Alexandria University

Faculty of Science

Computer Science Department

Graduation Project

Quadcopter for detecting toxic gases

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Acknowledgements

To our professors,

we find no words to express how greatly value all of you are in our Hearts .It is so difficult to thank someone devoted himself to such a noble work. However we would like to express our gratitude with a simple yet so meaning word … thanks for all of you.

Finally, to every single person participated in this project Thank you all for making it a lifetime experience.

Abstract

A quadcopter is a helicopter that has four motors, these motor as well as the changeable environment make such system unstable and harder to control.

This project describes the build and development of a quadcopter and how it can be stable and controllable by implementing a control algorithm in order to get such an acceptable performance.

The implementation of such control algorithm will be processed on a control unit (Arduino). It works on converting the sensors reading to a meaning action which is taken by motors in order to make the quadcopter stable and controllable.

List of Abbreviations

RC : Remote control
PID : Proportional-integral-derivative
ESC : Electronic speed controllers
us : micro seconds
Hz : hertz
MHz : mega hertz
MDF : Medium-density-fibreboard
RPMs : Revolutions per minute
LIPO : lithuim polymer
IMU : Inertial Measurement Unit

1 Introduction

1.1 History

Quadrotor or quadcopter is a helicopter which is equipped with four rotors to create lift.The very first experimental attempts of taking off with a rotorcraft were mostly done with multirotor. Around 1907 Jacques and Louis Breguet, French brothers, built and tested Gyroplane No 1, a quadcopter. They managed take-off, although the design proved to be very unstable and hence impractical.

Another version of quadcopter has been developed in 1920s. It was another manned version named the De Bothezat helicopter .it was built and successfully flown. First developed and prototyped under a U.S. Army contract.

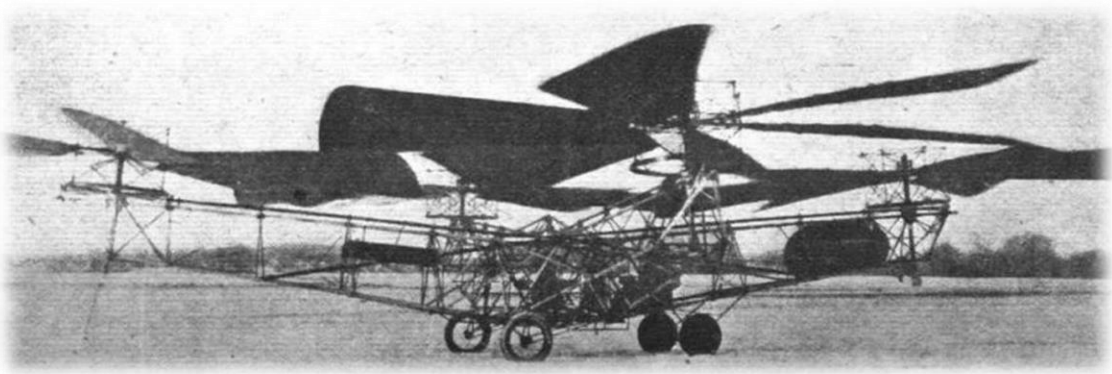


Figure 1.1

The helicopter actually started with six rotors, but eventually two were deemed unnecessary and were eliminated. It made more than 100 flights over a period of years but never flew more than 5 meters into the air and never with any lateral movement. This was due to the complexity and difficulty of simply trying to maintain level flight, never mind moving in a lateral direction. This lateral movement control was to be the bane of multirotor helicopters until the invention and use of computer-assisted flight-control systems that would lessen the pilot workload. The U.S. Army eventually lost interest in the De Bothezat project and discontinued it in the early 1930s, after spending more than $200,000 on the program.

Another attempt was in 1924, A French engineer Étienne Oehmichen flew his quadcopter a distance of 360m (1,181ft) setting a world record. In the same year he flew a 1km (0.62miles) circle in 7m and 40s.

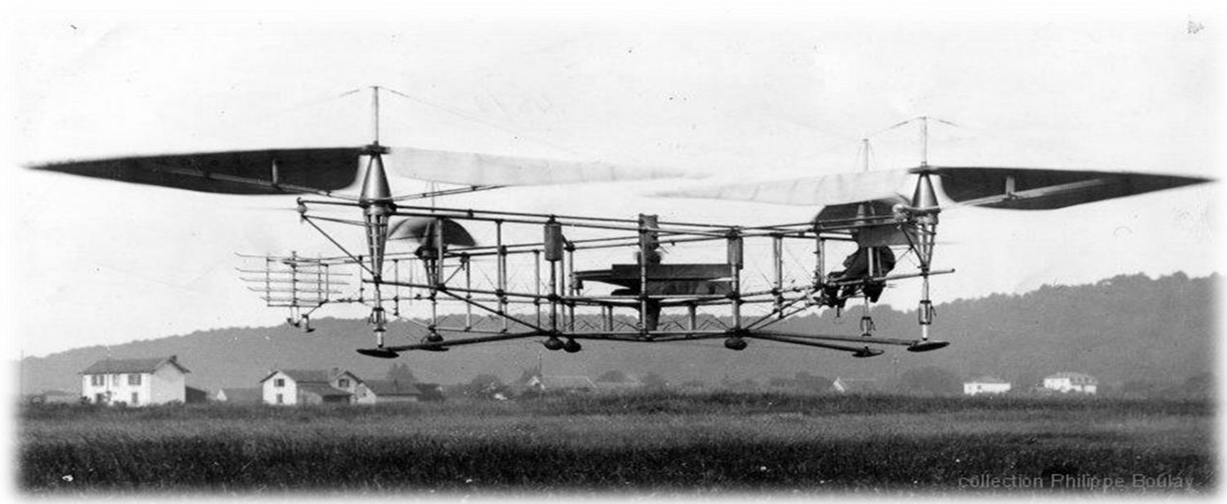


Figure 1.2

More recently there have been very interesting developments such as the Bell Boeing Quad TiltRotor, which has merged the quadcopter idea with the tilt rotor idea and has been designed jointly by Bell and Boeing, the Parrot AR.Drone and the Arducopter, an arduino based DIY quadcopter. All of these have been developed for different reasons such as carrying a large payload, Bell Boeing Quad Tiltrotor, or being a fun toy for people, Parrot AR.Drone.

Figure 1.3

In the last few decades, these small-scale unmanned aerial vehicles have been used for many applications. The need for aircraft with greater maneuverability and hovering ability has led to a rise in quadcopter research.

The four-rotor design allows quadcopters to be relatively simple in design yet highly reliable and maneuverable. Research is continuing to increase the abilities of quadcopters by making advances in multi-craft communication, environment exploration, and maneuverability.

If these developing qualities can be combined, quadcopters would be capable of advanced autonomous missions that are currently not possible with other vehicles.

1.2 Types of Multirotors

There are many different types of multirotor (also called multicomputer), they differ in the shape and number of motors. The commonly known helicopter has one motor, while multirotor is a unique kind of aircraft that is equipped with two or more motors. Multirotor often use fixed-pitch propellers, so the control of vehicle motion is achieved by varying the relative speed of each motor.

They are generally classified and named according to how many motors they have, for example a three-motored multirotor is a called a tricopter, and as known as the Y3.

