Position Control in Quadcopter Drones

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1. Introduction

1.1 Introduction

A **quadcopter** is also known as **quadrotor helicopter** or **quadrotor**. Quadcopter is a multirotor that is lifted by four rotors. Two pairs of identical propellers are used in Quadcopters out of which two rotate in clockwise and other two rotate in counterclockwise direction as shown in Fig 1.1. The red propellers are moving in clockwise and blue propellers are moving in counterclockwise direction.

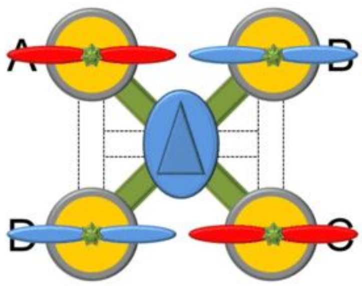


Fig 1.1: Direction of travel of each propeller

Due to mechanical simplicity, quadcopters are cheaper and more durable than conventional helicopters. Advantage of smaller blades is they possess less kinetic energy, reducing their ability to cause damage[1].

1.2 Flight Dynamics

The basic terminology of various axes[2] of quadcopters are defined as follows:

Pitch – To tilt it up and down from front to back. This causes the vehicle to move forwards or backwards depending in the way it is tilted.

Roll – To tilt side to side by moving the quadcopter in longitudinal axis. This moves the vehicle to left or right depending on the tilt.

Yaw – To move the Quadcopter around in a clockwise/anticlockwise rotation.

Equal thrust is applied to all rotors in order to adjust the altitude. Yaw of the quadrotor is adjusted by applying more thrust to the rotors moving in one direction. Pitch and Roll are adjusted by applying more thrust to one rotor and less thrust to its diametrically opposite rotor.

1.3 Working

Altitude at which the drone is flying is determined by the amount of power on all the rotors. For forward motion of the drone, the back propellers are to be driven fast than the front propellers. To move the drone sideways, corresponding rotors i.e., left or right propellers are to be driven faster.

Drones flying in air are controlled by the ground station controllers. The control signals are communicated between the drone and the controller using wireless technologies like bluetooth, wifi, radio frequency communication etc. The data from various sensors present on the drone is collected and sent to the controller to estimate the current position of the quadcopter. The transmitter referred here is the transceiver.

The work flow diagram as shown in Fig 1.3 includes the transmission of the data from the flight controller to the drone in which the input is analyzed and the speed of rotors is adjusted. Based on the drift of the drone due to air drift, gravitational force etc., the data from various sensors is collected and is sent to the stability control mechanism in the flight controller in which the errors are calculated and the counteraction is again transmitted to the drone from the controller.

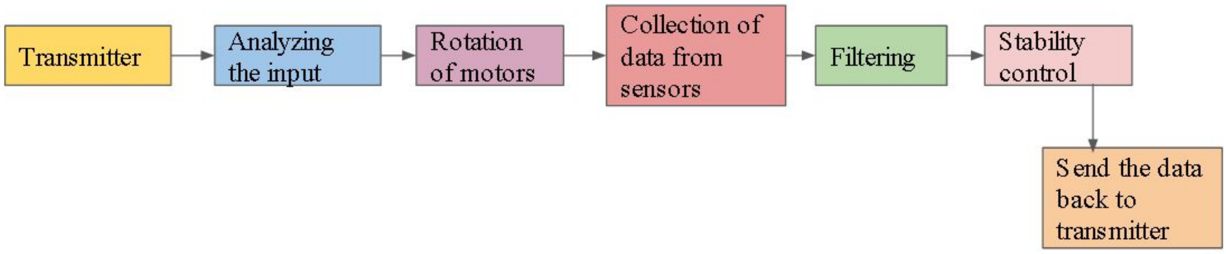


Fig 1.3: Work flow diagram

1.4 Challenges

Few challenges being faced in quadcopter drones are:

1. The response time between the data input and output at the drone and at the controller should be very less in order to maintain the flight of the drone. So the latency of the data sent should be very less for stable flight.
2. During the flight in air, many obstacles and interference with other signals in air might arise which is one of the major challenge to be addressed.
3. Speed of the wind is also a drawback.

