Quad-Copter Report

EENG 4010
TOPICS IN E.E

Team Members
Shabuktagin Photon Khan
Rene Hernandez
Julio Jo
Juan Martinez

Department of Electrical Engineering
University of North Texas

Table of Contents

Introduction

The aim of this project is to be able to create a wireless networking system with the utilization of Quad-Copters. The wireless networking system will be used to temporarily provide a wireless connection to users.

The motivation for this project is the need to provide wireless connections at specific times which will depend on the flight time of both Quad-Copters. One of the basic things that will be reached in this project is the idea that both Quad-Copters will be able to communicate with each other. The communication between both Quad-Copters will aid in the distance required by both of the Quad-Copters to maintain a reliable wireless connection to the users on the ground.

The objectives that will be covered in the project will be in a list that will be in chronological order that the group will take during the semester.

1. Install the proper software to fly the Quad-Copters.
2. Learn to connect the drones to the computer
3. Learn to fly one drone to carry out a simple takeoff and landing mission
4. With the first drone carry out more complex missions
5. Measure the distance the drone can travel while maintaining connection
6. Fly two drones using the same base station (computer)
7. Allow for the 2 drones to communicate and know where the other one is located at
8. Create a network system to provide a wireless connection with both of the drones
9. Measure the height and distance between both Quad-Copters to allow the best wireless connection coverage
10. Test the connection in different areas and scenarios
11. Test the time that the wireless connection will provided depending on the battery life
12. Improvements that can be made

Results and Discussion

Constraints and Standards

We have several constraints involved with this design. The first is the Wi-Fi range, our solution involved placing Wi-Fi-repeater or range extenders to increase the range. Second constraint is weight to thrust proportions, this constrain is not so simple to solve. We could replace the current 850Kv motors with more powerful motors to create great thrust but this reduces our flight time. Our solution was to keep the same motors and work with light Quad-copter frames that would be 3D printed. Other constraint included flight formation and control over the copters so that the same position can be kept and power for all components on board the copters.

What will the server be doing

The server is designed to be very light and for it to not need much power to operate so as to not reduce the Quad-copters flight time. Its main purpose is to connect the aerial Wi-Fi network and collect GPS coordinates. In addition it will also have the capability to act as a 911 call receiver through the aerial network.

Quad-Copter Flight Formation and Coverage

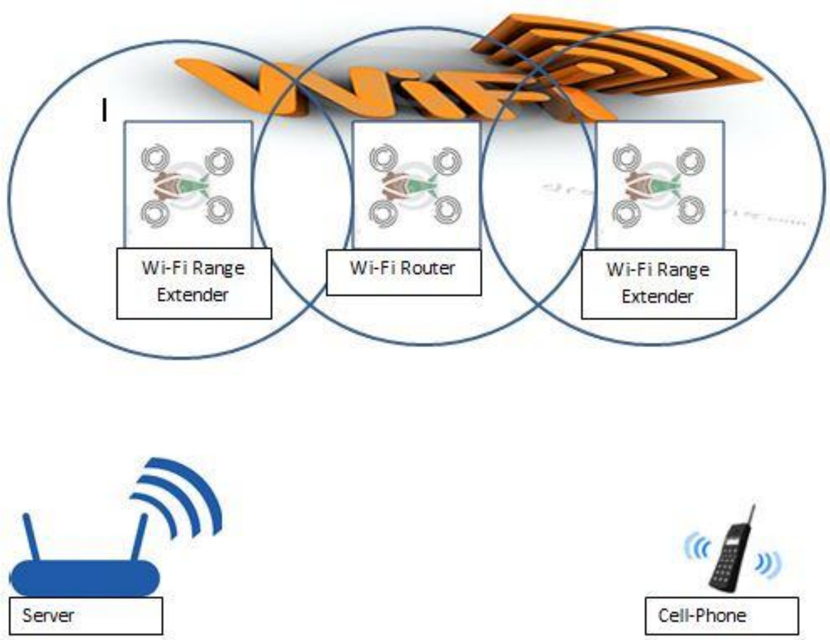

Figure 1: Flight formation and Coverage

How the Quad-Copter Works

A Quad-Copter is a helicopter with four rotors. It allows a more stable platform, making Quad-Copters ideal for tasks such as surveillance, aerial photography and UAV research.