The number of motors and configuration of each type of multirotor bring some up and down sides to their performance. For instance the more motors the more power (more lift capacity) and it can carry more batteries (bigger battery) to gain more flight tie. But the downside is more expensive for the additional powerful motors, ESCs and battery packs.

BiCopter – 2 Motors multicopter

This is the least popular configuration. BiCopter has two motors that can be moved by servos. It is considered as the cheapest multicopter because it uses only two motors and two servos, but it's the least stable platform and is hard to tune. It's also the least robust and have less lifting power (given the fact that it's got only 2 motors).

Figure 1.4

TriCopter – 3 Motors multicopter

The Tricopter has 3 motors in a "Y" shape usually 120 degrees apart, or sometimes "T" shape. Two propellers on the front arms pointing to the sides or slightly forwards, and one arm backwards. The rear motor can be tilted laterally via a servo to enable the yaw mechanism.

It's a relatively cheap configuration because it only requires 3 motors. It's generally less stable than multicopters with more motors and it's not as robust especially the tail servo and mechanics in crashes. It's also harder to build because of the yaw mechanism.

Tricopter has **more yaw authority** when turning than a quad. What that means is when a quad or hex yaws, they do that by slowing down some motors and speeding some up. If the copter is already at full throttle (full speed), it will have to lower the speed (thrust) to make yaw happens. However on a Tricopter, it uses a servo to achieve yaw so it loses less thrust when doing this. It also has lower lifting power because of the smaller motor numbers.

Figure 1.5

QuadCopter – 4 Motors multicopter

A typical quadcopter has 4 motors mounted on 4 arms of a frame that is symmetric, each arm is 90 degree apart (for X4 config). There are two sets of CW and CCW propellers mounted on the motors to create opposite force to stay balance. The quadcopter configuration is the most popular type and mechanically the simplest and easiest to understand. There are 2 configurations: ‘X’ or ‘+’. For photography X config is more popular as you can keep the propellers out of the screen. For Sport flying, some people fly the plus (+) config because it’s more like an airplane and easier to figure out the orientation and fly around.

Figure 1.6

Recently the “H” configuration become really popular for aerial photography and first person view (FPV). It allows a camera to be placed on the frame well forward to avoid having propellers in the view of the camera.

Figure 1.7

Y4 – 4 motors

It looks like a tricopter but without the tail servo. There are two normal propellers and motors in front on separate arms and two coaxial motors in the rear mounted to one arm. Mechanically it’s simpler than tricopters because of the absence of the servo. While they weigh almost the same they have about 1/3 more lifting power than tricopters. They are usually more reliable than Tricopters because there is no potential servo issues.

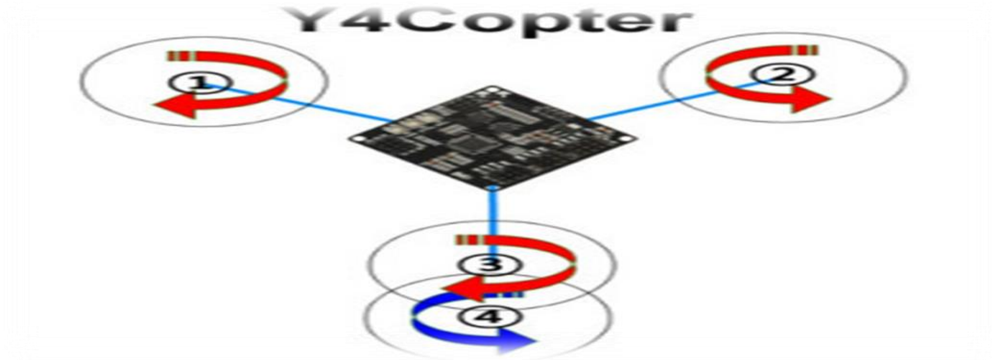


Figure 1.8

VTail – 4 motors

The Vtail is a quadcopter config with the front motors on normal quadcopter arms, while the rear motors located in close proximity, tilted at a vertical angle. It’s a mix between a quadcopter and a tricopter and very similar to Y4 config.This is not a popular configuration becase it should give lower power efficiency and flight times (at the tail motors, air blow interference). However it provides a better orientation visibility.

Figure 1.9

HexaCopter – 6 Motors

The hexacopter has 6 motors mounted on 6 arms 120 degree apart on a symmetric frame, with three sets of CW and CCW propellers.

Figure 1.10

It’s very similar to the quadcopter, but it provides more lifting capacity with the larger number of motors. It’s also possible that if one motor fails, the aircraft can still land safely. The downside is that they tend to be larger in size and a more expensive.

Y6 – 6 Motors

The Y6 has 6 motors in a “Y” shape frame. Similar in shape to a tricopter but it has two motors per arm, one above and one below (6 motors in total). It uses both CW and CCW propellers on the same arm rather than a servo to enable yaw.

Figure 1.11

This type of multicopter can be made more compact (as big as a tricopter) for the similar lifting capability as the hexacopter. However it is less efficient due to the coaxial motor-arrangement.

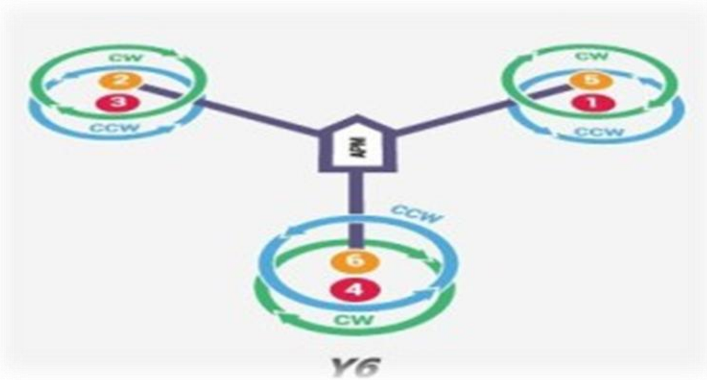


Figure 1.12

Octocopter – 8 Motors

A typical octocopter has 8 motors on the same level with four sets of CW and CCW propellers. Again it is similar to quadcopter and hexacopter. It’s an upgrade version of the hexacopter with even more lifting capacity. It’s also reliable because if one or two of the motors or ESCs fail, it should still be supported by other working motors and able to land safely.But it will draw more current from the 8 motors, and you will probably need to carry a couple of battery packs. Also it’s going to be expensive.

Figure 1.13

X8 – 8 Motors

An octocopter uses 8 motors that are mounted on four arms on an “X” shaped frame with four sets of CW and CCW props. Characteristics are similar to the Y6.

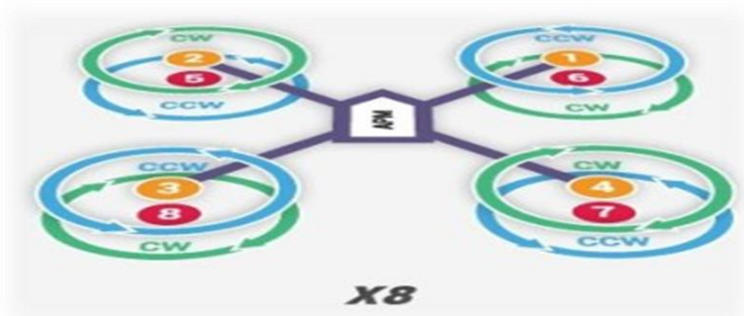


Figure 1.14

Choosing the right multicopter configuration:

Weight is the key, First thing you have to decide which task the multicopter will do. Just for fun, a quadcopter or tricopter would be great. But more stable aerial photography you might want to consider Hexacopter or Octocopter.

