CHAPTER THREE

Methodology

3.1 Overview

In this chapter the proposed architecture and its implementation will be described in details in addition to the ground station that handles the interface with the user. For a better understanding, it should be noted that software architecture refers to the idle design of the system, while hardware architecture refer to the actual implementation based on the available components in the market.

3.2 The Design of the Autonomous Quadcopter

The quadcopter can be implemented to be an autonomous robot through the explained design architecture and can be utilized to do several jobs in both civilian and military applications.

The focus of this thesis is to design the quadcopter for civilian applications, specifically for search and rescue missions. In the past ten years there have been a large number of urban disasters throughout the world due to weather and earthquakes Hurricane Katrina in (2005), the (2010) Haiti earthquake, or the (2011) Tohoku earthquake and tsunami. In urban disaster scenarios, USAR (Urban Search and Rescue) teams respond to find and save victims. Unfortunately, rescue teams typically have less than 48 hours to rescue victims before their chance of survival decreases dramatically. The quadcopter may be the most effective solution for such time constrained and dangerous rescue missions.

- **Quadcopter dynamics:-**

The quadcopter consists of four rotors that are mounted at the end of two perpendicular axes driven by a DC brushless electric motor.

The quadcopter has two configuration of rotors' rotation:

Plus configuration (+): where rotors at opposite ends of an arm turn in the same direction and rotors on a perpendicular axis rotates in the opposite direction. This concept is illustrated in Figure 3-1.

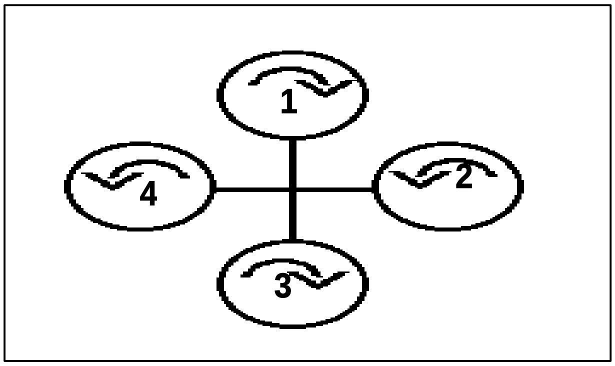


Figure 3.1:Plus quadcopter schematic.

When all four motors spine at the same speed, the rotors create thrust that lifts the quadcopter into the air [9]. As there are pairs of rotors spinning in opposite directions, the torque produced in each direction around the yaw axis cancels out and the yaw angle remains constant. To change the pitch attitude, the speed of motor (1) is reduced while the speed of motor (3) is increased, or vice versa, creating a non-zero pitch angle. As both motor (1) and motor (3) are rotating in the same direction the total counteracting torque provided is not changed so the quadcopter maintains its yaw angle. The roll attitude is adjusted in a similar manner. To adjust the yaw angles the speed of motors (1) and (3) are increased while the speed of motors (2) and (4) are decreased, or vice versa. This creates imbalance in the total torque in the yaw axis and so the quadcopter will change yaw angle.

The quadcopter should maintain a relatively constant thrust during yaw and the height of the aircraft should remain constant.

X configuration: is quite similar to the plus configuration in everything except that the pitch movement is achieved by increasing the speed of motor (1) and (2) at the same time and decreasing the speed of motor (3) and (4) or vice versa; the roll movement is achieved by increasing the speed of motor (2) and (3) at the same time and decreasing the speed of motor (4) and (1) or vice versa.

X configuration is preferred when using a camera because the camera will have enough space to take clear photos without interfering with the rotors

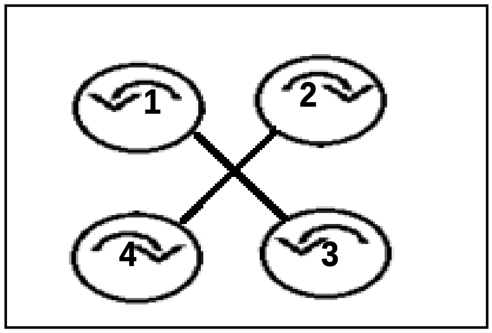


Figure 3.2:X quadcopter schematic.

While the above description provides a simplified overview of how a quadcopter maneuvers, the dynamics of the quadcopter are complex and tightly coupled. These dynamics make it extremely difficult for a human to control the quadcopter without an onboard flight augmentation system to reduce the unwanted response down to an acceptable level.

- **Quadcopter control**

Roll, pitch, and yaw dynamics are controlled by increasing or decreasing the speed of four motors by the controller to achieve the desired value.

Different control strategies of the quadcopter have been studied in commercial, academic, and military platforms such as PD-PID controller, inverse control, back stepping control, and sliding mode control [4].

Four rotors increase the maneuverability of the vehicle. Having four rotors increases load carrying capacity, on the other hand, constrains it to consume more energy.

- **The quadcopter design consideration**

  - Take-off throttle:

It is the throttle that should be applied to every motor to make the quadcopter leave the ground. Take-off throttle can be calculated from the basic static laws of beams; which state that the beam will remain static if the resulting forces in the opposite directions are the same. For example (figure3-3) if the beam in the ground the downward force of it is its weight which can be calculated from the equation[3.1] [10]:

$$w = m * g \qquad [3.1]$$

Where w is the weight, m is the mass of the beam and g is earth gravity. To make the beam move in up direction, the resulting upward force should exceed the weight.