A Quad rotor has four rotors all work together to produce upward thrust and each rotor lifts only 1/4 of the weight, so we can use less powerful and therefore cheaper motors. The Quad-Copter's movement is controlled by varying the relative thrusts of each rotor.

These rotors are aligned in a square, two on opposite sides of the square rotate in clockwise direction and the other two rotate in the opposite direction. If all rotors turn in the same direction, the craft would spin would spin just like the regular helicopter without tail rotor. Yaw is induced by unbalanced aerodynamic torques. The aerodynamic torque of the first rotors pair cancelled out with the torque created by the second pair which rotates in the opposite direction, so if all four rotors apply equal thrust the Quad-Copter will stay in the same direction.

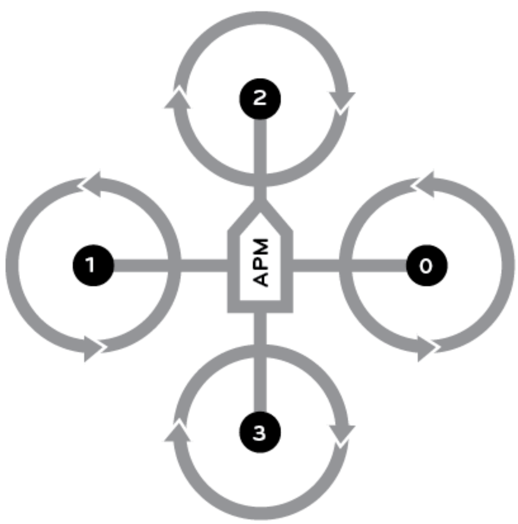

Figure 2: Rotor direction

To maintain balance the Quad-Copter must be continuously taking measurements from the sensors, and making adjustments to the speed of each rotor to keep the body level. Usually these adjustments are done autonomously by a sophisticated control system on the Quad-Copter in order to stay perfectly balanced. A Quad-Copter has four controllable degrees of freedom: Yaw, Roll, Pitch, and Altitude. Each degree of freedom can be controlled by adjusting the thrusts of each rotor.

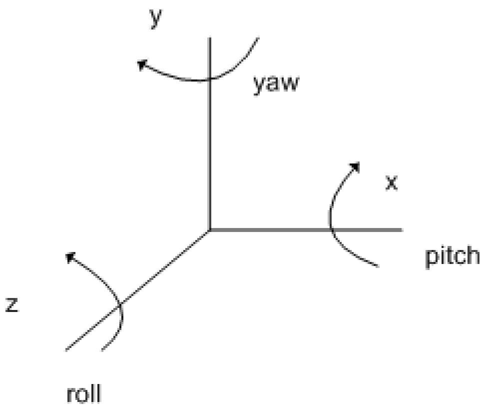

Figure 3: Yaw, Roll and Pitch

Yaw (turning left and right) is controlled by turning up the speed of the regular rotating motors and taking away power from the counter rotating; by taking away the same amount that we put in on the regular rotors produces no extra lift but since the counter torque is now less.
Roll (tilting left and right) is controlled by increasing speed on one motor and lowering on the opposite one. Pitch is controlled the same way as roll, but using the second set of motors.

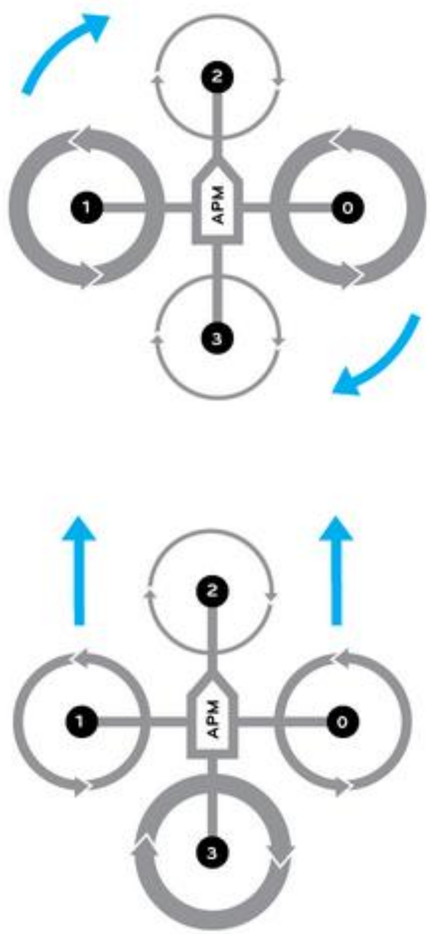

Figure 4: Rotations

Quad-Copter Components

There are sensors connected to a microcontroller to make the decision as to how to control the motors. The essential Quad-Copter components are listed below:

