Limerick Institute of Technology Engineering Week Presentation 2018

LIT
FACULTY OF APPLIED SCIENCE, ENGINEERING AND TECHNOLOGY

Leaving Certificate Engineering Prescribed Topic 2018

"Basic Principles of Operation and Applications of Drone Technology"

Presented by:

David Sims
Department of Electrical and Electronic Engineering
Limerick Institute of Technology

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1 Introduction

A drone, more formally known as an Unmanned Aerial Vehicle (UAV), is an unmanned aircraft. A drone may be operated via remote control or it may use an autopilot mechanism to guide it. The last decade has seen the cost of drones reach professional and consumer levels, with the popularity of flying drones as a hobby or for the purposes of aerial photography increasing significantly.

The most popular type of consumer drone is a multi-rotor, quadcopter design.

2 History of Drone Technology

What we recognise today as drone or UAV technology has been in development for over a century. In September 1917, the first flight of Hewitt-Sperry Automatic Airplane took place, which was developed by the USA during World War I to serve as a pilotless aircraft capable of carrying explosives to its target. The first drones used gyroscopes to stabilise the aircraft and barometers to regulate the height of the aircraft where both of these mechanisms are still at the core of modern drone technology.

During World War II more than 9,400 Radioplane OQ-3 drones were produced in the United States to serve as gunnery targets for training. The design was modified from a remote control model plane originally sold to hobbyists. Towards the end of World War II Germany launched the first cruise missile, the V-1, in 1944. 9,521 cruise missiles were fired at south-east England during the final months of the war, the missiles used an automatic guidance system to find their targets. The US military also used drones to measure radiation during nuclear tests, sometimes flying the drones directly above nuclear explosions.

Figure 1 Hewitt-Sperry Automatic Airplane in 1918 (wikimedia.org)

While the development of drone technology has been led by the military, not all of the drones are related to weaponry and during the Vietnam War in the 60s and 70s, the US deployed Reconnaissance Drones to fly over Vietnam. These drones would record still pictures of the terrain and once they were outside of Vietnamese airspace, the drone would land using a parachute where it would be recovered and its imagery processed.

Figure 2 Radioplane OQ-3 on launch platform (wikimedia.org)

Beginning in the 1920s, several attempts were made to produce a manned Quadcopter vehicle but none of them have met the standard for military use due to the difficulty in creating efficient components at the size required. The Quadcopter, which is most commonly seen in consumer drones today, was among the first VTOL (Vertical Take Off and Landing) vehicles, a capability that is now also possessed by jet fighters.

As with most technology given sufficient research and development, the cost of building or purchasing a drone has dropped significantly from a time when only governments could afford them to the present where they are on sale in toy shops.

3 Types of Drone

As there are many different types of aircraft, there are many types of drone. Each configuration has its own advantages and disadvantages. While the multi-rotor quadcopter design gets the most attention today in the consumer and prosumer space, other types of drone are widely in use.

3.1 Multi-Rotor

The Multi-rotor drone, usually seen as a Quadcopter with four propellers, is an accessible drone type suitable for use by hobbyists because of its VTOL ability. Multi-rotor drones require a lot of power to keep them in flight as they need to use the propellers to generate lift, the battery life on most of these types of drones rarely exceed 30 minutes with a small payload. Drones that are capable of carrying heavier loads will often do so at the expense of battery life.

The limited speed and battery life of the multi-rotor drones makes them suboptimal for land surveying, pipeline inspection and other uses which would require a longer flight time. Liquid fuel engines can't be used on multi-rotor drones due to the speed at which the rotors are required to change their speed to balance the drone.

Figure 3 A Multi-rotor drone featuring six propellers

3.2 Fixed Wing

Fixed wing drones are airplanes that use their wings to generate lift, instead of the rotors in the quadcopter. This allows the fixed wing drone to use less energy as it only has to move forward and doesn't have to generate lift separately. These aircraft can use liquid fuel engines and some military models can stay airborne for several days.

Fixed wing drones, like airplanes, require space for take-off and landing. In the event that a runway is not available, a catapult may be used to launch the drone and a parachute may be used to land the drone safely. Unlike multi-rotor drones which can hover in place, a fixed wing drone is always moving. Manual control can be difficult and require a lot of practice.