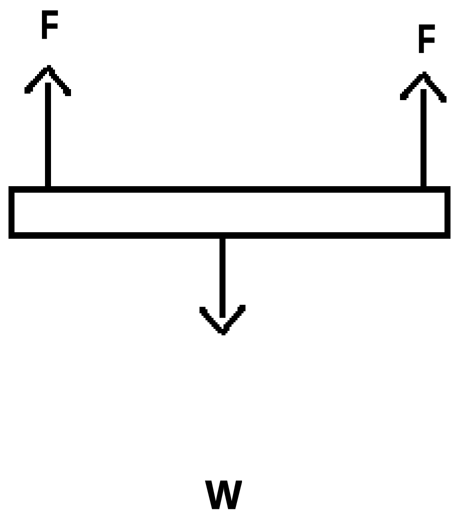


Figure 3.3: Illustration of the forces on a beam

In the quadcopter the total forces generated by the motors should exceeds its weight in order to take off from the ground. Every motor has a specification of the maximum thrust that can be generated (in grams) written in the data sheet of the manufacturer. The thrust of the motors is controlled as a percentage of the maximum thrust. For example sending (40%) throttle means that the motor will generate (40%) of the maximum thrust. And the take-off throttle in percentage can be calculated according to the following equation:

$$\text{takeoffthrottle} = \frac{\text{totalmassofthequadcopter}}{4 * \text{maximumthrustofthemotor}} * 100\% \quad [3.2]$$

- **The advantages of the quadcopter**:

Despite the complex control systems required for a quadcopter aircraft, there are many benefits to this aircraft over other platforms. Having four rotors as opposed to a single rotor in a traditional helicopter allows each of the rotors on a quadcopter to be smaller and lighter, hence carrying less kinetic energy [2]. This is advantageous when working within indoor environments. For example, in the undesired case of a blade striking an object, due to the design of a quadcopter, much less damage will result when compared to a helicopter in the same situation. It is also possible to mount the rotors within a duct or shroud to protect both the aircraft and any object if contact occurs.

The mechanics of the quadcopter are relatively simple and the aircraft is able to use fixed pitch propellers. This reduces setup, maintenance, and manufacturing costs and time associated with a quadcopter. The relatively simple mechanical setup of a quadcopter also leads to limited vibration making it a friendly environment for inertial sensors and cameras.

3.2.1Motion control layer

Because of the difficulties of designing all the controllers from scratch a flight controller is used to do the final stabilization control but the attitude and altitude controllers as well as the position controller will be designed as a cascaded loop P-controller in the on-board computer.

Attitude and altitude inner loop controller receives the current altitude from the barometer and attitude from the IMU sensor fusion then it calculates the error between the current and desired values and calculates the control command to decrease that error[3]. If all the errors become below deified thresholds for every process then the controller declares completing the mission (static planning) but the thresholds is going to be selected large so that to reduce dramatically the number of the correction iterations (semi-dynamic planning).

3.3 Hardware Architecture

This section describes the system hardware thatthe quadcopter is made of which has been classified into five categories: sensors, actuating system, raspberry pi ,frame and flight controller.

3.3.1 Sensors

The quadcopter has a set of sensors that help in identifying its state and the environments around it. These sensors are: ultrasonic, barometer, GPS sensor and a camera.

- **Ultrasonic sensor (HC-SR04 Module):**

Ultrasonic distance sensors are designed to measure distance between the source and target using ultrasonic waves. It uses sonar to measure distance with high accuracy and stable readings.
Ultrasonic ranging module (HC-SR04) provides (2cm – 400cm) non-contact measurement function, the ranging accuracy is (3mm). The module includes ultrasonic transmitters, receiver and control circuit. The transmitter transmits short bursts which gets reflected by target and are picked up by the receiver. The time difference between transmission and reception of ultrasonic signals is calculated. Using the speed of sound and (‘Speed = Distance/Time’) equation, the distance between the source and target can be easily calculated.
The basic principles of work:

(1) Using IO trigger for at least (10us) high level signal;
(2) The Module automatically sends eight (40 kHz) anddetect whether there is a pulse signal back.
(3) If the signal back, through high level, time of high output IO duration is the time from sending ultrasonic to returning.

$$\text{Test distance} = \frac{\text{high level time} \times \text{speed of sound (340m/s)}}{2}$$

Table 3.1:Ultrasonic (HC-SR04) distance sensor module pins

Name	Function
VCC	5V, input power
TRIG	Trigger Input
ECHO	Echo Output
GND	Ground

The ECHO output is of (5V). The input pin of Raspberry Pi GPIO is rated at (3.3V). So (5V) cannot be directly given to the unprotected (3.3V) input pin. Therefore, we use a voltage divider circuit to bring down the voltage to (3.3V).

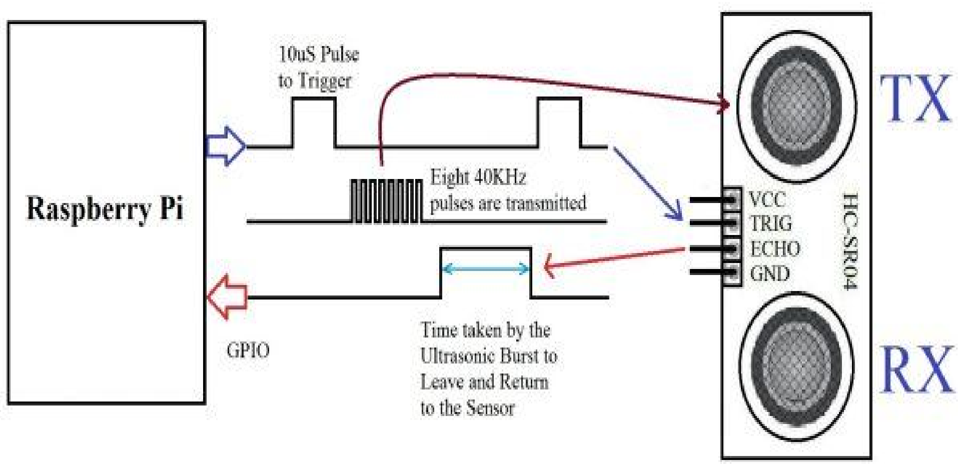


Figure3.4: Interfacing Raspberry Pi with ultrasonic(HC-SR04)

- **Barometer:**

The barometer sensor is used to measure the altitude from sea level. An I2C bus is used to control the sensor, to read calibration data from the EEPROM and to readthe measurement data when A/D conversion is finished. SDA (serial data) and SCL (serialclock) have open-drain outputs. The I2C is a digital two wire interface and has Clock frequencies up to (3.4Mbit/sec).

