NESAC

North Eastern Space Applications Centre

Government of India, Department of Space, Umiam, Shillong, Meghalaya

PROJECT REPORT ON
(Assembling, Calibration and Tuning of Quadcopter)

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We would firstly like to thank the Director of NESAC for accepting us as Interns and providing us this opportunity to work in this prestigious Institution.

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ABSTRACT

Our project required the understanding of UAVs, the classification, components and the working of each. It also required the manufacturing of a drone and to test out the flight capabilities and other aspects related to it. With the help of a 3D printed frame designed by Abhilekh Mukherjee (one of the people guiding us on this project), we were able to mount the required components. These components were obtained from the NESAC UAV lab itself. We were also able to calibrate and tune the drone (which was an ‘X’ Quadcopter) with the facilities provided by NESAC.

In the following sections, we discuss each part of our project in details.

INTRODUCTION

An **unmanned aerial vehicle** (**UAV**) (or **un-crewed aerial vehicle**, commonly known as a **drone**) is an aircraft without a human pilot on board. UAVs are a component of an unmanned aircraft system (UAS); which include a UAV, a ground-based controller, and a system of communications between the two. The flight of UAVs may operate with various degrees of autonomy: either under remote control by a human operator or autonomously by on-board computers.

Compared to crewed aircraft, UAVs were originally used for missions too "dull, dirty or dangerous" for humans. While they originated mostly in military applications, their use is rapidly expanding to commercial, scientific, recreational, agricultural, and other applications, such as policing, peacekeeping, and surveillance, product deliveries, aerial photography, smuggling, and drone racing. Civilian UAVs now vastly outnumber military UAVs, with estimates of over a million sold by 2015.

TYPES AND CLASSIFICATION OF UAVS

Based on the type of aerial platform used, there are 4 major types of drones.

1. Multi Rotor Drones
2. Fixed Wing Drones
3. Single Rotor Helicopter
4. Fixed Wing Hybrid VTOL

Multi Rotor Drones

Multi Rotor drones are the most common types of drones which are used by professionals and hobbyists alike. They are used for most common applications like aerial photography, aerial video surveillance etc. Out of all the 4 drone types (based on aerial platform), multi-rotor drones are the easiest to manufacture and they are the cheapest option available as well.

There are many types of multirotor. They are generally categorized by the number of motors used, for example a three-motored multicopter is a called a tricopter, and the configuration can also be referred to as Y3. In this post we will discuss the following types of multirotors:

- **Bicopter**
- **Tricopter (Y3, T3)**
- **Quadcopter (X4, Y4, V-Tail, A-Tail)**
- **Pentacopter**
- **Hexacopter (Y6)**
- **Octocopter (X8)**

The number of motors and configuration have impact on flight performance, and each has its own advantages. For instance, more number of motors, more is the power and lift capacity, which means you could carry more payload. More motors also mean better redundancy in case of motor failure. But the downside is decrease in power efficiency, and increase in the cost of purchasing additional hardware and maintenance.

Although easy to manufacture and relatively cheap, multi-rotor drones have many downsides. The prominent ones being it’s limited flying time, limited endurance and speed. They are not suitable for large-scale projects like long distance aerial mapping or surveillance. The fundamental problem with the multicopters is they have to spend a huge portion of their energy (possibly from a battery source) just to fight gravity and stabilize themselves in the air. At present, most of the multi-rotor drones out there are capable of only a 20 to 30 minutes flying time (often with a minimal payload like a camera).

Fixed Wing Drones

Fixed Wing drones are entirely different in design and build to multi-rotor type drones. They use a ‘wing’ like the normal airplanes out there. Unlike multi-rotor drones, fixed wing type models never utilize energy to stay afloat on air (fixed wing types can’t stand still on the air) fighting gravity. Instead, they move forward on their set course or as set by the guide control (possibly a remote unit operated by a human) as long as their energy source permits.

Most fixed wing drones have an average flying time of a couple of hours. Gas engine powered drones can fly up to 16 hours or higher. Owing to their higher flying time and fuel efficiency, fixed wing drones are ideal for long distance operations (be it mapping or surveillance). But they cannot be used for aerial photography where the drone needs to be kept still on the air for a period of time.

