# - Introduction

## Unmanned Aerial Vehicles (UAVs)

(UAVs) are also known as drones. \* \* \* Drones for war The United States is the undisputed world leader in drone technology. It has built up a large fleet of unmanned aircraft for military and surveillance purposes. These are controlled by a human operator at a ground station thousands of miles away, or controlled by a satellite link. The most common drones are the MQ-1B Predator, which weighs 2,800 pounds and can fly up to 15,000 feet; the MQ-9 Reaper, which weighs 3,600 pounds and can fly up to 50,000 feet; and the RQ-7 “Raven”, which weighs 500 pounds and has a range of 60 miles. The US Army uses → “RQ-11B Raven” (see page 146); the US Marine Corps uses the “RQ-21A Blackjack” (see page 146). \* \* \* THE US ARMY’S RQ-11B RAVEN The Raven is a small hand-launched UAV with an endurance of 90 minutes and an range of five miles. It is used for battlefield surveillance. The Raven has no remote control: it is launched by hand and lands automatically after its mission is complete. The cheapest drones – such as the Raven – are expendable. They are used for reconnaissance missions or for flying into enemy territory to detonate mines or deliver bomb payloads in support of troops on the ground. More expensive drones – such as the Predator – are reusable. They have greater endurance and range, and are used for longer missions over enemy territory. There are now dozens of different types of UAV available, including some that can take off vertically like a helicopter, some that can hover like a helicopter, some that can land vertically like a helicopter and some that can carry missiles or bombs like an attack aircraft. \* \* \* “Sending robots to do our dirty work is not much different from sending in troops.

<https://www.auav.com.au/articles/drone-types/>

<https://medium.com/aerial-acuity/choosing-the-right-mapping-drone-for-your-business-part-i-multi-rotor-vs-fixed-wing-aircraft-6ec2d02eff48>

Types of UAVs There are basically two types of UAVs—fixed-wing and rotary wing. Fixed-Wing UAVs These have wings and a tail, which make them similar to an airplane. They are best suited for long-range missions as they can carry more fuel and endurance. They can land on a runway. Fixed-wing UAVs can fly at very high altitudes, as they have a fixed wing configuration with horizontal and vertical stabilizer surfaces. They can fly at very high speeds, as they have a streamlined body design. They are capable of carrying heavier payloads as compared to rotary wing UAVs. The primary disadvantage of this type of UAV is that they cannot hover for a long time, as they rely on air currents for flying. These require a runway to land and take off.

Rotary Wing UAVs These have a main rotor, tail rotor, and wings to provide lift. These are designed for short missions where the payload is lighter and the endurance is lower. These have the capability to hover in one place for a long time, which makes them ideal for surveillance purposes or target acquisition missions. They are best suited for a variety of missions such as recce, surveillance, target acquisition, communication relay, target spotting, combat support, casualty evacuation ( CASEVAC), and convoy escort duties (Figure 7-6). Figure 7-6 . Types of rotary wing UAVs UAV weights vary from 2 kg to more than 1,000 kg. The weight varies depending upon the purpose of the mission (Table 7-1). Table 7-1 . Weight of different types of UAVs Types of UAVs Weight (kg) Payload (kg) Ultra micro/mini size 2–5 kg 0.5–1 kg Micro size/small size 10–15 kg 1–5 kg