Secondly, how much the payload weight should it carry, then build a platform to pick it up safely. For example if a quadcopter needs to lift a payload, it might consume more power to do it than a hexacopter that is using more but smaller motors to an extent.

1.3 Flight mechanism of quadcopter

As mentioned above mutlicopters use set of motors with propellers to create thrust to give the aircraft lift. For quadcopters two of the motors rotate counter clockwise and the other two rotate clockwise. This configuration cause the torque from each motor to cancel by the corresponding motor rotating the opposite direction .What is very different about quadcopters from other vertical takeoff and landing aircraft (VTOL) is that in order to control pitch, yaw, and roll the pilot uses variable thrust between the four motors.

Unlike helicopters, quadcopters don't have a variable pitch propellers, so the pitch of the blades doesn't change.

Control is achieved by varying the relative thrusts of individual rotors. The rotation speed of the rotors change to control the flight dynamics. There are basic operation which any multirotor is supposed to do it. These operations are pitch, roll and yaw.

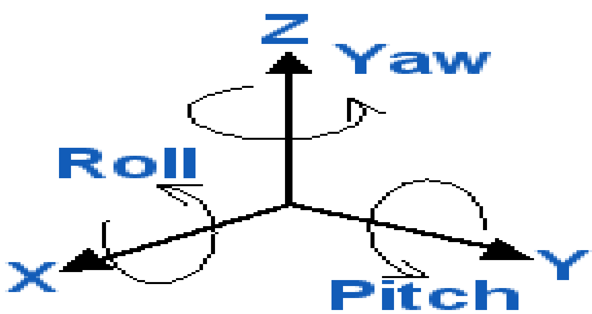


Figure 1.15

1.4 The basic operations

1. Pitch

Pitch is simply meaning the forward and backward motion of a multirotor. It is controlled by increasing and decreasing the rpms of the front and back rotors causing a moment which causes the copter to pitch up or down. (Forward or backward).

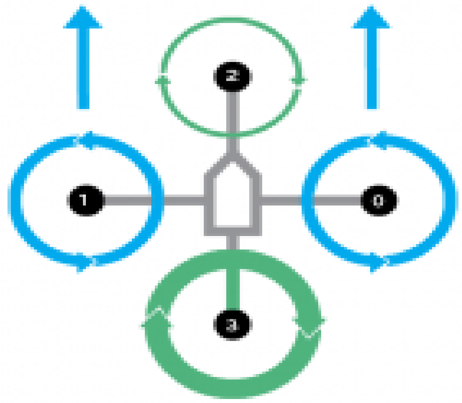


Figure 1.16

2. Roll

It is the motion to the right or to the left. It is the same mechanism as pitch but using left and right rotors instead of front and rear.

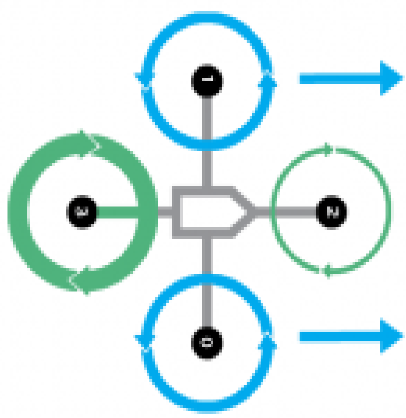


Figure 1.17

3. Yaw

In a quadcopter the rotors are counter rotating. Two of the rotors rotate in one direction and two rotate in the other. If the rpms of all rotors are the same then no moment about the yaw axis is created. By altering the rpms of the sets of counter rotating rotors, a moment will be created and the copter will yaw.

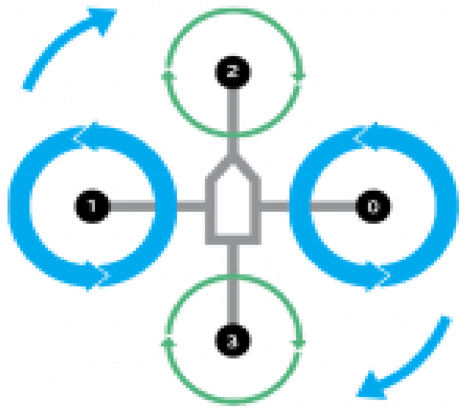


Figure 1.18

There is another variable to take in consideration which is throttle, in other words how a multirotor is able to move vertically. An equal adjustment of all motors would result in a change in altitude.

