Design & Development of Intelligent Drone (Quad-Copter) for Security & Surveillance

Major Project Report

Submitted in fulfillment of the requirements
for the degree of

Master of Technology
in
Electronics & Communication Engineering
(Embedded Systems)

By

Khushboo Kumari Yadav
(15MECE10)

Electronics & Communication Engineering Department
Institute of Technology
Nirma University
Ahmedabad-382 481

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Under the guidance of

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May 2017

Declaration

This is to certify that

a. The thesis comprises my original work towards the degree of Master of Technology in Communication Engineering at Nirma University and has not been submitted elsewhere for a degree.

b. Due acknowledgment has been made in the text to all other material used.

- Khushboo Kumari Yadav

15MECE10

Disclaimer

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Certificate

This is to certify that the Major Project entitled **"Design & Development of Intelligent Drone (Quad-Copter) for Security & Surveillance"** submitted by **Khushboo Kumari Yadav (15MECE10)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in Communication Engineering, Nirma University, Ahmadabad is the record of work carried out by him under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination.The results embodied in this major project, to the best of our knowledge,haven't been submitted to any other university or institution for award of any degree or diploma.

Date: Place: Ahmedabad

Dr. Dilip Kothari

Internal Guide

Program Coordinator

Dr. Dilip Kothari

Prof. & Head, EC Department

Dr. Alka Mahajan

Director, IT

Certificate

This is to certify that the Major Project (Phase- I) entitled **"Design & Development of Intelligent Drone (Quad-Copter) for Security & Surveillance"** submitted by **Khushboo Kumari Yadav (15MECE10)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in Communication Engineering, Nirma University, Ahmedabad is the record of work carried out by her under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination.

Mr. Deepak Sharma
Deputy Manager, I.T
JK Lakshmi Cement Ltd.
Kalol

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- Khushboo Kumari Yadav

15MECE10

Abstract

Security and surveillance is a major area of concern for any industry. To reduce the man power a low cost surveillance system is developed in form of drones. Drone is an emerging technology of 21st century. They are Unmanned Aerial Vehicles (UAV) that are simple to model and control and with the integration of many low cost technologies a quadrotor can be assembled easily. The project aims at developing a quadrotor from off-the-shelf parts for surveillance based applications and also use it as research platform for tackling autonomous navigation problems, obstacle detection and obstacle avoidance.

Quadrotors key parts are its navigation systems comprising of hardware as well as software components. Hardware part for navigation system includes a combination of MEMS sensors like accelerometers, gyroscopes, magnetometers and also a GPS unit. During actual flight if the communication between Ground control station and quadrotor breaks down then to overcome this failure of autonomous systems point to point link is formed for a manual over- ride.

Pixhawk is the autopilot flight controller developed by PX4 group from ETH Zurich, Switzerland which is used in this project and the software is adapted from the ardupilot-arducopter (APM) project by the diydrones (www.diydrones.com) community. The communication protocol used in this project is MAVlink which was developed by Loren Meier, head of the PX4 group.

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Abbreviation Notation and Nomenclature

UAV .... Unmanned Air Vehicle

MEMS .... Microelectromechanical systems

GPS .... Global Positioning System

GCS .... Ground Control Station

APM .... Ardupilot Mega

MAVlink .... Micro Air Vehicle link

IDSC .... Institute of Dynamic Systems and Control

CVG .... Computer Vision and Graphics

ABS .... Acrylonitrile butadiene styrene

BLDC .... Brushless DC

RPM .... Rotations Per Minute

LiPo .... Lithium Polymer

ESC .... Electronic Speed Controller

FC .... Flight Controller

PPM .... Pulse Position Modulation

LED .... Light Emitting Diode

3DR .... 3D Robotics

OS .... Operation System

SIMD .... Single Instruction Multiple Data

USB .... Universal Serial Bus

SPI .... Serial Peripheral Interface

CAN .... Control Area Network

PWM .... Pulse Width Modulation

RSSI .... Received Signal Strength Indicator

IMU .... Inertial Measurement Unit

RTL .... Return to Launch

Chapter 1

Introduction

1.1 Motivation

In recent days drones are the new emerging technology. Its applications are vast and it includes the areas where humans cannot reach easily. The motivation behind this project was to develop a drone, basically a quadcopter, that can reach the areas that are unreachable by humans and also to reduce the human intervention. The key purpose is to build a drone for security and surveillance of the plant. It will definitely reduce the man power, time as well as the errors made by humans and will reach out to those areas in the plant that cannot be reached by humans.

1.2 Problem Statement

For an organization busy doing continuous production the main focus is to increase the production and maximum man power of the industry is dedicated for this purpose. But at the same time there are many areas where man power is needed and are mandatory to serve. One of such mandatory areas is the security and surveillance of the production plant. In such a big plant humans cannot reach everywhere so some technology has to be developed to cater those areas to reduce the man power and increase the accuracy and cover those areas too where humans cannot reach.

1.3 Overview

Quadrotors are four armed, four rotor propelled helicopter with inherently unstable and nonlinear dynamics. Though it is difficult to develop control system achieve stability, the final system develop can be very agile and with the capability of omnidirectional movement much more than other UAVs such as planes and helicopter (with single rotor). In the UAV world Quadrotors features one of the highest payload capacity making it possible to load it with myriad of Sensors. Quadrotors can be utilized for both indoor and outdoor data collection such as surveillance, building mapping etc. Nowadays multirotor UAVs especially quadrotors with state of the art controllers have gained quite a huge interest from engineering community because of many reasons some of which are listed below:

- Possibility to have variety of movements such as it can fly like a plane attaining comparable speed on the other hand it can also hover at a certain point in space like a helicopter.
- Because of its symmetric build it can move in any direction in negligible instant of time whatever its heading or attitude maybe which attributes to its property of agility.
- The size of Quadrotors can be as small as 10 cms. Swarms of such Quadrotors can be very useful for disaster management.
- Its maneuvering is far simpler than that of helicopter and plane, making it easier for pilot to control.

Majority in the field of quadcopter development is attributed to **ETH, Zurich IDSC (Institute for Dynamic Systems and Control) lab** and **CVG (Com-**

puter Vision and Graphics) lab , the latter providing benchmark for quadrotor research and the former providing benchmark for quadrotor as a personal drone. IDSC lab of ETH has provided with a variety of Control Algorithm and Failsafe Mechanisms while CVG lab is attributed to the development of state of the art OpenSource Autopilot fulfilling all the requisite performance criteria for Quadrotor Controller namely **Pixhawk**. All the development done under this Project is performed over Pixhawk.

1.4 Thesis Organization

The rest of the thesis organized as follows.

Chapter 1 contains brief introduction of the UAVs and the problem statement also including the overview and the time-line for the project.

Chapter 2 describes Literature review part, and the background study of the basic tools, technologies and hardware used in the quadrotor systems.

Chapter 3 describes the hardware actually used for the UAV and the selection criteria of the hardware, particularly for the UAV developed.

Chapter 4 deals with software tools used in the project and the interfacing of the hardware and software. This chapter also includes the autonomous commands and calibration procedure for the UAV. This chapter also describes results achieved by this project and explains significant effects of results.

Chapter 5 Describes the hardware required and procedure of live video streaming for surveillance.

Chapter 6 Describes how optical flow can be used in drones for obstacle avoidance along with the implementation methods, flow chart of our algorithm and test results.

Chapter 7 Contains conclusion and future scope of the project.

1.5 Gantt Chart

The timeline of overall project is shown in Fig 1.1.

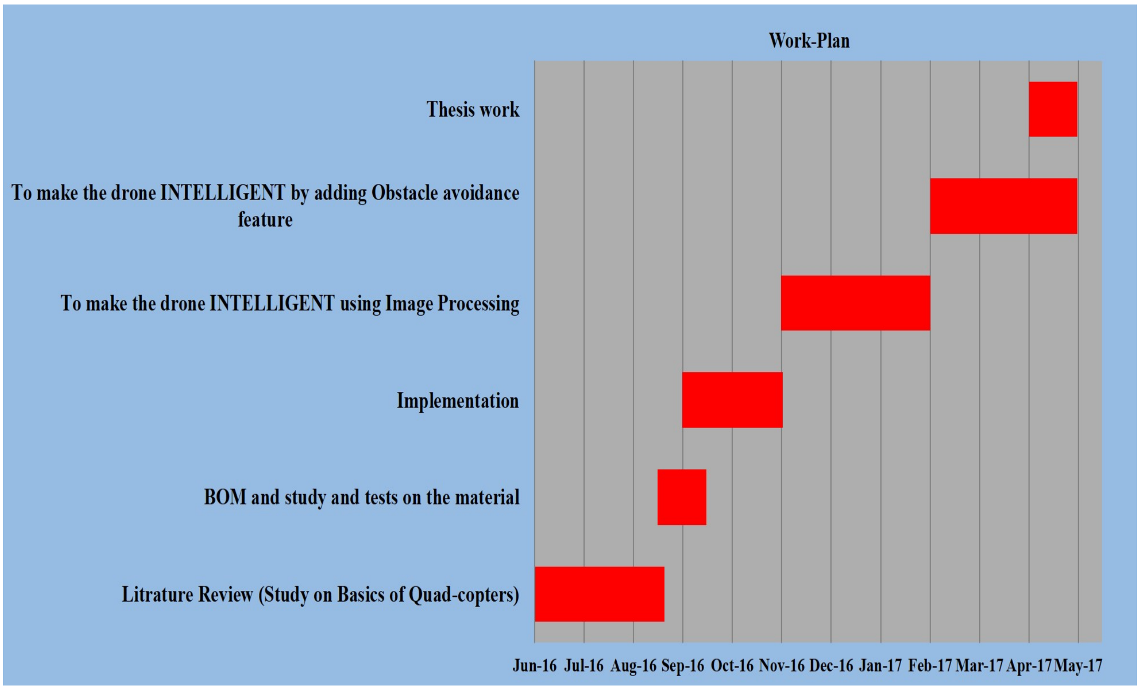


Figure 1.1: Gantt Chart

Chapter 2

Background Study & Literature Survey

2.1 Quadrotor System

The quadrotor consist of four arms with one rotor and propeller at the end of each arm. In the following section the working principle and flying mechanism is explained.

In a usual quadcopter, neighboring propellers prefer to spin in opposite ways, which results for the propellers on the other side to rotate in the same direction as shown in Fig 2.1. To put the concept in the different words, two of four propellers will rotate in clockwise manner while the other two in anticlockwise manner. These two opposite rotation bolsters to nullify the torque produced by them. All the drive powers are also nullified, resulting in zero pitch and roll momentum. The UAV would not rotate about two axis that are signified using the wings that connect motor. Main driving force which allow quadcopter to work is the symmetry and balance.
However, in certain situations we want the UAV to perform rotational motion. Observing bottom left picture, we can decrease the motor power in one loop while