- Frame – The structure that holds all the components together. They need to be designed to be strong but also lightweight.
- Rotors – Brushless DC motors that can provide the necessary thrust to propel the craft. Each rotor needs to be controlled separately by a speed controller.
- Propeller
- Battery – Power Source
- IMU – Sensors
- Microcontroller – The Brain
- RC Transmitter

Frame

Frame is the structure that holds all the components together. It should be rigid and be able to minimize the vibrations coming from the motors.

Figure 4: Frame

A Quad-Copter frame consists of two to three 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

Most available materials for the frame are:

- Carbon Fiber
- Aluminum
- Wood, such as Plywood or MDF (Medium-density fiberboard)

Carbon fiber is the most rigid and vibration absorbent out of the given three options. Aluminum square rails is affordable, lightweight and lightweight. However, aluminum faces a lot of vibrations. Therefore its damping effect is not as good as carbon fiber. Hence the severe vibrations can mess up the measurements from the sensor. In the other hand wood board is a very good absorbent of the vibration but it is not rigid. Therefore, the quad-copter is more likely to break apart if it crashes

As for arm length, the term “motor-to-motor distance” is sometimes used, meaning the distance between the centers of one motor to that of another motor of the same arm in the Quad-Copter terminology.

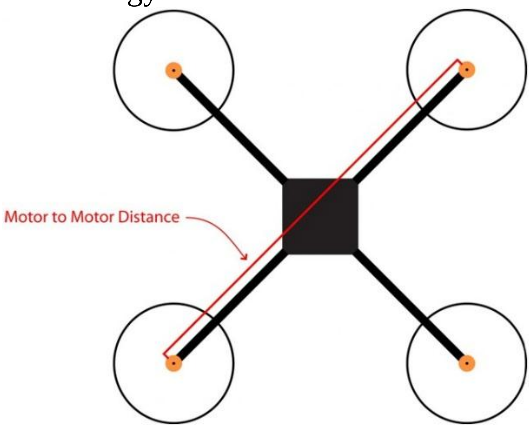

Figure 4: Motor to Motor Distance

The motor to motor distance usually depends on the diameter of the propellers. To make you have enough space between the propellers and they don’t get caught by each other.

Brushless Motors

The brushless motors do not have a brush on the shaft which takes care of switching the power direction in the coils. Instead the brushless motors have three coils on the inner (center) of the motor, which is fixed to the mounting.

Figure 5: Brushless Motor

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 therefore there is no need for a brush.

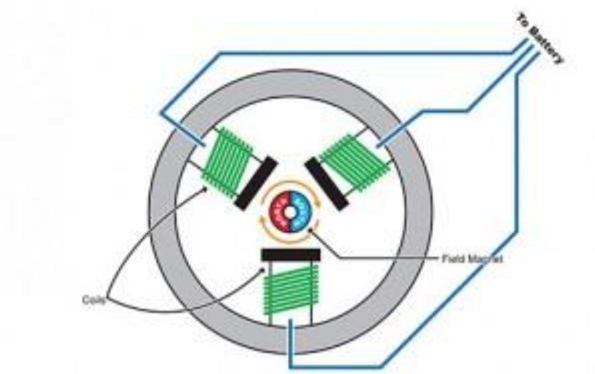

Figure 6: Motor

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. When selecting our brushless motor we took care of the weight, the size, and which kind of propeller are we going to use. So that everything links up with the current consumption

We looked for 'Kv-rating' for specifications. The Kv-rating indicates how many RPMs (Revolutions per minute) the motor will provide with x-number of volts.
The formula for RPMs is: RPM=Kv*U

Propellers

On each of the brushless motors there are mounted a propeller. The propellers are made to spin in pairs in each direction, but also having opposite tilting, all of them will provide lifting thrust without spinning in the same direction. This makes it possible for the Quad-Copter to stabilize the yaw rotation, which is the rotation around itself. The propellers come in different diameters and pitches (tilting).

