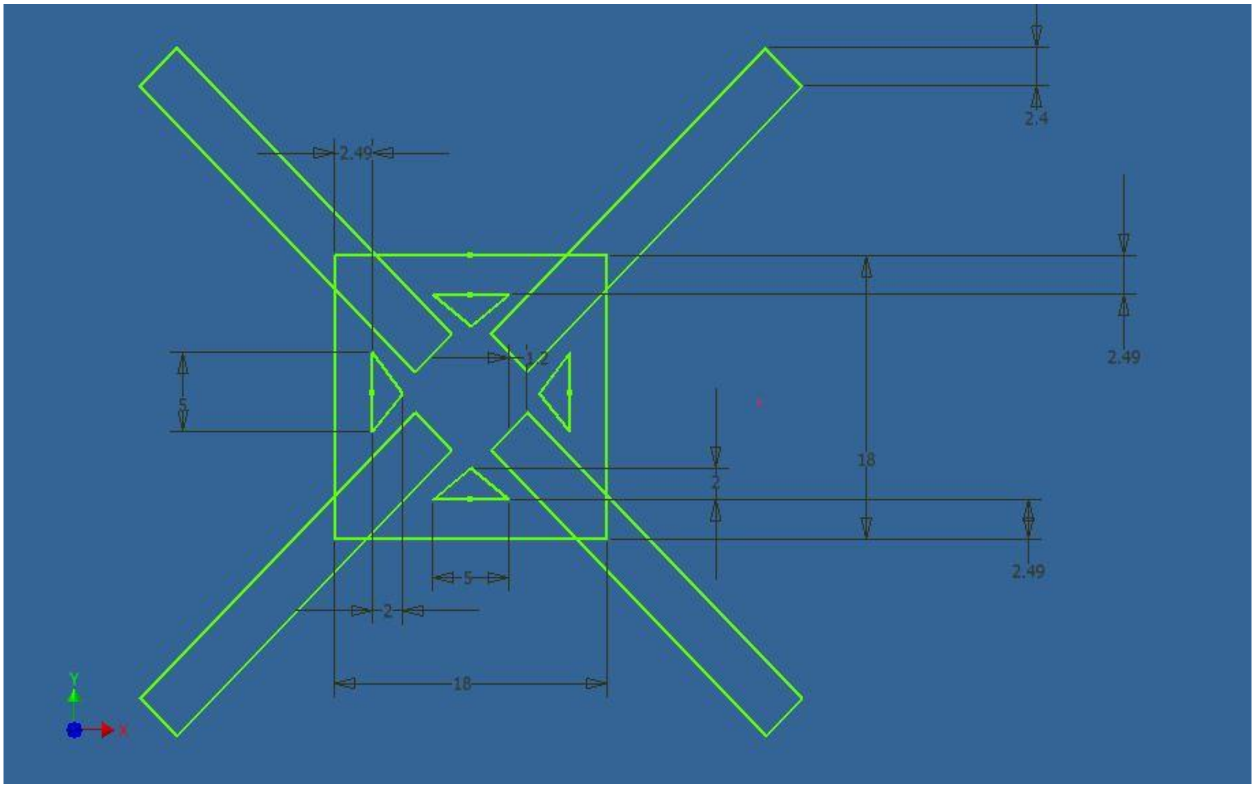


Fig 2.4: Dimension with 2D view

2.1.2 MOTORS

- **Brushless vs. Brushed:**

A Brushed Motor has a rotating set of wound wire coils (armature) which acts as an electromagnet with two poles. A mechanical rotary switch (commentator) reverses the direction of the electric current twice every cycle, to flow through the armature so that the poles of the electromagnet push and pull against the permanent magnets on the outside of the motor. As the poles of the armature electromagnet pass the poles of the permanent magnets, the commentator reverses the polarity of the armature electromagnet. During the instant of switching polarity, inertia keeps the motor going in the proper direction.

A Brushless Motor uses a permanent magnet external rotor, three phases of driving coils, one or more devices to sense the position of the rotor, and the associated drive electronics. The coils are activated, one phase after the other, by the electronic speed controller as cued by the signals from the rotor position sensors.
Here, we are using brushless motor for better efficiency and work.

- **Out runner vs. In runner:**

Out runner motors have the magnets mounted on the outer casing and the outer casing is spun around the fixed coils in the center of the motor casing. In runner motors have the fixed coils mounted to the outer casing and the magnets are mounted to the armature shaft and this spins inside the casing.

The out runners, because of the torque generated by the rotating outer case, can turn a large-diameter prop without using a gearbox ("direct Drive"). Therefore they are used on slower models that require a lot of thrust, like aerobatic and 3D models. Their drawbacks are; Limited prop selection, large outside diameter may not fit inside some cowls and slightly lower efficiency than geared in runners.

Geared in runners allow the motor to run close to its optimum motor speed/efficiency while turning a large-diameter prop (reduction gearing), and by varying the gear ratio a large number of prop sizes can be used. Their disadvantages are; Gear drive noise, somewhat heavier than out runners, more maintenance, longer/bulkier than direct drive.

Direct-Drive in runners have a limited number of uses; Since they won't swing a large-diameter prop they are best for high-speed models like Pylon Racers or Ducted Fans. They are generally not very efficient so high-discharge capacity batteries are required.

Both types of motors have their supporters and motor choice is also dependent on the size/voltage of the battery used, the type of model, expected flight performance, size of the motor compartment, etc.

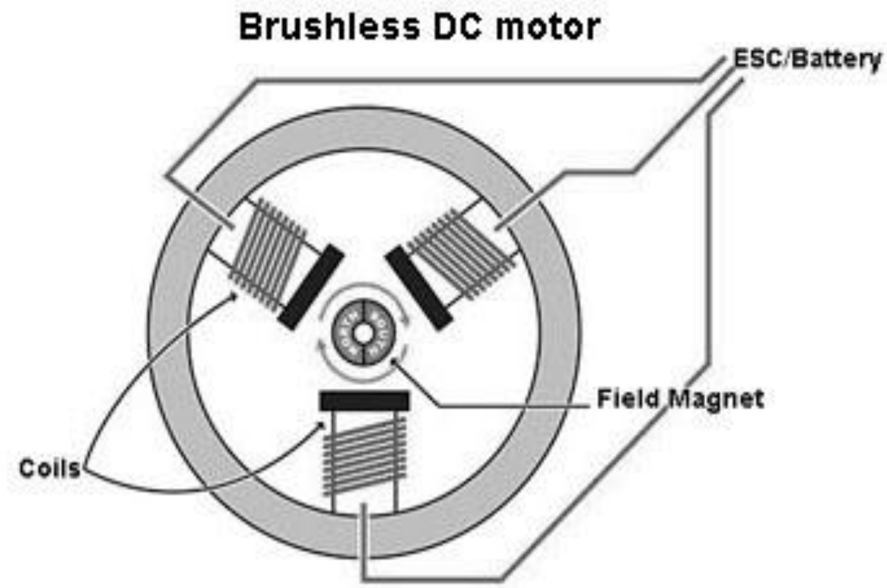


Fig 2.5: Brushless DC motor

- **3-phase powered:**

Three-phase electric power is a common method of alternating-current electric power generation, transmission, and distribution. It is a type of polyphone system and is the most common method used by grids worldwide to transfer power. It is also used to power large motors and other heavy loads. A three-phase system is generally more economical than others because it uses less conductor material to transmit electric power than equivalent single-phase or two-phase systems at the same voltage. In a three-phase system, three circuit conductors carry three alternating currents (of the same frequency) which reach their instantaneous peak values at different times. Taking one conductor as the reference, the other two currents are delayed in time by one-third and two-thirds of one cycle of the electric current. This delay between phases has the effect of giving constant power transfer over each cycle of the current and also makes it possible to produce a rotating magnetic field in an electric motor. Three-phase systems may have a neutral wire. A neutral wire allows the three-phase system to use a higher voltage while still supporting lower-voltage single-phase appliances. In high-voltage distribution situations, it is common not to have a neutral wire as the loads can simply be connected between phases (phase-phase connection).