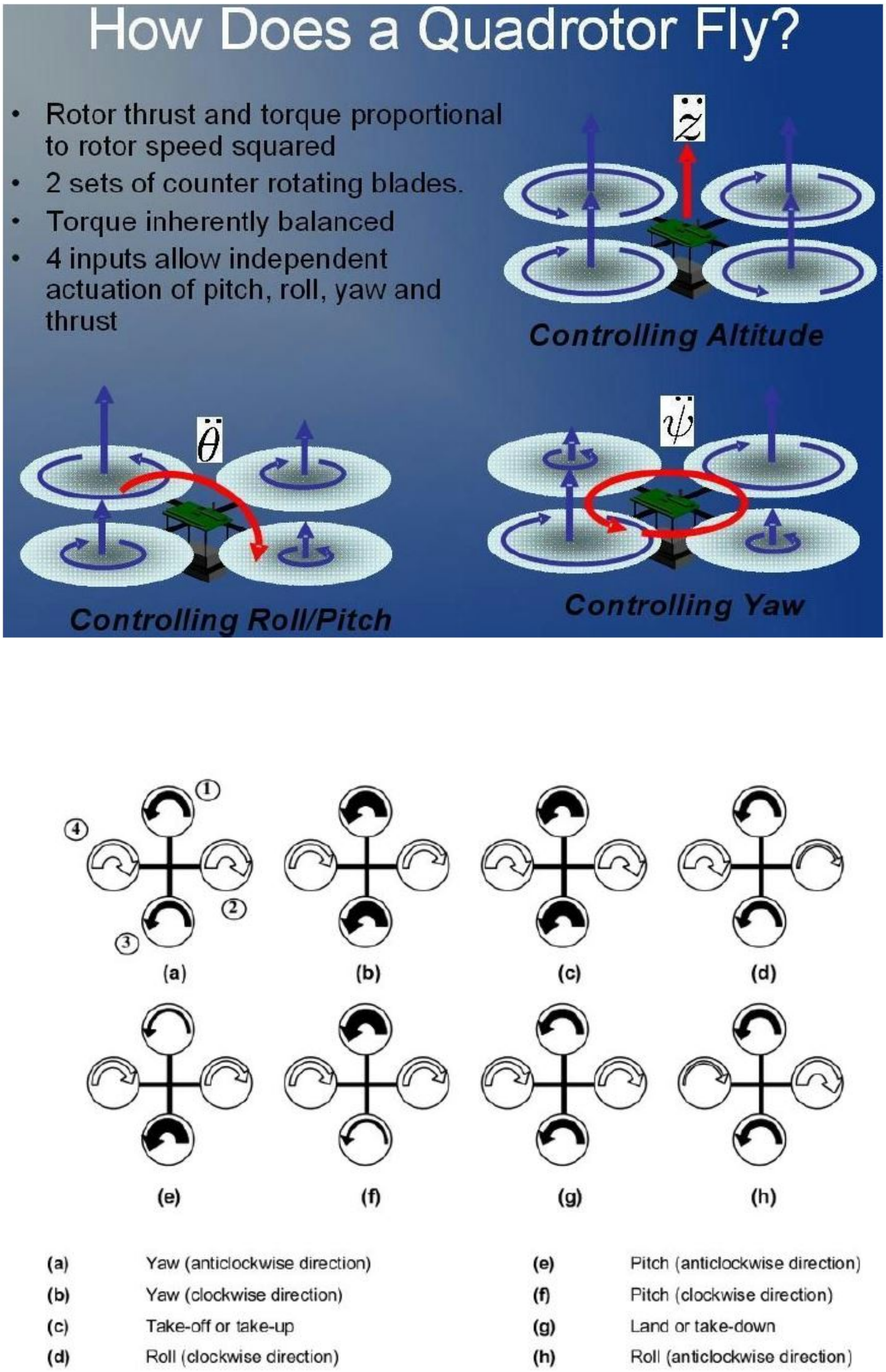


Figure 2.1: Flying mechanism of Quadrotors

increasing in the opposite motor. This will result in balanced yaw: meaning the axial torque will not change. Hence, The quadcopter is still in balanced condition. Similarly, the gross thrust will also remain the same. The variation is only in shape, these will cause to accelerate propellers.
When we want to provide yaw to the UAV, observing bottom right image, up the throttle for clockwise motors and down the thrust for anticlockwise motors. The net thrust will again be zero, rolling and pitching forces are also balanced. However, the yaw moment is unbalanced and that is what we actually want.
With the aim to raise or lower the height of UAV, only thing we are required to do is changing the throttle value i.e. rotational speed of wings. Based on the picture, roll, pitch and yaw are going to be balanced. The only variation is observed in throttle value.
The moment of inertia depends on the size of motor and the length of the arms of UAV. The winds used in our practices and designed to produce more thrust but less inertia. Because with more torque the battery power is reduces quickly.

2.2 Components

2.2.1 Frames

The structure, shown in Fig 2.2, that holds or houses all the components together is called frame. They are designed to be strong and lightweight.
It consists of 3 parts :

- The center plate where the electronics are mounted
- Four arms mounted to the center plate
- Four motor brackets connecting the motors to the end of the arms

Frames are usually made of:

Figure 2.2: Frame

- Carbon Fiber
- ABS (Acrylonitrile Butadiene Styrene) Plastic
- Aluminum
- Wood/ Plywood /MDF (Medium-density fiberboard)
- Normal Plastic

2.3 Propellers

Fig. 2.3 shows how propellers look like. Capability of a UAV is largely reliant on on how swiftly we change the throttle that is the rate of change of rpm value for wings. selection of wings is done based on:

a. The size and shape of the copter

b. The weight

Figure 2.3: Propellers

2.4 Motors

When selecting motors, there usually are specification that comes with the motor either provided by the seller or manufacturer. One should be able to find information about the power, thrust, rpm etc. Basically the brushless DC (BLDC) motors, shown in Fig. 2.4, are used in quadcopters.

Figure 2.4: Motors

Why BLDC?

a. It is small and light weight.

b. It provides comparatively more RPM

c. More torque is required to control the quad-copter

2.5 Battery- Power Source

Figure 2.5: Battery

Li-ion poly power supply, shown in Fig. 2.5, widely known as lithium polymer (LIPO Batteries) are batteries which can be recharged. These batteries are made of parallel connected secondary cells, they are usually available in packs to increase the voltage level.

2.6 Electronic Speed Controllers

Figure 2.6: ESC

Electronic Speed Controllers (ESCs), shown in Fig. 2.6, are used to control the speed of the motors.All the motors must spin at precise speeds to achieve accurate flight, so that ESC is very important.

2.7 Flight Controller

A flight controller (FC) is a small circuit board of varying complexity. Its function is to direct the RPM of each motor in response to input. A command from the pilot for the multi-rotor to move forward is fed into the flight controller, which determines how to manipulate the motors accordingly.
The majority of flight controllers also employ sensors to supplement their calculations. These range from simple gyroscopes for orientation to barometers for automatically holding altitudes. GPS can also be used for auto-pilot or fail-safe purposes.

2.7.1 Approach to choose best flight controller for quadcopter

A quadcopter can fly in the sky must need all parts such as frame, ESCs, motors, flight controller, lipo battery, transmitter and receiver, propellers etc. Flight controller is the most important one, regarded as brain which will stop flying when its components fail. Under such circumstance the flight controller can control all of the following aspects of flight - possibly more.

a. Gyro Stabilization: the ability to easily keep the quadcopter stable and level under the pilots control. This is a standard feature of all Flight controller.

b. Self Leveling: the ability to let go of the pitch and roll stick on the transmitter and have the quadcopter stay level.

c. Orientation mode- The pilot can control the orientation of the quadcopter.

d. Altitude Hold: the ability to hover a certain distance from the ground without having to manually adjust the throttle.

e. Position Hold: the ability to hover at a specific location.

f. Return Home: the ability to automatically return to the point where the quadcopter initially took off.

g. Waypoint Navigation: the ability to set specific points on a map that quadcopter will follow as part of a flight plan.

h. GPS: the ability to record the data of flying,it will shorten search time for next time.

Before buying a flight controller two things have to be kept in mind:

- The flight controller board must be open source board: Open source is quite popular, flight controller is not exception.It is a very flexible method and you can always modify any of it to suit your own needs .
- The price of flight controller: Before purchasing the flight controller, one should really compare the quality and cost of the two platforms. For the beginners the cheaper the better, but the quality of the flight controller should be good.

2.7.2 Overview of popular controller boards

A lots of flight controllers have come out in the market. Some of the popular Flight Controller Boards are listed below:

ARDUPILOT

The opensource format of ArduPilot, shown in Fig. 2.7, has allowed for simple use of many open source platforms created by Jordi Muoz and Chris Anderson. The features are:

- Programmable 3D way points
- Return to launch
- in flight reset
- fully programmable actions at waypoints
- Stabilization options to negate the need for a third party co-pilot
- Fly By Wire mode
- Optimization of 3 or 4 channel airplanes.
- Flight Simulations

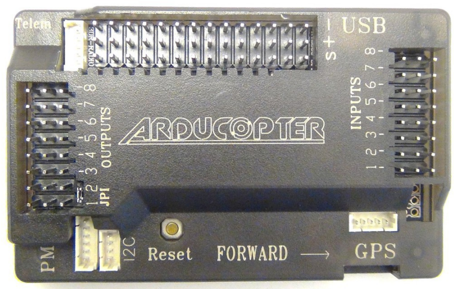


Figure 2.7: Ardupilot Flight Controller

VR MicroBrain

Virtual Robotix presented the MicroBrain, shown in Fig. 2.8, which is the smallest 32bit Autopilot released by VirtualRobotix.

characteristics are:

- 168Mhz ARM CortexM4F micro controller with DSP and hardware fpu.
- 1024KiB flash, 192KiB of RAM.
- Accelerometer, MEMS gyroscope and barometer.

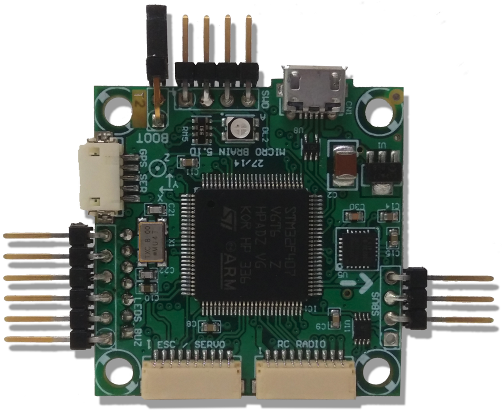


Figure 2.8: VR MicroBrain Flight Controller

- 8 RC standard input PPM, PPMSUM, SBUS.
- 8 RC output at 490 hz.
- 1 SD Card Slot until 64 gigabyte.
- 1 I2C Bus.
- 3 serial porti:1 for option GPS 1 for SBUS 1 telemetry.
- 3 digital switch (ULN2003) 2 LED 1 BUZZER.
- Jtag port for realtime debug.
- 1 Input analog lipo voltage control.
- Dimension 3.8 cross 3.8 cm 10 gr hole distance 3.2 x 3.2 cm.
- GPS and Magnetometer as option.

PixHawk

Pixhawk, shown in Fig. 2.9, is an innovative selfpilot system developed by PX4 and constructed by 3D Robotics. It demonstrates high level of processor with sophisticated sensor tech provided by ST Microelectronics. There is a real time OS with excellent performance and reliability called NuttX which features autonomous control of UAV. PIXHAWK is the all in one unit, combining FMU and IO into a single package. With hardware floating point unit and SIMD. Fig. 2.10 shows comparison chart of different flight controllers.

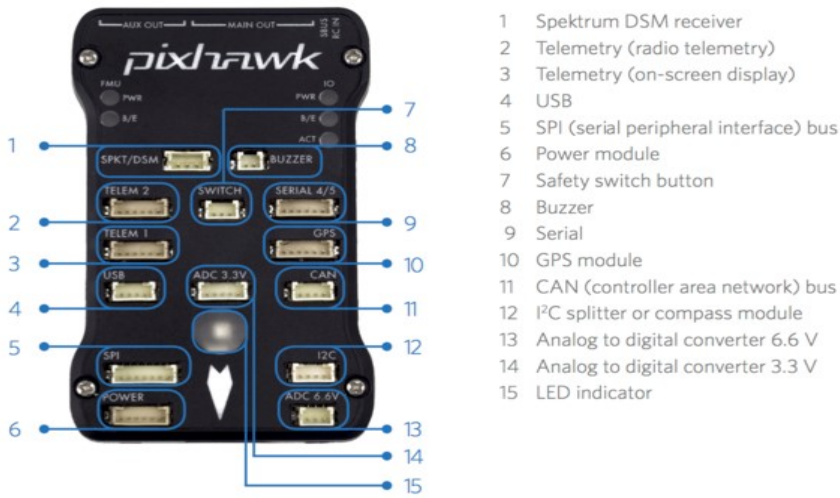


Figure 2.9: Pixhawk Flight Controller Pin Description

2.7.3 Details

MICROCONTROLLER:

a. 32bit controller with core Cortex M4

b. Processing : 168 MHz RAM Memory: 256 KB Flash Memory: 2 MB

c. Also contains failsafe controller of 32 bit

SENSORS SPECIFICATIONS:

a. 16 bit gyroscope from ST Microelectronics

b. 14 bit magnetometer from ST Microelectronics

c. Barometer

INTERFACES SPECIFICATION:

a. serial ports uart 5x

b. Telemetry based Spectrum DX7s

c. I/P O/P bus from Futuba

d. Ppm signal measurement module

e. RSSI (PWM or voltage) input

f. Analog to digital converter

g. Outsider microUSB

POWER SYSTEM:

a. Conditional Diode Control

b. 7 Volt Servo

c. Current threshold protected

WEIGHT AND DIMENSIONS:

a. Heaviness: 38 gram

b. Breadth: 50 millimeter

c. Width: 15.5 millimeter

d. Span: 81.5 millimeter

MATRIX : BRAIN (PRO) vs uBrain vs PixHawk

OS and Software Specification

PRO 5	VR BRAIN 5 (PRO)	VR micro BRAIN	PIXHAWK
APM Copter	YES	YES	YES
APM Plane	YES	YES	YES
APM Rover	YES	YES	YES
Nuttx	YES 6.28 - 7.10	YES 6.28 - 7.10	YES
BARE BONE IMPLEMENTATION	YES	YES	NO
WIFI	YES SPI OPTION WIP	NO	NO
MASS STORAGE	YES	YES	NO
SUPPORTED OTHER PROJECT			
JAVA OS	IST JAVA YES	IST JAVA YES	NO
OPEN PILOT TAU LAB	YES (Stefan)	YES working progress	NO
AUTOQUAD	work in progress	work in progres	NO
Advanced Accessories			
VR BEACON (follow me and special function)	YES	YES	NO
CAN ESC	YES	NO	YES
VR LINK PMU + OSD + TEL MODULE	YES	YES	YES
VR micro LINK on board plugin module	NO	YES	NO
CLUSTER INTERFACE	YES	YES	NO
Mission Planner Firmware Update	YES	YES	YES
VR micro and standard GIMBAL 2-3 axis	YES	YES	YES
PAD and SMARTPHONE Ground Station	VR PAD , DROID P, ANDROPILOT	VR PAD , DROID P, ANDROPILOT	VR PAD, DROID P , ANDROPILOT

Figure 2.10: Comaprision Chart of Different Flight Controllers

Chapter 3

Design, Selection & Testing of Hardware

3.1 Flight Controller PixHawk: Overview, Selection and initial Setup

The basic initial setup to fly the quadcopter includes the setting up of the flight controller (PixHawk) on the quadcopter and how to connect things like GPS as external compass module, the buzzer, the press button (safety switch) and the receiver. Then the firmware is flashed on to the board and it get itself configured with the radio and then it is ready to start installing all the cable onto the model.