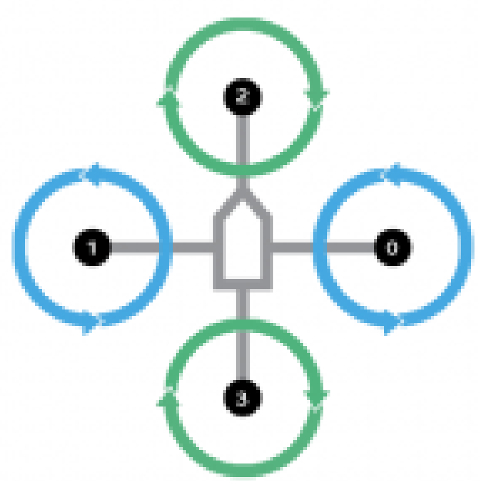


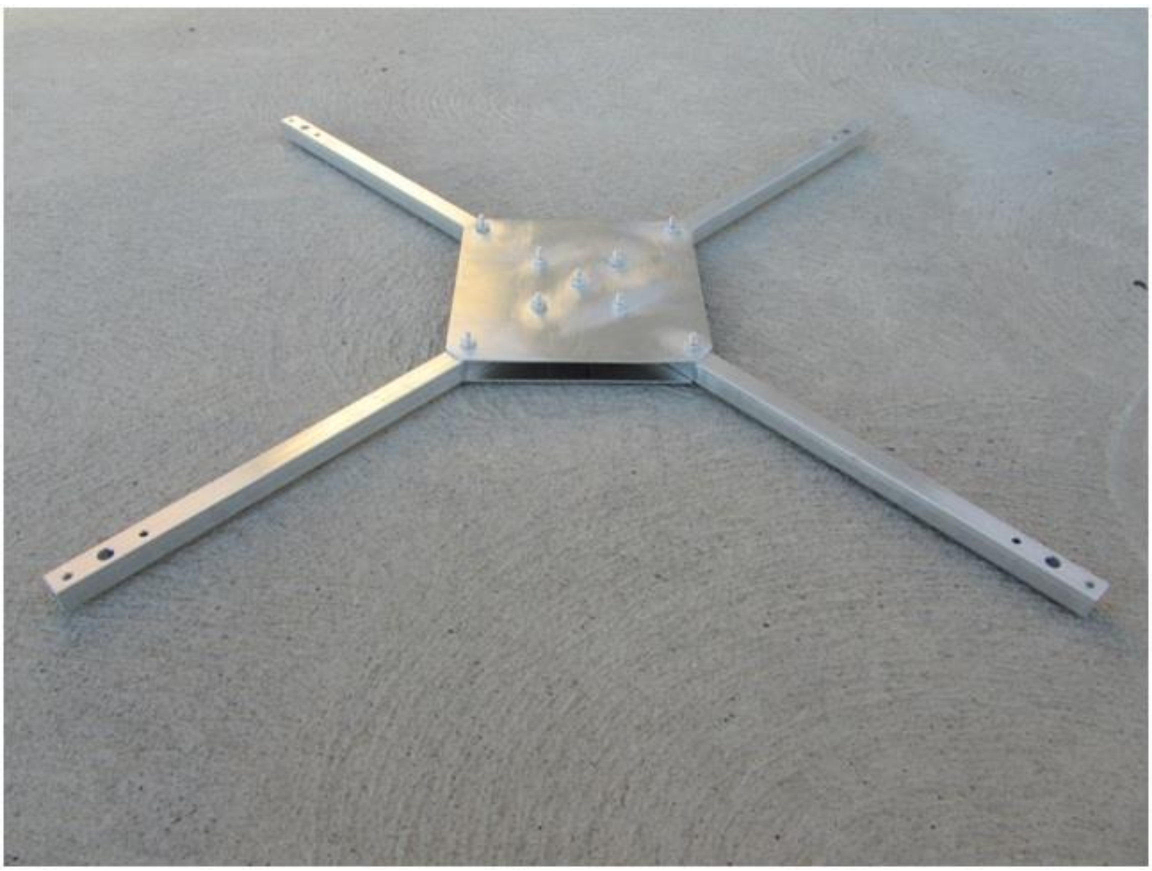
Figure 1.19

2 Quadcopter components

Each quadcopter can have a very different hardware component which mostly depends on application in which it will be implemented.
There are sensors connected to a microcontroller to make the decision as to how to control the motors. Depending on how autonomous you want it to be, one or more of these sensors are used in combination .

2.1 Frame

Frame is the structure that holds all the components together. The Frame should be rigid, and be able to minimize the vibrations coming from the motors ,They need to be designed to be strong but also light weight.



A QuadCopter frame consists of two to three parts which don't necessarily have to be of the same material:

- 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.

- Aluminium.

- Wood, such as Plywood or MDF (Medium-density fibreboard).

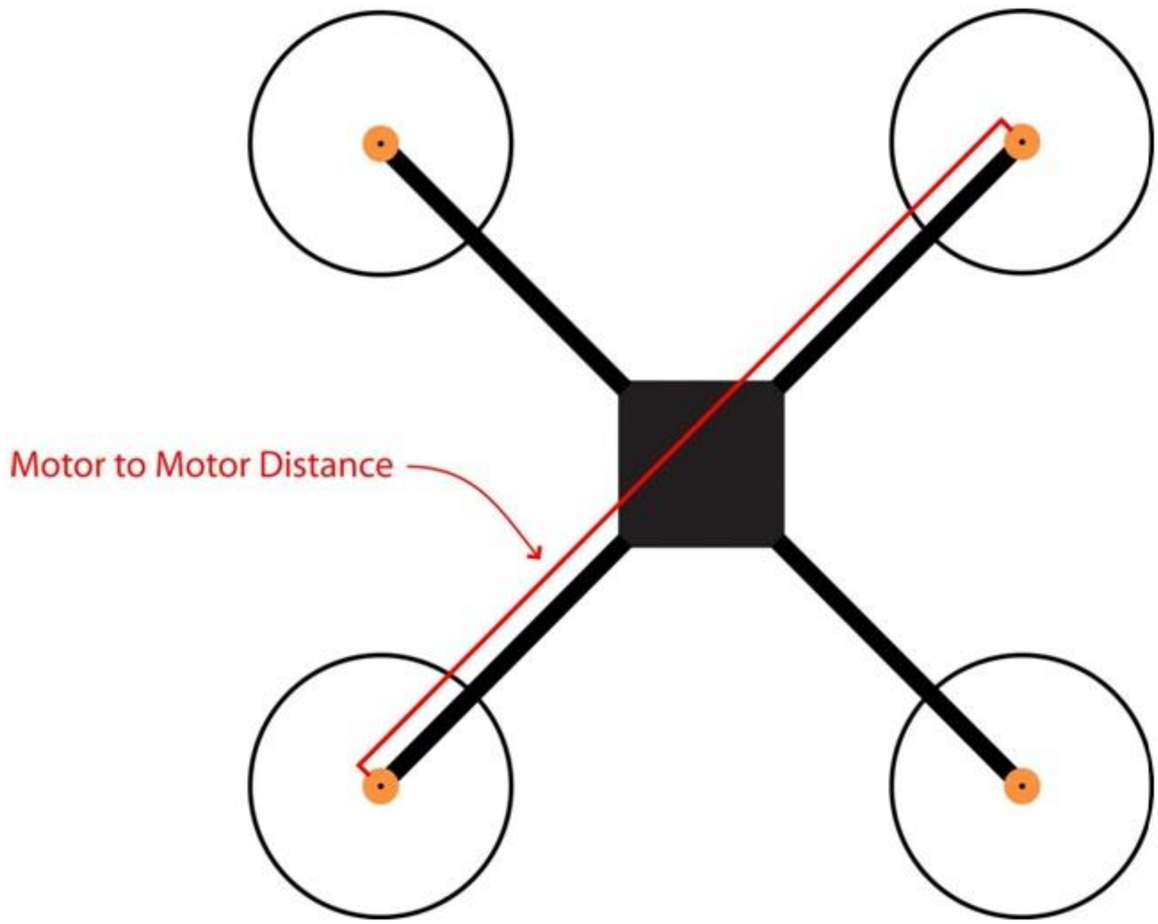
Carbon fiber is most rigid and vibration absorbent out of the three materials but also the most expensive.

Hollow aluminium square rails is the most popular for the QuadCopters' arms due to its relatively light weight, rigidness , affordability and cheap . However aluminium could suffer from motor vibrations, as the damping effect is not as good as carbon fiber. In cases of severe vibration problem, it could mess up sensor readings.

Wood board such as MDF plates could be cut out for the arms as they are better at absorbing the vibrations than aluminium. Unfortunately the wood is not a very rigid material and can break easily in quadcopter crashes.

Although it is not as important as for the arms which of the three material to use for the center plate, aluminium is most commonly used because of its the light weight, easy to work with and good vibration absorbing features.