- **GPS:**

GPS which is usually used for the automated flying has become a common part for multicopters. It is used for functions like flying through the waypoints, return home and geofencing. Return home functionality enables the copter to return back to the location where it was started in problem situations, like when the connection to the controller is lost. A simple version of geofencing prevents the multicopter flying too far from the starting point. A more advanced version prevents the multicopter from entering to areas, like airports.

Figure 3.5:GPS Module

Table 3.2:GPS (Ublox 7N) pin layout

Pin name	Function
VCC	Power supply
TX	Digital pin for Transmit data
RX	Digital pin for receive data
GND	Ground

- **The camera:**

The camera was used to stream image captures from the environment that the quadcopter navigates.The Raspberry Pi camera module is capable of taking full HD 1080p photo and video and can be controlled programmatically.

Figure 3.6: Raspberry pi camera

3.3.2 Actuating System

The Actuating systemsresponsiblefor performing the movement by adjusting the forces and the torques around the quadcopter, it consists of three components: brushless motors, electronic speed controllers (ESCs) and propellers.

- **Brushless Motors:**

Brushless DC motors provide the necessary thrust to the propellers. Each rotor needs to be controlled separately by a speed controller.

Brushless motors are a bit similar to normal DC motors in the way that coils and magnets are used to drive the shaft. Though the brushless motors do not have a brush on the shaft which takes care of switching the power direction in the coils, and this is why they are called brushless. Instead the brushless motors have three coils on the inner (center) of the motor, which is fixed to the mounting. On the outer side it contains a number of magnets mounted to a cylinder that is attached to the rotating shaft. So the coils are fixed which means wires can go directly to them and therefor there is no need for a brush.

Generally brushless motors spin in much higher speed and use less power at the same speed than DC motors. Also brushless motors don't lose power in the brush-transition like the DC motors do, so it's more energy efficient.

Brushless motors come in many different varieties, where the size and the current consumption differ. To select brushless motor the KV-rating, weight, thrust per motor, size, type of propeller should be put in consideration.

Figure 3.7: typically brushless motor

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

The brushless motors are multi-phased, normally 3 phases, so direct supply of DC power will not turn the motors on. That where the Electronic Speed Controllers (ESC) comes into play. The ESC generates three high frequency signals with different but controllable phases continually to keep the motor turning. The ESC is also able to source a lot of current as the motors can draw a lot of power. It has three input ports (two for the battery and one for the PWM) and three output ports to the motor as shown in below Figure.

Figure 3.8: Typical Electronic Speed Controller

This is fully programmable 30A BLDC ESC with 5V, 3A BEC. Can drive motors with continuous 30Amp load current. It has sturdy construction with 2 separate PCBs for Controller and ESC power MOSFETs. It can be powered with 2-4 lithium Polymer batteries or 5-12 NiMH / NiCd batteries. It has separate voltage regulator for the microcontroller for providing good anti-jamming capability. It is most suitable for UAVs, Aircrafts and Helicopters.

- Specifications

• Output: 30A continuous; 40Amps for 10 seconds
• Input voltage: 2-4 cells Lithium Polymer / Lithium Ion battery or 5-12 cells NiMH / NiCd
• BEC: 5V, 3Amp for external receiver and servos
• Max Speed: 2 Pole: 210,000rpm; 6 Pole: 70,000rpm; 12 Pole: 35,000rpm
• Weight: 32gms
• Size: 55mm x 26mm x 13mm

- Features

• High quality MOSFETs for BLDC motor drive
• High performance microcontroller for best compatibility with all types of motors at greater efficiency
• Fully programmable with any standard RC remote control
• Heat sink with high performance heat transmission membrane for better thermal management
• 3 start modes: Normal / Soft / Super-Soft, compatible with fixed wing aircrafts and helicopters
• Throttle range can be configured to be compatible with any remote control available in the market

- **The propeller:**

A propeller is a type of fan that transmits power by converting rotational motion into thrust. A pressure difference is produced between the forward and rear surfaces of the airfoil-shaped blade, and a fluid (such as air or water) is accelerated behind the blade.
The propellers come in different diameters and pitches (tilting) according to the frame size and the type of the motors.
*In this project we use 1045 propellers (12cm).

Figure 3.9: Typically (12cm) Propellers

- **Frame :**

  Flamewheel445 airframe made of glass fiber used in this thesis.

  Specifications:

Diagonal Wheelbase	450mm
Frame Weight	282g
Takeoff Weight	800g ~ 1600g

Figure 3.10: Typically F445 Airframe

3.3.3 LTE Connection

After choosing the multicopter, it is time to create the LTE connection from the PC used for controlling to the Flight Controller (FC) of the multicopter. On a PC it is simple to create an LTE connection to the Internet. A plethora of LTE Universal Serial Bus (USB) dongles are available and usually they support plug and play.

Figure3.11: Huawei LTE dongle

In this thesis, a Raspberry Pi (RPi), shown in the Figure 8 below and running Raspbian Linux distribution was chosen as a router between the LTE and the FC. It is a fitting device for this purpose, because it is easy to use, lightweight which is an important factor on drones, flexible for other possible needs, and can also be used for streaming the video. It is powered by a micro USB port, so it is possible to use a 5 volt Battery Eliminator Circuit (BEC) with a micro USB adapter to power the RPi.

3.3.4Raspberry pi 3 model B

The Raspberry Pi is a single-board small computer that has computational power could be compared with the big PCs. It is used to perform the top level perception, localization, planning and control tasks.