Figure 7: Propellers

Some of the standard propeller sizes used for Quad-Copters are:

- EPP1045 10 diameter and 4.5 pitch this is the most popular one, good for mid-sized quads
- APC 1047 10 diameter and 4.7 pitch much similar to the one above
- EPP0845 8 diameter and 4.5 pitch regularly used in smaller quads
- EPP1245 12 diameter and 4.5 pitch used for larger quads which requires lot of thrust
- EPP0938 9 diameter and 3.8 pitch used in smaller quads

The general rules when selecting propellers are listed below:

1. The larger diameter and pitch the more thrust the propeller can generate. It also requires more power to drive it, but it will be able to lift more weight.
2. When using high RPM (Revolutions per minute) motors you should go for the smaller or mid-sized propellers. When using low RPM motors you should go for the larger propellers as you can run into troubles with the small ones not being able to lift the quad at low speed.

Pitch Vs Diameter: The diameter means area while pitch means effective area. With the same diameter, larger pitch propeller would generate more thrust and lift more weight but also use more power.

A higher RPM of the propeller gives us more speed and maneuverability, but it is limited in the amount of weight it will be able to lift for any given power. Also, the power drawn (and rotating power required) by the motor increases as the effective area of the propeller increases, so a bigger diameter or higher pitch one will draw more power at the same RPM, but will also produce much more thrust, and it will be able to lift more weight.

ESC – Electronic Speed Controller

The brushless motors are multi-phased, normally 3 phases, so direct supply of DC power will not turn the motors on. Instead of using dc motors we used Electronic Speed Controllers (ESC) comes into play. The ESC generating 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.

Figure 8: Electronic Speed Controller

The ESC is an inexpensive motor controller board that has a battery input and a three phase output for the motor. Each ESC is controlled independently by a PPM signal (similar to PWM).

The frequency of the signals also vary a lot, but for a Quad-Copter it is recommended the controller should support high enough frequency signal, so the motor speeds can be adjusted quick enough for optimal stability (i.e. at least 200 Hz or even better 300 Hz PPM signal). ESC can also be controlled through I2C but these controllers are much more expensive. When selecting a suitable ESC, the most important factor is the source current. We always chose an ESC with at least 10A or more in sourcing current. Second most important factor is the programming facilities, which means in some ESC we are allowed to use different signals frequency range other than only between 1ms to 2ms range, but we could change it to whatever we need. This is especially useful for custom controller board.

Battery Voltage
LiPo battery can be found in a single cell (3.7V) to in a pack of over 10 cells connected in series (37V). A popular choice of battery for a Quad-Copter is the 3SP1 batteries which means three cells connected in series as one parallel, which should give us 11.1V.
Battery Capacity
As for the battery capacity, we need to do some calculations on:

- How much power do our motors will draw?
- Decide how long flight time we want?
- How much influence the battery weight should have on the total weight?

A good rule of thumb is that with four EPP1045 propellers and four Kv=1000 rated motor will get the number of minutes of full throttle flight time as the same number of amp-hours in your battery capacity. This means that if we have a 4000mAh battery, we will get around 4 minutes of full throttle flight time though with a 1KG total weight you will get around 16 minutes of hover.

Figure 9: Battery

Battery Discharge Rate
Another important factor is the discharge rate which is specified by the C-value. The C-value together with the battery capacity indicates how much current can be drawn from the battery. Maximum current that can be sourced can be calculated as:
MaxCurrent = DischargeRate x Capacity

IMU – Inertial Measurement Unit

The Inertial Measurement Unit (IMU) is an electronic sensor device that measures the velocity, orientation and gravitational forces of the Quad-Copter. These measurements allow the controlling electronics to calculate the changes in the motor speeds.

The IMU is a combination of the 3-axis accelerometer and 3-axis gyroscope, together they represent a 6DOF IMU. Sometimes there is also an additional 3-axis magnetometer for better Yaw stability (in total 9DOF).