**Multirotor quadcopter** They are also known as quadcopters or drones. These have four rotors, which provide lift and stability to the UAV. They can be used for surveillance missions in urban areas where there is no need for a runway. The most common type of UAVs are multirotor copters that use GPS-based navigation systems and autopilot technology to fly themselves without any human intervention. The flight plan is programmed into the system before takeoff, and once it takes off, it will follow its preprogrammed route until it reaches its destination point. It then lands itself automatically on a predetermined spot using GPS coordinates or radio control signals from an operator on the ground (Figure 1). Multirotor quadcopter  (Courtesy: Wikipedia) There are many types of multirotor copters available commercially today—quadcopter , hexacopter , octocopter , etc., depending upon how many motors they have per rotor (Figure 2). Multirotor copters with more than four rotors are referred to as "helicopters."   Quadcopter Hexacopter Octocopter Figure 2: Types of MultiRotor Copters Today's commercial multirotor copter has evolved from hobbyist projects around 2000 AD by pioneers such as Jordi Muñoz . Hobbyists modified remote controlled helicopters by adding multiple motors onto them so that they could hover in one place instead of flying forward like normal RC helicopters do. This gave rise to what we call today's multicopters/drones/UAVs (unmanned aerial vehicles). The first successful project was done by Jordi Munoz in 2005 when he designed his own custom built quadcopter named "El Pollo" ("the chicken"). He made this device out of spare parts lying around his house including an old computer fan! His design inspired other enthusiasts who started building their own versions based on his design principles but with better materials and components such as carbon fiber frames, brushless electric motors, lithium polymer batteries, microcontrollers etc.. Some even went ahead and built their own circuit boards for controlling these devices! Over time these hobbyist projects led to some very interesting innovations such as autonomous hovering capabilities using gyroscopes coupled with accelerometers along with software algorithms written specifically for controlling these devices autonomously without any human intervention at all! In fact some people were able to make their multicopters capable enough so that it could fly just like a hummingbird making those really nice 360 degree in-flight turns to left and then right using only buzzer blades as its propulsion mechanism. Amazing! A new age of innovation had dawned, which can perhaps be best summed up by Prof. Kenneth Richards when he said "For a long time aircraft were made for men; now, they are being made for women and children and if they don't feel comfortable flying them, something is wrong." This has led to many interesting applications in the field of robotics such as surveillance systems , mapping ground extents , package delivery services etc.. Lots of research is also underway to convert these multicopters into mini UAVs or drones that have onboard navigation computers using GPS for navigation instead of cameras alone for keeping it on course while taking 3D Images  of any arbitrary location that you want! But wait ... There's more! What about converting these multicopters into mobile wireless access points providing Internet connectivity wherever we want? How far away would you travel with an internet connection? Way too exciting isn't it? The future of UAVs is very bright indeed!

**Multirotor quadcopter** with four rotors of the same size. Multirotor quadcopter with four rotors of different sizes. Multirotor Quadcopters A multirotor or multicopter is a rotorcraft that has more than two rotor blades, typically three to six. It differs from a helicopter in that only one engine drives the main rotors and there is no tail rotor (except for some models). Multi-rotor aircraft have found uses in unmanned aerial vehicle applications where their ability to hover makes them more suitable than conventional helicopters. The most common configurations have four, six, and eight rotors. Octocopters (such as the DJI S1000) are also becoming increasingly popular for aerial filming because of their stability in flight and ease of use in comparison to traditional helicopters. They can be programmed to fly autonomously using GPS waypoints or radio control from a distance much larger than that which is possible with other vehicles. Multirotor aircraft were originally designed for aerial photography and cinematography, but have since been put to many other uses. Multirotor aircraft can be classified by the number of rotors and their configuration. The following configurations are used in multirotor aircraft: Tractor - A large main rotor with several smaller tail rotors attached to it. Tricopter - An arrangement where three identical sets of two counter-rotating propellers are mounted on each arm of a Y-shaped frame X8 octocopter Hexacopter Quadcopter - Four rotors arranged in a square or rectangle, typically with two on top and two below. Hexacopter Octocopter - Six rotors arranged in a circle around the vehicle. Quadcopter The most common arrangement for multirotor aircraft is to have four rotors, each mounted at 90° to its neighbors. This configuration is known as quadcopters (quadrotors) or X4s when referring to more than one unit being used. A variation of this type uses eight identical motors and propellers mounted together on an octagonal frame, giving it the name "octocopter" (octocopters).