Figure 3.12:Raspberry pi 3 model B

Table 3.3:Characteristics of raspberry pi 3 model B

Board	Raspberry Pi 3 Model B
Processor	Broadcom BCM2837
CPU Core	QuadcoreARM Cortex-A53, 64Bit
Clock Speed	1.2GHz (Roughly 50% faster than Pi2)

RAM	1 GB
GPU	400 MHz VideoCore IV®
Network Connectivity	1 x 10 / 100 Ethernet (RJ45Port)
Wireless Connectivity	802.11n wireless LAN (WiFi) and Bluetooth 4.1
USB Ports	4 x USB 2.0
GPIOs	2 x 20 Pin Header
Camera Interface	15-pin MIPI
Display Interface	DSI 15 Pin / HDMI Out / Composite RCA
Power Supply (Current Capacity)	2.5 A

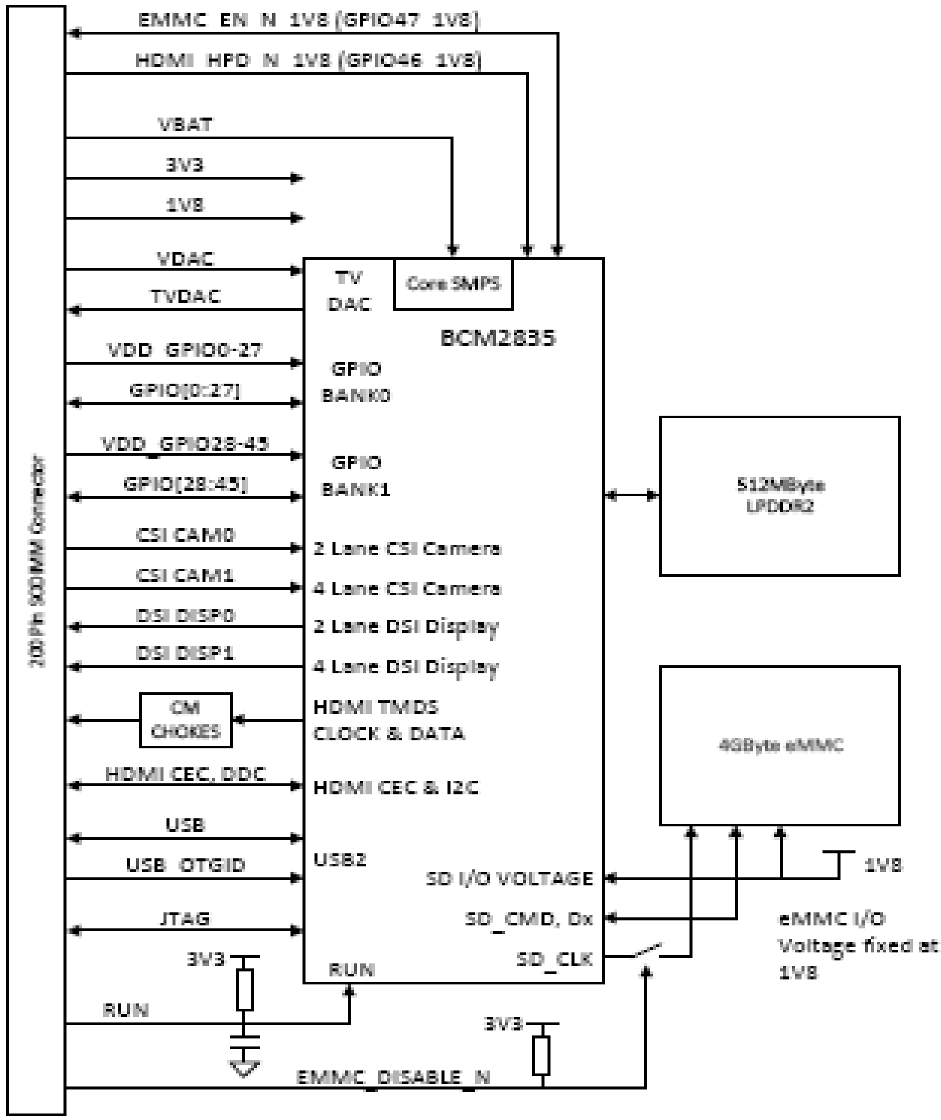


Figure 3.13: block diagram of Raspberry pi

3.3.5 Flight Controller (pixhawk)

Pixhawk flight controller is used to stabilize the movement of the quadcopter by stabilizing at the Raspberry Pi commands and compensating for any unusual movement caused by the air currents or any other external force.

Multicopter is an unstable by design as it has many separate motors. Thus it needs a powerful controller and a good program to keep it balanced. To know about the forces affecting, location and the current angle of the multicopter, the FC has lots of sensors on-board. (Gentile, 2012) They include sensors such as gyroscopes to know the tilt, accelerometers to know the inertia, and barometer to measure the altitude of the multicopter. (3D Robotics, 2015) Many differences between FCs exist, with the simplest only stabilizing the multicopter and the most advanced having many different modes and automated flying. Furthermore, most of the FCs can be only used with the traditional RC controller, while some support any kind of optional controller. The optional controller, for example, can be a Nintendo Wii controller using a WLAN or Bluetooth connection. One of the important features of a research multicopter is a high quality black box which records all information during the flight. An example picture of an advanced FC is shown below in Figure 3-10.