- **ESC (Electronic Speed Control):**

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 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.

An ESC can be a stand-alone unit which plugs into the receiver's throttle control channel or incorporated into the receiver itself, as is the case in most toy-grade R/C vehicles. Some R/C manufacturers that install proprietary hobby-grade electronics in their entry-level vehicles, vessels or aircraft use onboard electronics that combine the two on a single circuit board.

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 DC motor controllers are much more complicated than brushed motor controllers.

The correct phase varies with the motor rotation, which is to be taken into account by the ESC: Usually, back EMF from the motor is used to detect this rotation, but variations exist that use magnetic (Hall Effect) or optical detectors. Computer-programmable speed controls generally have user-specified options which allow setting low voltage cut-off limits, timing, acceleration, braking and direction of rotation. Reversing the motor's direction may also be accomplished by switching any two of the three leads from the ESC to the motor.

2.1.3 PROPELLER

- 12x3.8 or 8x3.8 or 10x4.5 propellers
- 2 blades
- It is needed to have counter rotating propellers for quadrocopter, both pusher and puller props, it could be possible to simply flip a pusher propeller and reverse the direction of the motor to provide backwards thrust.
- Directly attached to motor
- 2 each rotating clockwise (CW) and counter clockwise (CCW)
- Proper balance reduces vibrations

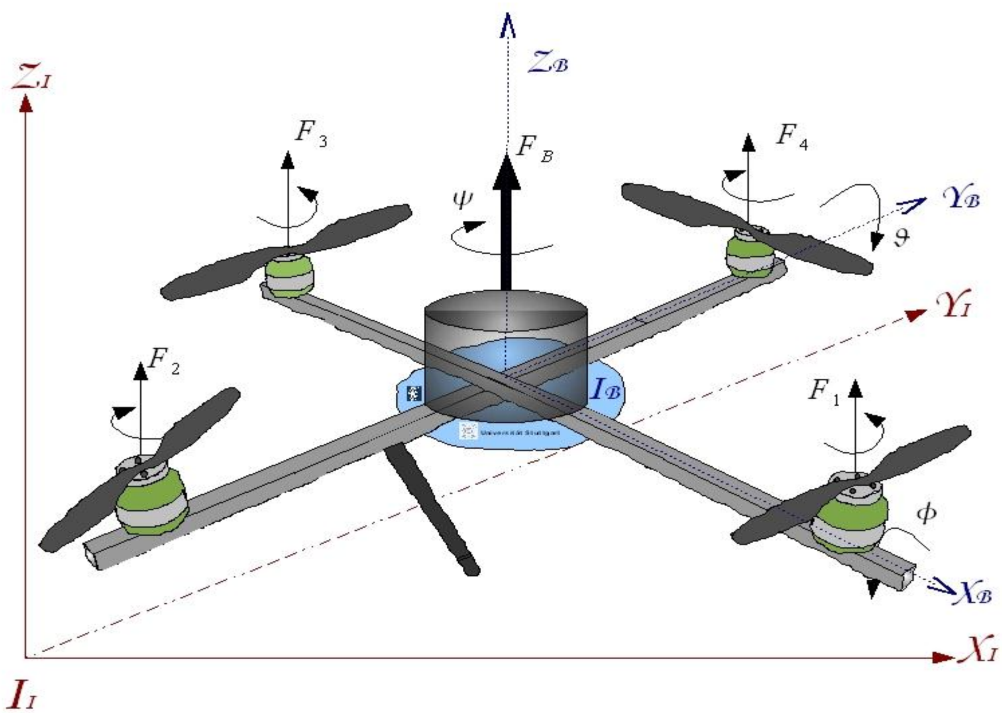


Fig 2.6: Propeller with dynamic state

2.1.4 BATTERY

Lithium polymer (Li-Po) (or Lithium Iron Phosphate, LiFePo4) batteries are built with a Li-Co Nano-technology substrate complex greatly improving power transfer making the oxidation/reduction reaction more efficient, this helps electrons pass more freely from anode to cathode with less internal impedance. In short; less voltage sag and a higher discharge rate than a similar density lithium polymer (non Nano-tech) battery. For those that love graphs, it means a straighter, longer curve. For pilots it spells stronger throttle punches and unreal straight-up performance.

The nano-core technology in lithium ion batteries is the application of nanometer conductive additives.

1) The nanometer conductive additives form ultra strong electron-conducting networks in the electrodes which can increase electronic conductivity.

2) These additives create a super strong ability for imbibitions in the carrier liquid to supply more ion channels. This improves the ability of ion transmission and ion diffusion.

Through improving electronic conductivity and ion transmission, the impedance is reduced and the polarization of high rate discharge decreases greatly.

Advantages over traditional Li-po batteries:

-- Power density reaches 7.5 kw/kg.
-- Less Voltage sag during high rate discharge, giving more power under load.
-- Internal impedance can reach as low as 1.2mΩ compared to that of 3mΩ of a standard Li-poly.
-- Greater thermal control, pack usually doesn't exceed 60degC
-- Thickness swelling during heavy load doesn't exceed 5%, compared to 15% of a normal Li-poly during heavy load.
-- Higher capacity during heavy discharge. More than 90% at 100% C-rate.
-- Fast charge capable, up to 15C on some batteries.
-- Longer Cycle Life, almost double that of standard Li-poly technology.

Fig 2.7: Electronics Speed Controller

CHAPTER 3

CONNECTION SETTINGS

3.1 ELECTRONICS

- Power Distribution / Wiring
- Sensors
- Flight Controller Board
- Transmitter / Receiver

3.1.1 POWER DISTRIBUTION:

Power distribution can be tricky - we have one main source of power, which is a Li-Po battery. This lone source is to be distributed among the ESCs - the best way to do this is with the help of a power spider. Once the spider is made, the connections are super straightforward and simple - power goes to power and ground goes to ground.

The quadrocopter PDB can be used with any frame. It distributes the power from the flight battery to four ESC's to power the quad's motors. The main power cable, attached to the two Wago connectors that distribute the power to the four ESCs.