Introduction - The use of unmanned aerial vehicles (UAVs) in military and civilian applications has become increasingly popular over the last decade [ 1 ]. UAVs are also known as remotely piloted aircrafts or RPAs. They have been used for reconnaissance missions since World War I but their use was limited due to technological limitations until recently when they were equipped with Global Positioning Systems (GPS), allowing them to fly autonomous missions without human intervention [ 2 ]. In addition, advancements in microelectronics technology has enabled the integration of advanced sensors into UAV platforms which can be used for surveillance and reconnaissance operations. These include infrared cameras that detect radiation at wavelengths longer than visible light; Synthetic Aperture Radar (SAR) systems that utilise radio waves to produce high resolution images regardless of weather conditions; Electro-Optical (EO) cameras that capture images using visible light; Light Detection And Ranging (LIDAR) devices that collect precise data on distances by measuring differences between time it takes an emitted laser pulse to return from a target and when it is reflected back by a mirror mounted on the vehicle itself; among others. This increased interest in both military and civil applications has driven research efforts towards developing more efficient autonomous flight control systems [ 3 - 8 ] which aim at enabling UAVs to complete complex missions independently without requiring constant human supervision. Several studies have proposed different approaches for implementing autonomous flight control systems based on various design paradigms such as Model Predictive Control [ 9 ], Nonlinear Adaptive Control[ 10 ], Neural Networks[ 11 , 12 ], Fuzzy Logic[ 13 , 14 ] etc . However, most of these methods suffer from two main drawbacks: Firstly, they require a large amount of computational resources because they rely heavily on modelling techniques such as Dynamic Models or Estimated State Estimators which consume significant amounts of computation power during execution. Secondly, some designs require iterative computations during every sampling period while others do not ensure convergence even if there is enough computational power available because their implementation does not guarantee stability under certain nonlinearities inherent in real world dynamics like saturation effects or oscillatory behaviours associated with multi-body interactions.[ 15 - 17 ] Thus poor performance may occur especially when dealing with highly nonlinear problems involving multiple degrees-of-freedom where traditional linearization techniques fail completely.[ 18 ] Some recent studies have investigated new ways for designing adaptive controllers capable of handling saturation effects within specific frequency bands through novel mathematical formulations derived from Volterra series expansions applied directly onto system states instead of modeling techniques such as state estimators.[ 19 - 22 ] However these methods still remain purely theoretical developments rather than practical implementations suitable for real time implementation purposes due mainly to their excessive complexity leading to very long simulation times required even just for preliminary evaluations before any actual experiments could begin. Therefore this paper presents an alternative approach designed specifically around quadcopters/helicopters so called “quad” rotor helicopters because they possess four rotors arranged symmetrically about the vertical axis making them inherently stable machines compared with other types like “tricopters” having three rotors arranged asymmetrically about the vertical axis resulting in less favourable aerodynamic characteristics requiring active feedback mechanisms usually implemented via servo motors whereas quad copter/helicopter rotor blades are operated passively using gravity alone eliminating mechanical linkages altogether reducing weight significantly thus increasing payload capacity considerably compared with tricopters.[ 23 , 24 ]. This study aims at investigating how well one can design adaptive controllers capable of stabilising quadcopter/helicopter motion simply based on sensory information provided by onboard inertial measurement units(IMUs). Sensory information here refers only to measurements collected from IMUs since no additional external sensors are used apart from those already installed onboard each individual vehicle platform involved in this research project except perhaps GPS receivers which provide positional information related only indirectly though estimated position errors calculated based upon dead reckoning calculations performed using gyroscope angle rates measured internally inside each IMU device themselves.) The rest will be explained later below once we discuss details regarding experimental setup issues firstly followed by detailed discussions regarding previous work done along similar lines including our own contributions made previously then finally conclude our findings summarising all results obtained together after discussing possible future direction(s).

UAV are different types. There are different types of UAVs. Remotely piloted aircraft (RPA), also known as remote piloted aircraft (RPA) or Unmanned Aerial Vehicle (UAV). The drones are able to fly on their own, but they usually rely on human control and monitoring. Under the law of the United States, under US Code Title 18 Section 32: "It is illegal for any person to use a drone without first obtaining permission from the FAA." This section also prohibits using a drone in an unsafe manner that could jeopardize safety. In order to prevent accidents and other negative consequences, you must follow these rules when flying your UAV: always keep it within sight; avoid flying near people or airports; never fly over 400 feet above ground level; maintain awareness at all times; don't fly near manned aircrafts etc...

The second type of UAV is often referred to as unmanned helicopters because they have rotors instead of wings like planes do. They may not be capable of fully autonomous flight like RPA's yet, but some can operate autonomously for short periods of time thanks to autopilot systems. Helicopters are more complicated than airplanes because maneuvering around obstacles requires more specialized software as opposed to simply adjusting altitude/speed settings.. Because they require different controls requirements than RPA, they also require different types of hardware, and helicopters are more expensive than RPA's.

The third type of UAV is also known as autonomous drone. This kind of UAV does not require human control and can fly on its own with no pilot, but still requires a remote operator in order to receive commands from the ground. Autonomous drones are currently being experimented on by government agencies such as NASA and the FAA, who cite that these types of aircraft could be able to replace humans in many dangerous situations such as firefighting or search & rescue operations.

The fourth type of UAV is known as a hybrid drone. This kind of drone combines features from different previous types in order to make it easier to operate and control. For example, the Parrot AR Drone uses an autopilot system similar to that found in many helicopters, but has four fixed-pitch propellers for vertical takeoff and landing like RPA's do.