RC Transmitter

Quad-Copters can be programmed and controlled in many different ways but the most common ones are by RC transmitter in either Rate (acrobatic) or Stable mode. The difference is the way the controller board interprets the orientations feedback together with the RC transmitter joysticks. In Rate mode only the Gyroscope values are used to control the Quad-Copter. The joysticks on your RC transmitter are then used to control and set the desired rotation speed of the 3 axes, though if you release the joysticks it does not automatically re-balance.

For the beginners the Rate mode might be too difficult and that is why we started with the Stable mode. All the sensors are used to determine the Quad-Copters orientation in the stable mode. The speed of the 4 motors will be adjusted automatically and constantly to keep the Quad-Copter balanced. We can control and change the angle of the Quad-Copter with any axis using the joystick. For example: to go forward, we can simply tilt one of the joysticks to change the pitch angle of the Quad-Copter. When releasing the joystick, the angle will be reset and the Quad-Copter will be balanced again.

Quad-Copter Layout

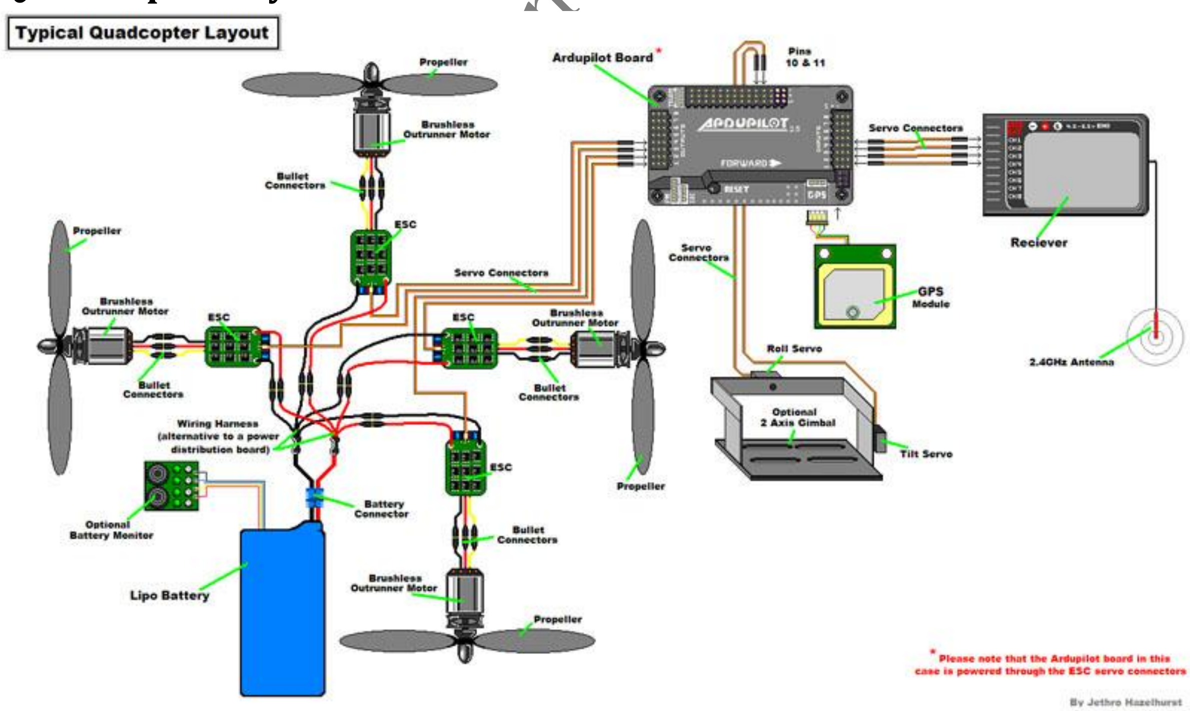

Figure 10: Connecting to APM

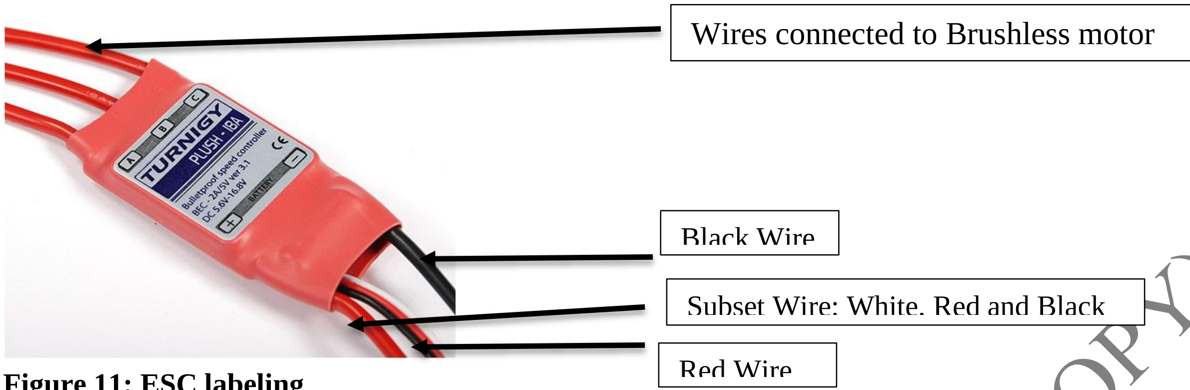

Figure 11: ESC labeling

Steps

- The wires from receiver are connected to the input pins of the APM
- ESC has three sections of wires: One is Black wire, the other is red wire and the final section has subset of wires which consists of black, red and white
- The red wire and black wire from the ESC are connected to the battery
- The subset section of wires are connected to the output of the APM
- In the subset section of wires: white wire receives signal from the receiver, the other red and black wire are just applying voltage to the APM
- One ESC have enough power to turn on the APM. This is the reason why three other pair of red and black wire from the subset section are not connected to the APM outputs
- Soldering was done to the wires which are connecting the motor and the wires from ESC

Connecting the ESCS and Motors

Figure 12: Connecting the Right motor and ESC to APM

The electronic speed controllers (ESCs) are connected to APM directly. When connecting the ESCs directly to APM, the power (+), ground (-), and signal (s) wires for each ESC are connected to the APM main output pins by motor number.