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

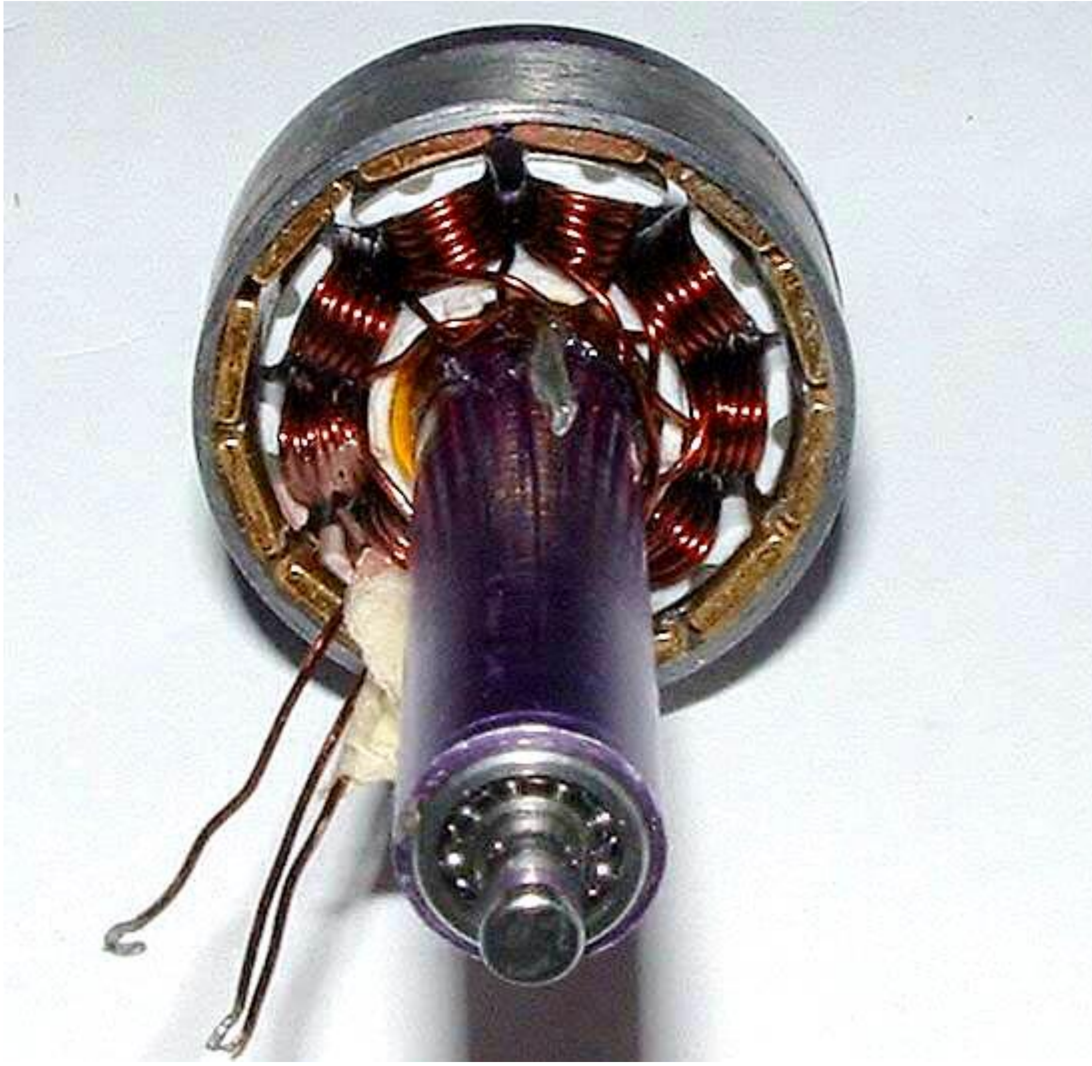


The motor to motor distance usually depends on the diameter of the propellers. To make you have enough space between the propellers and they don't get caught by each other.

2.2 Rotors (motors)

A little background of Brushless motor. They are a bit similar to normal DC motors in the way that coils and magnets are used to drive the shaft. Though the brushless motors do not have a brush on the shaft which takes care of switching the power direction in the coils, and this is why they are called brushless. Instead the brushless motors have three coils on the inner (center) of the motor, which is fixed to the mounting.

On the outer side it contains a number of magnets mounted to a cylinder that is attached to the rotating shaft. So the coils are fixed which means wires can go directly to them and therefor there is no need for a brush.



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

Brushless motors come in many different varieties, where the size and the current consumption differ. When selecting your brushless motor you should take care of the weight, the size, which kind of propeller you are going to use, so everything matches up with the current consumption. When looking for the brushless motors you should notice the specifications, especially the "Kv-rating".

The Kv-rating indicates how many RPMs (Revolutions per minute) the motor will do if provided with x-number of volts. The RPMs can be calculated in this way:

$$RPM=Kv*U$$

which is an easy way to calculate rating of motor you need.

2.3 Propeller

On each of the brushless motors there are mounted a propeller.
it might not be noticed this on the pictures, but the 4 propellers are actually not identical. You will see that the front and the back propellers are tilted to the right, while the left and right propellers are tilted to the left, 2 rotors rotates in the opposite directions to the other two to avoid body spinning . By making the propeller pairs spin 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 Quadcopter to stabilize the yaw rotation, which is the rotation around itself.

The propellers come in different diameters and pitches (tilting). You would have to decide which one to use according to your frame size, and when that decision is made you should chose your motors according to that. Some of the standard propeller sizes used for QuadCopters 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.

-Aerodynamics is just way too complex for non-academic hobbyists. It's even unlikely we can explain all that theory stuff in a few words. But in general when selecting propellers you can always follow these rules:

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.

Analysis of Propeller Pitch, Diameter, and RPM:

-Pitch VS Diameter: the diameter basically means area while pitch means effective area. So 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 will give you 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.

-In choosing a balanced motor and propeller combination, you have to figure out what you want your quadcopter to do. If you want to fly around stably with heavy subject like a camera, you would probably use a motor that manages less revolutions but can provide more torque and a longer or higher pitched propeller (which uses more torque to move more air in order to create lift).

2.4 ESC

The brushless motors are multi-phased, normally 3 phases, so direct supply of DC power will not turn the motors on. Thats where the 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.

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 Quadcopter 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. You should always choose an ESC with at least 10 A or more in sourcing current as what your motor will require. Second most important factor is the programming facilities, which means in some ESC you are allowed to use different signals frequency range other than only between 1 ms to 2 ms range, but you could change it to whatever you need. This is especially useful for custom controller board.

2.5 Battery – (Power Source)

As for the power source of the quadcopter, I would recommend lithuim polymer Battery(LiPo) because firstly it is light, and secondly its current ratings meet our requirement. NiMH is also possible. They are cheaper, but it’s also a lot heavier than LiPo Battery.

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 QuadCopter 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, it's needed to do some calculations on:

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

A good rule of thumb is that you 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 having a 4000mAh battery, will getting around 4 minutes of full throttle flight time though with a 1KG total weight will get around 16 minutes of hover.

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:

$$MaxCurrent = DischargeRate \times Capacity$$

For example if there is a battery that has a discharge rate of 30C and a capacity of 2000 mAh. With this battery you will be able to source a maximum of 30Cx2000mAh = 60A. So in this case you should make sure that the total amount of current drawn by your motors won’t exceed 60A.