The other downsides of fixed-wing drones are higher costs & skill training required in flying. It’s not easy to put a fixed wing drone in the air. You either need a ‘runway’ or a catapult launcher to set a fixed wing drone on its course in the air. A runway or a parachute or a net is again necessary to land them back in ground safely. Flying a quadcopter doesn’t require special training. You just take them to an open area and fly it. Guiding and controlling a quadcopter can be learned on the go.

Single Rotor Drones

Single rotor drones look very similar in design & structure to actual helicopters. Unlike a multi rotor drone, a single rotor model has just one big sized rotor plus a small sized one on the tail of the drone to control its heading. Single rotor drones are much efficient than multi rotor versions. They have higher flying times and can even be powered by gas engines. In aerodynamics, the lower the count of rotors the lesser will be the spin of the object and that’s the big reason why quadcopters are more stable than octocopters. In that sense, single rotor drones are much efficient than multi-rotor drones.

However, these machines come with much higher complexity and operational risks. Their costs are also on the higher side. The large sized rotor blades often pose a risk (fatal injuries have been recorded from rc copter accidents) if the drone is mishandled or involves in an accident. Multi-rotor drones, often owing to their small rotor blades have never been involved in fatal accidents (though a scar on human body is likely). They also demand special training to fly them on air properly (though they may not need a runway or a catapult launcher to put them on air).

Hybrid VTOL

These are hybrid versions combining the benefits of Fixed wing models (higher flying time) with that of rotor based models (hover). This concept has been tested from around 1960’s without much success. However, with the advent of new generation sensors (gyros and accelerometers), this concept has got some new life and direction.

Components of UAV and their Functions

1. Standard Propellers

The propellers are usually located at the front of the drone/quadcopter. There are very many variations in terms of size and material used in the manufacture of propellers. Most of them are made of plastic especially for the smaller drones but the more expensive ones are made of carbon fiber. Propellers are still being developed and technological research is still ongoing to create more efficient propellers for both small and big drones. Propellers are responsible for the direction and motion of the drone. It is therefore important to ensure that each of the propellers is in good condition before taking your drone out for flight. A faulty propeller means impaired flight for the drone and hence an accident. You can also carry an extra set of propellers just in case you notice some damage that was not there before.

2. Pusher Propellers

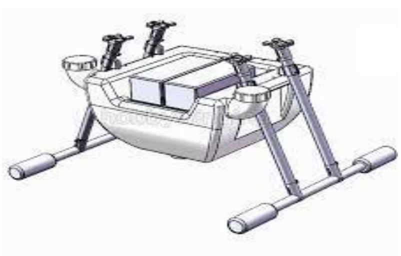
Pusher propellers are the ones responsible for the forward and backward thrust of the drone during flight. As the name suggest, the pusher propellers will determine the direction the drone takes either forward or backward. They are normally located at the back of the drone. They work by cancelling out the motor torques of the drone during stationary flight leading to forward or backward thrust. Just like the standard propellers, the pusher propellers can also be made of plastic or carbon fiber depending on the quality. The more expensive ones are usually made of carbon fiber. There are different sizes depending on the size of the drone. Some drones provide for pusher prop guards that will help protect your propellers in the event of an unplanned crash. Always ensure you inspect your pusher propellers before flight as this will determine the efficiency pf the flight.

3. Brushless Motors

All drones being manufactured lately use the brushless motors that are considered to be more efficient in terms of performance and operation as opposed to the brushed motors. The design of the motor is as important as the drone itself. This is because an efficient motor means you will be able to save on costs of purchase and maintenance costs. In addition to that, you will also save on battery life which contributes to longer flight time when flying your drone. Currently, the drone motor design market is pretty exciting as companies try to outdo each other in coming up with the most efficient and best developed motors. The latest in the market is the DJI Inspire 1 which was launched recently. This offers more efficient performance and saves on battery life. It is also relatively quiet and does not produce a lot of unnecessary noises.

4. Landing Gear

Some drones come with helicopter-style landing gears that help in landing the drone. Drones which require high ground clearance during landing will require a modified landing gear to allow it to land safely on the ground. In addition to that, delivery drones that carry parcels or items may need to have a spacious landing gear due to the space required to hold the items as it touches the ground. However, not all drones require a landing gear. Some smaller drones will work perfectly fine without a landing gear and will land safely on their bellies once they touch the ground. Most drones that fly longer and cover longer distances have fixed landing gears. In some cases, the landing gear may turn out to be an impediment to the 360 degrees view of the environment especially for a camera drone. Landing gears also increase the safety of the drone.