Figure 3.14:Pixhawk(FC)

Like stated in the multicopter definition earlier, controlling the multicopter happens by the FC changing the rotation speed of the rotors, which creates the required inertias. An important factor to notice with the multicopters is that excluding some special cases, like the tricopter, the rotors are rotating to different directions always in pairs, but still giving lift. This way the copter stays at the same spot or goes up or down when all the rotors are rotating at the same speed. It tilts to specific direction, when all the rotors on one side accelerate and on one side slow down. Rotation (yaw) is created with one of the rotor pairs slowing down, while the other pair speeds up. This creates torque and rotates the craft. (Gentile, 2012)

- **SPECIFICATIONS:**

  - Processor

32-bit ARM Cortex M4 core with FPU
168 Mhz/256 KB RAM/2 MB Flash
32-bit failsafe co-processor

  - Sensors

ST Micro 16-bit gyroscope
ST Micro 14-bit accelerometer/magnetometer
MEAS barometer
MPU6000 accelerometer/magnetometer

  - Power

Ideal diode controller with automatic failover
Servo rail high-power (7 V) and high-current ready
All peripheral outputs over-current protected, all inputs ESC protected

  - Interfaces

5x UART serial ports, 1 high-power capable, 2x with HW flow control
Spectrum DSM/DSM2/DSM-X Satellite input
Futaba S.BUS input and output
PPM sum signal
RSSI (PWM or voltage) input
I2C, SPI, 2x CAN, USB
and 6.6 ADC inputs

  - Dimensions

Weight 38 g (1.3 oz)
Width 50 mm (2.0”)

Height 15.5 mm (.6”)
Length 81.5 mm (3.2”)

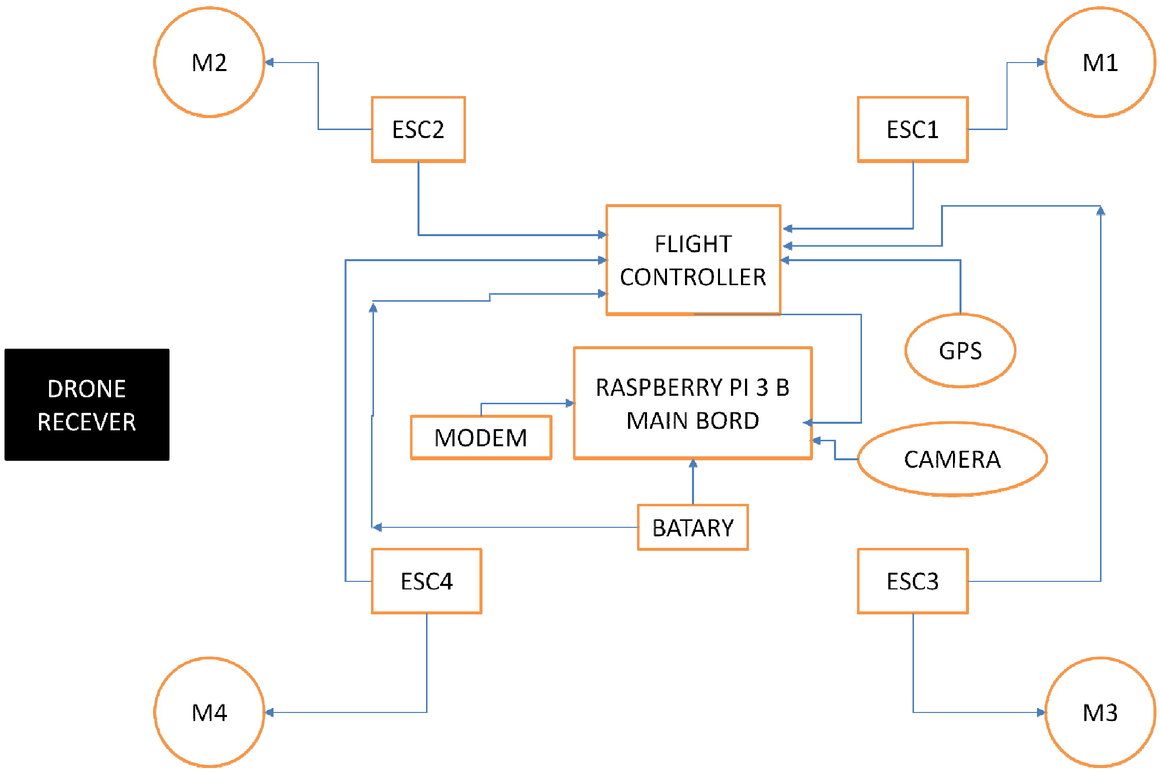
3.3.6 Battery

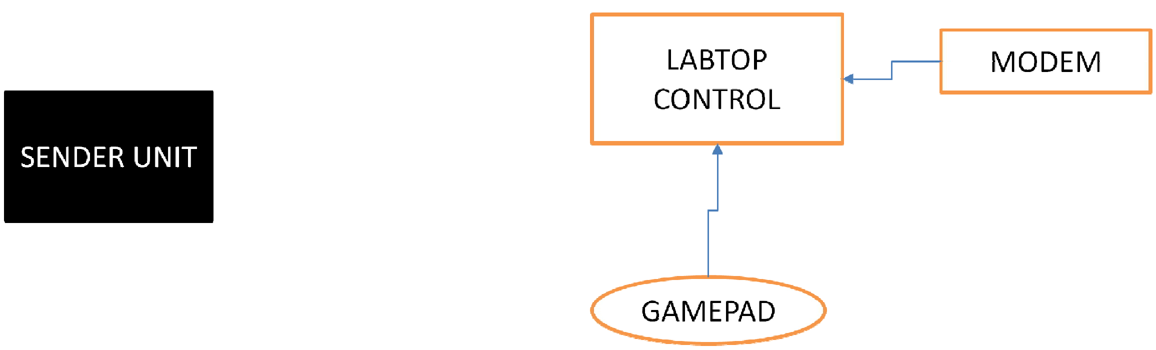
When looking for a battery to use for a quadrotor, there are a number of specifications to consider in order establishing a balance between the weight of the battery and its capacity. A battery cannot be chosen solely on its own specifications, but the other components of the drone must also be taken into consideration. Each part has an impact on each other and therefore there are multiple combinations of components that could be used to create the ideal UAV.