Connecting the Radio Receiver and APM

Figure 13: Connecting the Radio Receiver and APM

Mission Planner

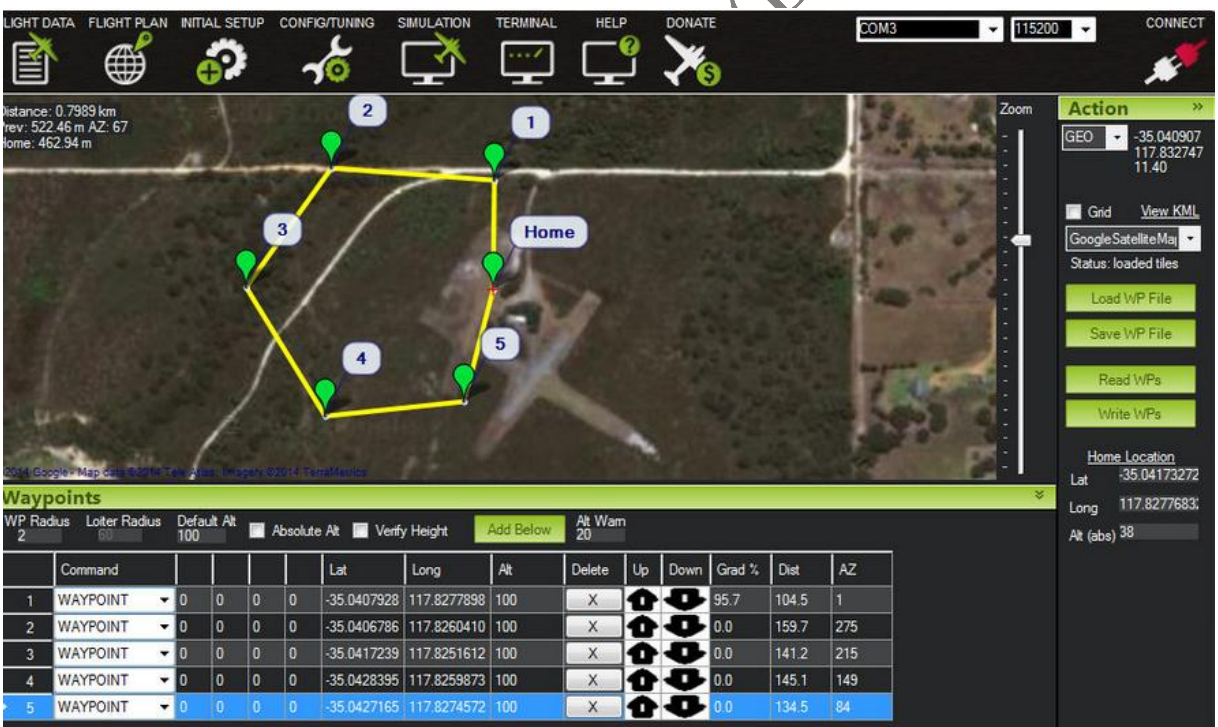

Figure 14: Mission Planner

Mission planner can be used in two ways. One by using the telemetry and other is connecting the USB port of the APM to Laptop or Personal Computer. Laptop/PC will have the mission planner software which can easily be downloaded from the ardupilot website. Mission planner is used to calibrate the motors and to set the way points.

Some of the work that mission planner can do are listed below:

- Point-and-click waypoint entry, using Google Maps.
- Select mission commands from drop-down menus
- Download mission log files and analyze them
- Configure APM settings for the airframe
- Interface with a PC flight simulator to create a full hardware-in-the-loop UAV simulator.
- See the output from APM’s serial terminal

Using the Mission Planner, a user can pre-program the flight path of a conservation drone simply by clicking and defining waypoints on a Google map or other available map layers (Bing, Yahoo, OpenStreetMap, Ovimap, etc). The drone can also be programmed