So now, the big question is why to use Pixhawk in place of APM (Ardu Pilot Mega)? Both APM and PixHawk run similar softwares. Apm is the Pixhawk predecessor. But the advantage of Pixhawk is that it provides super stable and smooth flight, perfect aerial video, mission flying and it has the best GPS implementation of the board. So one can do things like GPS return to home, GPS hold etc. one can program individual waypoints onto the software and allow it to fly missions autonomously. So, basically Pixhawk is a new version of APM.

APM is an 8-bit device, but , the amount of code and processing that has been dumped into the software that is going onto this board is now running the processor inside the APM 90+ % pretty much all the time . So the pixhawk has come around as the new kid on the blog. Pixhawk is more feature proof then the APM. It provides everything that the APM does but also continues to support the latest and greatest firmware and features as they are released via the software.

3.1.1 Difference between Pixhawk and APM

It did not go straight from APM to Pixhawk. It was a smooth delivery, shown in Fig. 3.1. There was actually an intermediate step called the PX4 and the PX4 became the pixhawk with some changes with the pinouts and the setup. Pixhawk has all the connections on the top. So all the sensors, receivers and the external components can be connected to it easily. So the APM 2.5, 2.6, APM mini basically all the APM 2s and 3s actually have an 8-bit controller. So this is a very mature technology now.

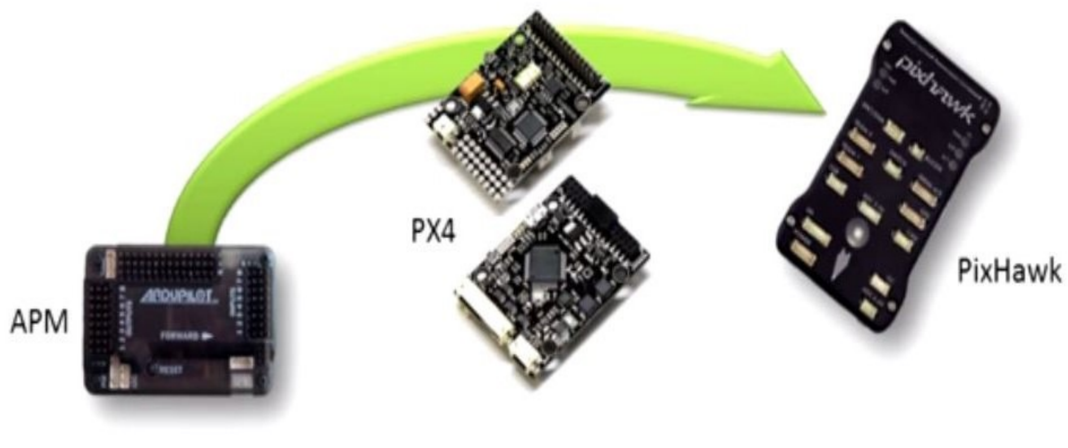


Figure 3.1: Evolution of Pixhawk from APM

3.1.2 New features in the software

APM : Copter 3.3 (Improvements/Additions Highlights):

a. Reduced spline overshoot after very long track followed by very short track

b. Log entire mission to data flash whenever it is uploaded

c. Altitude reported if vehicle takes off before GPS lock

d. High speed logging of IMU

e. AutoTune reliability fixes (improvements filtering to reduced noise interference)

f. Optical flow improvements

g. AltHold and Take-Off changes

h. Stop flight mode- causes vehicle to stop quickly and does not respond to user input or waypoint movement via MAVlink. Requires GPS, will be renamed to break mode.

i. Landing detector simplified to only check vehicle is not accelerating and motors have hit their lower limit AutoTune for yaw

j. Smooth throttle curve which should reduce wobbles during fast climbs and descents

k. New camera Gimbal features

3.2 Motor Selection and Specifications

Avionic C3536 KV1050 brushless motor is used in the quadcopter. The motor, propeller and battery selection is the key thing in a drone since it is selected based upon the amount of weight it has to lift which accordingly decides the flight time of the drone. In this project the drone would weigh about 2kg so the parts were selected accordingly. These motors are specifically designed keeping in mind on how to get the maximum torque at the most optimal RMP (rotations per minute) and are made for RC controlled models only. The specifications of the motor are:

a. Rotational Speed: 1050 (kv) RPM/V

b. Continuous Current: 15A

c. Max. Current: 25A

d. Max. Efficiency: 98%

e. No Load Current: 1.5A

f. Internal Resistance: 58 (m Omega)

g. Power: 520W

h. Motor Weight (Motor only): 110g

i. Motor shaft Diameter: 4mm

j. Recommended propeller: 9" x 5.5 " or 10" x 6 " or 11" x 5"

3.3 Selection of Counter Rotating Propeller

Based on the motor selected different combination of propellers can be used depending upon the thrust to be produced. Different combinations that can be used are:

3.3.1 Combination of usage:

PROP 9x6E

To Get 1000 Grams Thrust

Lipo 3cell 11.1V

ESC 30 amp.

PROP 11x7E

To Get 1300 Grams Thrust

Lipo 3cell 11.1V

ESC 30 amp.

PROP 14x8E

To Get 1600 Grams Thrust

Lipo 3cell 11.1V

ESC 30 amp.

PROP 9x6E

To Get 1050 Grams Thrust

Lipo 3cell 11.1V

ESC 40 amp.

PROP 11x7E

To Get 1350 Grams Thrust

Lipo 3cell 11.1V

ESC 40 amp.

PROP 14x8E

To Get 1650 Grams Thrust

Lipo 3cell 11.1V

ESC 40 amp.

Figure 3.2: Counter Rotating Propeller 1045/1045R for Quadrotor

3.4 Multicopter Calculation for selection of motors propellers and Battery

Different combinations of motors, propellers and batteries were tried in the multicopter calculator for checking which of these combinations gives the maximum flight time. Based on that the set of materials is finallized for the quadcopter with maximum weight 2000 gms.

After all the calculation the BLDC motor of 1100KV was decided to be used for lifting the quadcopter with the set of propellers of 10x4.5,shown in Fig 3.2, and 5000 mah battery. the calculations are shown in Fig. 3.3, Fig. 3.4, Fig. 3.5 and Fig. 3.6.