1.5 Headless Mode

Latest feature available in the drones is **"Headless Mode"**. In this mode, the drone movements will be always aligned to the flight controller i.e., it doesn't matter, whatever may be the forward direction of the drone is pointing to. When the pilot pushes the drone forwards, the drone moves forward relative to the controller but not the heading of the drone. Similarly to move towards left, right or backwards. The advantage of the headless mode is it eliminates to keep track of the orientation of the drone which is really difficult once the drone flies far out of sight. The prerequisite for the drone to function in headless mode is to position the drone such that its front is the front of the controller before take-off.

2. Position Control in Drones

2.1 Sensors

Various sensors being employed on drone to maintain its flight as shown in Fig 2.1 are:

1. Accelerometer
2. Gyroscope
3. Magnetometer
4. GPS
5. Camera
6. Distance Sensor (Ultrasonic or Infrared)

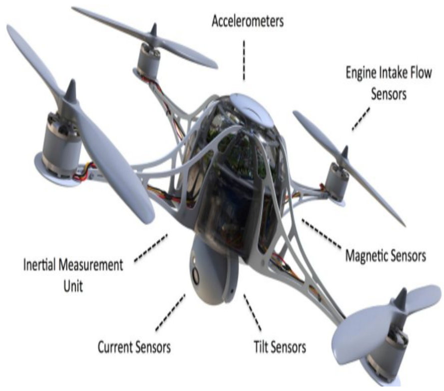


Fig 2.1: Types of sensors

Accelerometer and Gyroscope sensors are responsible for accurately measuring the rotation and linear axis of the quadcopter. These two form the majority of the sensors responsible for the flight of quadcopter. Failure of these sensors results in crash of the drone. Detailed functionality of each of these sensors is given in the following sections.

2.2 Gyroscope

The rotating information of the aircraft over its own axis i.e., Roll, Pitch and Yaw is given by the gyroscope. This information is sent to the stability control unit to stabilize the drone. When there is no deflection from pilot, the drone shouldn't face any deflection, if it deflects because of air drift then the readings are sent from gyroscope to the PID controller(stability control unit) which calculates the error and the counteraction is sent to the drone to prevent the unintended rotation. When there is a deflection from the pilot controlling, the controller translates the required deflection to desired rotation rate which is fed to the gyroscope to rotate the drone in the desired direction. The data is sent through I2C or SPI buses with frequency of 1kHz, 8kHz. The most commonly used gyroscope sensors in drones are MPU6000 and MPU6050.

2.3 Accelerometer

The linear acceleration of the aircraft is given by accelerometer i.e., the acceleration forces in X, Y and Z axes is reported. Accelerometer data helps to move the drone up, down and also to know the current altitude. The pilot's input for deflection is provided as the desired inclination by the controller. The limitations of accelerometers is they are easily affected by vibrations and they cannot differentiate the earth's gravitational force and the aircraft acceleration force.

2.4 Magnetometer

It is present in the drones equipped with GPS. Measures the magnetic field of the earth and helps in determining the direction of the compass located on the drone with respect to magnetic north.

2.5 GPS

GPS sensor is the primary sensor to locate the geographical position of the drone. The desired direction is compared with the current direction (sensed by GPS) by the controller and controller decides the direction in which the drone has to move to reach its destination.

2.5.1 Auto return home

Now-a-days many of the drones are being equipped with auto return home feature i.e., once the connectivity of the drone is lost or in case of low battery this feature can be enabled, then the drone return home i.e., the take off location. This feature can be present in drone with and without GPS sensor.

- Without GPS

  In this case, the quadcopter just flybacks in the opposite direction to the take off location in case of low power or lost connectivity.
- With GPS

  In this case, the quadcopter remembers the take off location(latitude and longitude) and uses GPS sensor to return to the saved location in case of low power or lost connectivity.