11.1V, 36.6Wh, 3300mAh 25C lipo high discharge battery 3cell was chosen show in figure3-15 below.

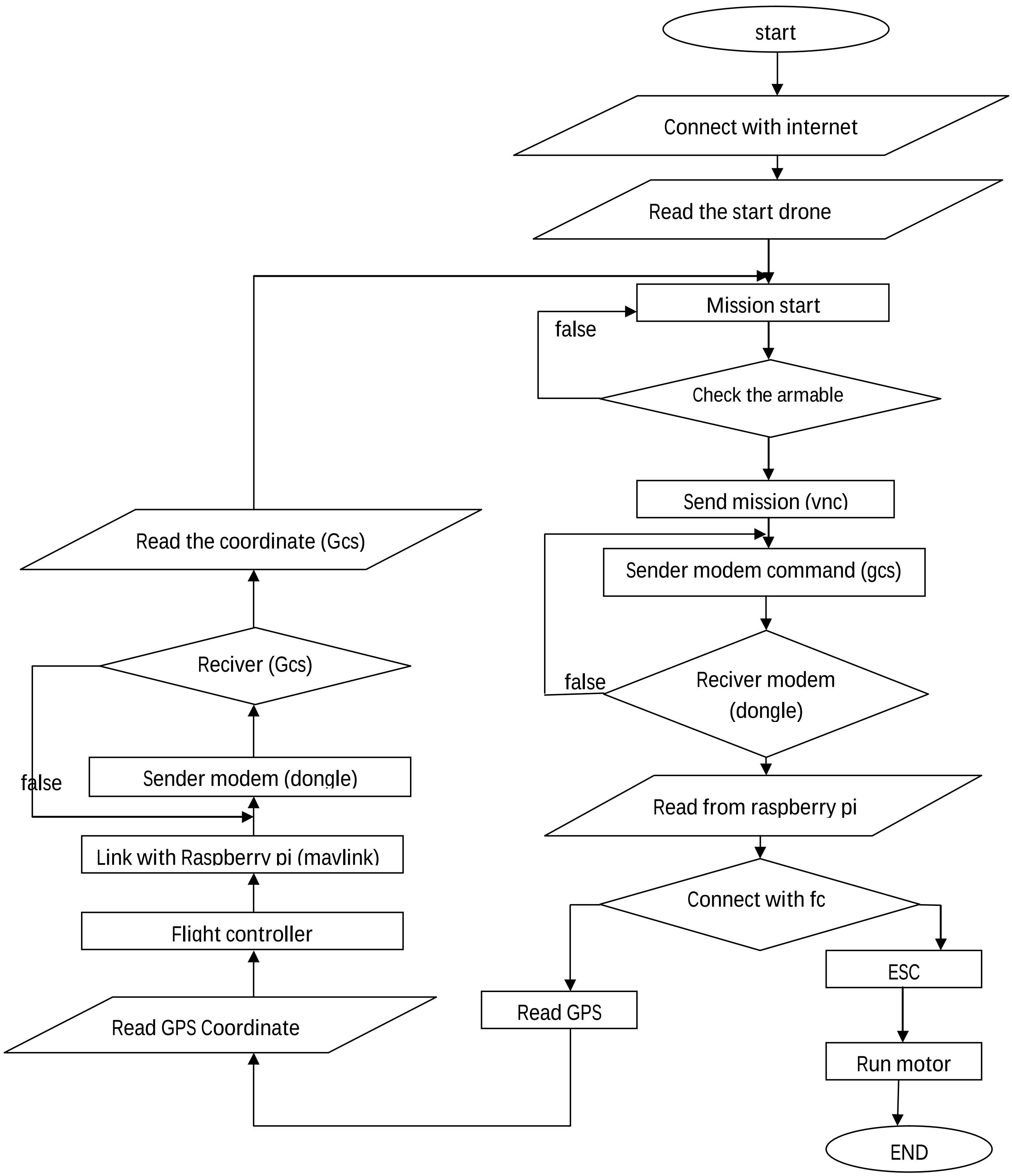
Figure 3.15: Battery

3.4 Block diagram





3.5 Flow chart



3.6 Practical Implementation of Drone

-Soldering and assembling frame and component

Figure 3.16: Assembling Frame

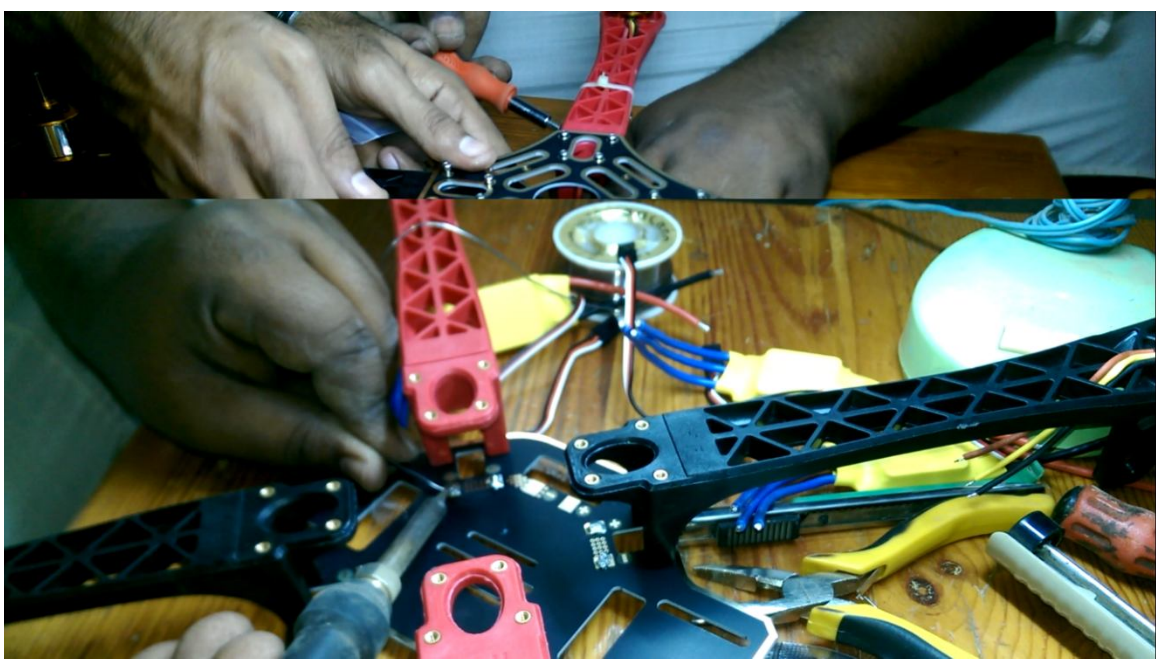


Figure 3.17: Soldering ESC

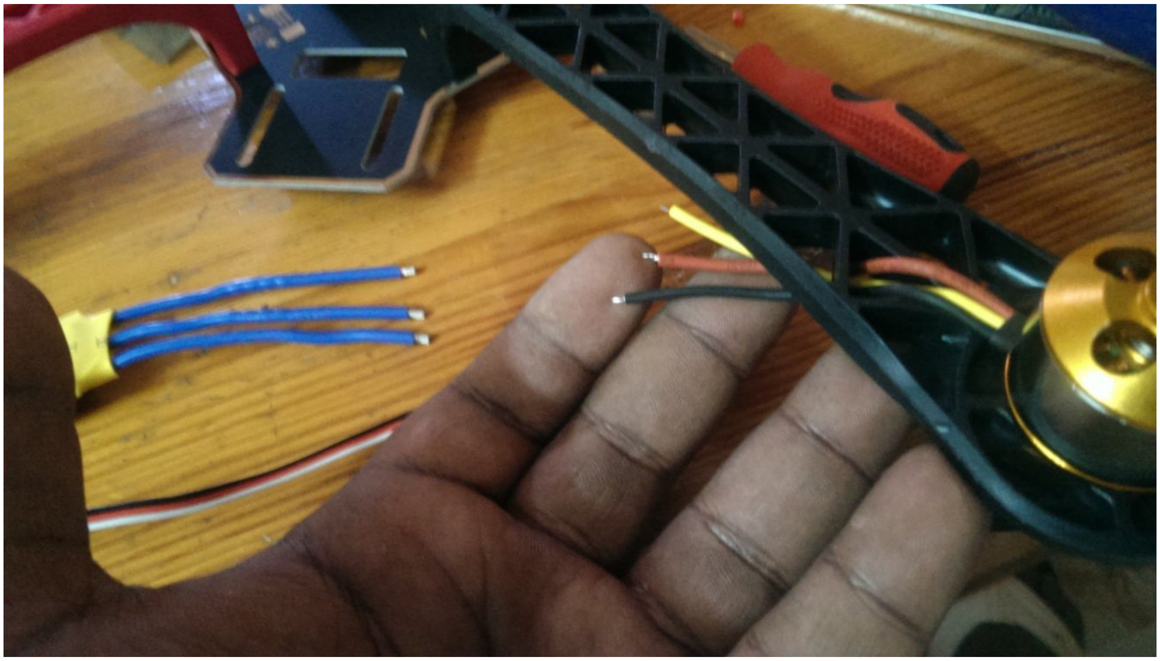


Figure 3.18: Solder Motor to ESC

Figure 3.19: Solder Motor to ESC

Figure 3.20: Solder Motor to ESC