5. Electronic Speed Controllers

An electronic sped controller (ESC) is an electric circuit whose main responsibility is to monitor and vary the speed of the drone during flight. It is also responsible for the direction of flight and variations in brakes of the drone. The ESC is also responsible for the conversion of DC battery power to AC power to propel the brushless motors. Modern drones depend entirely on the ESC for all their flight needs and for performance. More and more companies are coming up with better performing ESC that reduce power needs and increase performance, the latest one being the DJI Inspire 1 ESC. The ESC is mainly located inside the mainframe of the drone. It is unlikely that you will need to do anything or make any change on the ESC but in case you need to make any changes, you can locate it inside the mainframe of the drone.

6. Flight Controller

The flight controller is basically the motherboard of the drone. It is responsible for all the commands that are issued to the drone by the pilot. It interprets input from the receiver, the GPS Module, the battery monitor and the on-board sensors. The flight controller is also responsible for the regulation of the motor speeds through the ESC and for the steering of the drone. Any commands such as triggering of the camera, controlling the autopilot mode and other autonomous functions are controlled by the flight controller. Users will most likely not be required to make any alterations to the flight controller as this may often affect the performance of the drone. Flight controllers are the brains of your UAV, they help stabilize your motors and synchronize them so that even if the motors give a different output of thrust the UAV can steady itself.
Depending on the flight controller that the user purchased they can even be programmed to take off and fly to waypoints. Flight controllers are a huge part of the UAV design since it connects all of the pieces together. It is important that to know what the purpose of the UAV is in order to give it the right amount of processing power.

7. The Receiver

The receiver is the unit responsible for the reception of the radio signals sent to the drone through the controller. The minimum number of channels that are needed to control a drone are usually 4. However, it is recommended that a provision of 5 channels be made available. There are very many different types of receivers in the market and all of them can be used when making a drone.

8. The Transmitter

The transmitter is the unit responsible for the transmission of the radio signals from the controller to the drone to issue commands of flight and directions. Just like the receiver, the transmitter needs to have 4 channels for a drone but 5 is usually recommended. Different types of receivers are available in the market for drone manufacturers to choose from. The receiver and the transmitter must use a single radio signal in order to communicate to the drone during flight.
Each radio signal has a standard code that helps in differentiating the signal from other radio signals in the air.

9. GPS Module

The GPS module is responsible for the provision of the drone longitude, latitude and elevation points. It is a very important component of the drone. Without the GPS module, drones would not be as important as they are today. The module helps the drone navigate longer distances and capture details of specific locations on land. The GPS module also help in returning the drone safely "home" even without navigation using the FPV. In most modern drones, the GPS module helps in returning the drone safe to the controller in case it loses connection to the controller. This helps in keeping the drone safe.

10. Battery

The battery is the part of the drone that makes all actions and reactions possible. Without the battery, the drone would have no power and would therefore not be able to fly. Different drones have different battery requirements. Smaller drones may need smaller batteries due to the limited power needs. Bigger drones, on the other hand, may require a bigger battery with a larger capacity to allow it to power all the functions of the drone. There is a battery monitor on the drone that helps in providing battery information to the pilot to monitor the performance of the battery.

11. Camera

Some drones come with an inbuilt camera while others have a detachable camera. The camera helps in taking photos and images from above which forms an important use of drones. There are different camera types and qualities in the market and a variety to choose from.

These are basically the main component of a drone. If you ever need to make a drone, you will need to have all of these in order to have a working drone.

OBJECTIVES

- **Assembling a Quadcopter**
- **Calibrating the assembled Quadcopter**
- **Tuning the assembled Quadcopter**

In the following sections, we will discuss the procedures that we had to perform on the quadcopter so as to make it fly properly and also to make it stable so that efficient flight as well as prolonged flight time is achieved.