Drones are used not only by military organizations or government agencies but also by private individuals on commercial drones such as DJI Osmo Pocket which can be controlled with your smartphone using their app called DJI Go 4 app which allows you to easily take photos or videos with just few taps on your phone screen

Drone use is regulated by the Federal Aviation Administration (FAA). According to FAA regulations, any privately owned unmanned aircraft weighing over 250 grams (0.55 pounds) must register before its first flight outdoors. Registration costs $5 and offers several benefits including that the owner will receive an N-number assigned specifically for his/her model aircraft; although no two registration numbers may be alike within a state if applied for separately at different times they may be almost identical within less than 100 points); however each State can decide whether this rule applies statewide

Who uses UAV? The best example is Amazon Prime Air. They deliver your goods in 30 minutes or less using drones that follow a delivery route planned by the software in their computer systems. Other applications include: filming events (i.e., for movies and documentaries), aerial photography, taking pictures from high altitudes such as skyscrapers to capture surrounding sites, surveys, border patrol etc...

What are the best drones? Your options will be determined by your budget, what you need to do with it and how much space you have for flying. If your main focus is filming then look no further than the DJI Phantom 4 Pro or Inspire 2 (you'll probably want a more expensive camera too). For photography drone enthusiasts who want quality images without breaking their bank balance, we'd recommend either of these UAVs: DJI Mavic Air, Yuneec Breeze 4K or DJI Spark. If you're a beginner looking for an affordable drone that's easy to fly and has great features such as obstacle avoidance etc... then take a look at Parrot Bebop 2 FPV (which includes two cameras), Autel Robotics X-Star Premium Drone (with wide angle lens) or Altair Aerial Blackhawk Drone (with HD WiFi video feed via smartphone). There are other choices available from brand names like 3DR Solo, WLtoys V977 Plus Mini Quadcopter RTF RC Quadcopter with 6 Axis Gyroscope UFO Plan Toys Helicopter in Helicopter Style , LANTIAN LT100+ GPS Tracker Car Locator Smartwatch GSM /GPS Cell Phone Tracking Device

## The Miniature Quad-rotor Unmanned Aerial Vehicle

**History of quadcopters** and quadrotors

The idea of a flying machine with four rotors is centuries old. In 1714, French physicist and mathematician Leonard Euler worked out the basic equations that determined how quadcopters fly. By 1859, English inventor William Samuel Henson had come up with a design for such a craft. The first practical modern-day demonstration was by Elbridge Gale in 1909. As he flew his “quadrocopter” over Santa Rosa Island off California, it set the stage for today’s devices.[1]

Aerial photography using radio control electric model helicopters became popular in the late 20th century. This led to time-lapse video cameras mounted on small radio controlled helicopters used by farmers to get bird’s eye views of their fields without leaving their trucks or cars.[2][3] This also led to development of autonomous helicopters such as the AR.Drone by Parrot and radio-controlled helicopters that can be launched from the ground or air, such as those manufactured by AirCam.[4]

During the 2000s, advances in motors and electronics allowed UAV technology to expand rapidly. Quadcopters were used first for unmanned aerial vehicles in 2005.[5] The earliest known autonomous quadcopter flight was performed at Duke University’s Pratt School of Engineering on January 18, 2006 with a 5 cm (2 inch) foam aircraft designed by Zac Ward.[6][7] These hobbyist systems typically use digital signal processing chipsets to stabilize flight control systems.[8] By 2013 commercial off-the-shelf multirotor drones became more widely available; some fixed wing designs also exist. As of 2017, these are mainly used for aerial photography but will soon be deployed for search and rescue operations[9]. In December 2016 DJI released Zenmuse X5S capable of shooting 6K video footage at 30 frames per second,[10].

Uses

Multirotor UAVs may be used as a platform for carrying an infrared camera and other equipment, such as air quality sensors. The flight time can be extended by lifting more batteries into the aircraft; however, this increases weight and aerodynamic drag. Multirotors are also commonly equipped with GPS units to record position data.[11] They have been used in power line monitoring[12], agriculture,[13][14] heavy lift aerial photography,[15]and arson investigation.[16] Like most unmanned aerial vehicles, they are operated remotely from on the ground or a mobile device connected to an on-board Wi-Fi network. Most modern commercial drones use GPS/INS systems that allow autonomous flight without human intervention beyond launch and recovery (which is often handled by radio control). However some companies aim to develop fully autonomous drone technology that does not require external inputs after takeoff [17]. For instance Matternet hopes its drones will someday operate autonomously between networks of landing pads within cities.[18]. Amazon has applied for patents concerning delivery services using delivery drones they call Prime Air [19], while various Google projects involve Project Wing which envisions running deliveries via flying robots called "octocopters".[20][21] As of 2015 there was no consensus among industry experts about whether automated flying machines pose threats similar to computer viruses or worms when operating outside existing laws against unauthorized access to networks. In February 2014 the Federal Aviation Administration released new rules governing hobbyist UAV flights in US airspace: maximum 55 lb (25 kg) total load limit; daytime operation only (a pilot must keep visual contact at all times); limited operations around airports; best views must include front part of aircraft; height above ground limited by operator's vision plus 500 feet (150 m).[22][23]. On 30 January 2016 it was announced that Part 107 would take effect in August 2016 allowing routine commercial use under certain small conditions.[24][25]. On 23 May 2017 President Donald Trump signed into law S 735[26](H.R 6480)[27]: FAA Reauthorization Act of 2017 which allows package delivery via commercial drone technology making it legal nationwide if federal regulations do not restrict its implementation before 20 June 2018.[28][29]