2.6 Distance Sensor

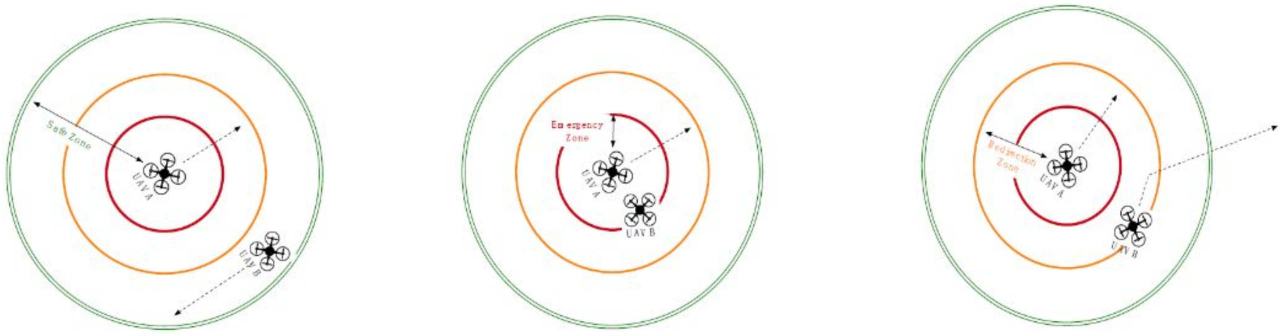
The distance sensor helps the drone to sense the obstacles so that the collision avoidance can be handled by the controller. Different types of distance sensors used in quadcopters include Ultrasonic, Laser and Infrared.

3. Collision Avoidance

3.1 UAV Flight Tracker

An increase in the number of drone practical applications, the traffic of drones flying is becoming dense. In such cases, collision of drones with each other is a major problem. To overcome this problem, a cloud based UAV monitoring and management system is developed known as 'UAV Flight Tracker'[8]. In this system potential collisions are detected and avoided by adjusting the flight paths and then alerting the users to change the paths.

It is a client-server model consisting of client, server and drone. Client is used to control the user added UAVs, receive the priority alerts and real time sensor updates. Server is used to implement the collision detection algorithm, to provide the sensor and collision information to the client, to manage the user profile information and update the flight control. It mainly consists of UAV monitoring module and UAV management module. The monitoring module keeps on monitoring the flight of the drones and provide the input to the management module. UAV management module includes UAV management, UAV control and collision management submodules.



Case 1: closely monitor UAV B in the safe zone. Case 2: stop movement for UAV B in the emergency zone. Case 3: change flight path of UAV in the redirection zone.

Fig 3.1 Cases considered for collision avoidance algorithm

Three different cases as shown in fig 3.1 are considered to implement the collision avoidance algorithm.

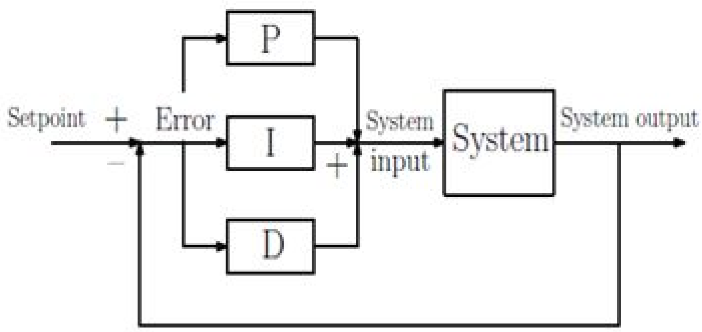
Case 1: Here, UAV B is flying in the safe zone of UAV A. Collision avoidance module will continuously monitor the UAV B so that redirection has to happen once it enters the redirection zone of UAV A.

Case 2: Here, UAV B entered the emergency zone of UAV A. It is prevented from immediate collision by preventing its motion for about 10sec (can be adjusted based on average speed of UAVs). The management module is provided with this information to stop the movement of UAV B and to keep hovering it in place.

Case 3: Here, UAV B is flying in the redirection zone of UAV A. The management module after receiving this information from collision avoidance module, redirects the path of UAV B so that it doesn't enter emergency of UAV A.

4. Stability Control

Stability control is drones is achieved by using various filters to estimate the correct sensor values and then once current parameters are ready they are fed to a PID controller as shown in Fig 4.1. Once stability in various input parameters is achieved, then we can control the height, speed, direction of the drone by varying speed on particular rotors.



$$out(t) = C_P e(t) + C_I \int_0^t e(\tau)d\tau + C_D \frac{d}{dt} e(t).$$

Fig 4.1: Block diagram of PID Controller

Stability in the position of a Quadcopter drone is achieved by using a standard PID controller. It is abbreviated as Proportional-Integral-Derivative controller. It operates using a generic control loop feedback mechanism and is popularly used in many industrial control system applications. The main objective of the PID controller is to minimize the total error of the system dynamically. It has three important phases in its operation flow namely proportional, integral and derivative terms. These three parts are functions of time and contribute in diminishing three different kinds of errors.