Figure 3.3: Multicopter Calculator

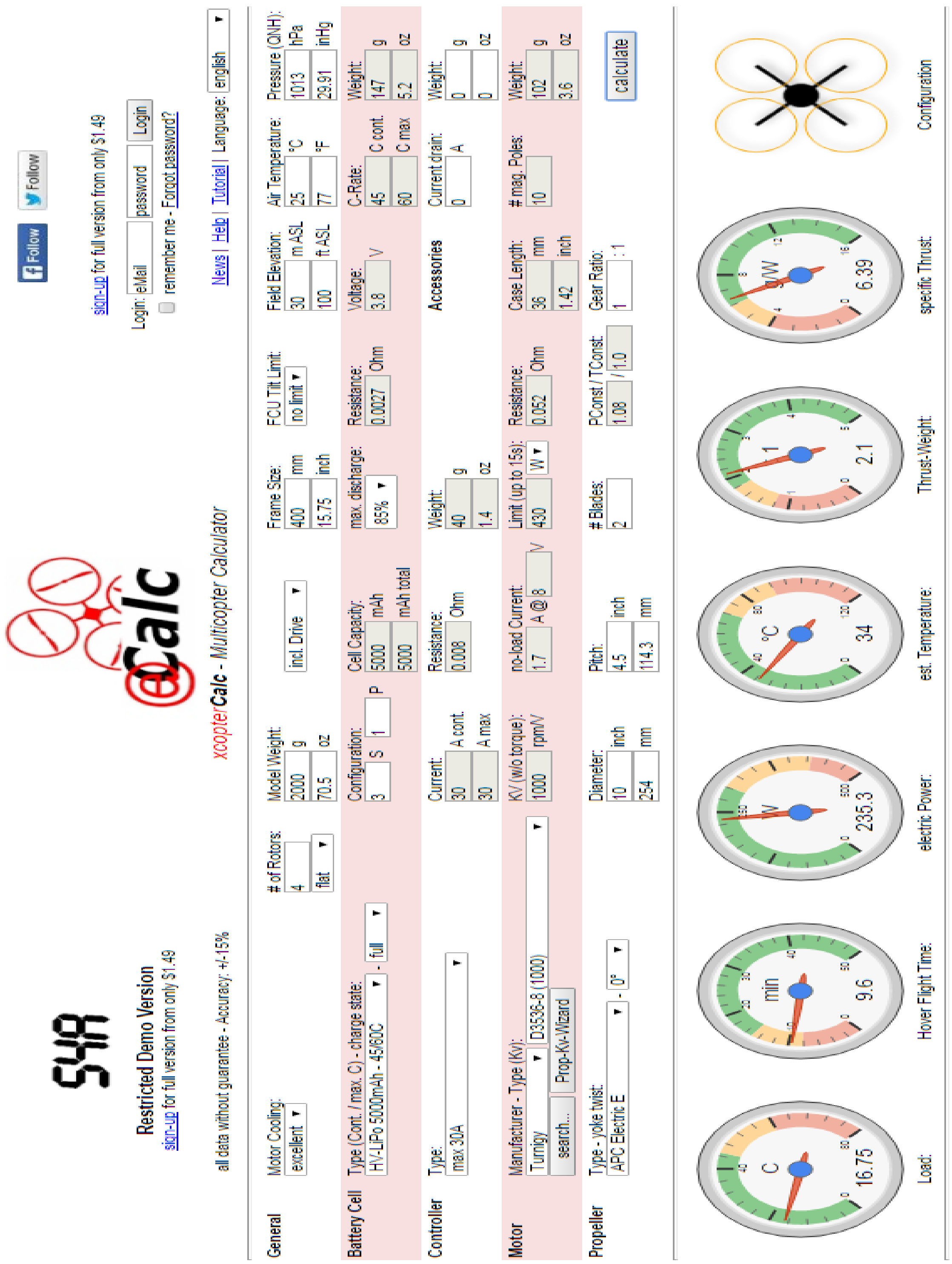


Figure 3.4: Multicopter Calculator

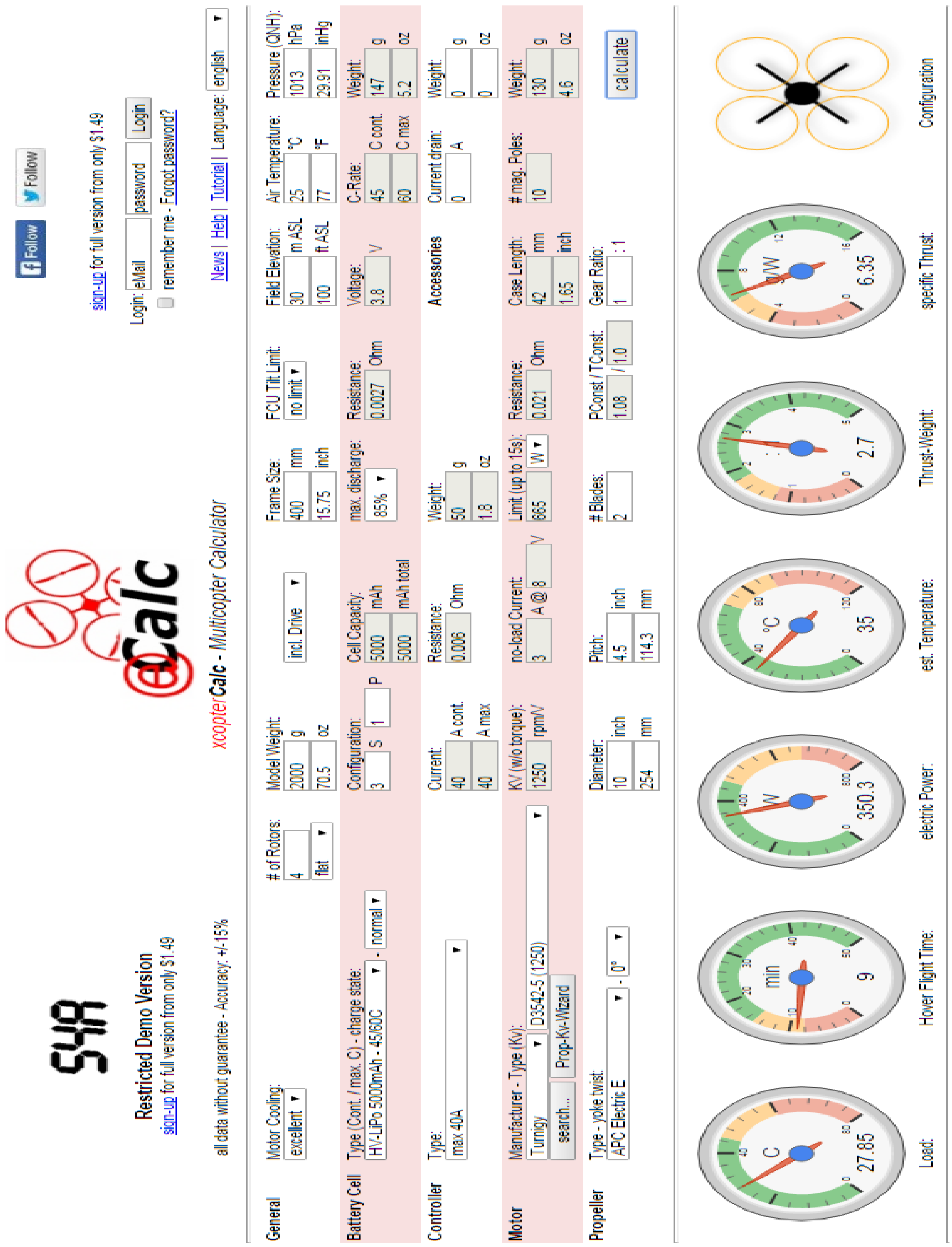


Figure 3.5: Multicopter Calculator

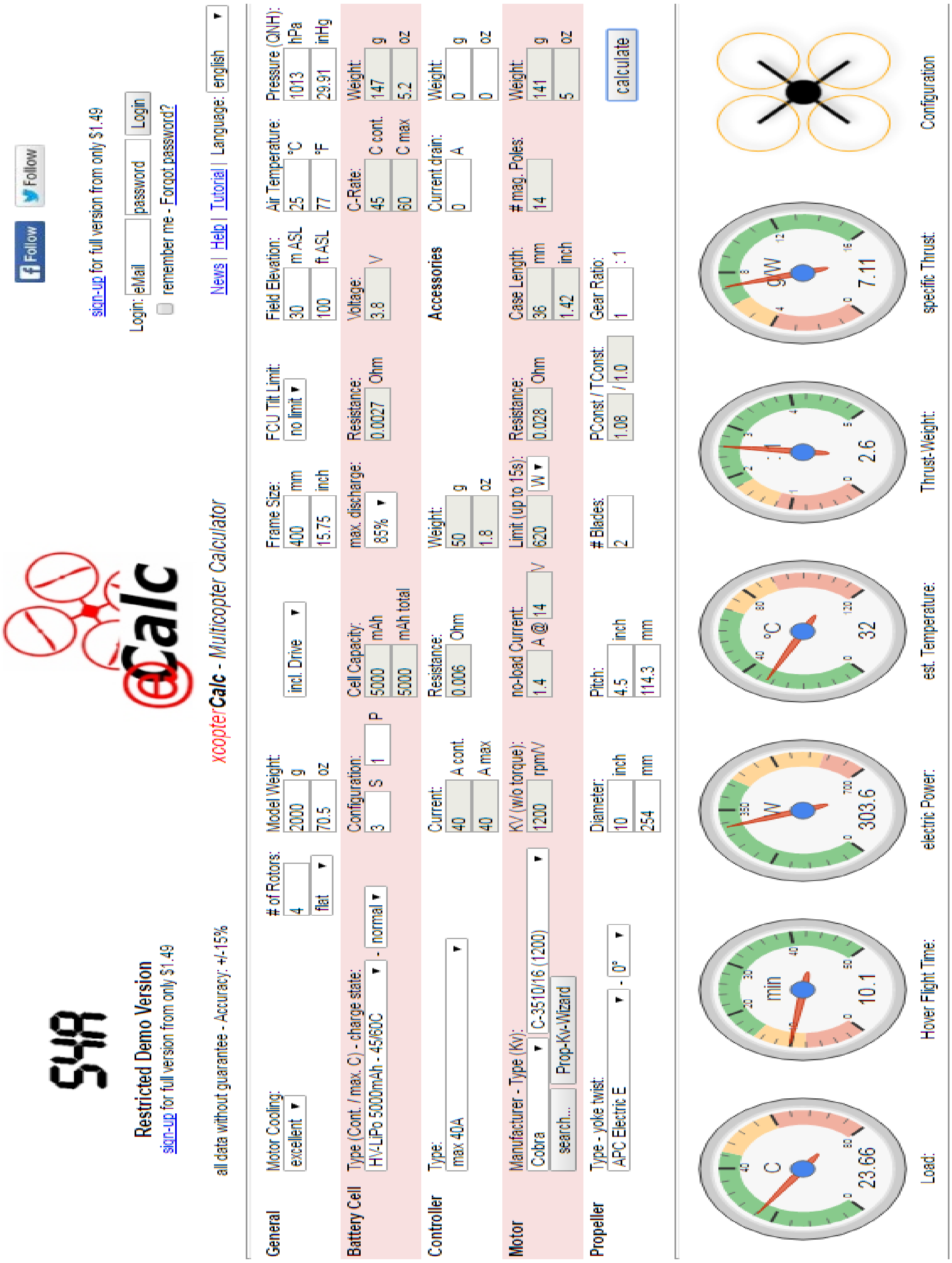


Figure 3.6: Multicopter Calculator

3.5 Radio Transmitter and Reciever

The radio transmitter and receiver, shown in Fig. 3.7, is used to control the quadcopter manually using the remote. The receiver of the remote is mounted on the drone and is connected with the flight controller. The remote is used to give the commands manually which is received by the receiver and is passed to the flight controller to control quadcopter. The receiver has different number of channels and supports flight modes.
For the project the radio transmitter and receiver used is of company Flysky. It has 9 channels.

- FS-TH9X uses AFHDS (automatic frequency hopping digital system) for better performance.
- It operates on 2.4GHz which puts the radio control out of frequency range of any noise generated by the other electronic components.
- It Gives range of 500meters - 3Km*.

The specifications of the Radio Transmitter and Receiver are:

a. Channels: 9channels TH9X

b. Model type: helicopter ,airplane, glider

c. RF power: less than 20db

d. Modulation: GFSK

e. Code type: PPM/PCM

f. Lcd type: 128*64 dot

g. Low voltage warning: yes

h. DSC port: yes

Figure 3.7: Flysky TH 9X 9 CH TX + 8CH RX, High Range, Fully Programmable Radio Transmitter and Reciever

i. Charger port: yes

j. Power:12VDC(1.5AA*8)

k. Weight:680g

l. ANT length:26mm

m. Size:190*80*240mm

<u>Range depends on lots of factors like</u>

a. Receiver mounting position and antenna direction. Other radio equipment on aircraft like video transmitter etc.

b. type of environment - will get less range in city where lot of wifi networks are working.

c. humidity-temperature etc.

Chapter 4

Software Modules, Commands & Calibrations

4.1 Ground Station

The Ground Control System provides a Graphical User Interface for both the outside as well as inside flights. Basically for UAVs the intermediate control station is the Ground Control System. Many UAVs are supported by these stations. At ETH Zurich this was constructed for the first time by Lorenz Meier basically for the PixHawk. Today many open source projects and universities are working on it. Some popular and most used ground station software are: Mission Planner, APMplanner, QGroundControl etc. All mentioned above are open source software.

4.1.1 Purpose

The Ground control station provides an interface to the UAVs. It does not work autonomously, its configurations and positional parameters requires changes.

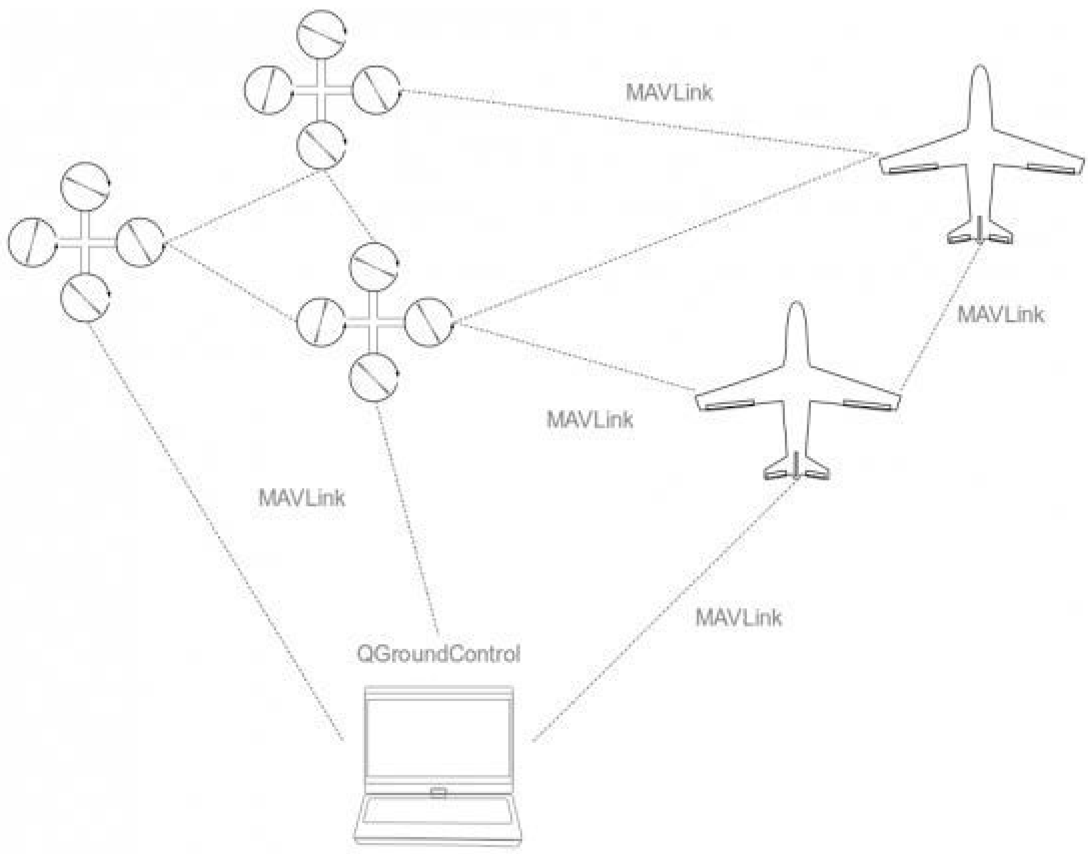


Figure 4.1: Communication Link

4.1.2 Features

QGroundControl has many applications containing numerous functionalities for views and interfaces.

- Multi-MAV support
- Multi-system support (multiple protocols, multiple autopilots/projects)
- 2D moving map (Google Satellite/Maps, OpenStreetMap, Yahoo Satellite/Maps)
- Mission planning (waypoints, system status)
- Support for rotary and fixed-wing (Airplanes, helicopters and quadrotor designs)

- Joystick control
- Voice/Audio output tested on Linux, Mac

4.1.3 Implementation

- Available across various Operating Systems
- Open Source
- Programming C++ based
- Adaptable to various styles using CSS

4.1.4 Supported Hardware

- Personal Computer/MAC
- iPad

4.2 Calibrations and Commands

Calibration is done to ensure that all the different parts are working properly well within their ranges. It also helps us to know the maximum and minimum values.

4.2.1 RC Calibration

All the channels are given its maximum values and these values get recorded in the Mission Planner (Fig. 4.3).

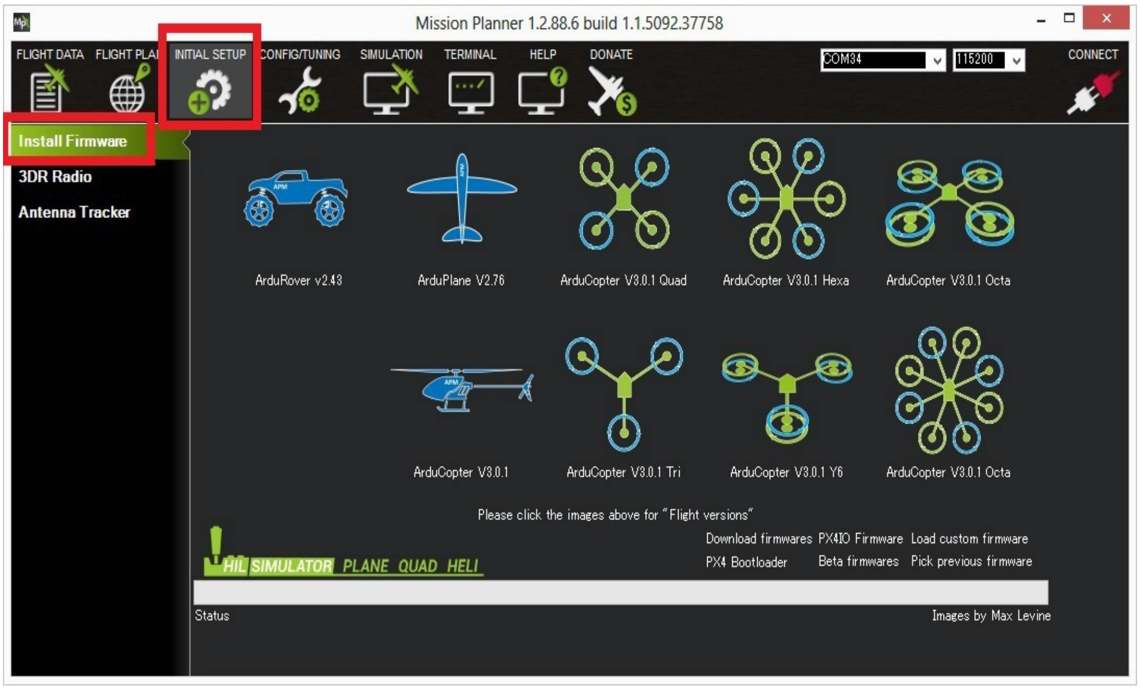


Figure 4.2: Misson Planner

Figure 4.3: RC Calibration

4.3 ESC Calibration

ESCs are used to change the speed of the motors command given to it by the controller ESCs need to be calibrated so that they can know the max and min values of the PWM send by Pixhawk. Steps to calibrate ESC:

a. Have the safety check first i.e. see that the pixhawk is not connected to the computer, the batteries are disconnected and the props are off.

b. Then turn on the transmitter and keep the throttle to maximum.

c. Then plug in the lipo battery. You see the LEDs cycle through the blue, yellow and red.

d. This gives the controller that the next time we plug in we want to do the ESC calibration.

e. So now unplug the lipo battery again and then plug it back with the throttle at the maximum.

f. Wait for the beeps to stop. This means that the esc has captured the maximum value. Then pull it down to the least point.

g. You get a long beep indicating that the esc calibration is complete.