Figure 4 An MQ-1 Predator Unmanned Fixed Wing Drone prepares for takeoff

3.3 Single-Rotor

Single-rotor designs, like helicopters, are more efficient in terms of their energy usage but require more hardware to stabilise them and they are more difficult to control. The Yamaha RMax, a single rotor drone, is said to be the most advanced non-military drone in production with prices ranging between $80,000 for the basic model and $250,000 for the most advanced model.

After the Fukushima nuclear disaster, the RMax was used to monitor radiation levels inside of the 'no-entry' zone. The RMax is capable of autonomous flight using GPS to determine its location.

Figure 5 A Yamaha RMax being prepared for use in agriculture - UC Davis College of Engineering

3.4 Fixed-Wing Hybrid

Fixed-wing hybrids attempt to marry the VTOL aspects of the rotor based designs with the efficiency of the fixed wing models. Recently Amazon announced that they were working on delivery drone technology which featured the hybrid design. This design would allow the drone to cover large distances using fixed wing flight, and to easily land in a customer's garden using the VTOL aspects of the rotor based design.

Figure 6 Amazon Prime Air - Fixed Wing Hybrid Prototype Delivery Drone (amazon.com)

4 Drone Law in Ireland

Figure 7 Drone Flying Guidelines from the IAA (iaa.ie)

All drones over 1KG in weight must be registered with the Irish Aviation Authority. The data protection commissioner also issued guidelines on how to handle data that could be captured with drones: “At all times, drone operators should ensure that their collection and processing of personal data is minimised to only that necessary or as a consequence of the job being undertaken.” If you are recording video in a public place it is also necessary under the Data Protection Act to notify the public, as they may not be aware that the drone is equipped with a camera.

Certain commercial operations are prohibited without permission, and the operator is required to have completed a drone safety course. Commercial drone operations require insurance whereas recreational drone use does not.

5 Drone Technology

The most popular type of consumer drone is the Quadcopter. The following section details the components and the basic principles of operation for a Quadcopter drone.

5.1 Parts of a drone

5.1.1 Chassis

The chassis of a quadcopter has to be as light as possible to enable the quadcopter to carry the rest of the electronics and motors. Drone chassis are usually made out of light material such as plastic, aluminium or carbon fibre. The carbon fibre and aluminium can block radio waves so you have to be careful with the placement of antennae so that the chassis doesn't block them.

Figure 8 Quadcopter Chassis (hobbyking.com)

5.1.2 Propellers

The quadcopter has four propellers for stability, two that spin clockwise and two counter clockwise. Light durable materials are generally used, with plastic propellers favoured among hobbyists due to their durability.

Figure 9 Carbon Fibre Propeller (hobbyking.com)

The length of the propeller affects the thrust, with longer propellers generating more thrust requiring more power. The propellers on quadcopters are often called rotors, rotor is the generic name for any rotating part of a mechanical device whereas propellers are designed to generate thrust.

5.1.3 Motors

The propellers are connected directly to a brushless DC motor which spins the propellers at a speed determined by a speed controller. Smaller drones may used brushed motors. It is important that the combination of the propellers and the motors generate enough thrust to not only lift the drone off the ground, but also to stay airborne against the wind. A general rule of thumb is that your motors and propellers should be able to generate 1.5 times the weight of the drone as thrust.

Figure 10 Brushless Motor (hobbyking.com)

5.1.4 Electronic Speed Controller

The Electronic Speed Controller (ESC) converts the digital output signal from the flight control board to a voltage that will determine how fast the motor spins.

5.1.5 Radio Transmitter and Receiver

The Remote Control (RC) radio transmitter is used to send signals to the radio receiver on the drone. These signals are used to control the drone and they are sent to the flight control board. You need a minimum of four radio channels (throttle, pitch, roll and yaw) to control a quadcopter. A separate transmitter and receiver would need to be used to send back live video.

Some drones also contain WiFi modules, but the range is limited.

5.1.6 Battery

The battery in a drone dictates how much flight time the drone will have, but it also contributes to the weight of the drone. The battery also has to power each of the components on the drone, including the flight board, sensors, and communication, but the main power draw on the battery is the motors.

5.1.7 Sensors

The drone contains multiple sensors that are used as input to the flight controller board to be combined with the Remote Control input to generate the movement of the drone. Gyroscopes are capable of detecting angular velocity or rotation. Accelerometers are capable of detecting acceleration. The gyroscope and accelerometer are often combined into an Inertial Measurement Unit.