Fig 3.1: Board and wire

3.1.1.2 WIRING:

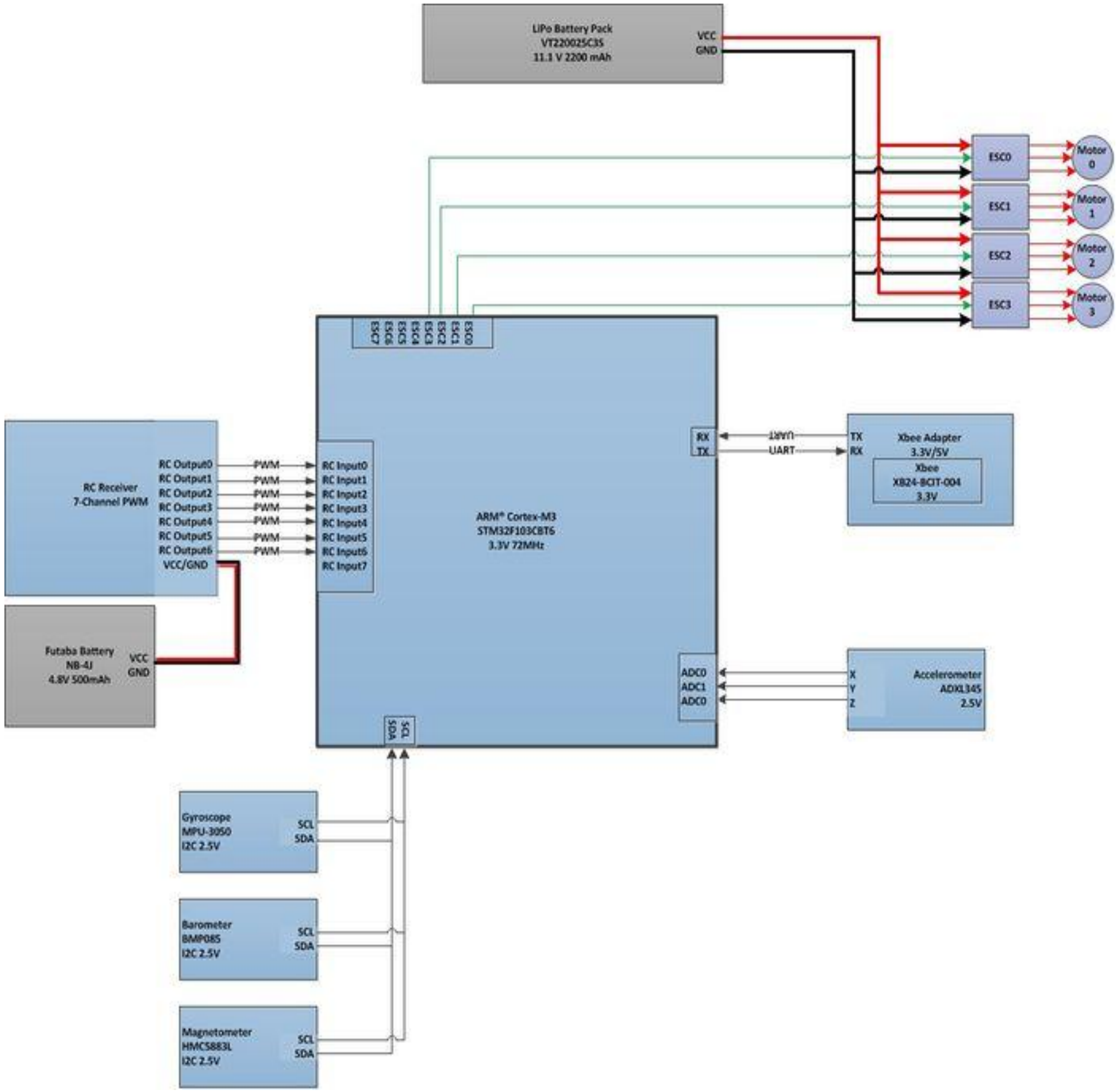


Fig 3.2: Power distribution and wiring

3.1.2 SENSORS:

- **IMU**

  - Gyroscopes (Rotation):

    A gyroscope is a device for measuring or maintaining orientation, based on the principles of angular momentum. Mechanically, a gyroscope is a spinning wheel or disk in which the axle is free to assume any orientation. Although this orientation does not remain fixed, it changes in response to an external torque much less and in a different direction than it would without the large angular momentum associated with the disk's high rate of spin and moment of inertia.

  - Accelerometers (Movement):

    An accelerometer is a device that measures proper acceleration, also called the four-acceleration. This proper acceleration is associated with the weight of a test mass. However, the proper acceleration measured by an accelerometer is *not necessarily* the coordinate acceleration (rate of change of velocity), when gravity becomes involved. Instead, the accelerometer sees the acceleration associated with the phenomenon of weight experienced by any test mass at rest in the frame of reference of the accelerometer device. An accelerometer thus measures all accelerations, except those accelerations due to gravity. An accelerometer measures weight per unit of (test) mass, a quantity with dimensions of acceleration that is sometimes known as specific force, or g-force (although it is not a force).

- **Optional**

  - Pressure Sensor (Altitude):

    A pressure sensor measures pressure, typically of gases or liquids. Pressure is an expression of the force required to stop a fluid from expanding, and is usually stated in terms of force per unit area. A pressure sensor usually acts as a transducer; it generates a signal as a function of the pressure imposed. Pressure sensors can also be used to indirectly measure other variables such as fluid/gas flow, speed, water level, and altitude. There is also a category of pressure sensors that are designed to measure in a dynamic mode for capturing very high speed changes in pressure.

- Compass/Magnetometer (Altitude):

A compass is a navigational instrument that measures directions in a frame of reference that is stationary relative to the surface of the earth. The frame of reference defines the four *cardinal directions* (or *points*) – north, south, east, and west. Intermediate directions are also defined. When the compass is in use, the rose is aligned with the real directions in the frame of reference, so, for example, the "N" mark on the rose really points to the north. The magnetic compass consists of a magnetized pointer (usually marked on the North end) free to align itself with Earth's magnetic field. A compass is any magnetically sensitive device capable of indicating the direction of the magnetic north of a planet's magnetosphere. The face of the compass generally highlights the cardinal points of north, south, east and west. Often, compasses are built as a standalone sealed instrument with a magnetized bar or needle turning freely upon a pivot, or moving in a fluid, thus able to point in a northerly and southerly direction. In navigation, directions on maps are expressed with reference to *geographical* or *true north*, the direction toward the Geographical North Pole, the rotation axis of the Earth. Since the Earth's magnetic poles are near, but are not at the same locations as its geographic poles, a compass does not point to true north. The direction a compass points is called *magnetic north*, the direction of the North magnetic pole, located in northeastern Canada. Depending on where the compass is located on the surface of the Earth the angle between true north and magnetic north, called *magnetic declination* can vary widely, increasing the farther one is from the prime meridian of the Earth's magnetic field. The local magnetic declination is given on most maps, to allow the map to be oriented with a compass parallel to true north.