-The air frame F450 does not come with landing gear so there are no high enough to but battery under frame only 3cm so landing gear are modified to make it high enough 10.5 cm another reason that for safty landing to make component safe.

-The airframe (F 450) has been modified by adding a landing gear locally manufactured through the technique of 3D printer.

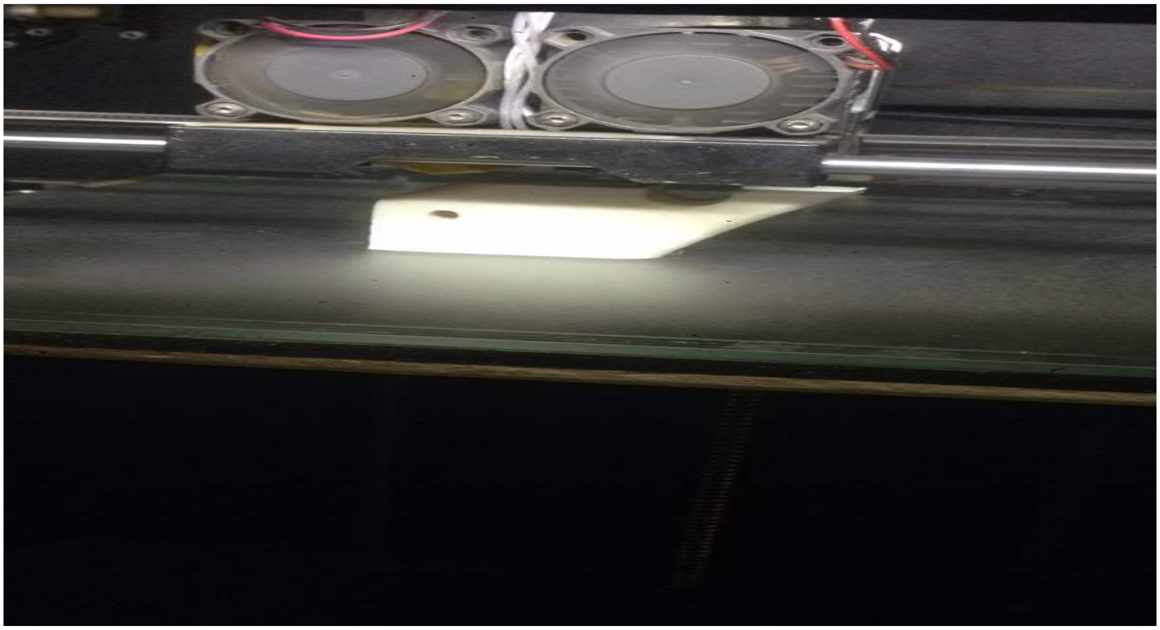


Figure 3.21: 3D Printer

Figure 3.22: 3D Printed Landing Gear

Figure 3.23: Modified Landing Gear to Frame

Figure 3.24: Modified Landing Gear to Frame

Figure 3.25: Modified Landing Gear to Frame

-The motors and other component have been fixed on the frame by screws, tie and soldered and linked together.