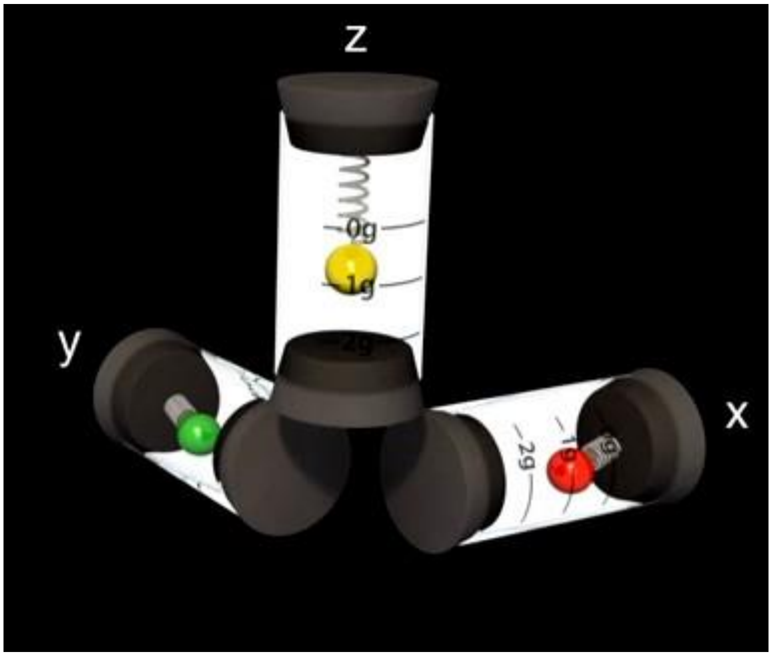
2.6 IMU – Sensors

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

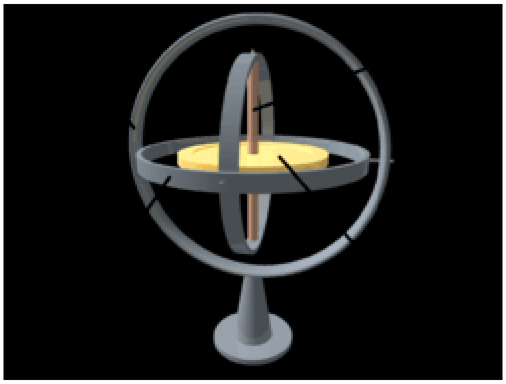
The IMU is a combination of the 3-axis accelerometer and 3-axis gyroscope, together they represent a 6DOF IMU. Sometimes there is also an additional 3-axis magnetometer for better Yaw stability (in total 9DOF).

How does IMU work?

-The accelerometer measures acceleration and also force, so the downwards gravity will also be sensed. As the accelerometer has three axis sensors, we can work out the orientation of the device.



-A gyroscope measures the angular velocity, in other words the rotational speed around the three axis.



-A magnetometer measures the directions and strength of the magnetic field. This magnetic sensor can be used to determine which way is south and north. The pole locations are then used as a reference together with the Yaw angular velocity around from the gyroscope, to calculate a stable Yaw angle.it is sometimes used as The accelerometer cannot sense yaw rotation like it can with roll and pitch.

What about using Only Gyroscope?

Since the gyroscope can tell us the rotational movement, why can’t we just use the gyroscope alone?!

The gyroscope tends to drift a lot, which means that if you start rotating the sensor, the gyroscope will output the angular velocity, but when you stop it doesn’t necessarily go back to 0 deg/s. If you then just used the gyroscope readings you will get an orientation that continues to move slowly (drifts) even when you stopped rotating the sensor. This is why both sensors has to be used together to calculate a good and useful orientation.

2.7 RC Remote .

QuadCopters can be programmed and controlled in many different ways but the most common ones are by RC transmitter in either Rate or Stable mode. The difference is the way the controller board interprets the orientations feedback together with your RC Remote joysticks.

In Rate mode only the Gyroscope values are used to control the quadcopter. The joysticks on your RC Remote 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. This is useful when doing acrobatics with your quadcopter as you can tilt it a bit to the right, release your joysticks, and then your quadcopter will keep that set position.

For the beginners the Rate mode might be too difficult, and you should start with the Stable mode. All the sensors are used to determine the quadcopters orientation in the stable mode. The speed of the 4 motors will be adjusted automatically and constantly to keep the quadcopter balanced. You control and change the angle of the quadcopter with any axis using the joystick. For example to go forward, you can simply tilt one of the joysticks to change the pitch angle of the quadcopter. When releasing the joystick, the angle will be reset and the quadcopter will be balanced again.

3 Flight controller system

3.1 Introduction

In this chapter , description to the flight controller system needed for the quad-copter . flight controller system contains input data , algorithm for manipulations and output data , so like any other system . For a robot , there always be a microcontroller as a brain performing an algorithm as a though .

3.2 The problem and its solution

The following lines talk about a quad-copter flying control as a problem and the flight controller system as its solution .

Problem

for a quad-copter , achieve flying stability with pilot commands .

Considerations

start hovering , stay flying and stable while in air till landing command .
for more clearance start hovering , landing , moving right or left , up or down and forward or
backward movements all is controlled by a pilot with a RC .

Input

the RC signals (commands from the pilot) , the gyroscope readings and battery voltage drop .

Output

proper signals for each of the four motors to achieve the considerations .

Solution

A closed loop control system including PID algorithm in the flight controller system .This chapter starts describing how the control system works , then designing it as a solution of our flight controller system .

3.3 Start working on the solution

A brief introduction why to choose a PID with closed loop control system ? to calculate the error in feedback mechanism which is the difference between desired state and the current state of the system then re-correct the actions of system to reach what is desired , so the controller is a way to convert the error into a signal command to the system to correct its actions , and its goal to reduce the error over time .