5.1.8 Global Positioning System

More recently drones have started to incorporate Global Positioning System (GPS) receivers that allow them to locate themselves on the planet surface using signals from GPS satellites and also to auto-navigate to waypoints based on GPS coordinates. DJI, a popular maker of consumer drones, has control software that enables the programming of a flight path based on GPS coordinates and the generation of a search grid to assist in search and rescue operations. The GPS also enables the drone to calculate and reserve enough battery power to make a return journey to base.

5.1.9 Flight Control Board

The flight control board contains the brains of the drone, a micro-controller. Micro-controllers are small self-contained computers which are used to control all aspects of the drone's flight. While you can use an off the shelf micro-controller (like the Arduino or Raspberry Pi) and add the sensors yourself, the specialised flight control boards are lighter and contain all the parts that are necessary for flying the drone.

The micro-controller operates on an "input, process, output" loop, where it captures all of the inputs (remote control input, gyroscope, accelerometer, GPS, etc.), processes the data and produces an output in the form of a signal that controls the motors.

Figure 11 APM Flight Control Board (geetech.com)

There are many Open Source versions of flight control software in existence which means that they can be modified freely. The open source project PX4 includes autopilot controls for a variety of different drone types, all of which are free to use.

5.2 Closed Loop Control

The stabilisation of drones using the micro-controller is one of the main reasons that they have grown in popularity. This allows a less skilled pilot to control the drone as the flight controller automatically adjusts the motors to keep the drone stable.

The drone is not directly controlled, meaning that the input from the remote control isn't directly controlling the motors, instead the remote control conveys the intention of the operator and the micro-controller uses this input in combination with the gyroscope and accelerometer to calculate the speed of each motor. This kind of stabilisation is achieved by using a closed loop control system.

A closed loop control system is one that monitors the process and takes feedback into account. It constantly monitors the sensors on the drone and compares them to where they should be based on the input from the pilot. It also keeps the drone hovering in a stable manner when there is no input provided from the controller. The most widely used control system in quadcopters is proportional control.

Proportional control generates an output that is proportional to the change that it needs to make. For example, if the quadcopter is off balance, successive changes to the speed of the motor will be made proportionally, taking the sensors readings into account, until the quadcopter is level. This change is calculated by an algorithm known as PID or Proportional-Integral-Derivative.

5.3 Flight Dynamics of a Quadcopter

As mentioned earlier, the four propellers on the quadcopter are comprised of two sets, one rotating clockwise, the other rotating anti-clockwise. Each propeller produces thrust, to control altitude, and torque, the torque causes the quadcopter to rotate in the direction of the propellers rotation. Rotating two of the propellers clockwise and two counter-clockwise negates the torque created which should ensure that the angular acceleration around the yaw axis (around which the quadcopter rotates left or right) is zero. This enables the quadcopter to stay still, and to move effectively by adjusting the speed of the propellers.

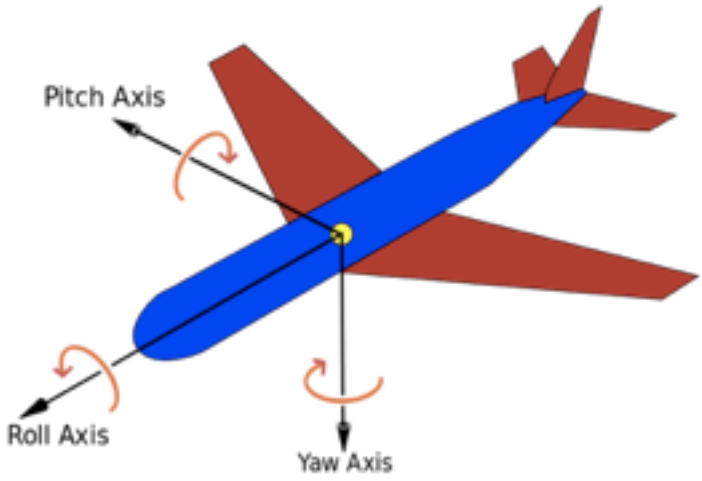

Figure 12 Pitch, Yaw and Roll on a Fixed Wing Aircraft

A quadcopter in flight, like any aircraft, is free to rotate in three dimensions about its centre of gravity, in aviation terms each of the three axes are called pitch, yaw and roll. As the quadcopter is symmetrical, these axes are easier to visualise on a fixed wing aircraft.