ASSEMBLING THE QUADCOPTER

The components that we needed to assemble together in our quadcopter include: -

1. **Pixhawk px4 flight controller**

2. **Cube**

3. X8R Receiver

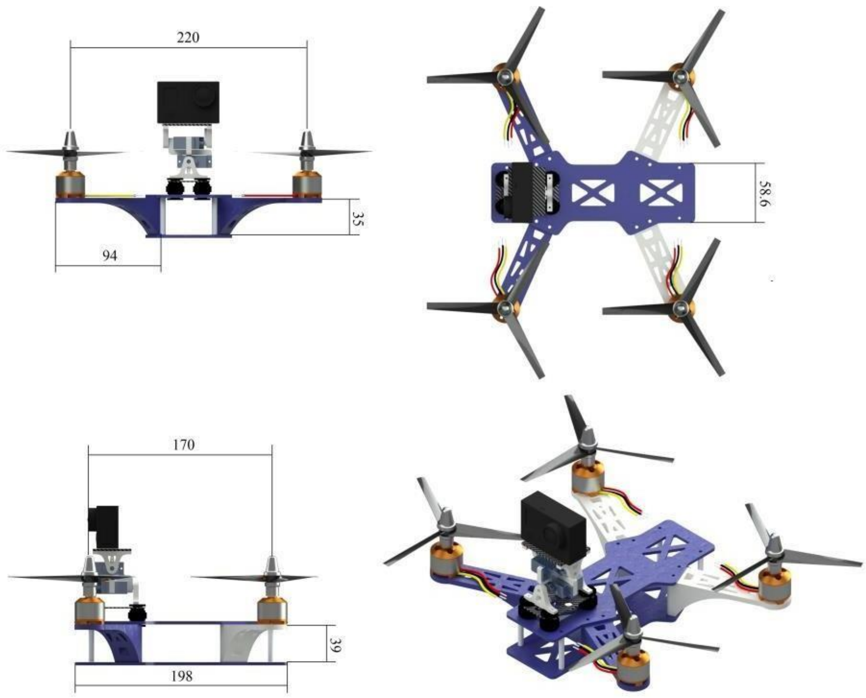
4. Telemetry and Radio Modem

5. GPS Unit

6. Battery

7. Propellers

8. Quadcopter Frame



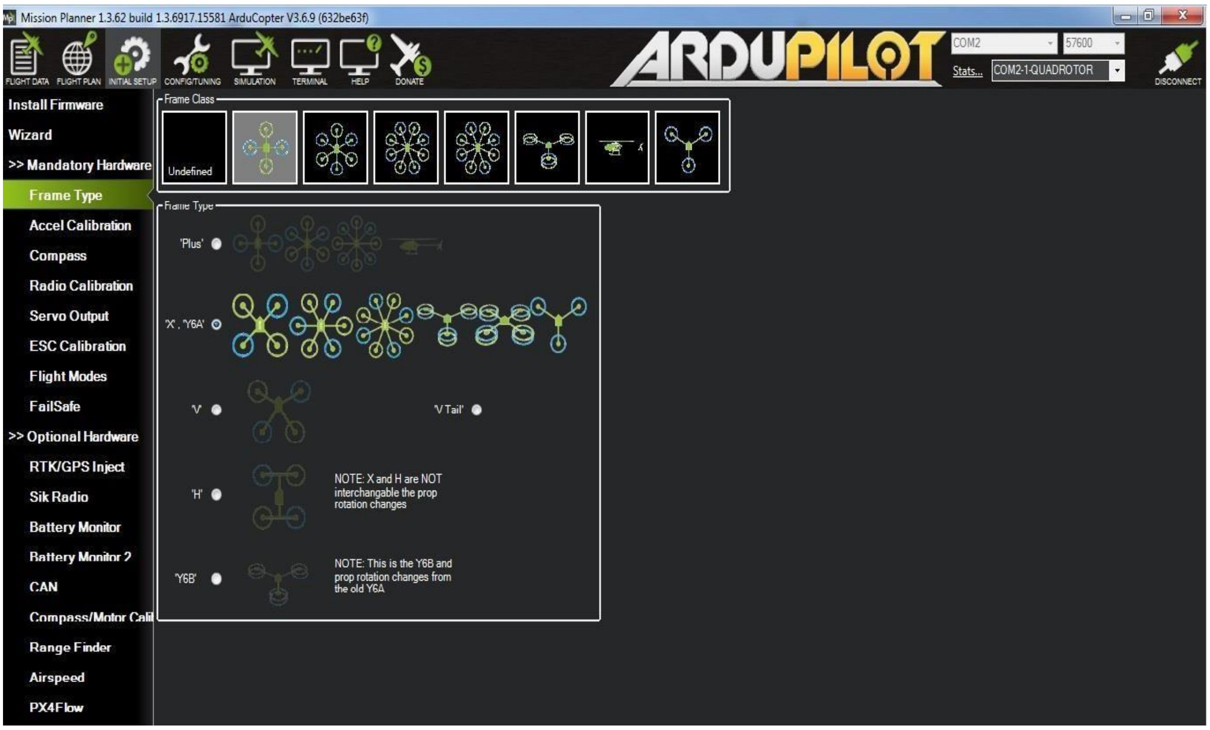
We were able to find a particular setup where the weight was relatively balanced and the final structure of the quadcopter was as follows: -