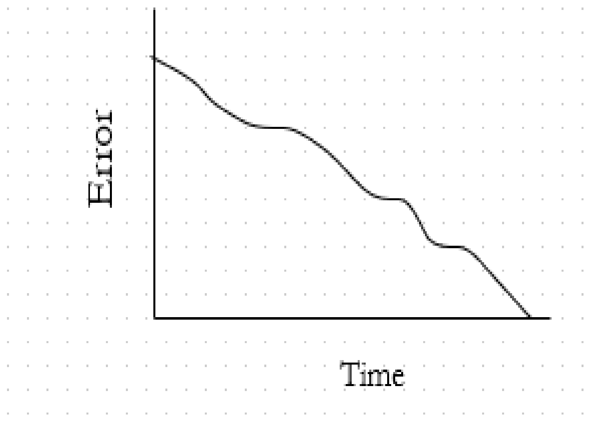


Figure 3.1 : example plot of controller goal

3.3.1 Describing a feedback controller system

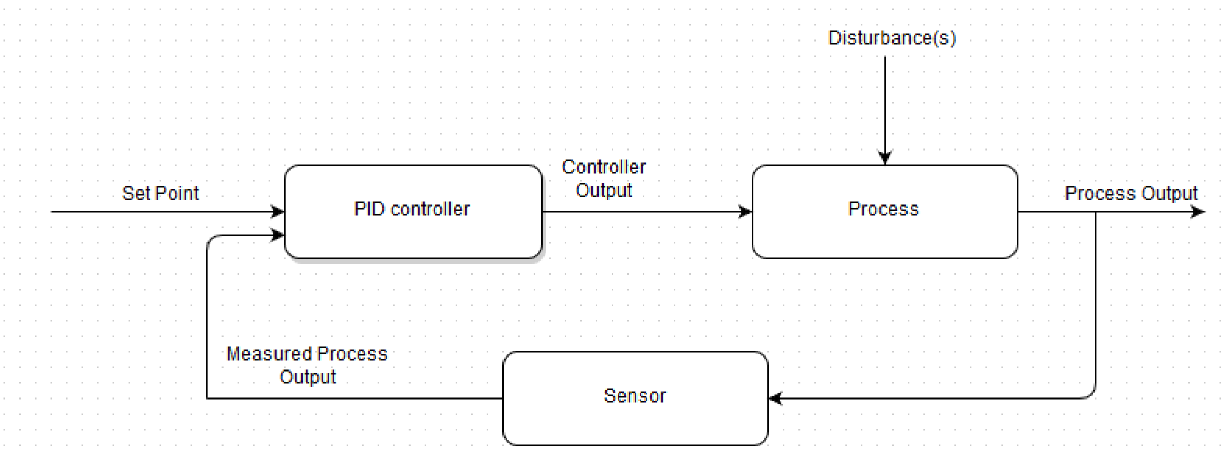


Figure 3.2 : Flow diagram of the controller system

System Input :

- Set point : is the desired point (state) we want the system to reach .
- Measured process output : is the measured (sensed) state of the system after the process actions applied , sent as a feedback to feed the system again .

System Manipulations :

- PID controller : measures the error of the system's actual state value and the desired set point
  , then calculates the corrective values to send it (as Input) to the process .
- Process : actuators of the system actuating depending on incoming values of the PID controller .
- Sensor : measures the current system state and return it as an input to the system to keep track of the current state values .

System Output :

- Process output : the values of the real actions has been made by the system actuators .

When the set point value is the same of the measured value , then the error is equal to zero and the controller do nothing .
If there is a disparity between the set point and the measured value , then there is an error and corrective actions is needed .

4.3.2 Describing the PID controller

The PID formula is simple and can be written as follows :

$$Output = K_P e(t) + K_I \int e(t)dt + K_D \frac{d}{dt} e(t)$$

To make the calculations more clear , the PID calculations can be described as follows

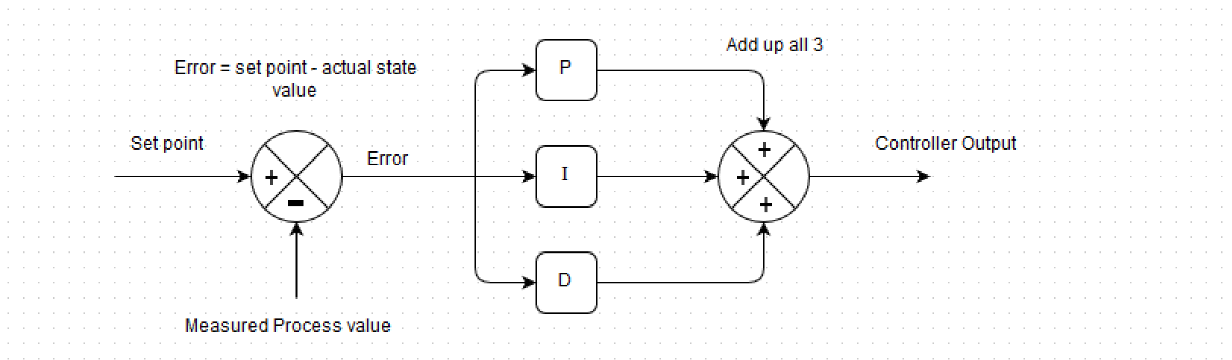


Figure 3.3 : Flow diagram of the PID controller

The P entity represent the $K_P e(t)$ term ,
The I entity represent the $K_I \int e(t)dt$ term ,
and the D entity represents the $K_D \frac{d}{dt} e(t)$ term .

PID theory :

1 - Proportional Response

The proportional component **depends only on the difference between the set point and the process value**. This difference is referred to as the Error term. The *proportional gain* K_p determines the ratio of output response to the error signal. increasing the proportional gain will increase the speed of the control system response. However, if the proportional gain is too large, the process value will begin to oscillate. If K_p is increased further, the oscillations will become larger and the system will become unstable and may even oscillate out of control.

2 - Integral Response

The integral component **sums the error term over time**. The result is that even a small error term will cause the integral component to increase slowly. The integral response will continually increase over time unless the error is zero, so the effect is to drive the Steady-State error to zero. Steady-State error is the final difference between the process value and set point. A phenomenon called integral windup results when integral action saturates a controller without the controller driving the error signal toward zero.

3 - Derivative Response

The derivative component causes the output to decrease if the process value is increasing rapidly. The derivative response **is proportional to the rate of change of the process value**. Increasing the *derivative time* (T_d) parameter will cause the control system to react more strongly to changes in the error term and will increase the speed of the overall control system response. Most practical control systems use very small derivative time (T_d), because the Derivative Response is highly sensitive to noise in the process variable signal. If the sensor feedback signal is noisy or if the control loop rate is too slow, the derivative response can make the control system unstable.

And still there the tuning part , where to choose the P,I and D gains . tuning differs a lot of what the system controls , controlling the temperature in a room differs from controlling the angle of the driver's foot on the gas pedal for the cars speed or position .

4 - Tuning

The process of setting the optimal gains for P, I and D to get an ideal response from a control system is called *tuning*. There are different methods of tuning of which the "guess and check" method and the Ziegler Nichols method will be discussed.

The gains of a PID controller can be obtained by trial and error method. Once an engineer understands the significance of each gain parameter, this method becomes relatively easy. In this method, the I and D terms are set to zero first and the proportional gain is increased until the output of the loop oscillates. As one increases the proportional gain, the system becomes faster, but care must be taken not make the system unstable. Once P has been set to obtain a desired fast response, the integral term is increased to stop the oscillations. The integral term reduces the steady state error, but increases overshoot. Some amount of overshoot is always necessary for a fast system so that it could respond to changes immediately. The integral term is tweaked to achieve a minimal steady state error. Once the P and I have been set to get the desired fast control system with minimal steady state error, the derivative term is increased until the loop is acceptably quick to its set point. Increasing derivative term decreases overshoot and yields higher gain with stability but would cause the system to be highly sensitive to noise.

Often times, engineers need to tradeoff one characteristic of a control system for another to better meet their requirements.

The Ziegler-Nichols method is another popular method of tuning a PID controller. It is very similar to the trial and error method wherein I and D are set to zero and P is increased until the loop starts to oscillate. Once oscillation starts, the critical gain K_c and the period of oscillations P_c are noted. The P, I and D are then adjusted as per the tabular column shown below.

Control	P	Ti	Td
P	0.5Kc	-	-
PI	0.45Kc	Pc/1.2	-
PID	0.60Kc	0.5Pc	Pc/8

Figure 3.4 : Table Ziegler-Nichols tuning, using the oscillation method.

3.3.3 Designing solution

Designing quad-copter solution based on closed loop control system can be done by adding quad-copter components to the system , the following figure demonstrates the flow diagram of the quad-copter controller system .