- GPS (Location):

The Global Positioning System (GPS) is a space-based satellite navigation system that provides location and time information in all weather, anywhere on or near the Earth, where there is an unobstructed line of sight to four or more GPS satellites. It is maintained by the United States government and is freely accessible to anyone with a GPS receiver. The GPS program provides critical capabilities to military, civil and commercial users around the world. In addition, GPS is the backbone for modernizing the global air traffic system.

3.1.3 FLIGHT CONTROL BOARD:

Our flight controller board is capable of sending data in different formats for different devices (Adriano, Bluetooth, or raw data for the GUI). We are using the full stream of raw data that is compatible with the GUI software we want to utilize. In the flight controller's main loop, it waits for certain 'op codes' to send back appropriately formatted data. This process is interrupt driven and sends data over UART. In this case, our op code of interest is 'M'. This causes the following steps to be performed until completion.

Our board used only one task. We chose to modify the already existent user Interface task given in our lab because it already uses interrupts and is setup to use UART0. We had to write a driver for UART1 in order to receive data from the flight controller board (using Xbee). Once received, we had to parse the data into appropriate sized containers and then forward that to a terminal or SD card. We also interfaced the board directly through UART to the GUI software we were using. This was as simple as creating a wireless UART bridge between the flight controller board and our PC. Once done, we used the GUI to open a serial connection and adjusted the polling frequency to take into account delays in wireless data transmission.

It collects sensor data, receives control commands, calculates orientation/location, and sends updated motor commands to BLCs.

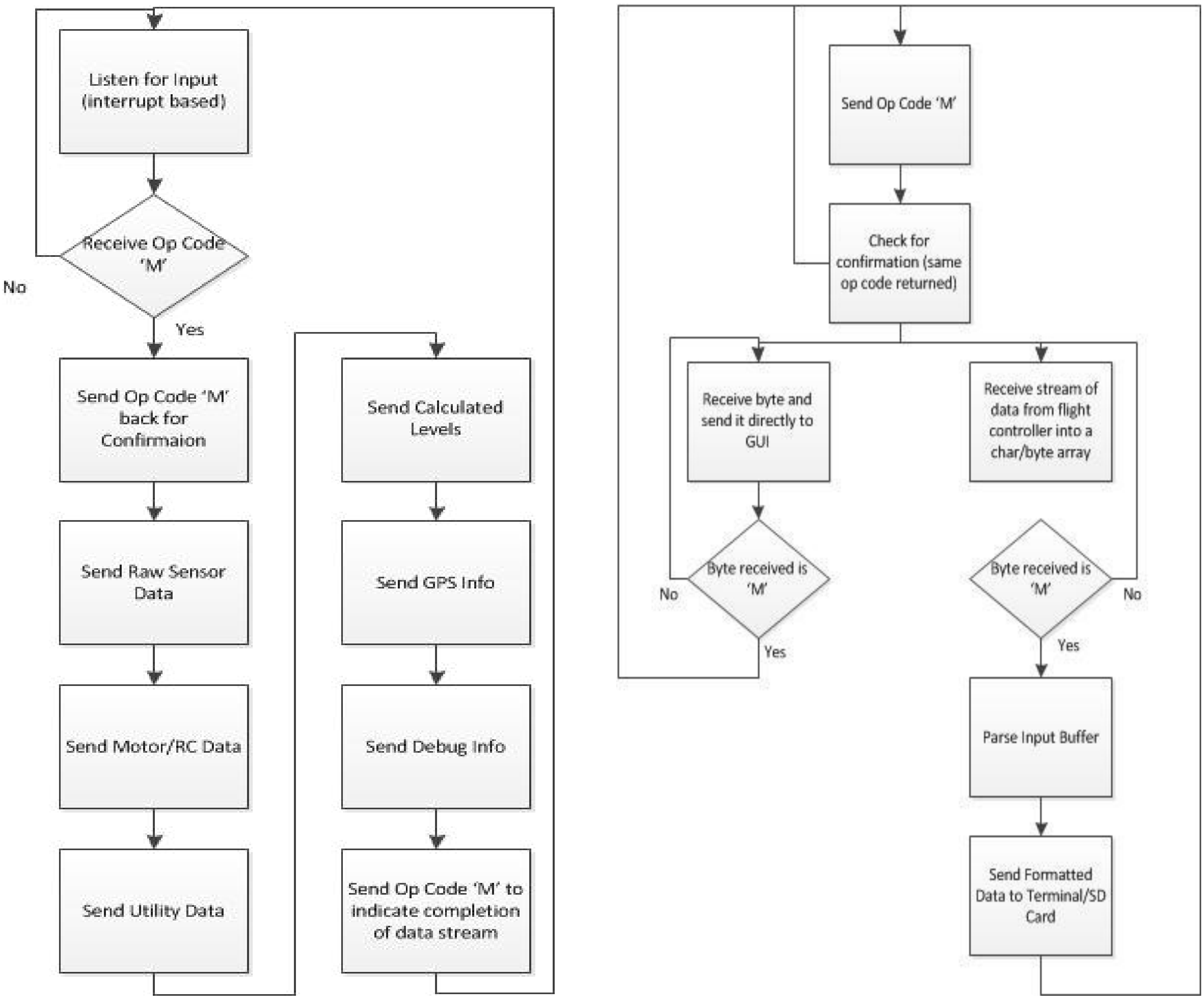


Fig 3.3: Flight controller flow chart

3.1.4 TRANSMITTER / RECEIVER:

With v2 firmware update, correcting many flaws of the previous 9X, plus inbuilt 2.4 GHz (no baggy second antenna) this is a quality, reliable 2.4 GHz system suitable for beginners and pro pilots alike.

Get that locked-in feeling that only 2.4 GHz glitch free technology can provide.

Ultra fast reaction times and interference free control of your model is only achievable with this 2.4 GHz technology.

- **Frequencies:** 35/40 MHz, 2.4 GHz
- **Minimum:** 4 channels
- **Receiver output:** PPM (sum signal) or Individual channels from receiver (PWM)
- **Number of Channel:** 8ch ppm/9ch pcm
- **Display:** 128*64 LCD
- **Support user:** 8

Fig 3.4: Transmitter controller

3.1.5 MOTORS AND ROTATE REGULATORS

In solving the control, the stabilization and for example display some data is needed a higher computing power, for this reason it used a kit with MCU. The MCU on the kit is the ARM Cortex-M3, which is a 32bit MCU. The quadrocopter needs relatively a high thrust of a motor. For this purpose are good AC brushless motors. The thrust is possible continuously control with PWM pulses. Generated PWM pulses for motors are form output ports of a kit whit the MCU brought on an ESC (Electronics Speed Control) of each motors. An ESC needs to know the position a rotor of motor. AC motors are about 30-50% lighter against DC motors with a same performance and have up to half the greater efficiency. AC motors have a beneficial torque. For flying is better use out runner motors. A motor of this construction has important feature in the high torque. Most important thing for build the quadrocopter is choosing the optimal performance of motors, which ensure takeoff the device with the concrete weight, but is good to have some reserve, to avoid overload of motors.