CALIBRATION

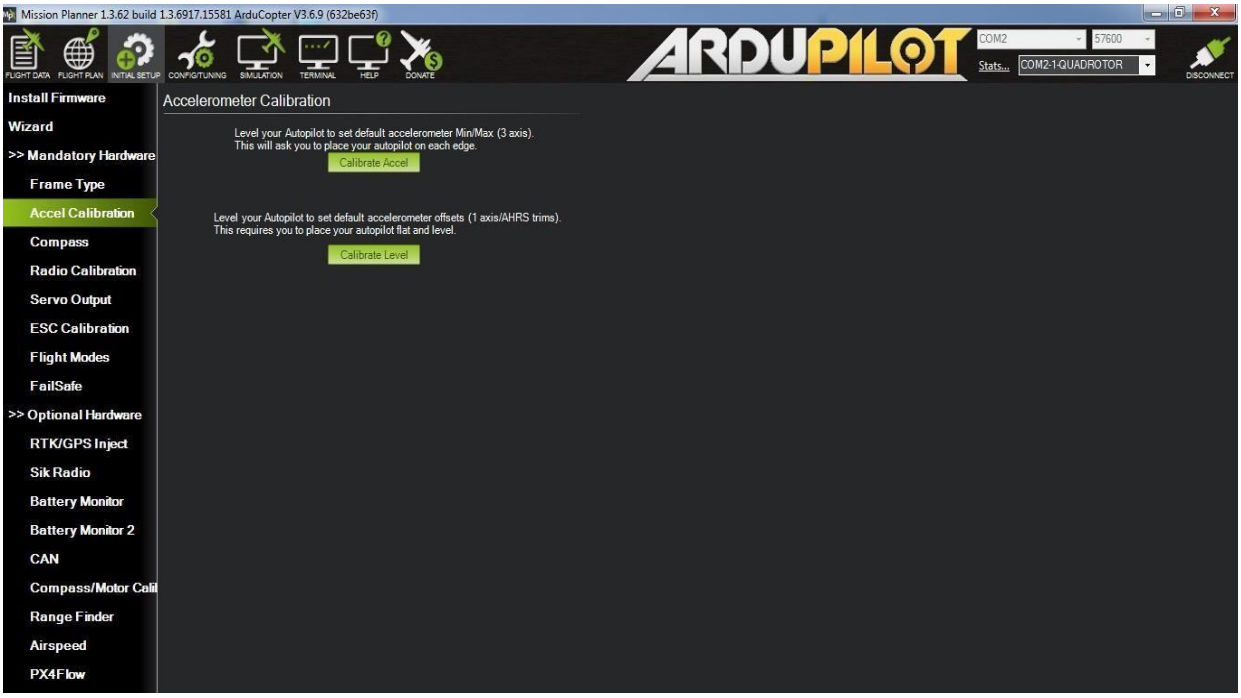
Calibrating a drone or a controller is the process of setting or correcting errors which caused inaccurate sensor measurements. It checks, adjusts or determines by comparison with a standard model and to make corrections accurately. Drones have a lot of sensors working on to maintain flight efficiency, such as gyro, accelerometer, barometer, magnetometer, etc. You got to make sure these sensors have accurate measurements to fly safely.