## Anatomy of the Quad-rotor Helicopter

### Frame

The frame is designed to take a lot of abuse. It’s made from thick carbon fiber and has been tested extensively in the field by FPV pilots. The arms are reinforced with CF rods for added strength, and the VTX antenna protector will help prevent damage if you crash land into trees or other objects. This frame is also very easy to work on because it doesn’t have any soldered connections between components like ESCs and motors. Everything simply plugs together using XT60 connectors, which makes repairs much easier! You can even swap out your flight controller if you want to change things up later on down the road! This makes this one of the best drone frames for beginners who plan on adding upgrades over time as they learn more about flying drones. The only downside here is that there isn’t enough room for a full-sized camera gimbal underneath (you can still use smaller ones though).

**Different types of quadcopter frame** There are many different types of quadcopter frames. They vary in size and materials used, but the main thing they have in common is that they all provide a mounting platform for the components that make up the quadcopter. The frame is what holds everything together and gives it its shape. The frame will also determine how much payload you can carry, which is important if you want to be able to carry a gimbal or other accessories. Carbon fiber vs plastic When choosing a quadcopter frame, you’ll need to decide whether you want one made from carbon fiber or plastic. Carbon fiber frames are generally lighter than plastic ones, and they tend to be more durable too. However, they are also more expensive, so if you’re on a budget then plastic might be your best option – just remember that they won’t last as long as their carbon fiber counterparts. Frame material Weight Carbon Fiber 3-4 grams (per square inch) Plastic 3-4 grams (per square inch) Quadcopter Frame Weight Frame weight is measured in grams per square inch. The higher the number, the heavier the frame. A heavier frame will be more durable and stable, but it will also be harder to maneuver. If you’re a beginner, then you might want to opt for a lighter frame. The weight of your quadcopter frame will have a direct impact on its durability, how much payload it can carry and how easy it is to fly. As such, it’s important that you choose one that is well suited to your needs. Frame strength and stiffness Frame strength refers to how strong the frame is – how much force it can withstand before breaking or being damaged. Frame stiffness refers to how flexible it is – how much bending there is when you apply pressure to the frame. Frame stiffness is generally more important than strength if you are planning on doing aerial acrobatics with your drone. Frame strength and stiffness are usually measured in pounds per square inch (psi). The higher the number, the stronger and stiffer the frame. Frame strength and stiffness Weight Frame strength Frame stiffness 3-4 psi 5-10 psi Quadcopter Frame Strength and Stiffness The strength of your quadcopter frame will have a direct impact on its durability, how much payload it can carry and how easy it is to fly. As such, it’s important that you choose one that is well suited to your needs. Frame size and shape There are three main sizes of quadcopter frames: 250, 350 and 450mm. If you’re new to flying drones then you should probably start with a smaller frame – they are easier to maneuver and less likely to cause damage if you crash them. Larger frames are more stable but harder to control. If you want to take aerial video or photos, then a larger frame is better as it will be more stable. Frame size Size Max flight time 250mm 5-10 minutes 350mm 10-15 minutes 450mm 15-20 minutes Quadcopter Frame Size The size of your quadcopter frame will have a direct impact on its durability, how much payload it can carry and how easy it is to fly. As such, it’s important that you choose one that is well suited to your needs. Frame weight vs flight time Flight time refers to how long the battery will last when flying your drone. The heavier your quadcopter frame, the longer it will last. If you want to take aerial video or photos, then a lighter frame might be better as you won’t need as much power for maneuvering. However, if you plan on doing acrobatics then you might want to opt for a heavier frame as this will make it more stable and less likely to break in an accident. Frame weight vs flight time Frame weight Flight time 3-4 grams (per square inch) 5-10 minutes 3-4 grams (per square inch) 10-15 minutes 3-4 grams (per square inch) 15-20 minutes Quadcopter Frame Weight vs Flight Time The weight of your quadcopter frame will have a direct impact on its durability, how much payload it can carry and how easy it is to fly. As such, it’s important that you choose one that is well suited to your needs. Frame size vs flight time Flight time refers to how long the battery will last when flying your drone. The larger your quadcopter frame, the longer it will last. If you want to take aerial video or photos, then a smaller frame might be better as you won’t need as much power for maneuvering. However, if you plan on doing acrobatics then you might want to opt for a larger frame as this will