4.4 Gyroscope Calibration

Gyroscopes are calibrated from the factory itself in terms of the sensitivity and the zero-rate level. But due to its mounting on the PCB these calibrations may get disturbed. The L3GD20H has a full scale of 245/500/2000 dps and is capable of measuring rates with a user selectable bandwidth. At the voltage of calibration is 3 v.but in my system gyroscope calibrated at the range: [-42 124 145]

4.5 Accelerometer Calibration

The accelerometer has to be calibrated in six directions i.e. the level, nose up, nose down, left side , right side and on the back of the quad (Fig. 6.3). The off-set has to be taken care and this is done automatically.

Figure 4.4: Accelerometer Calibration

4.6 Autonomous Commands and Flight Modes

Each of the commands below is either Navigation command or Do command. Navigation commands (i.e. Takeoff and Waypoint) affect the location of the vehicle while Do commands (i.e. Do-Set-Servo and Do-Cam-Trigg-Dist) are for auxiliary functions and do not affect the vehicles position. During mission at most one Navigation command and one Do command can be running at one time. The Do commands will be run in order as soon as the proceeding navigation command before them starts.

All the navigation points (or waypoints) are specified in terms of GPS location, and the controller is programmed (through GUI) to navigate through the GPS points provided through the map, thus carrying out the trajectory.

Figure 4.5: Different Flight Modes

4.6.1 Takeoff

The vehicle will climb straight up from its current location to the altitude specified (in meters). This should be the first command of nearly all missions. If the mission is begun while the copter is already flying, the vehicle will climb straight up to the specified altitude, if the vehicle is already above the specified altitude the takeoff command will be ignored and the mission will move onto the next command immediately.

4.6.2 Waypoint

The vehicle will climb straight up from its current location to the altitude specified (in meters). This should be the first command of nearly all missions. If the mission is begun while the copter is already flying, the vehicle will climb straight up to the specified altitude, if the vehicle is already above the specified altitude the takeoff command will be ignored and the mission will move onto the next command immediately.

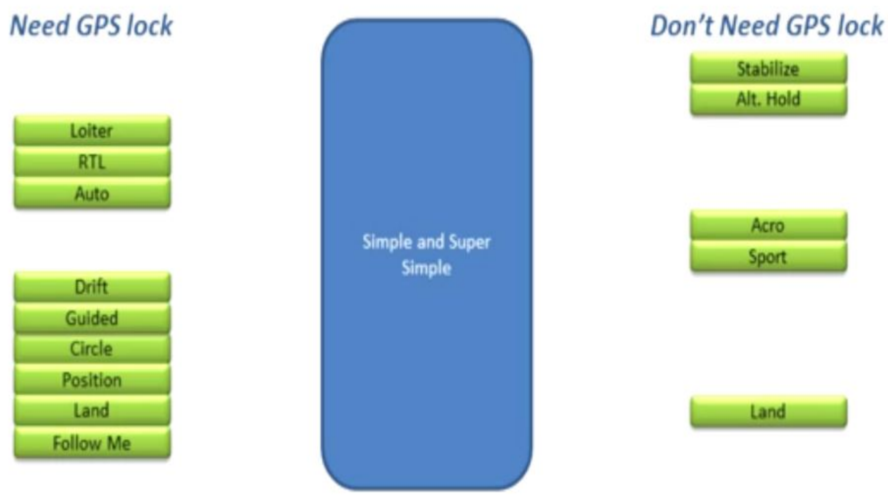


Figure 4.6: flight modes needing and do not needing GPS lock

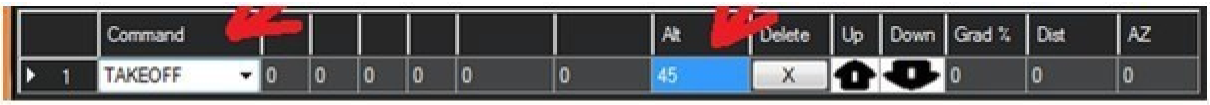


Figure 4.7: Takeoff

4.6.3 Return-To-Launch

Mission equivalent of the RTL flight mode. As described on the RTL flight mode wiki page, the vehicle will first climb to the RTL ALT parameters specified altitude (default is 15m) before returning home. The home location is where the vehicle was last armed. This command takes no parameters and generally should be the last command in the mission.

4.6.4 Land

Vehicle will land at its current location or at the lat/lon coordinates provided. This is the mission equivalent of the LAND flight mode. Lat, Lon the latitude and longitude targets. If left as zero it will land at the current location.

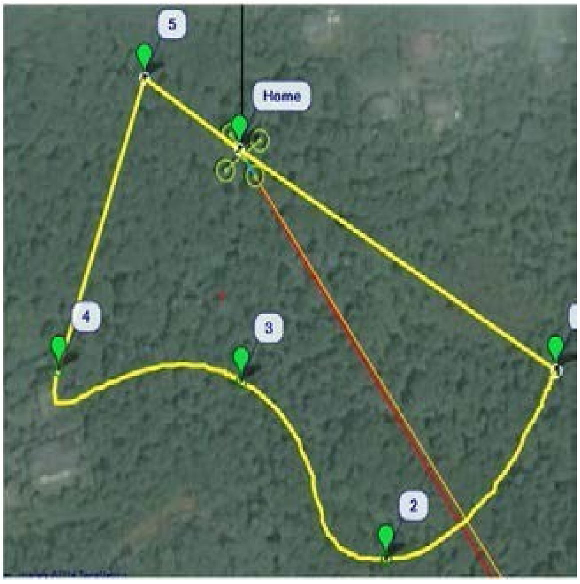
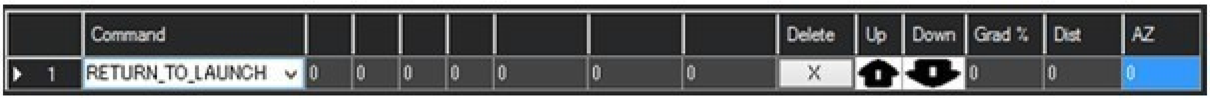


Figure 4.8: Waypoint



	Command								Delete	Up	Down	Grad %	Dist	AZ
1	RETURN_TO_LAUNCH	0	0	0	0	0	0	0	X			0	0	0

Figure 4.9: Return-To-Launch

4.6.5 Condition-Delay

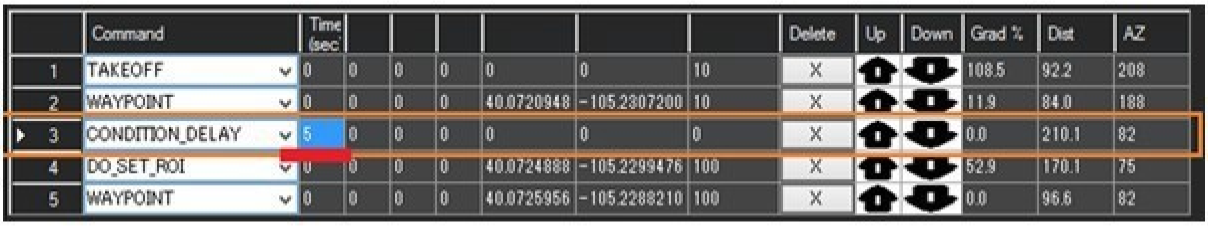
Delays the starts of the next (do) command for the specified number of seconds. In the example above, Command 4 (Do-Set-ROI) is delayed so that it only starts 5 seconds after the vehicle has passed Waypoint 2. Note: this command does not stop the vehicle. Also note that the delay timer is only active until the next waypoint is reached, so if the Do command hasnt been triggered by then it never will be.

4.6.6 Example

For the square shape flight the quadcopter move like fly at 5 meter altitude and make square at 5 meter altitude and come back to land itself.

	Command								Delete	Up	Down	Grad %	Dist	AZ
1	LAND	0	0	0	0	40.0718813	-105.2294219	0	X			0.0	145.0	139

Figure 4.10: Land



	Command	Time (sec)							Delete	Up	Down	Grad %	Dist	AZ
1	TAKEOFF	0	0	0	0	0	0	10	X			108.5	92.2	208
2	WAYPOINT	0	0	0	0	40.0720948	-105.2307200	10	X			11.9	84.0	188
3	CONDITION_DELAY	5	0	0	0	0	0	0	X			0.0	210.1	82
4	DO_SET_ROI	0	0	0	0	40.0724888	-105.2299476	100	X			52.9	170.1	75
5	WAYPOINT	0	0	0	0	40.0725956	-105.2288210	100	X			0.0	96.6	82

Figure 4.11: Condition-Delay

4.6.7 MAVlink

MAVProxy is a fully-functioning GCS for UAV's. The intent is for a minimalist, portable and extendable GCS for any UAV supporting the MAVLink protocol (such as the APM).

Features

- It is a command-line, console based app. There are plugins included in MAVProxy to provide a basic GUI.
- Can be networked and run over any number of computers.
- It's portable; it should run on any POSIX OS with python, pyserial, and select() function calls, which means Linux, OS X, Windows, and others.
- The light-weight design means it can run on small netbooks with ease.
- It supports loadable modules, and has modules to support console/s, moving maps, joysticks, antenna trackers, etc.

4.6.8 Running under Ubuntu

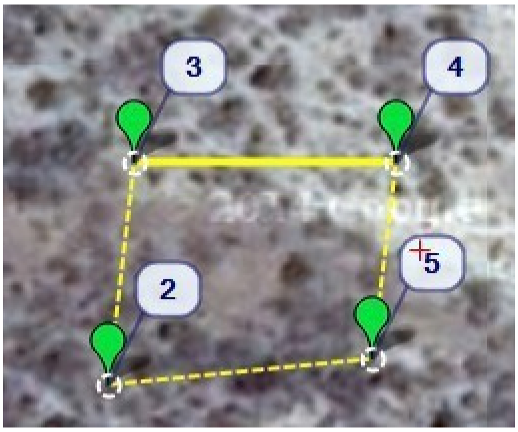


Figure 4.12: Way Points of Square

	Command					Lat	Long	Alt	Delete	Up	Down	Grad %	Dist	AZ
1	TAKEOFF	0	0	0	0	22.0931207	71.3885728	10	X			0.0	8094947.8	83
2	WAYPOINT	0	0	0	0	22.0927927	71.3885486	5	X			0.0	8094940.7	83
3	WAYPOINT	0	0	0	0	22.0931257	71.3885915	5	X			0.0	37.3	7
4	WAYPOINT	0	0	0	0	22.0931257	71.3890153	5	X			0.0	43.7	90
5	WAYPOINT	0	0	0	0	22.0928325	71.3889778	5	X			0.0	32.8	187
6	LAND	0	0	0	0	0	0	0	X			0	0	0