to take off and land autonomously, and circle over any waypoint for a specified number of turns or duration, while acquiring aerial photographs or video. The user can also program other flight parameters such as ground/air speed and altitude of the drone over each waypoint. A pre-programmed mission can be uploaded to the drone before launch. But even when the drone is already in the air, a new mission can still be programmed and uploaded via data telemetry to give new instructions to the drone.

Data Collected

Figure 15: Quad-copter and the RC transmitter

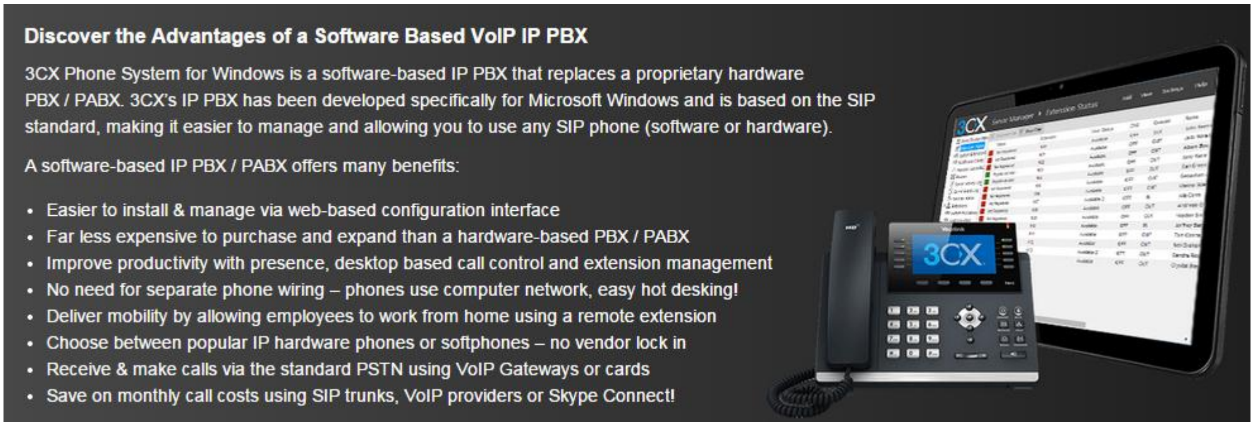

Figure 16: Voice over IP 3CX software

Summary and Conclusion

Final Thoughts

Overall this project has the ability to be used in a real life scenarios and it can be implemented in many different ways. The use of quad-copters has increased in recent times and we have proven that this is a great way to show the good that they can bring. The addition of the Wi-Fi range extenders allows for emergency personnel to have a better and more efficient way to communicate with each other.

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