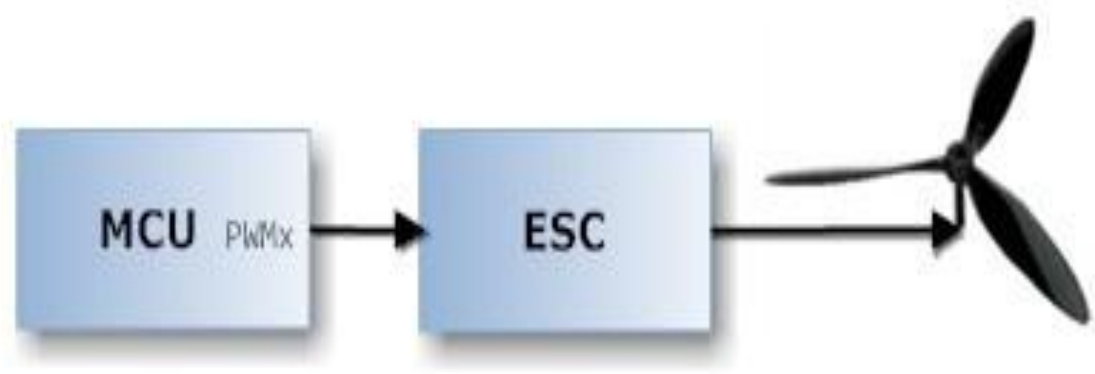


Fig 3.5: One motor connection

CHAPTER 4

METHODOLOGY

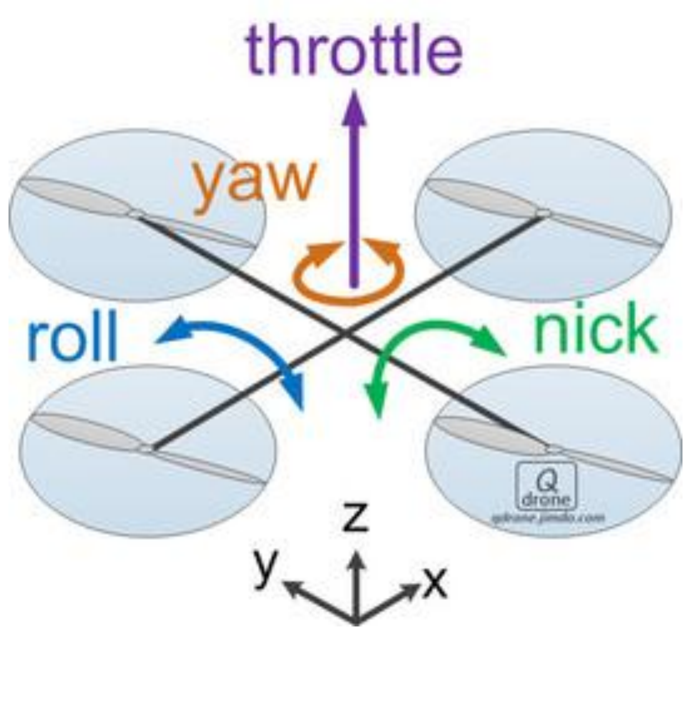
4.1 FLIGHT PHYSICS

It is impossible to realize a project like this without a bit of theory. The mathematical and physical concepts and calculation that are used are can be seen here.

1. Steering
2. Hovering
3. Tilting

4.1.1 STEERING

Before we take a look on the physics, it is important to understand how a quadrocopter moves and how we can control it. The figure below shows the different movement of a quadrocopter and how we control it.



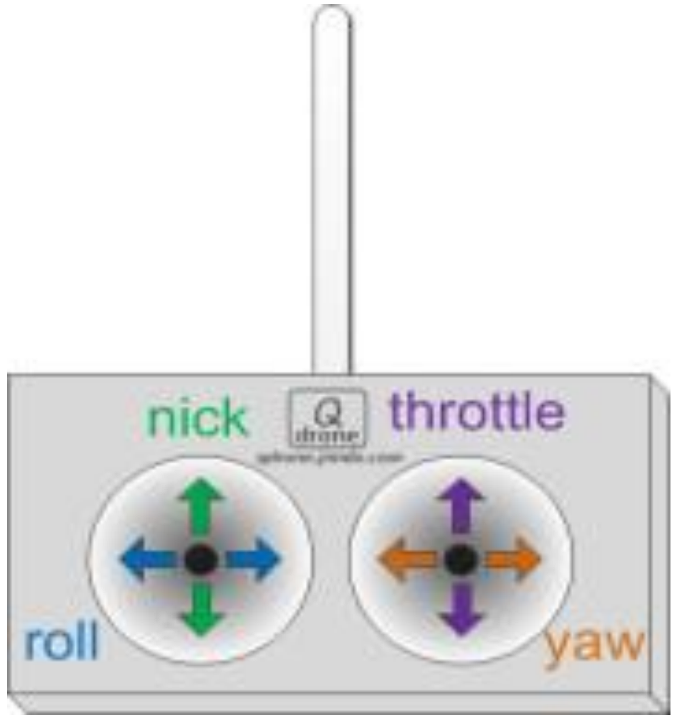


Fig 4.1: Steering system with controller

Nick and roll angles are generated with different speed of opposed rotors. To move the quadrocopter upward (throttle), the speed of every motor is increased. The tricky part is the yaw angle. If every rotor would turn in the same direction, the quadrocopter would start turning around the *z* axis (like a helicopter without a rear rotor). Therefore rotation directions are configured as seen in figure 3.

With this configuration we are able to neutralize the momentum. Late we will have a controller for the yaw angle.

4.1.2 HOVERING

For hovering a balance of forces is needed. The picture below shows such a situation. If we want the quadrocopter to hover, **SUM (F_1)** must be equal **m.g** (where **m** is the mass of the quadrocopter, **g** the gravity acceleration and **F_1** - **F_4** the forces of the motors). For this simple example we assume all motors are equal and have the same force. So if **SUM (F_1)** is smaller then **m.g** than the quadrocopter is declining, if it is greater, it is climbing.