Figure 4.13: Commands of Autonomy Square

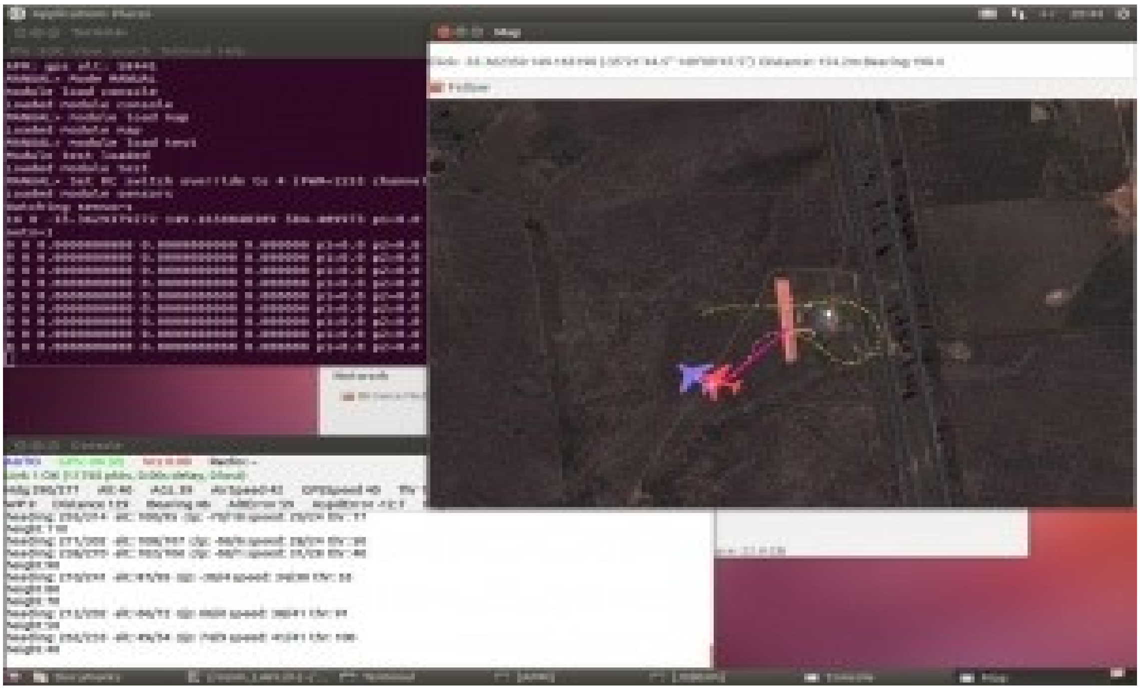


Figure 4.14

Chapter 5

LIVE VIDEO STREAMING FOR SURVEILLANCE

The main objective of the project was to build a drone for the surveillance purpose. To solve this purpose the whole work was divided into two phases. The first phase was to develop the system that was the drone and the second was to add the extra hardware and software features required for the main objective that is surveillance. The previous chapters describes the work for first phase. From this chapter onwards the focus is on objective solved in the second phase. In this chapter we will discuss about the hardware required for surveillance and live video streaming and their specifications.

5.1 FPV 32Ch 5.8G 600mw Wireless AV Mini Transmitter TX TS5823 Receiver RC832

Description of FPV transmitter-receiver kit shown in Fig. 5.1:

- 32 channels: Cover A,B,E bands and F band(Airwave band), 4 bands and all frequencies compatible.

Figure 5.1: FPV transmitter-receiver

- Two switching buttons: CH button for frequencies channels switching, FR button for frequencies bands switching.
- Two digits display : one for CH and the other for FR , real-time positioning which frequency band and which chennel received.
- power off memory: Replay the very last frequency band and channel.
- Independent video and audio signal outputs.
- Smaller size with lighter weight.
- RC832 Specification:The RC832 Receiver is nice and small in size for easy integration into your ground station, but big in quality and features.
- Power input: 12V
- Working current: 200mA max

- Antenna impedance: 50
- Antenna gain: 2db
- Video impedance: 75
- Video format: NTSC/PAL auto
- Product size:54mm*32mm*9mm(excluding antenna)
- Package size:123mm*62mm*40mm
- Product Weight:35g
- Package Weight: 68g
- Antenna connection: SMA
- TS5823 Specifications:The TS5823 transmitter packs 200mW of ultra clean 5.8GHz power in a micro sized video/audio transmitter! Smallest and lightest, easy to carry.Micro sized and light weight - perfect for use with small models.
- Name: Transmitter Module
- NO: TS5823
- Modulate: Wideband FM Modulate
- Video Format : NTSC/PAL
- Output Impedance:50 Ohm
- Output Power : 23-24dBm
- Channel:32 CH
- Operating Voltage: 7V-24V
- Supply Current : 190mA

- Operating Temperature: -10-85C
- Video Band Width : 0-8.0 MHz
- Audio Carrier Frequency : 6.5 MHz
- Video Input Level: 0.8-1.2 Vp-p
- Video Input Impedance : 75 Ohm
- Audio Input Level : 0.5-2.0 Vp-p
- Audio Input Impedance : 10K Ohm
- Connector: SMA Female(outer hole),RP-SMA Female(outer needle)
- Antenna Connector: SMA Male(Inner needle),RP-SMA Male(Inner hole)

5.2 Camera: Xiaomi Yi Sports Action Camera

The Yi Action Camera hardware, shown in Fig. 5.2, is equipped with Ambarella A7LS, the worlds leading image processor for sports camera. It records Ultra-HD videos and photos with advanced image stabilization and noise reduction. It records upto 90 minutes of footage without running out of power. It is a 16MP camera with 1080P resolution. It has a 155 degree wide angle to capture images. it comes with inbuilt wi-fi to connect wirelessly

Figure 5.2: Xiaomi Yi action camera

5.3 TV Tuner

Figure 5.3: TV tuner

The wireless camera which has inbuilt wi-fi, transmits the continuous video frames but the range of its inbuilt wi-fi is very less. so the FPV transmitter-receiver module is used to send signals upto 2.5Km. To stream this video on the laptop screen the TV tuner, shown in Fig. 5.3, is used.

Chapter 6

Obstacle Avoidance in Drones using Optical Flow

6.1 What is Obstacle Avoidance and Why it is required?

Obstacle detection and avoidance are the techniques which scientists and researchers are working upon to add on the robots nowdays to make them more reliable and efficient. This feature when added makes the mobile robots more intelligent to perform the higher level tasks. The mobile robots incorporated with these feature can be a terrestrial bot or an aerial bot. The aerial bots are basically known as drones in the modern language. Obstacle avoidance is the feature or task that is used to save the moving robot from collision with any mobile or stationary obstacle coming in its vicinity or path.

For autonomous robots and UAVs the obstacle avoidance feature is required to avoid any damage that can be caused due to the collisions with the objects coming in the trajectory. For non-autonomous robots also this feature is helpful for humans because it helps in easier controlling.

6.2 Different approaches for Obstacle Avoidance

There are various approaches that can be followed for obstacle avoidance, implemented in both hardware and software. In following subsections three such methods are explored.

6.2.1 Using Ultrasonic Sensors

Ultrasonic sensors can be used for obstacle detection and avoidance using a controlling device or board. The ultrasonic sensors can be mounted on the arm of the drone to predict the presence of obstacle in the path. The ultrasonic sensors contains both transmitter and receiver of the signals in it. Continuous sound waves are emitted by the sensor and when any moving or stationary obstacle comes in the vicinity, the waves after striking the object are received by the receiver of the ultrasonic sensor and then the controller signals the drone to move from its path to avoid the obstacle. This method has certain limitations like additional hardware that are the sensors and the controlling device need to be mounted on the drone, which in turn increases the weight. Increase in weight directly affect the flight time of the drone. Also additional hardware increases the cost.

6.2.2 Using Depth Map Generation

This method is based on the depth map generation using image processing. For creating depth map stereo camera is used. The stereo camera has two or more lenses with separate image sensor for each lens. At a particular point of time two images are captured in camera having two lenses. Since it is a stereo camera the distance between the two lenses is known. The two images captured by the two cameras will have parallax between them. Using this parallax the depth map is generated. Hence a 2D image is generated using depth map on a gray scale. Farther the distance of the object darker will be the shade and vice versa. This method has limitation of costlier stereo cameras and more computation power is needed to generate the depth map. Also more data will be needed to be transmitted.

6.2.3 Using Optical Flow

The third method is Obstacle avoidance using Optical flow. The whole concept is based on image processing and OpenCV. The advantage is that no extra hardware is required to be mounted on the drone since lighter the drone lesser will be the load on the motors and more will be the flight time which is the main constraint in any Unmanned Air Vehicle. The camera mounted on the drone itself solves the purpose. The whole frame is divided in two parts- left frame and the right frame. When any obstacle coming from left is found the drone leaves its path and moves to right and vice versa. Optical flow has many advantages over above discussed methods like its calculation is easier and faster. Due to its advantages this method has many applications like traffic analysis, video compression, vehicle tracking etc.

6.3 Theory of Optical Flow

For humans an image is the 2D representation of the 3D objects but if we talk about the computers an image is the collection of pixels with varying intensity values and these pixels are represented in the matrix form. The whole concept of obstacle avoidance in this drone lies on the concepts of IMAGES and IMAGE PROCESSING using OpenCV.

Optical flow is the representation of motion caused by displacement of vectors in a visual scene. The composition of pattern of any scene obtained by relative motion between the camera and scene. Optical flow can be used in applications related to robotics, navigation, image Processing, Motion detection etc. In application related to drone technology optical flow can be used for obstacle detection and obstacle avoidance. Optical flow algorithm enables to know the displacement of object in a visual scene. The motion between two consecutive frames at time t and Δt can be calculated using optical flow method. For any 2D+t dimensional image present at location (x, y, t) with intensity I(x, y, t), at instance Δt, will have moved by location Δx and Δy. The brightness constancy constraint between these two consecutive image frames can be given as:

$$(x, y, t) = I\ (x + \Delta x, y + \Delta y, t + \Delta t)$$

There are different techniques to implement optical flow which are classified based on differential techniques, region-based matching and frequency-based methods. Differential techniques are classified into two methods, global and local. Out of these methods most popular are Lucas and Kanade and Horn and Schunck.

The vector is defined as anything which has magnitude and a direction is known as a vector. The same concept of vectors is applied on the images too. The images have pixels. Each pixel has some value. These values vary depending upon the intensity of the light.

6.4 Algorithm for Obstacle Avoidance using Optical Flow

6.4.1 Mechanism of obstacle avoidance using optical flow in quadcopters

The optical flow algorithm chosen for obstacle avoidance is completely based on image processing. This was done using the camera mounted for surveillance. The camera solves two purposes here, surveillance and obstacle avoidance. Video is basically a sequence of images. Depending upon the frame rate, number of image frames per second are identified in a video sequence. The camera captures the video, in turn the sequence of images. In optical flow each consecutive frame is compared based on the change in pixel value. If there is any change in the pixel value in the next frame then the movement is captured. Based on the changed pixel values the vectors are generated. The pixel values are represented in the form of vectors in the algorithm. If the pixel value changes in current frame in comparison to the previous frame, the magnitude and direction of the vectors associated with the pixel also changes. So basically to detect objects in optical flow edges are found and for that, local information is described by distribution of Intensity gradient or direction of edges. After these calculation of displacement of vectors in the consecutive frame, the flight controller takes appropriate actions to avoid the obstacle by moving left or right accordingly. The mechanism for obstacle avoidance in the quadcopter is shown in Fig. 6.1.

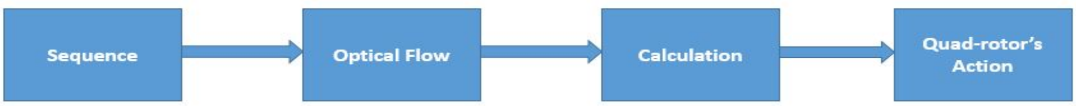


Figure 6.1: Block level design of obstacle avoidance algorithm using optical flow for quadrotors

6.4.2 Algorithm for obstacle avoidance

Fig. 6.2 gives an overview about how the quadrotor communicates with the Ground Control Station (GCS). The computer having droneapi installed in it, runs the obstacle avoidance code. It sends command to the quadcopter to move left or right after detecting the obstacle. The flight controller sends the acknowledgement to the computer after performing the action.

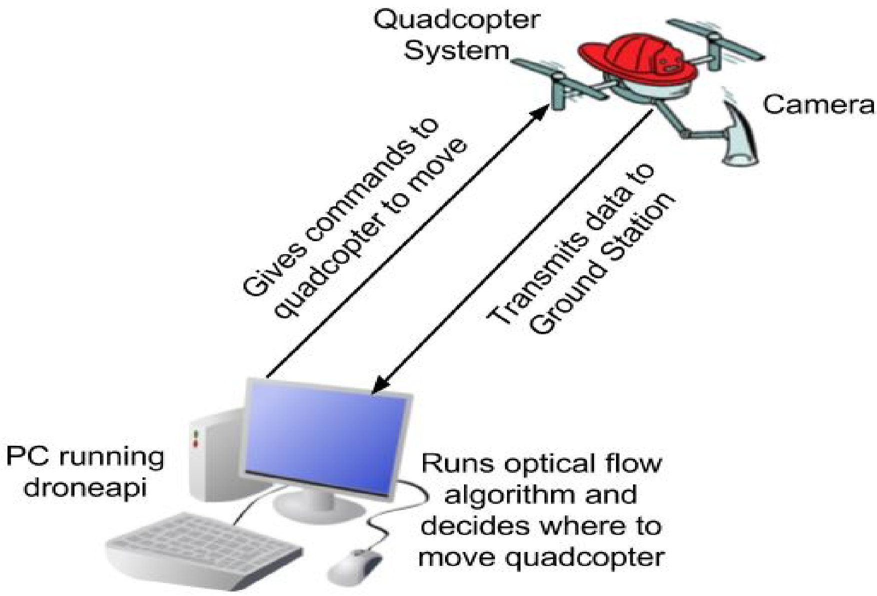


Figure 6.2: Communication between quadcopter and GCS

Fig. 6.3 shows the flow chart of the algorithm for obstacle avoidance. The optical flow module performs the optical flow task.