Figure 3.26: Airframe After Modified

-Motors and ESC has been calibrate with pixhawk

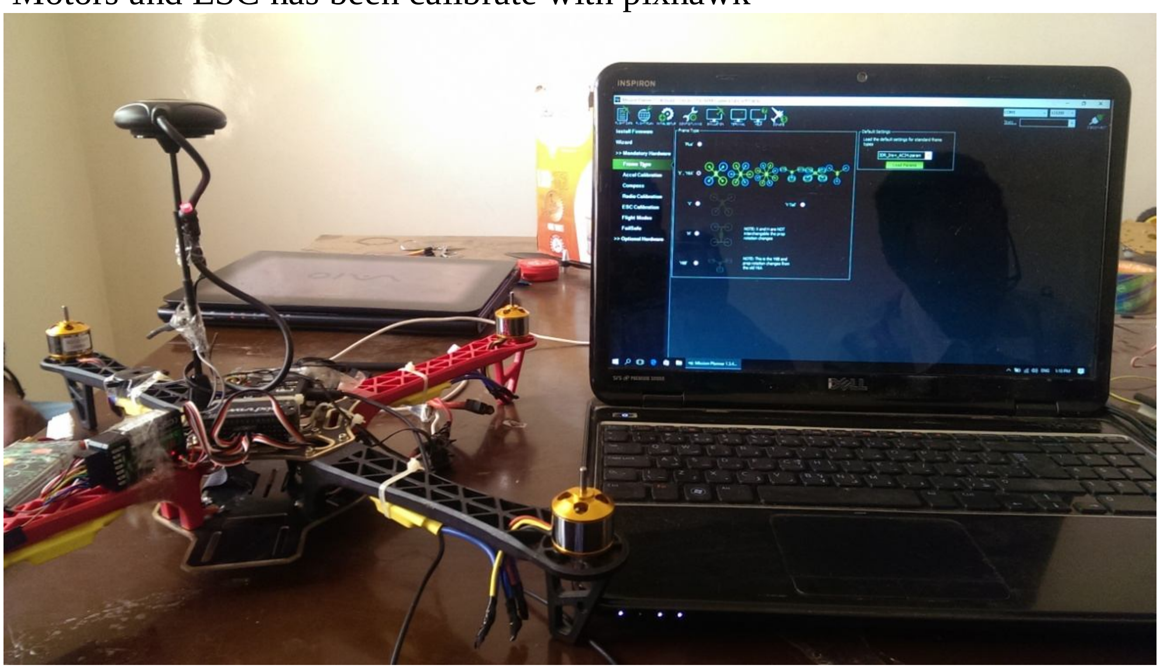


Figure 3.27:Calibrate With Mission Planer

-Raspberry pi Connected with Pixhawk via Mavlink

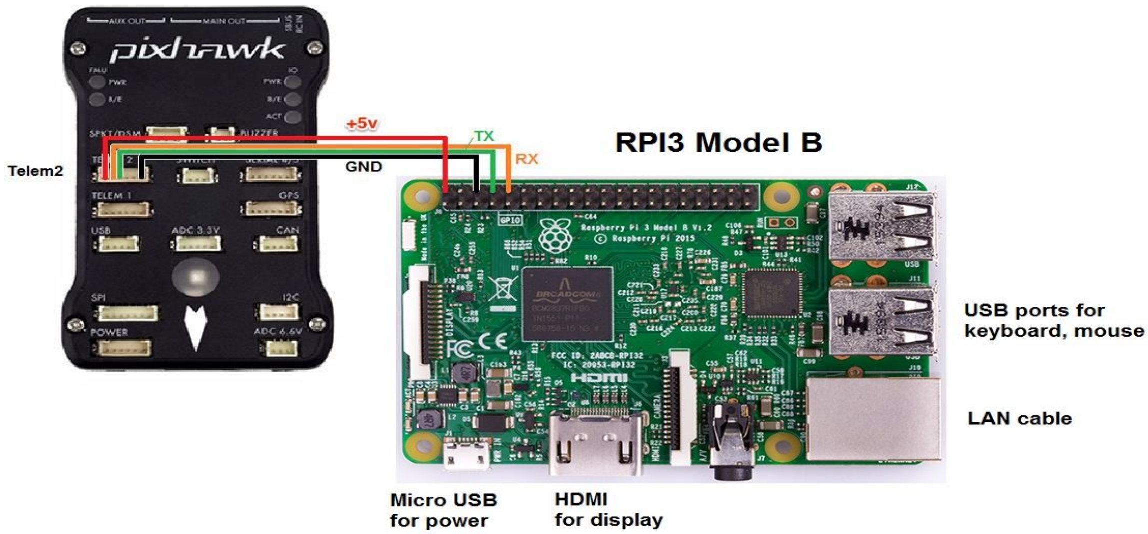


Figure 3.28: Mavlink Connection Throw GPIO

-The raspean operation system has been installed in raspberry pi.
-The code written by python language.
-Raspberry pi connected to the internet via LTE modem.
-The ground station (pc) connected to the internet via LTE router.