Proportional term takes care of current error of the system and helps in minimizing the current error. It is very essential part of the PID controller and is always required.Integral term takes care of past errors of the system and helps in eliminating steady state errors. This part has a drawback of slowing down the process of reaching a set point. If the system is biased, then absence of integral part might help in stabilizing the system near the steady state but the system can never reach steady state. Derivative part helps in predicting future errors and avoids oscillations in the drone system when it is around its steady state.

The weighted sum of the above three parts along with coefficients C_P, C_D, C_I enables us to calculate output at a time 't' as shown in the above equation and this output is fed to the system components and a stable state of the drone is achieved. The correct value of the coefficients used in calculating the output are calculated using standard techniques depending on the application.

5. Communication Technologies

Quadcopter drones predominantly use three means of wireless communication namely Wifi, Radio Communication and Bluetooth.

5.1 Bluetooth

Bluetooth can be used to control the flight of the drone but it can support a very limited range of around 40-100 metres distance between the controller and drone. Hence, it is practically not beneficial and only can be used in applications such as toys etc.

5.2 Wifi

Wifi can be used to control the flight of the drone at frequencies around 2.4 GHz. It is also useful in ultra-high radio frequency range supporting distance of around 600 metres between the controller and drone. It can support both image and data transmission between the controller and drone. It is practically beneficial and can be used in wide variety of applications.

5.3 Radio Communication

Radio communication technology can be used to control the flight of the drone in radio frequency range. If we use radio communication then the transmitter and receiver has to be tuned to the same frequency. In order to have proper identification and to enable a secure and authenticated communication we use RFID while establishing connection between transmitter and receiver. Generally, transmission frequency of 900 MHz is used in remote control drones. It is practically beneficial and can be used in wide variety of applications.

6. Real Time Systems

6.1 Need for Multi-core

Real time drone programming is a challenging task. For any drone to control the flight, it has to keep track of all the sensors (IMU, camera, ultrasonic etc). Process the data from camera sensor using computer vision while simultaneously, keeping track on the path of drone can be made easy using processors with multiple cores. But if we choose most powerful processors with higher clock frequency, the power consumption comes into picture. As drones work with batteries, and have very limited flight time, we have to keep an eye on these trade offs. Recently, companies like Intel, Qualcomm and Ambarella etc., are collaborating with various drone makers like Yuneec, Airware, PrecisionHawk etc., around the globe and designing processors that are especially suitable on such environments.

6.2 Case study

In this section, we discuss about a case study on programming an SDK required for drone control. Generally, most organizations and academic institutions choose multi core processors in order to support parallelism. There has been a lot of research being done in this area.

One such work is done using Java programming language in using ExoTasks scheduling on drones[9]. The drone is equipped with a 400MHz XScale with 64MB of memory. The implementation is approximated on AMD64 (2 GHz) and Intel Pentium M processors (1.4GHz). Here the author(s) considered variety of modes and did an in depth analysis of WCET and performance of schedulers. Here they have considered multiple tasks with a period of 20ms. As Java has an additional overhead of garbage collector, the authors also did an in depth analysis by including the overhead of Java's garbage collector to WCET.

Also there is some similar kind of work done by another group of researchers. They have developed a library called VOLTRON based on C++ and Java as host languages. This is supposed to be working the best in multi threading environments by their state-of-the-art "futures" and "promise" operational semantics. They have designed this library in such a way that it can control multiple drones (more than 100) simultaneously in order to perform some batch level jobs. The experiments are conducted on AR.Drone equipped with an ARM Cortex A8 CPU, 128 Mb of RAM, a WiFi interface, two cameras, and a range of sensors for navigation. It runs an embedded version of Linux[11]. Their library has the lowest run time overhead when compared to built in SDK.

One of leading drone maker DJI has used a 1.5 GHz Quad-Core Cortex A7 Artosyn AR8001 Processor and a Movidius MA2100A Vision Processor with 1 GB Mobile DDR2 SDRAM on its powerful drone Phantom 4.

7. Research Work

A good amount of research work is currently going on in the field of Quadcopter drones to improve existing object detection, and tracking algorithms.