Fig. 6.4 shows the flow chart of optical flow module extracted from Fig. 5.

The code for the above flow charts was written in Python using OpenCV libraries.

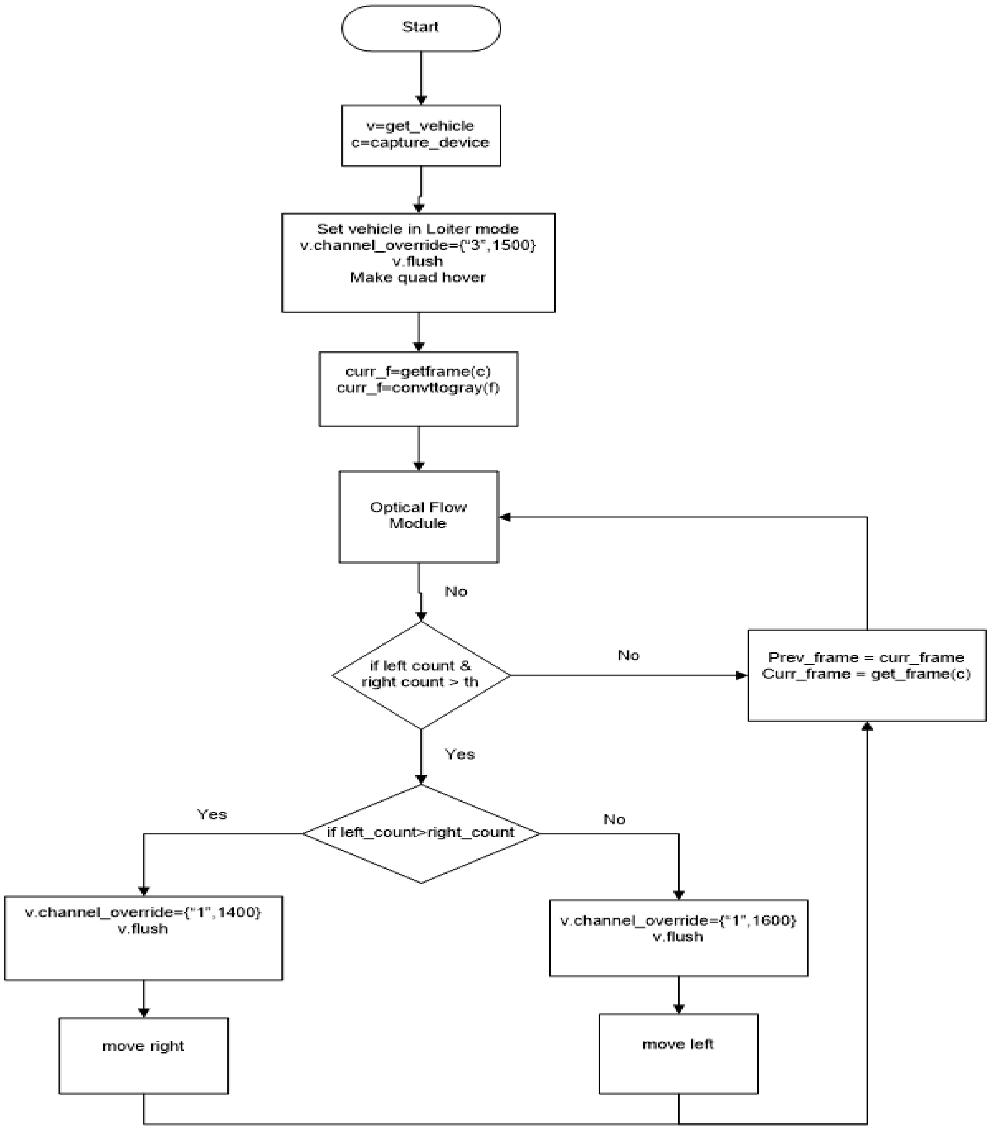


Figure 6.3: Block level design of obstacle avoidance algorithm using optical flow for quadrotors

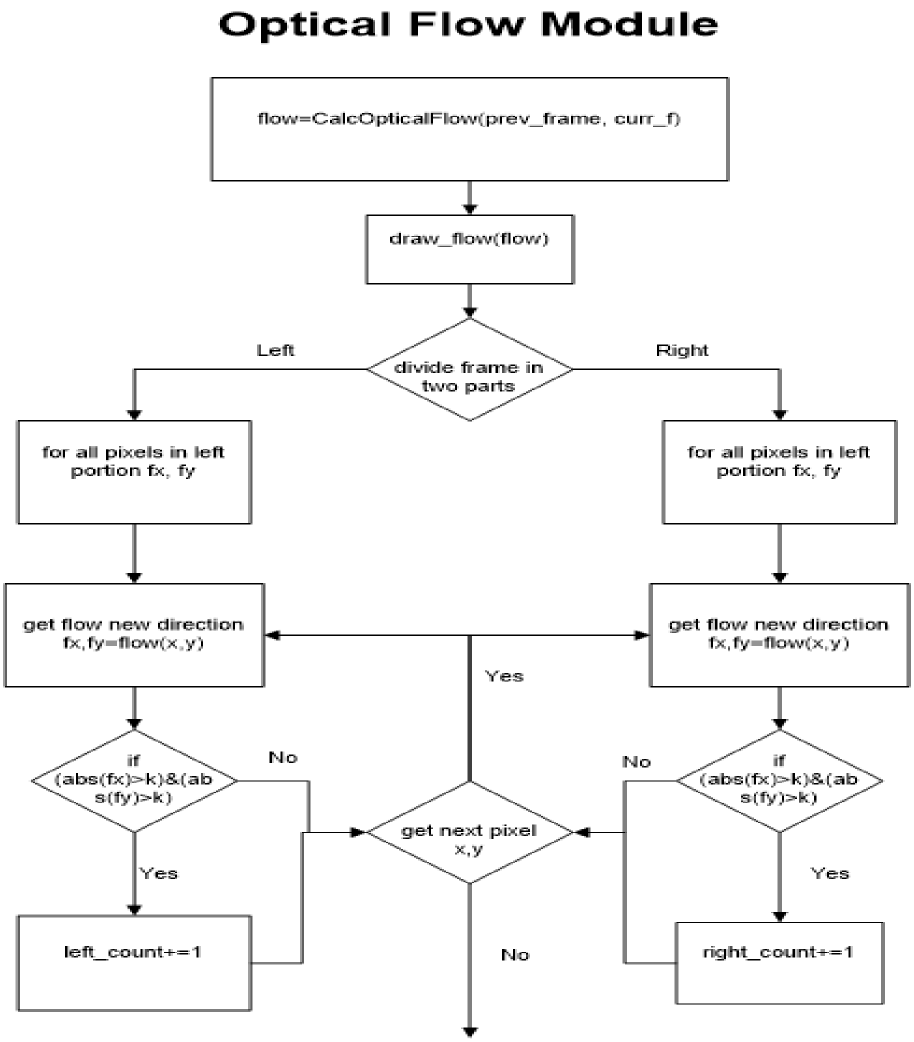


Figure 6.4: Block level design of obstacle avoidance algorithm using optical flow for quadrotors

6.5 Algorithm for Obstacle Avoidance using Optical Flow

To test the system two methods were adopted. First was based on software completely and the other was tested on the actual hardware.

6.5.1 Testing on Software

Before testing on actual hardware the algorithm is tested on software for checking its integrity and results. This was done using the droneapi. The autopilot software of the Pixhawk flight controller was dumped on the computer and then a virtual quadcopter was created to test the obstacle avoidance code. Using the droneapi and mavproxy a communication link was established between the virtual quadcopter and the Ground Control Station (GCS). Instead of actual camera the webcam on the computer was used to test obstacle avoidance code which is written in Python using OpenCV library. The test was performed by moving the hands in front of webcam in left and right directions. Detecting the movement of hand as an obstacle the virtual quadcopter moves in left or right direction to avoid the obstacle accordingly. The figures from 7 to 10 shows the test results.

Fig. 6.5 shows the initialization of APM. On software the virtual quadcopter has been loaded. Using droneapi and MAVlink communication between the virtual quadcopter and the GCS has been established.

Fig. 6.6 shows the results after establishing the communication between virtual quadopter and the GCS. The result window contains parameters like altitude, roll, yaw, pitch, current flight mode etc.

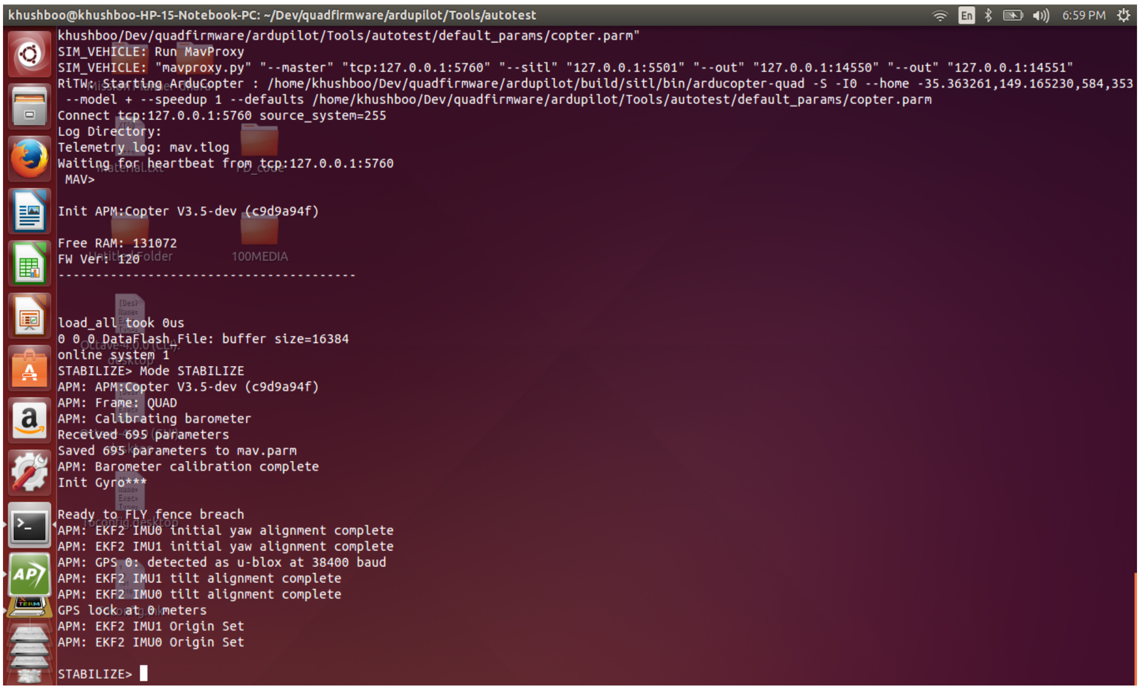


Figure 6.5: Initialization of APM

Fig. 6.7 shows the window after initiation of optical flow code. The first window is divided into two halves, left and right, with blue and green color respectively. The second window shows the output of detection of motion in the form of comments like left, right or no hurdle. In the frame there is no movement of hand so the result window shows no hurdle since no obstacle has been detected.

When the hand is moved slightly in the left half, the motion has been detected. This can be observed since vectors has been generated. In Fig. 6.8 the generated vectors can be seen which are green in color. Also when the obstacle gets detected the appropriate action to move the quadcopter in left direction has been taken. The second window in the figure shows the action that is left.

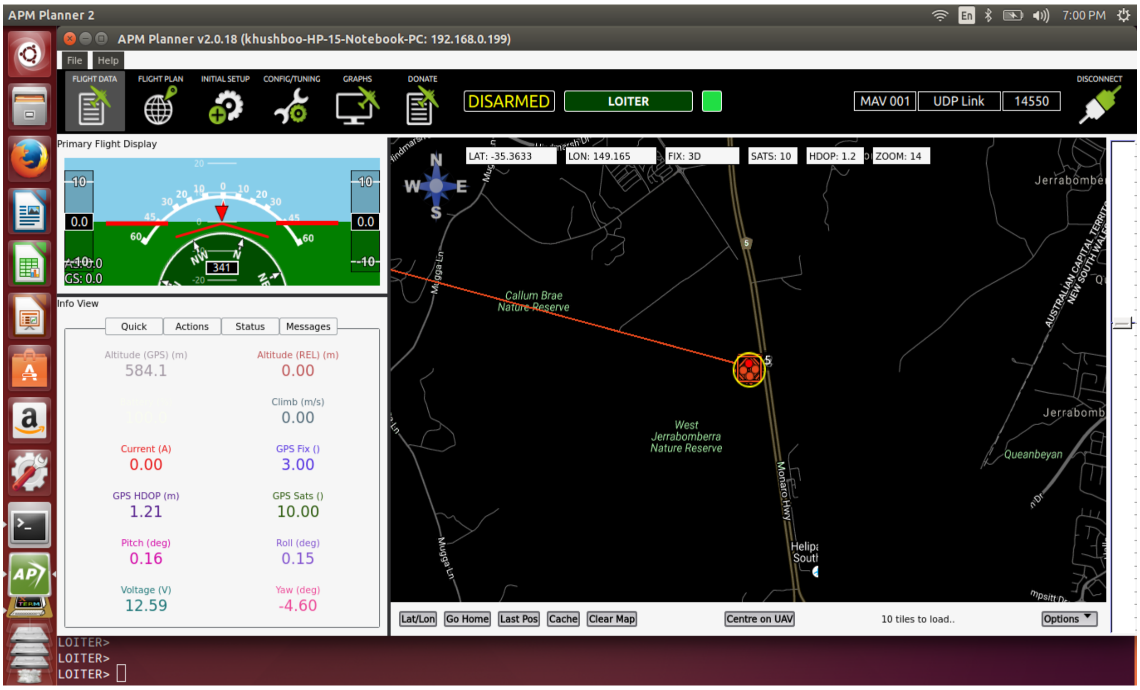


Figure 6.6: Parameters and mode on GCS after initialization

6.5.2 Testing on actual hardware

After successful testing of code on virtual quadcotper the code was tested on the actual quadcopter system. In place of the webcam of the computer, Xiaomi Yi action camera was used which was mounted on the drone for surveillance. The wireless camera sent the captured frame to the GCS. Python OpenCV analysed the frame using image processing on GCS (Here optical flow algorithm was used to fetch any information about any object coming towards quadcopter using flow vectors). Based on direction from which disturbance was noticed, droneapi gave command to quadcopter to deviate its path in order to escape from it. Here commands were sent in MAVlink packets which were received by ardupilot and corresponding action was taken by the quadcopter.