SUM (F_1) > m . g <=> climb

SUM (F_1) = m . g <=> hover

SUM (F_1) < m . g <=> decline

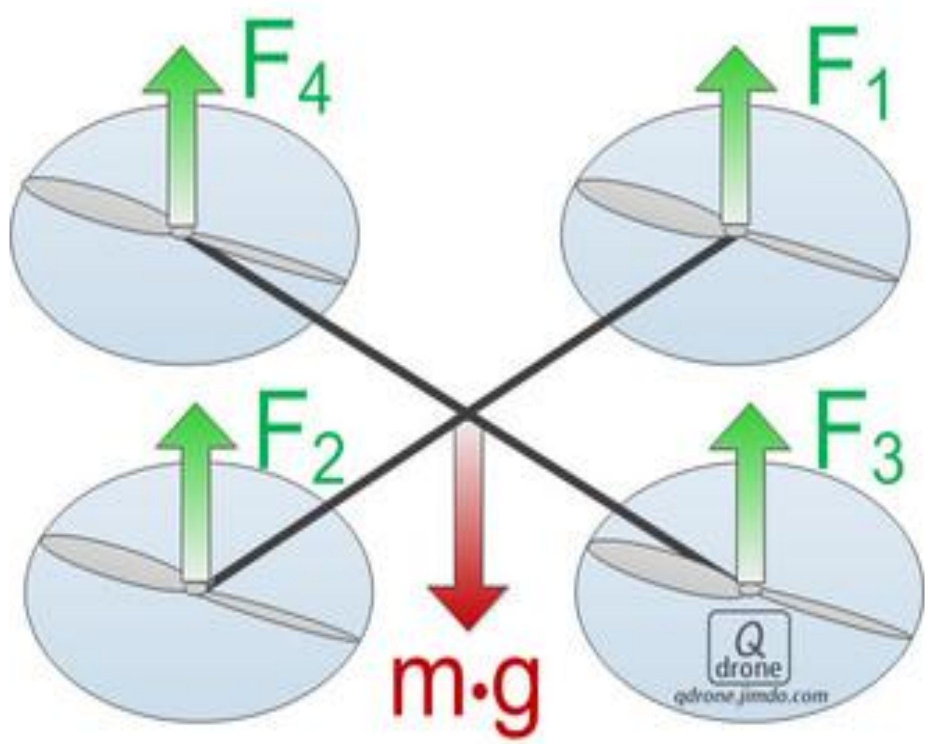


Fig 4.2.1: Hovering system

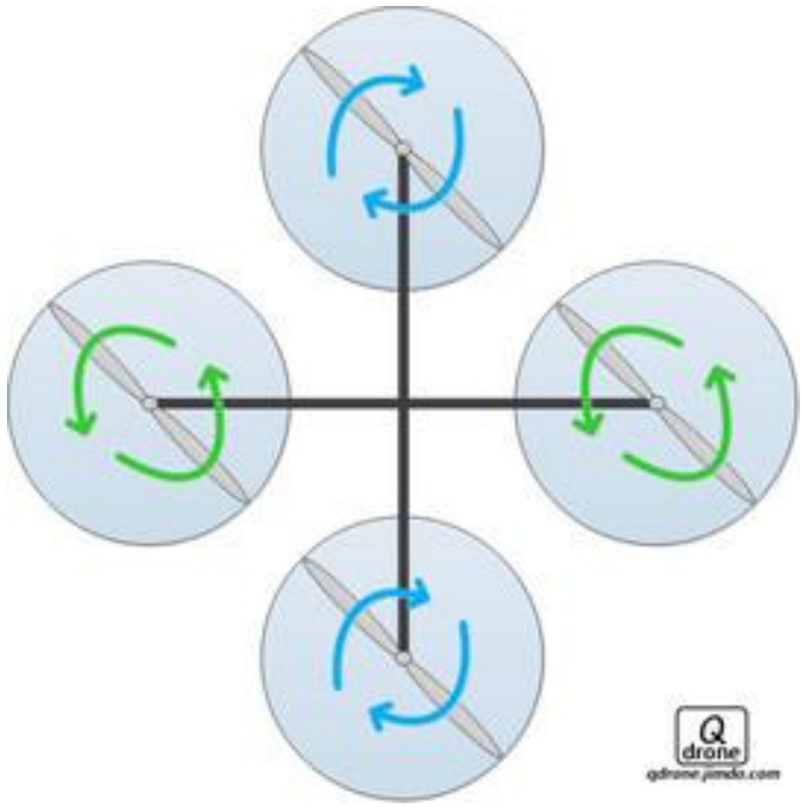


Fig 4.2.2: Balance of power while hovering

4.1.3 TILTING

Now let us take a look on what is happening when we tilt the quadrocopter. Figure 5 shows such a situation. For simplification only two of the four rotors are shown. We see that the force is divided in two different parts. $\mathbf{F_{L1}}$ and $\mathbf{F_{L2}}$ are the part of the force used to lift the quadrocopter. $\mathbf{F_{T1}}$ and $\mathbf{FT_2}$ represent the part used for the translation. It is obvious that the lift part becomes smaller with increasing $\boldsymbol{\varphi}$.

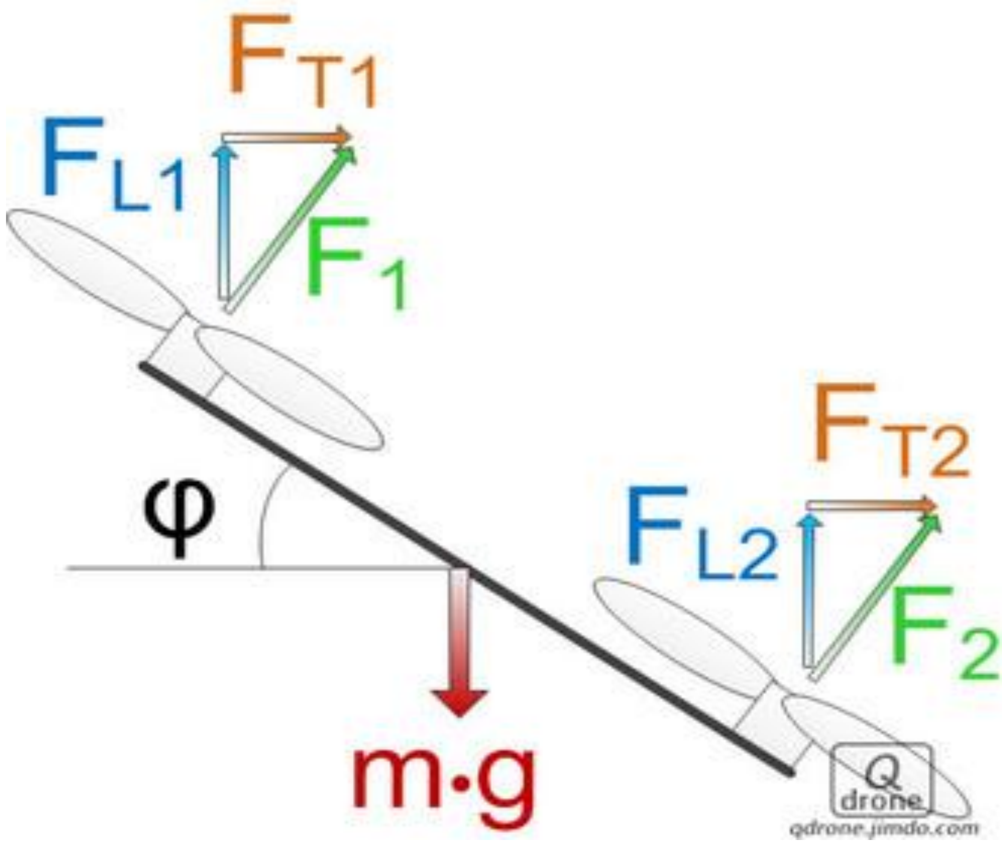


Fig 4.3: Force distribution for tilt

If we want to move the quadrocopter forwards, we have to tilt it so that a translation force pulls it in the desired direction.