For the calibration, we open the Mission Planner software. On the top left corner we will find an option "Initial setup" and click on it. There are a few procedures that we have to complete and we click on each option and follow the steps mentioned in each. They are as follows:-

1. **Frame Type:** Here we simply choose which type of frame that our Quadcopter is built in. As our drone is an 'X' quadcopter, we click on that option.



2. **Accel Calibration:** This option is to setup our accelerometer. After clicking on the calibrate option, we will have to follow a few instructions and then click on the button as we finish each. The instructions include placing the drone on its base, left, right and on its belly.



3. **Compass**: This will setup the compass on our drone. After clicking on the calibrate option, we will have to rotate the drone in both the vertical and horizontal axes until the two bars that are generated will be filled.

4. **Radio Calibration**: We need to connect the transmitter and plug in the battery to switch on the receiver for this portion. This is to check the signals from the transmitter. Once connected we can move the controls on our transmitter and see the corresponding motion on our software.

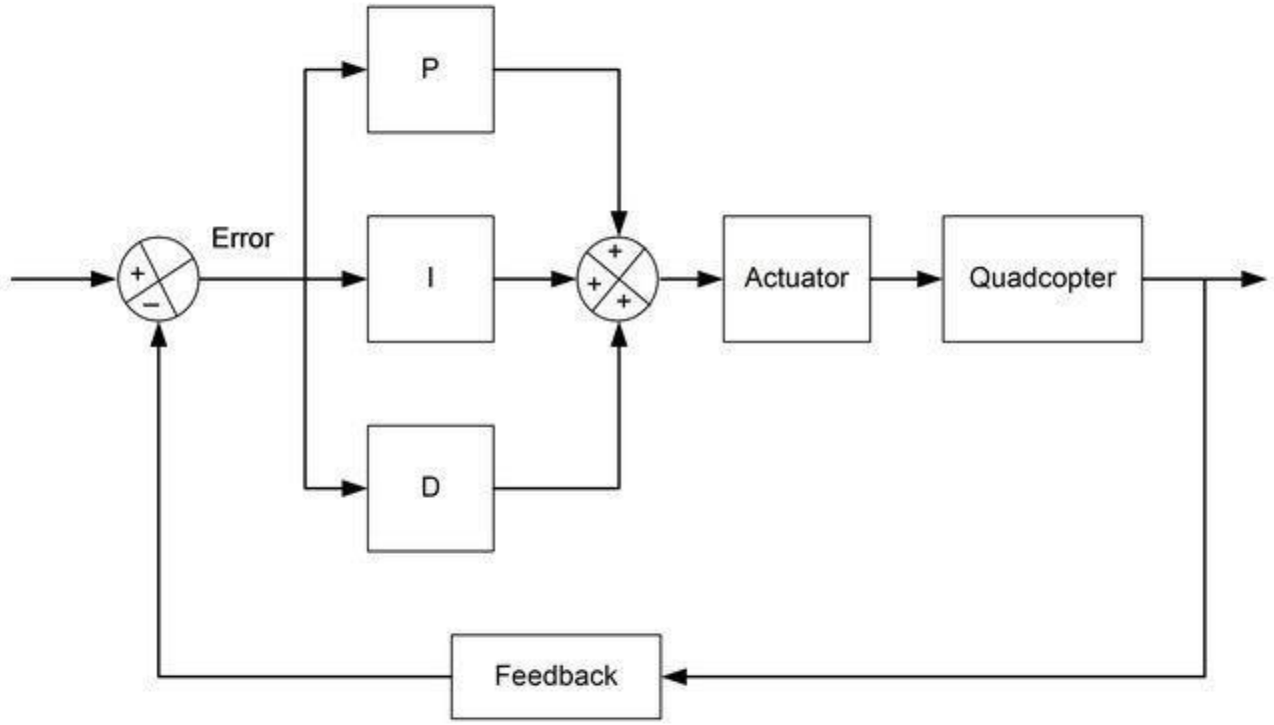
5. **ESC calibration**: The following steps have to be taken to finish this calibration
    a. We turn on our transmitter and put the throttle stick at maximum.
    b. Connect the Lipo battery.
    c. With the transmitter throttle stick still high, disconnect and reconnect the battery.
    d. The autopilot is now in ESC calibration mode. We wait for our ESCs to emit the musical tone, the regular number of beeps indicating our battery's cell count and then an additional two beeps to indicate that the maximum throttle has been captured.
    e. Pull the transmitter's throttle stick down to its minimum position.
    f. The ESCs should then emit a long tone indicating that the minimum throttle has been captured and the calibration is complete.
    g. The long tone indicating successful calibration was heard, the ESCs are "live" now and if we raise the throttle a bit they spin. We

test that the motors spin by raising the throttle a bit and then lowering it again.