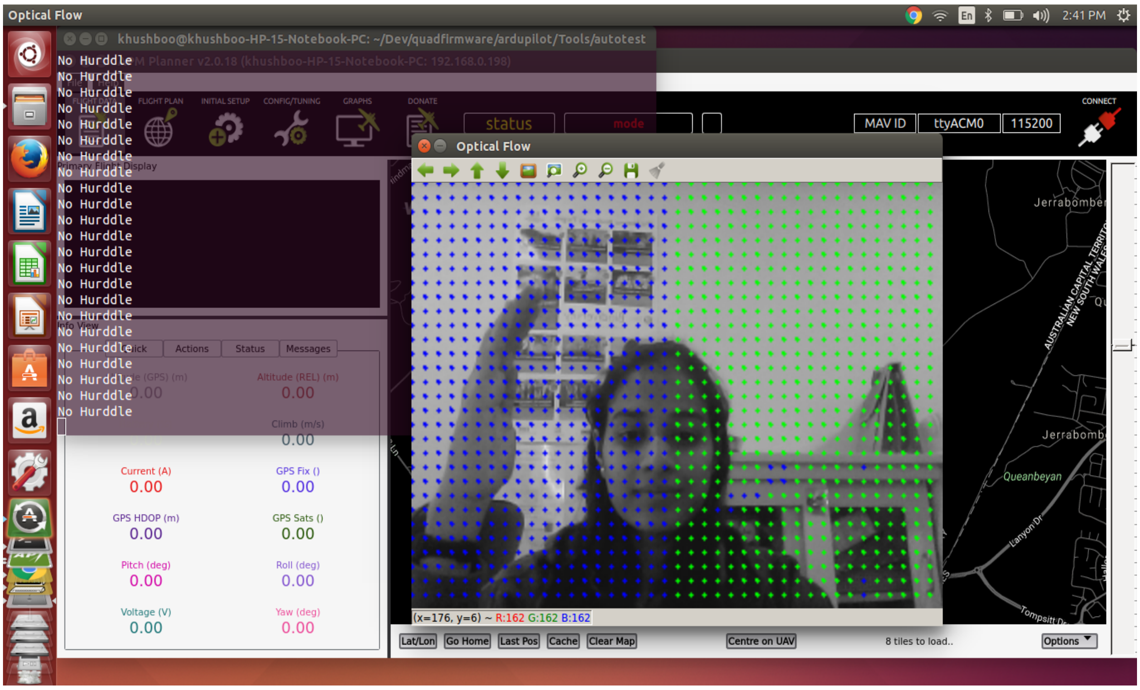


Figure 6.7: Initiating Optical flow code

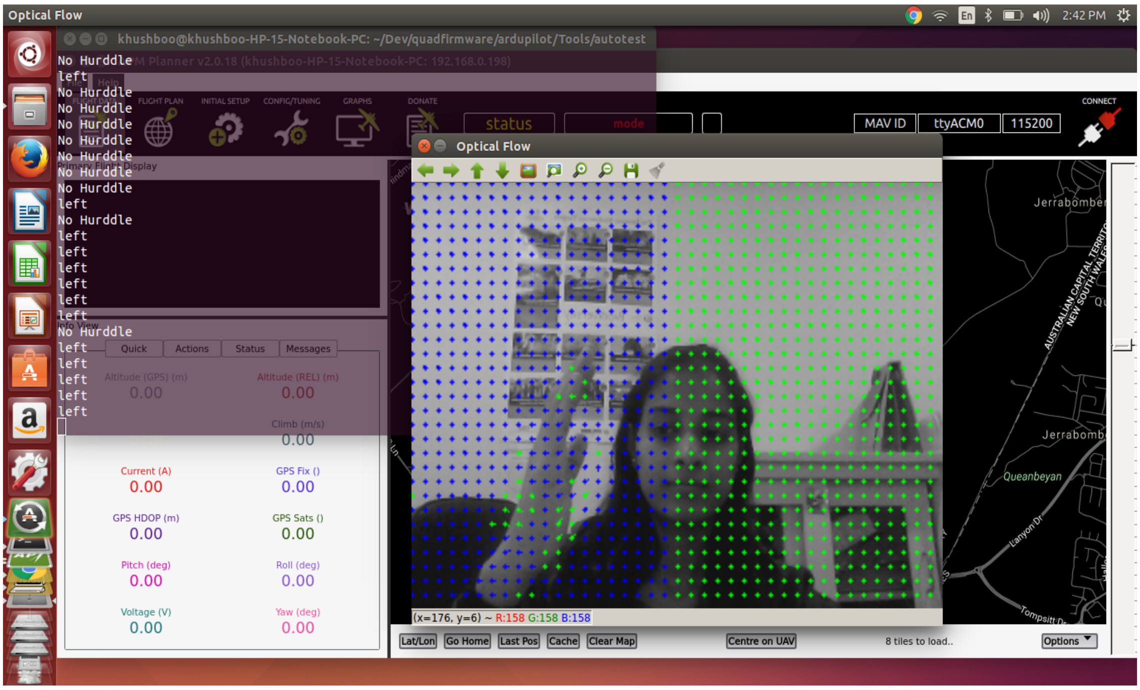


Figure 6.8: Movement of quadcopter in left direction after detecting motion of hand

Chapter 7

Conclusion And Future Scope

In this chapter, conclusion of the project work is described.

7.1 Conclusion

This report concludes the completion and successful flying portion of the drone. Calibration and mounting of the hardware on the drone is completed along with that for testing purpose initial setup is done and first flight is tested successfully. Also a wireless communication link is setup between the ground control station and the quadrotor. The manually controlled remote is programmed according to the channel required for the flight. The remote modes are programmed and testing of flight modes like stabilize, land, loiter etc. is performed on the drone.

In this project a quadcopter was successfully designed for surveillance purpose. Real time images and videos were captured and transmitted on to the server or ground control station. Also in order to detect and avoid obstacles coming in the path of the quadcopter various techniques were investigated and based on the study optical flow approach was selected. An algorithm for realization of this algorithm is also developed. The same was tested on the drone. From the test & measurement, the drone was found to successfully detect and avoid obstacle coming in the path.

7.2 Future Scope

In future the project can be extended by making the drone autonomous. The camera can be mounted on a 3-axis gimble so that it can cover majority of area for surveillance. Also without rotating the actual drone the images can be captured from different angles by using the gimble.

The accuracy of the code for obstacle avoidance can be increased by experimenting and changing the threshold.

References

[1] S. Bouabdallah et al., Design and control of an indoor micro quadrotor, in Proc. (IEEE) International Conference on Robotics and Automation (ICRA04), (New Orleans, USA), 2004.

[2] S. Bouabdallah, A. Noth, et al., PID vs LQ control techniques applied to an indoor micro quadrotor in Proc. (IEEE) International Conference on Intelligent Robots (IROS04), (Sendai, Japan), 2004.

[3] S. Bouabdallah and R. Siegwart, Backstepping and sliding-mode techniques applied to an indoor micro quadrotor, in Proc. (IEEE) International Conference on Robotics and Automation (ICRA05), (Barcelona, Spain), 2005.

[4] M. Krstic et al., Nonlinear and Adaptive Control Design. New York, USA: Wiley Interscience, 1995. [6] B. Marck, Histoire de lAviation. Flammarion, 1997.

[5] J. Boulet, Histoire de lHlicoptre. France-empire, 1991.

[6] "C. Eck, Navigation Algorithms with Applications to Unmanned Helicopters. PhD thesis, ETHZ, 2001. [9] Aerovironment, *http : //www.aerovironment.com* .

[7] "Epson, ", [Online], Available: *http : //www.epson.co.jp/*.

[8] "RCtoys, ", [Online], Available: *http : //www.rctoys.com/*.

[9] D. Pines and F. Bohorquez, Challenges facing future micro air vehicle development, AIAA Journal of Aircraft, vol. 43, no. 2, pp. 290305, 2006.

[10] A. Elfes et al., Robotic airship for exploration of planetary bodies with an atmosphere autonomy challenges, Autonomous Robots, 2003.

[11] "MARV, ", [Online], Available: *http : //www.enae.umd.edu/AGRC/Design00/MARV.html*.

[12] P. Samuel et al., Design and testing of rotary wing mav with an active structure for stability and control, in Proc. AHS Annual Forum 61, (Grapevine, USA), 2005.

[13] J. Watkinson, The Art of the Helicopter. Elsevier, 2004.

[14] S. Bouabdallah et al., Design and control of an indoor coaxial helicopter, in Proc. (IEEE) International Conference on Intelligent Robots (IROS06), (Being, China), 2006.

[15] "Pixhawk autopilot system, ", [Online]. Available: $https://pixhawk.org/start$.

[16] G. Done and D. Balmford, Bramwells Helicopter Dynamics. Oxford Butterworth-Heinemann, 2001.

[17] P. Mullhaupt, Analysis and Control of Underactuated Mechanical Nonminimum-phase Systems. PhD thesis, EPFL, 1999.

[18] S. Bouabdallah and R. Siegwart, Towards intelligent miniature flying robots, in Proc. of Field and Service Robotics, (Port Douglas, Australia), 2005.

[19] R. Murray et al.,Mathematical Introduction to Robotic Manipulation. CRC, 1994.

[20] J. G. Leishman, Principles of Helicopter Aerodynamics. Cambridge University Press.

[21] G. Fay, Derivation of the aerodynamic forces for the mesicopter simulation, 2001.

[22] N. Guenard et al., Control laws for the tele operation of an unmanned aerial vehicle known as an x4-flyer, in Proc. (IEEE) International Conference on Intelligent Robots (IROS06), China, 2006.

[23] I. Cheeseman and W. Bennett, The effect of the ground on helicopter rotor in forward flight, Aeronautical Research Council, no. 3021, 1957.

[24] D. Griffiths and J. Leishman, A study of dual-rotor interference and ground effect using free-vortex wake model, in Proc. of the 58th Annual Forum of the Ameriacan Helicopter Society, (Montral, Canada), 2002.

[25] J. Nicoud and J. Zufferey, Toward indoor flying robots, in Proc. (IEEE) International Conference on Intelligent Robots (IROS02), (Lausanne, Switzerland), 2002.

[26] D. DeMenthon and L. Davis, Model-based object pose in 25 lines of code, International Journal of Computer Vision, vol. 15.

[27] "OpenCV, ", [Online]. Available: $http://www.intel.com/research/mrl/research/opencv/$..

[28] P. Pounds et al., A practical quad-rotor robot, in Proc. Australasian Conference on Robotics and Automation (ACRA06), (Auckland, New Zealand), Dec. 2006.

[29] G. Hoffmann et al., The stanford testbed of autonomous rotorcraft for multi agent control (starmac), in Proc. 23rd Digital Avionics Systems Conference (DASC04), (Salt Lake City, USA), Oct. 2004.

[30] R. Sepulchre et al., Constructive Nonlinear Control. Springer, 1997.

[31] S. Arimoto, Control Theory of Non-linear Mechanical Systems. Oxford Science, 1996.

[32] R. Longchamp, Commande Numrique de Systmes Dynamiques. PPUR, 1995.

[33] R. Longchamp, Commande Sous-optimale Adaptative de Systmes Nonlineaires. PhD thesis, EPFL, 1978. [34] P. Naslin, Introduction la Commande Optimale. Dunod, 1966.

[34] F. Franklin et al., Digital Control of Dynamic Systems. Addison Wesley,1990.

[35] Kahlouche Souhila and Achour Karim, Optical Flow based robot obstacle avoidance, Centre de Dveloppement des Technologies Avances CDTA, 2007

[36] Sebastian Thrun, Artificial Intelligence for Robotics for implementing SLAM, Udacity Course by Georgia Tech University.