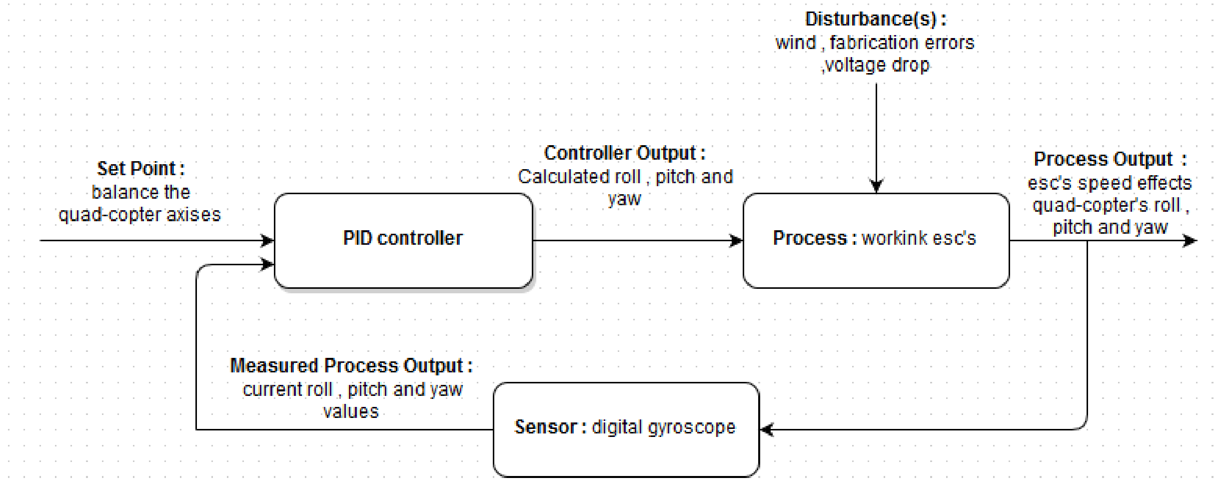


Figure 3.5 : Flow diagram of the quad-copter controller system

System Input :

- Set point will be balancing quad-copter axes, making desired orientation point to zero .
- Measured process output : gyroscope measures the current orientations about the axes , i.e roll , pitch and yaw values .

System Manipulations :

- PID controller : calculates the error which is the difference between current roll , pitch and yaw and the set point for each , then calculates corrective values to send it as input to the esc's .
- Process : Esc's controlling speed of four motors actuating depending on the incoming values of the PID controller .
- Sensor : digital gyroscope measures the current roll , pitch and yaw then returns it as an input to the system which the PID controller to keep track of the system current orientations .

System Output :

- Process output : working esc's feed by the PID controller to control four working motors .

3.3.4 Pseudo code

```
void setup function
            initialize the gyroscope
            calibrate gyroscope
            bind the receiver with the transmitter
            start calculating battery voltage drop

void loop function
            get gyroscope current readings
            calculate PID values for roll pitch and yaw
            calculate voltage drop to compensate it
            update the Motors with the new measured values
```

Figure 4.6 : Pseudo code for the flight controller

4 System Implementation

The processing time for each components considers a major factor before choosing which microcontroller to use , the component processing time is as follows :
the gyroscope getting roll , pitch and yaw readings in approximately in 300us ,
the esc's speed varies needs from 1000us to 2000us ,
PID calculations needs approximately 600us to be done .
This controller is working on a 250Hz refresh rate which means there is available 4000us of time for each new corrective cycle in the main loop , this is 250 corrections done every second .

Arduino is the most common and easy to use microcontroller nowadays .

4.1 Arduino as a platform for Implementation

Arduino Uno is quite simple and good for the flight controller application , Arduino Uno specifications can be found on the original website
www.arduino.cc
The Arduino Uno is a microcontroller board based on the ATmega328
main specifications :

Microcontroller	ATmega328
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

4.2 Technical problems and its solutions

while the implementations , the ready functions in arduino standard libraries like
attachInterrupt(PinNum,InterruptServiceRoutine,State) causes some problems with microcontroller with such a sensitive application especially hanging out and stop responding .
A technical advice from Joop Broking channel on Youtube shows the problem and its solution ,
otherwise using this ready functions , Arduino offers talking to the ATmega328 registers directly in the code , these may make the code hard to be read but has two advantages :

1- as the Arduino Uno runs on 16 MHz which is quite not too fast to omits operations operating on the controller , using the registers directly saves time and more CPU cycles as the ready functions saved on libraries needs to be linked and loaded .

2- using the ready functions need more space to be occupied on the Flash memory after uploading the code on the Arduino board .

4.3 Tuning

The previous chapter explained tuning process , in this section the tuning is done in practical steps .

4.3.1 PID tuning parameters

while tuning the quad-copter we followed these steps , note the pitch gains are set to roll gains .
- step 1 :
set the P gain of 1 for every gain , hold the quad-copter firmly in your hand then increase the throttle , now you can feel the controller corrections in the right direction , if this is not the case , check the gyroscope directions .

- step 2 :

when the directions is right , set all the P gains back to zero , then P gain of 3 and I of 0.02
for the Yaw , this basic setup will prevent the quad-copter of yawing when we try flying it , you can raise the setting later in .

step 3 :

set the D gain for Roll and Pitch to 3 , put the quad-copter on grass or a carpet then raise throttle to the point it is almost start to hover , increase D gain up to the point when become raiseless , then lower the D gain down till it run smooth again .

step 4:

at last , lower it again of 25% and this its final settings for the D gain .

Step 5 :

start to increase the P gain for Roll and Pitch in step of 0.2 , when the P gain is decent enough quad-copter should be able to fly .

Step 6 :

increase the P gain till is start to over compensate , lower this P gain by 50% and this its basic setting for the P gain .

Step 7 :

start increasing the I gain for Roll and Pitch in step of 0.01 , notice flying become more stable , keep increasing the I gain till it start to oscillate slowly . when this happens , lower the I gain by 50% and keep this as a final settings for the I gain .

Step 8 :

increase the P gain up to point of fast oscillation , take back a few points and it will fly good in stable performance , keep this as a final settings for the P gain .

5 Future Work

Working on task control which is detecting toxic gases within air around the factory's buildings in order to measure how the air is affected by those chemicals used by such factories

What about using Accelerometer , Gyroscope and magnetometer ?

With the accelerometer , the orientation can be measured with reference to the surface of earth. But the accelerometer tends to be very sensitive and unstable sometimes, when motor vibration is bad, it could mess up the orientation. Therefore we use a gyroscope to address this problem. With both the accelerometer and gyroscope readings we are now able to distinguish between movement and vibration , as the gyroscope tends to drift a lot, which means that if you start rotating the sensor, the gyroscope will output the angular velocity, but when you stop it doesn't necessarily go back to 0 deg/s. If you then just used the gyroscope readings you will get an orientation that continues to move slowly (drifts) even when you stopped rotating the sensor. This is why both sensors has to be used together to calculate a good and useful orientation.

magnetometer measures the directions and strength of the magnetic field. This magnetic sensor can be used to determine which way is south and north. The pole locations are then used as a reference together with the Yaw angular velocity around from the gyroscope, to calculate a stable Yaw angle.it is sometimes used as The accelerometer cannot sense yaw rotation like it can with roll and pitch.