### Landing Gear

### Motors and Propellers

Pulse-width modulation (PWM) and Pulse-frequency modulation (PFM), all of them gives analog output is a different type of communication protocol where master and the presence or absence, timing, or patterns in input from any sensors. And this information can best be converted into control signals for actuating various equipment such as limit switch contacts that operate relays; speed proportional load motors controlling one-directional motor speed using variable duty cycles with signal more precisely to detect characteristics, failures at wrong time should not happen.

PWM (Pulse Width Modulation) Control System

When changing throttle on multirotor quads with traditional electronic speed controllers (ESCs), pulse width modulation (PWM) is used. Pulse width modulation is a method of controlling DC electric motors so as to provide variable power to control flight stabilization in multirotor copters. It’s simple: if you want the blade to spin faster, feed it more power by increasing the pulse width (increase voltage level); but if you want the blade to slow down, feed it less power by decreasing the pulse width (decrease voltage level). So what exactly does “pulse width” mean? You can think of pulse width as defining how much time a square wave signal spends at its high or low level over a given period of time—the longer the high level or low level lasts over time, then wider is considered a “longer pulse width” for that signal—and that signal can be used to control how fast a motor spins or slows down depending on whether it’s getting fed more or less power respectively. Here’s an example: if you set up your ESC with 25% PWM duty cycle instead of 50%, what this means is that after one second elapses (over time), your servo will only spend 25% of that time at its “high level” and the rest 75% of the time will be spent at its “low level”; but this is still considered a 50% duty cycle because your servo spends half of a second at the high level, then it turns off for half a second, then turns back on again for half a second at its high level again.

In addition to PWM being used to control roll/pitch movement in multirotor copters with ESCs, most quadcopter flight controllers also use PWM signals for controlling flight modes such as GPS-stabilized hovering, forward-facing orientation control (e.g., flying nose first) mode, and attitude mode (e.g., tail-in position). The figure below shows how PWM signals are generated using a microcontroller (MCU):

PWM frequencies range from 8KHz to 35KHz depending on the microcontroller you are using (for instance, Arduino UNO uses 1Mhz while STM32 F1 board uses 48Mhz). The higher the frequency—the more resolution and more precise commands can be given to each propeller. This allows faster responses and greater accuracy while maneuvering in midair. For instance if you were flying straight up, making small pitch movements would cause instant changes in thrust force acting on each rotor blade because your controller has more precision and resolution; so when you increase pulse width to one particular motor by 2%, that particular motor can now produce enough additional thrust force needed to make instant changes to avoid hitting something ahead when you stick pushed forward or down on your stick simultaneously when flying nose-first (attitude mode) because they have much better response times than brushed motors that work at low frequencies such as 100Hz or 200Hz.

Another reason why we want variable pulse widths with multirotors is based on physics: spinning blades create forces that act against other parts of the same blade or frame structure through gyroscopic effects resulting from precession or torque (imagine spinning around a flag pole—it would try to rotate around its central point—that’s what happens with a spinning propeller and the forces from centrifugal motion). This precession or torque effect in multirotors acts like pushing one side of quadcopter frame harder into the air than another side causing it to tilt out of the way; you can actually see this effect happening to quadcopters and helicopters in slow motion. The only way to fight these precession or torque effects is to apply differing PWM levels, otherwise they’ll fight each other. With a variable PWM control system—you can modify this PWM frequency based on different movements that you are making with your transmitter stick, which effectively allows you to vary the force of the propellers during rotation (e.g., higher the frequency for more precision during small pitch adjustments).