The quadcopter will have the axes defined by the gyroscope and accelerometer connected to the flight control software as opposed to its physical layout.
Pitch is the up and down movement of the nose of the aircraft, yaw is the left/right rotation and roll is the axis along which an aircraft would turn over while still travelling forward.

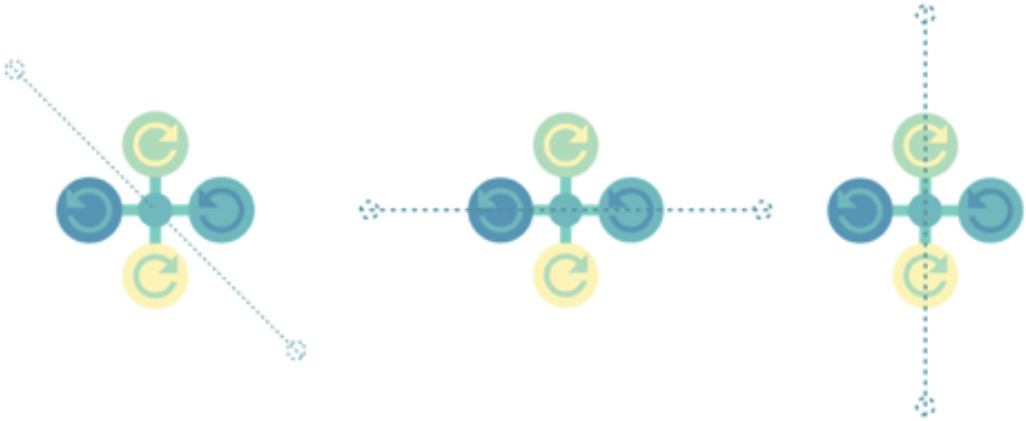

Figure 13 Yaw, Pitch and Roll Axes on a Quadcopter

5.3.1 Hovering

The quadcopter hovers, or adjusts its altitude by applying equal thrust to all four rotors. To hover, the rotors will have to generate thrust equal to the weight of the quadcopter. Reducing the thrust will cause the quadcopter to lower and increasing the thrust will cause the quadcopter to fly higher.

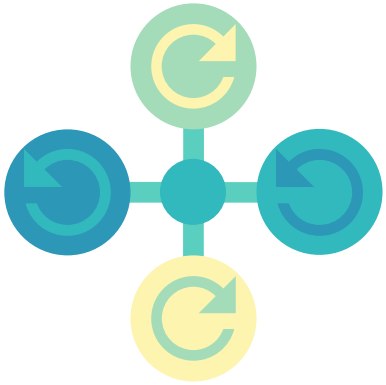

Figure 14 Quadcopter Hovering Showing Directions of Propeller Movement

5.3.2 Controlling Yaw

To control the Yaw, more thrust is applied to the set of propellers rotating in one direction. This will increase the torque and cause the drone to rotate.

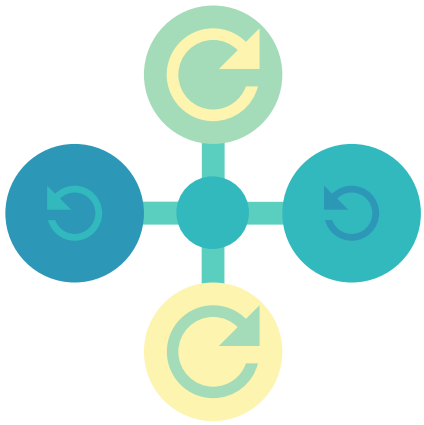

Figure 15 Quadcopter Rotating About Yaw Axis

5.3.3 Controlling Pitch and Roll

The pitch and yaw are controlled by applying more thrust on the propeller in the direction of rotation and less thrust to the opposite rotors.

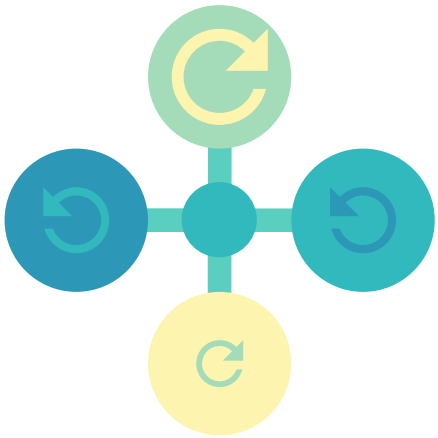

Figure 16 Quadcopter Adjusting Pitch By Varying The Speed of Its Motors

6 Applications of Drone Technology

While the initial development and application of drone technology came mainly from the US military, the subsequent generations have found their way into several other areas of industry.