7.1 Academia

Quadcopter drones have many sensors on board that continuously sense and transmit the data to the controller. These sensors require lot of power in order to operate. Research is underway to develop auto-charging platforms and flight algorithms including auto landing on a moving carrier object. One of the most important function of drones is object detection and tracking. Critical part of target tracking is the detection of target from video stream captured by the drone's front camera. Research is going on to utilize cloud based convolutional neural networks for real time object detection that helps in detecting hundreds of objects while decreasing power consumption by offloading computation. Currently, there is ongoing research to control drones with android phones boarded onto the Quadcopter drones, which provide all the sensor support to the quadcopter drones. By connecting phones to the internet servers, we can have the privilege of controlling the drones even from long distances.

7.2 Industry

Industrial research on quadcopter drones has come to the limelight from the Intel's recent show in a Football match with 500 drones called as "Intel Shooting Star", which were made to fly by a single pilot with a computer creating guinness world record. The drones consisted of LED lights that were controlled by the automation software developed by them and can travel upto 22 miles per hour. The weight of each drone is 280 grams and is built with optimized algorithms that can sense distances correctly to avoid collisions while landing and launch. Intel has also developed maximum collision avoidance technology that enables with perfect object tracking and avoids collision with objects.[3]

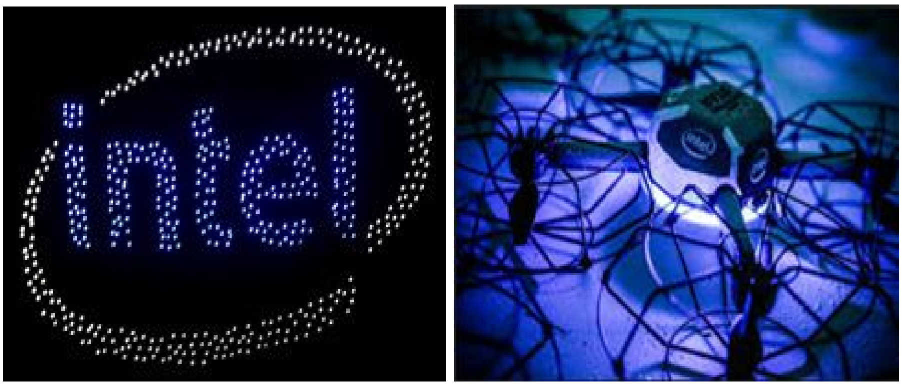


Fig 7.1: Intel Shooting Star Drone

In order to support the usage of drones in robotic and consumer applications, Qualcomm has developed a drone platform "Qualcomm Snapdragon Flight" as shown in Fig 7.2, that consists of both software and hardware features useful for navigation control, optical flow and uses advanced Computer Vision features that are integrated.[6] This platform uses a "Qualcomm Snapdragon 801" processor operating at 2.4 GHz frequency and is in the size of 58x40 mm providing support for a 4K camera resolution for image capturing and video streaming. It also provides 5 Hz GNSS support for location sensing with real time flight control using "Hexagon DSP" supporting Dual-band 2x2 802.11n Wi-Fi and Bluetooth 4.0 for communication purposes. In order to overcome the issue of flying blind i.e., not knowing the reason for the motors spinning fast or slow, a closed loop system 'Electronic Speed Control(ESC)' is used to monitor and control the motor speeds. ESC is crucial to provide each motor's RPM to the flight controller to provide any corrective action if needed.

Fig 7.2: Qualcomm Snapdragon Drone

8. Applications

Quadcopter Drones have wide variety of interesting applications due to the advancement in technology. Few major applications include

1. Security
2. Inspection - can be used for aircraft inspection without the need for special platforms
3. Science and Research
4. Agriculture
5. Defense
6. Photography
7. Filming
8. Search and Rescue - to search and rescue in remote areas, flooded areas etc
9. Real Estate Photography
10. Mining - can be used to handle jobs which are harmful to humans or to enter hazardous locations
11. Product Delivery - to deliver products (Example - Amazon Prime Air shown in Fig 8.1)

Fig 8.1 Amazon Prime Air Drone

9. Limitations

Although there are wide variety of applications of drones there are limitations as well which include

1. Range - communication to drone and controller are limited within a specific range
2. Battery Life
3. Privacy
4. Weight Limit - Drones employed in cargo can carry less weight packages only
5. Property damage - due to drone collisions

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