If your flight controller is not using PWM for its throttle commands, then the ESC uses either current based or voltage based outputs instead. In short, because both current and voltage outputs require power consumption on the part of ESCs, they limit performance because at some point these types of systems simply can’t provide enough power because their supply has limits so it would eventually result in overheating motors and burnt ESCs when run continuously over long periods of time without proper cooling due to heat sink capacity. So if you want to build a fast/high-performance multirotor copter capable of flying hard accelerations, speeds up around 80 mph/130 kph all day long, then we highly recommend getting a flight controller with variable pulse width capabilities and brushless motors if possible (with lots of cooling) as they provide much better overall performance compared to brushed systems; although the price difference is not necessarily significantly greater since motor costs are usually pretty high as well anyway.

### Battery

**Quadcopter battery types** and their performance The three primary types of batteries for multirotor drones are LiPo (Lithium Polymer), LiFe (Lithium Iron) and NiMH (Nickel Metal Hydride). Lithium-based batteries have been used in consumer electronics for years, but they can be dangerous if not handled properly. They require a special charger to charge them safely and discharge at a controlled rate. The lithium battery is the most expensive option, with a typical 8 cell pack costing upwards of $100. However, it offers the best power to weight ratio of any battery type available today. Another benefit is that these packs typically last longer than other options due to less internal resistance within the cells themselves. NiMH batteries provide an economical solution with lower initial cost and good overall performance although they don’t deliver as much punch as lithium batteries when flying high performance models like racing quadcopters or acrobatic drones. The main drawback is that you will need to replace them after several hundred charges. Lithium iron batteries are similar to lithium polymer but cost less. They tend to have a lower power density than LiPo, but they also have a longer cycle life and can handle higher temperatures without the risk of failure. The downside is that you need to be very careful when charging these batteries as they are more prone to overcharging if not monitored properly. How many cells should I use? A lot of factors will determine how many cells your drone needs depending on what type of flying you plan on doing with it. Most drones for sale today come in packs between 4-8 cells and while it’s possible to get packs with more or fewer cells, most models are balanced around these numbers so that you don’t need additional weight distribution equipment (like an anti-gravity board). However, there is one advantage to having larger battery packs – flight time! A larger pack will give you more flight time before needing a recharge which makes them ideal for long distance flights where you can’t easily swap batteries. For most people, a 6 cell battery pack is the right choice for drones that are used for aerial photography or video. If you plan on flying acrobatic style drones then you will want to use a 8-cell pack as they have more power and allow for faster speeds and sharper turns. For racing quadcopters, the best option is to use an 8-cell lithium ion battery with a discharge rating of no higher than 30C (that means if your drone draws 20 amps out of your battery while flying, it should be rated at 5 amps per cell). A lower discharge rate like this will give you maximum run time but still allows for enough punch to fly high performance models. How many cells should I choose? You might be tempted to go all out and buy the biggest battery possible so that you get the longest flight times, but bigger isn’t always better when it comes to multirotor batteries. The reason is that bigger batteries usually have more cells which means they are heavier and harder to balance. A heavy battery will cause your quadcopter to fly less stable, especially in windy conditions. Balance is important because if one side of the quadcopter is heavier than the other it will spin uncontrollably when you try to fly it. In general, most drones use a 6-cell pack with a discharge rate of 20C (that means that each cell can handle up to 5 amps). This gives you enough power for acrobatic style flying while giving you decent flight times between charges. If you plan on using your drone for long distance flights or aerial photography then consider getting an 8-cell pack with a 30C rating instead. What do all those numbers mean? When comparing different batteries make sure you take a look at the discharge ratings and voltage before making your decision. Discharge rates are measured in C (or amps) so 10C would be ten times higher than 1C meaning that each cell can handle up to 5 amps. The higher the C rating, the more current your battery is capable of delivering which means that you get a lot more power out of them. Voltage is measured in volts and most multirotor batteries are between 11-14 volts although some models come with a lower voltage (usually 9 or 10). This shouldn’t be an issue unless you plan on using your drone for FPV flying as they will need a minimum of 12 volts to operate properly. What about capacity? Capacity refers to how much energy the battery can hold and it’s measured in mAh (milliamp hours) so 1000mAh would mean that each cell could hold 1 amp for one hour before being depleted. Again, bigger isn’t always better when it comes to capacity since larger packs are heavier and harder to balance. If you want longer flight times then you should look at getting a pack with a decent discharge rate but not too high. Most drones use a 6 cell pack with a capacity of 1000mAh or higher which gives you decent flight times, but for long distance flights you should look at packs that have a capacity of 1500-1800 mAh or higher (if possible). How many batteries should I buy? If your drone uses 6 cells then you will need to get two batteries so that you can fly continuously without having to recharge between flights. If it has 8 cells then get three and if it’s larger than 8 cells then make sure the battery is balanced properly before taking off! Having extra batteries on hand allows you to be more flexible when flying your drone as they are easy to swap out in seconds. They also allow you to keep flying even if one battery runs low by swapping them out during flight. This is an important safety feature as the last thing you want is for your drone to run out of power while flying!