CHAPTER 5

EXPERIMENTAL FIGURE

Fig 5.1: Propeller

Fig 5.2: Central controller

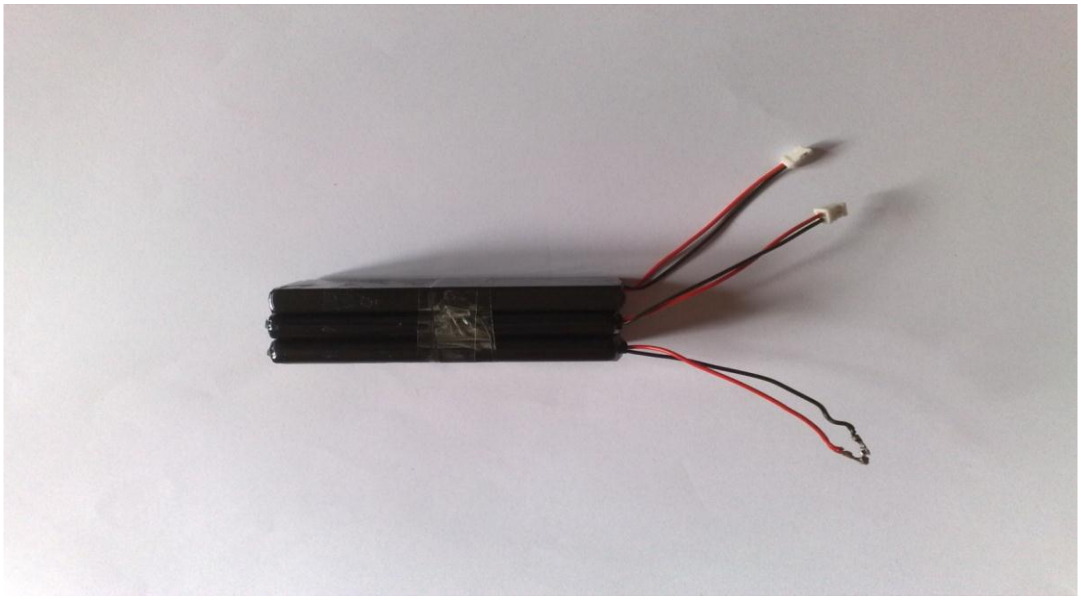


Fig 5.3: Battery

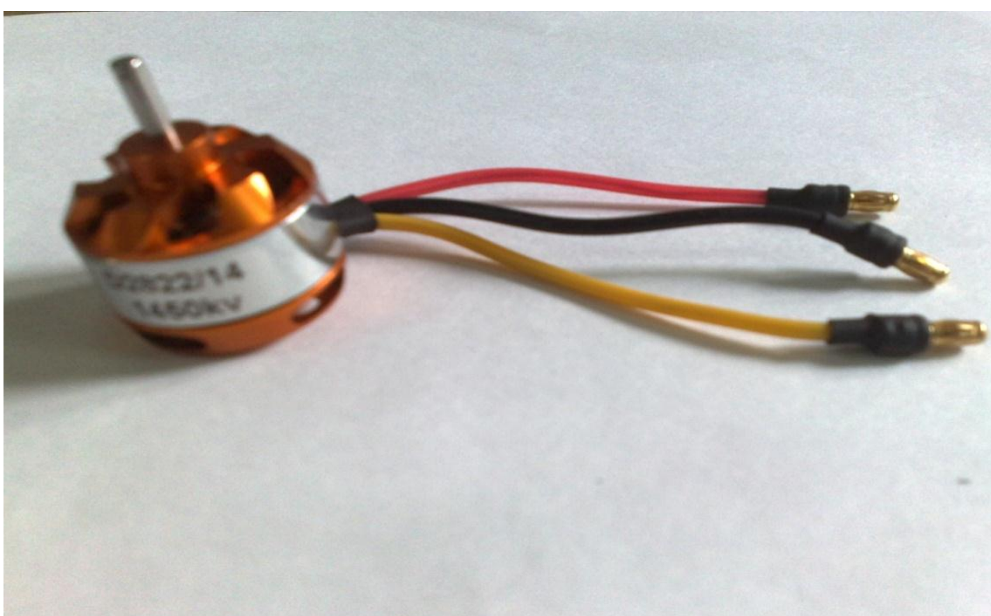


Fig 5.4: Motor

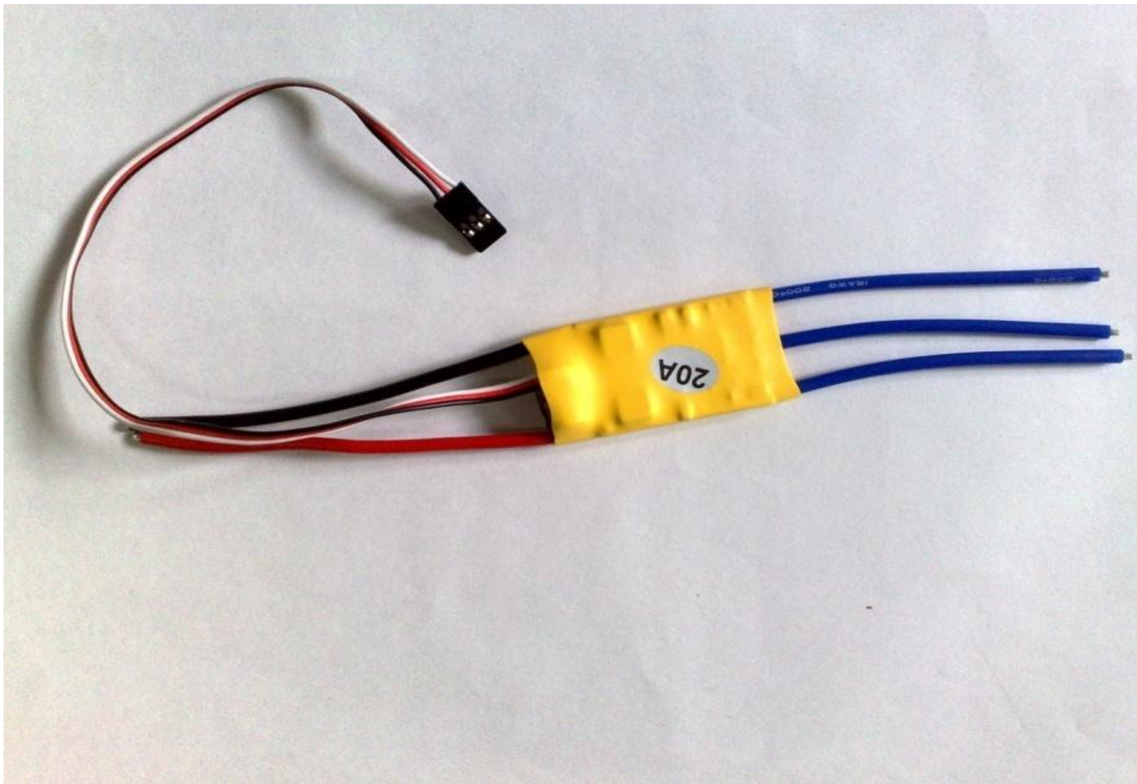


Fig 5.5: Electronics Speed Controller (ESC)