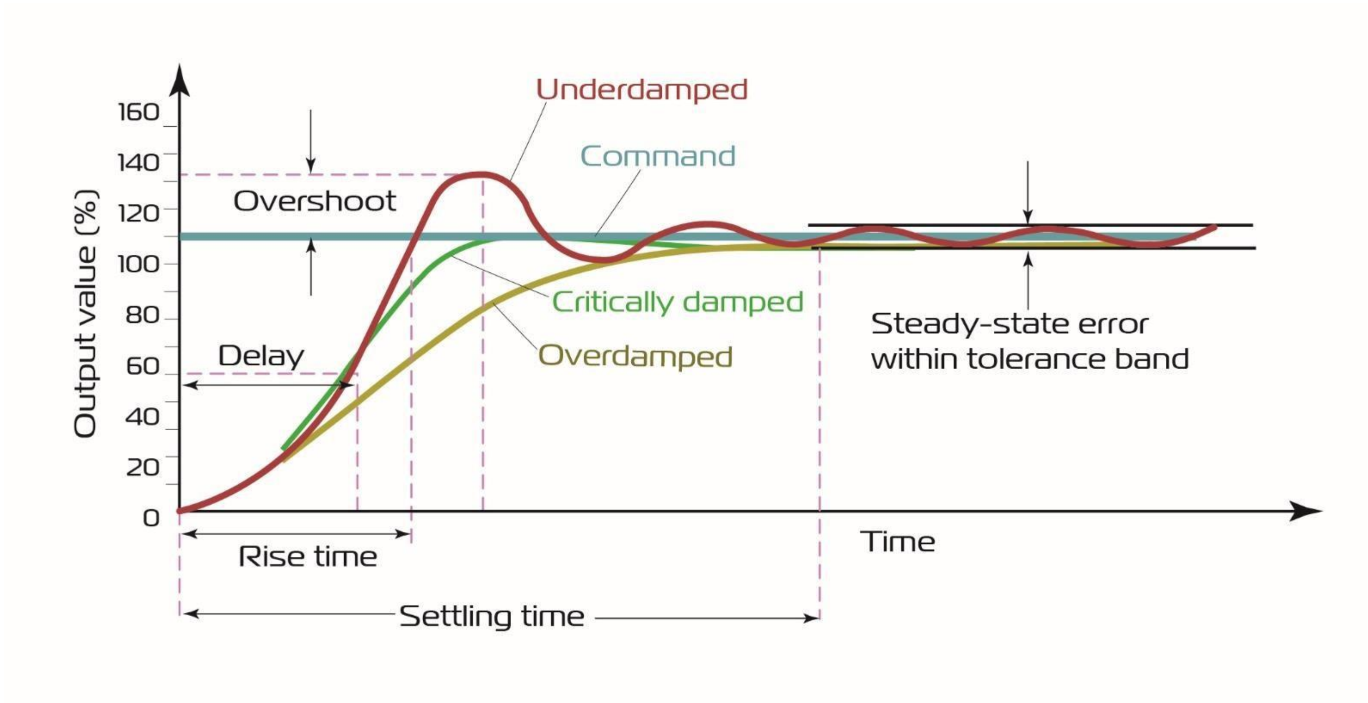
h. Set the throttle to minimum and disconnect the battery to exit ESC-calibration mode.

TUNING

PID stands for Proportional, Integral, Derivative, it is part of a flight controller software that reads the data from sensors and calculates how fast the motors should spin in order to retain the desired rotation speed of the aircraft.
The goal of the PID controller is to correct the "error", the difference between a measured value (gyro sensor measurement), and a desired set-point (the desired rotation speed). The "error" can be minimized by adjusting the control inputs in every loop, which is the speed of the motors.