6.1 Film and Photography

Advances in camera technology have led to the development of Movie and TV quality cameras that are light enough to be carried by a drone. Aerial shots that would previously have required a helicopter can now be carried out with a drone for a fraction of the cost.

In 2016 the US Federal Aviation Authority released new guidelines which allowed the use of drones for filming without previous permission having to be sought. The use of drones is now commonplace in big budget movies and TV shows, having been used in the filming of Jurassic World, Captain America: Civil War and Game of Thrones.

In 2014, Fly Cam won a technical Oscar for their Fly Cam filming drone.

In 2017, TV3 and The Smithsonian Channel US premiered a programme called “Aerial Ireland”, the footage of which was shot using drones.

Many auctioneers and estate agents are now using aerial photography taken using drones in their house listings.

6.2 Search and Rescue

Drones with the ability to send live video back to an operator are increasingly used in search and rescue operations. In addition, many drones now have the ability to follow a search pattern between GPS waypoints which ensures that the drone covers an entire area.

SWARM (Search With Aerial RC Multi-rotors, sardrones.org) operates a worldwide volunteer search and rescue network of over 1,100 search and rescue drone pilots dedicated to searching for missing persons. They aim to provide multi-rotor and fixed wing aerial search platforms for ongoing search and rescue operations at no cost to the SAR organisation or to the family.

6.3 Mapping and Surveying

Any drone with a camera can be used for mapping and surveying, the operator just needs to ensure that the photos taken during its mapping flight have coverage of the entire area that is to be mapped. This is often carried out automatically using drone mapping software such as DroneDeploy.

After the flight, these images are then processed to create the map. A 3D representation of the mapped area can be generated if there are enough images captured.

6.4 Wildlife Conservation and Monitoring

Any drone with a camera can be used for mapping and surveying, the operator just needs to ensure that the photos taken during its mapping flight have coverage of the entire area that is to be mapped. This is often carried out automatically using drone mapping software such as DroneDeploy.

After the flight, these images are then processed to create the map. A 3D representation of the mapped area can be generated if there are enough images captured.

6.5 Drone Racing

The Drone Racing League launched in the United State in 2016. First-person video from the drones is relayed back to the pilots who wear headsets. The drones race through a course built over multiple levels at speeds in excess of 130 km/h. Due to the speed at which the drones are required to fly, their battery life is limited to only a few minutes.

The RacerX drone, designed by Drone Racing League's engineers, set the Guinness World Record for the Fastest Ground Speed by a Battery-powered Remote-controlled Quadcopter. The RacerX hit a top speed of 179.6 m/ph or 289.04 km/h.

7 More Resources

https://www.iaa.ie/general-aviation/drones/ - The Irish Aviation Authority Drone Webpage
http://diydrones.com/ - The Leading Community for Personal UAVs
https://oscarliang.com/ - Share Knowledge and Ideas
https://myfirstdrone.com/ - Build Your First Drone
https://www.droneflyers.com/ - Helping beginning and intermediate pilots with buying and flying quadcopters
http://www.t4.ie/Technology/Resources%20-%20Options/Control_Technology/Introduction%20to%20Robotics.pdf - T4, Leaving Certificate Technology, Applied Control Technology, Introduction to Robotics (more detail on Closed Loop Control)

8 References

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Farmer's Journal, https://www.farmersjournal.ie/tag/drones

Yamaha Motor Sports, https://www.yamahamotorsports.com/motorsports/pages/precision-agriculture-rmax

Drone Racing League, https://thedroneracingleague.com/

Search With Aerial RC Multi-rotors, http://sardrones.org

History of UAVs, https://en.wikipedia.org/wiki/History_of_unmanned_aerial_vehicles

Pitch, Yaw and Roll on a Fixed Wing Aircraft By Yaw_Axis.svg: Auawisederivative work: Jrvz (talk) - Yaw_Axis.svg, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=9441238

A Yamaha RMax being prepared for use in agriculture - UC Davis College of Engineering - CC BY 2.0 https://www.flickr.com/photos/ucdaviscoe/16881955168

Q3 Radioplane on launch platform - By Bill Larkins - WTL and Radioplane OQ-3, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=29358346

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