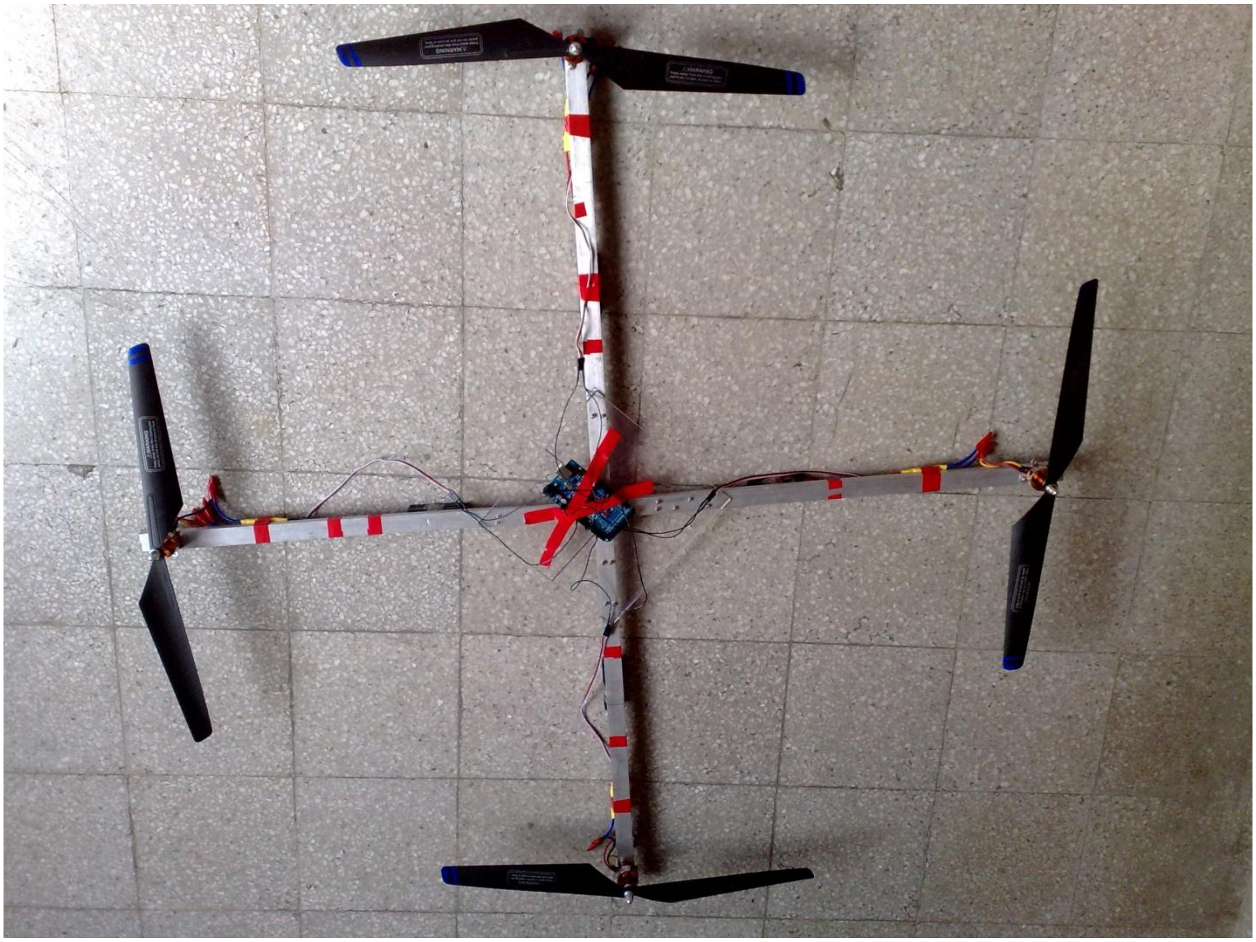


Fig 5.6: Total quadrocopter setup

CHAPTER 6

FEEDBACK

6.1 PROBLEM FACED

- We were unable to build a perfect propeller that can lift the quadrocopter.
- We want to use molded plastic propeller but we need time to design the aerodynamic shape for the molding.
- For wireless controlling we wanted to use a   channel 2.4Gz radio frequency system, but is was not available in the local market.
- For movement we need pressure sensor and gyroscope which was also not available in the local market.
- We tried to use a local made plastic propeller but that was to heavy (>370gm a pair) and long (25 cm) to give us the needed thrust.
- From calculation, our quad weighs 1.37 kegs' (without sensors and RX system). We use Brushless 3 phase motor that can easily provide a outstanding 1440 rpm/V. We use 11.1 volt battery so as a result each of the motor used here can provide 14400 rpm/min. That is more than enough to lift up to 2kgs. (reference dish)
- The main body we made was enough for the motors.
- We use stainless steel made mounting to hold the motor with the body.
- ESC was working well.
- Everything goes fine up to building the propeller and setting up the Rx-Tx system.
- If we get a little bit time to bid the propeller and if the Rx system is available in local market, we could fly the quadrocopter.

6.2 ACCESSORIES

- Camera mount
- Sensor for telemetry data
- Video goggles with Wi-Fi

6.3 CONCLUSION

The quadrocopter is now able to takeoff and reach a steady state at height, but Occasionally small corrections are still needed to keep the quadrocopter in one spot. Better settings of controller, for example with using another method for finding the controller actions or use a better control method it may help for a better stabilization. Also it possible to refine the positioning in space by adding more sophisticated filters. On flight of the quadrocopter acts also the wind effect; therefore it is needed to include this effect into the overall stabilization.
The remote control over a mobile application works very well. Now is implemented a basic control of the quadrocopter with possibility turn on/off controllers. Into the future can be added some advanced control functions for special maneuvers.
For improvement functions of quadrocopter can be added some another sensors like a camera or altimeter. One of the many advantages of the quadrocopter is ability to fly on places, which are for human complicated to reach or so quickly as he and with the help of a camera is possible explore inaccessible locations. With added devices we can to determinate a flight path or track some objects.

6.4 PROJECT COST

Table 6.1: Cost with quantity

Name of the components	**Quantity**	**Amount (BDT)**
• Different types of materials for propeller and body frame. Such as, carbon fiber, glass fiber, aluminum, ply-wood bars etc.	Minimum bar - 20 feet, sheet- 20 square feet.	1000
• Brushless AC motor (3 phase- 4 units) & motor mountings	4	4*1000=4000
• Electronic speed controller- 30 A 4 units	4	4*1000=4000
• Sensors – Pressure, Altitude, GPS, Heat	Each 1	4*500=2000
• Li-Po battery 2200mah, 11.2 V, 25 ~ 50 C	1	1000
• Programming card	1	500
• Radio transmitter and receiver (6 channel – 1 pair)	2	2*500=1000
• Main board equipments (Processor, Capacitor, Rom/ram)	1	500
• Battery charger set	1	200
• Power distributor circuit board	1	150
• Flight simulator software	1	150
• Connectors, wires, glue, soldering machine and accessories		500
Total		**15000**

APPENDIX I

* NOTES & REFERENCES

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APPENDIX II

LIST OF FIGURES

APPENDIX III

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