There are 3 values in a PID controller, they are the P term, I term, and D term:
"P" looks at present error – the further it is from the set-point, the harder it pushes.
"D" is a prediction of future errors – it looks at how fast we are approaching a set-point and counteracts P when it is getting close to minimize overshoot.
"I" is the accumulation of past errors, it looks at forces that happen over time.



The Effect of Each PID Parameter
When we change the PID values, it affects a quadcopter's behavior in different ways.

P Gain
P gain determines how hard the flight controller works to correct error and achieve the desired flight path (i.e. where the pilot wants the quad to go by moving the transmitter sticks).

In general, higher P gain means sharper control while low P gain means softer control.

If P is too high, the quadcopter becomes too sensitive and tends to over-correct, eventually it will cause overshoots, and we will have high frequency oscillations.

We can lower P to reduce the oscillations, but if we reduce it too much and our quadcopter will start to feel sloppy.

I Gain
I term determines how hard the FC works to hold the drone's attitude against external forces, such as wind and off-centered CG.

When I is too low we find some drifting of the quadcopter and we have to correct the quad's flying path a lot more with our sticks, especially when you are active with the throttle.

When I gain gets too high, our quadcopter will be overly constrained by this, and start to feel stiff and unresponsive. Excessive I gain in extreme cases can create a low frequency oscillation.

D Gain

D gain works as a damper and reduces the over-correcting and overshoots caused by P term. Like a shock absorber stops the suspension from being bouncy, adding D gain can “soften” and counteract the oscillations caused by excessive P gain.

When D is too low, our quad will have bad bounce-backs at the end of a flip or roll.

Increasing D gain can improve these problems, however, an excessive D value can introduce vibration in our quadcopter because it amplifies the noise in the system. Eventually this will lead to motor overheat and quad oscillation.

For our practical PID tuning, we flew the quadcopter with six different sets of PID values. We used the software Mission Planner to alter the values. We can find this on clicking on “Config/Tuning” and then on “Extended Tuning”:-

Case 1:

Here we changed the parameters as follows:-

Stabilize Roll: P=3

Stabilize Pitch: P=3

Rate Roll: P=0.08, I=0.040

Rate Pitch: P=0.08, I=0.040

Case 2:

Here we changed the parameters as follows:-
Stabilize Roll: P=3
Stabilize Pitch: P=3
Rate Roll: P=0.110, I=0.070
Rate Pitch: P=0.110, I=0.070

Case 3:

Here we changed the parameters as follows:-
Stabilize Roll: P=4.5
Stabilize Pitch: P=4.5
Rate Roll: P=0.150, I=0.100
Rate Pitch: P=0.150, I=0.100

Case 4:

Here we changed the parameters as follows:-
Stabilize Roll: P=4.5
Stabilize Pitch: P=4.5
Rate Roll: P=0.130, I=0.085
Rate Pitch: P=0.130, I=0.085

Case 5:

Here we changed the parameters as follows:-
Stabilize Roll: P=5.5
Stabilize Pitch: P=5.5
Rate Roll: P=0.20, I=0.150
Rate Pitch: P=0.20, I=0.150

Case 6:

Here we changed the parameters as follows:-
Stabilize Roll: P=6.5
Stabilize Pitch: P=6.5
Rate Roll: P=0.250, I=0.200
Rate Pitch: P=0.250, I=0.200

Summary:-

For the 1st case, with lower values in all three parameters, the drone felt sloppy and was flying with a sort of drunken haze. This effect slightly reduced with each iteration in cases 2, 3 and 4. In the 5th and 6th cases however the drone had violent oscillations and didn't seem very stable. This is expected with higher values of the parameters. In conclusion, the PID values used in the 2nd , 3rd and 4th cases were the ones that produced the most stability for our quadcopter.

CONCLUSION

Upon completion of the project assigned to us, we were able to learn and understand many things which we initially had little to none knowledge about. We were able to assemble, calibrate and tune the drone. This project of ours can pave the way for beginners like us so that they themselves will be able to perform the basic steps so as to make a drone fly and also fly it stably. We would like to thank our guide Shri Chirag Gupta Sir and also the people from the UAV lab for helping us achieve our objectives of the project. We would also like to thank NESAC for giving us the tools and also the opportunity to work with such high end equipment. This has certainly been a very educational and motivational experience for the both of us.