### Sensors

Aerial photography and videography are the most popular applications of quadcopters. Quadcopter aerial photography is a relatively new application, which has been made possible by the development of inexpensive GPS-based autopilot systems. It is also commonly used for aerial mapping, surveillance, and inspection. The first commercial use of an unmanned aerial vehicle for aerial photography was in 1995 in the Central African Republic. The quality and sophistication of cameras integrated with quadcopters has increased over time. In 2013 DJI released the Phantom FC40 equipped with a camera capable of shooting full HD video at 1080p. In 2014 3DRobotics announced the Iris Quadcopter that can carry a GoPro camera, which is not only able to take still pictures but also videos in high definition. In 2015, researchers from the University of Zurich published their work on using UAVs to assist photographers in taking group photos. They developed an algorithm that allows a quadcopter to identify the photographer and autonomously fly to pre-defined positions. The same group of researchers also developed an algorithm to autonomously generate flight paths for quadcopters that take into account the photographer's camera movements and preferences. Quadcopter aerial surveillance is used by public safety agencies, such as police departments, for search and rescue missions, and by private individuals for security purposes. Aerial inspection is a growing industry, with applications in construction site monitoring, power line inspections, oil pipeline monitoring, wind turbine inspections, bridge inspections, dam inspections, wildlife surveys, fire detection and more. The market for unmanned aerial vehicles (UAVs) has seen a surge in popularity over the last few years due to their increased capabilities and falling costs. There are many different types of UAVs that range in size from micro air vehicles (MAVs), which weigh less than 1 kg, to large UAVs that can carry payloads up to several hundred kilograms.

### Flight Control Board

### Transmitter and Receiver

## Basic concepts of the quad-rotor helicopter

The throttle control is the most important part of a quadcopter. It is the one that allows us to control the altitude and speed of our quadcopter. The throttle is also known as the elevator stick, because it controls the pitch of the quadcopter. The throttle control is used to adjust the power delivered by the motors to generate lift. Increasing or decreasing power results in increasing or decreasing lift, respectively. This gives us more control over our quadcopter. In order to understand how it works, let’s take a look at an example: When we increase power, we are increasing lift, which causes our quadcopter to rise up. When we decrease power, we are decreasing lift, which causes our quadcopter to fall down. If you want your quadcopter to stay still in place, you need to keep your throttle at zero (0). If you want it to move forward, you need to increase power; if you want it to move backward, you need to decrease power; if you want it to turn left/right, you need to tilt your throttle stick accordingly. If your quadcopter is hovering in the air, increasing power will cause it to rise up, while decreasing power will cause it to fall down. On the other hand, if your quadcopter is falling down, decreasing power will cause it to rise up and increasing power will cause it to fall down. In summary : Increase RPM → Increase Lift → Rise Up Decrease RPM → Decrease Lift → Fall Down Keep RPM at 0 → Stay Still (Hover) Of course there are various ways to adjust a throttle, but for now you should know how the concept works. We have covered this in much greater detail in our article about radio control transmitter. You can read it if you want more information on transmitter and receiver settings for different flight modes. Now let’s move on. There are many ways that allow you to control your quadcopter: Adjusting VR1/VR2/VR3 (vibrate resistance) on your radio transmitter, adding expo or dual rate to your radio transmitter or adjusting P value of PID controller using Betaflight Configurator etc. However I would like to mention one thing: you should never reach the maximum or minimum value of your throttle. This is because if you do so, your quadcopter will be uncontrollable. On one hand it will cause you to lose orientation and on the other hand it may result in a crash due to sudden power decrease or increase. How to increment/decrement RPM (throttle) This is how I control my quadcopter when flying FPV with a full-size transmitter: For left stick (channels 1-3), I hold it at the center position for basic hovering flight. If I want my quadcopter to move forward, I move the stick slightly upwards away from me, which increases power and causes my quadcopter to fly forward. If I want my quadcopter to move backwards, I move the stick slightly downwards away from me, which decreases power and causes my quadcopter to fly backward. If I want my quadcopter turn right/left, I use the same principle: increase power for right turn or decrease power for left turn (I don’t use right stick at all). Finally if I want to stop my copter

**Basic concept of quadcopter throttle, roll, pitch and yaw** While the concept of a quadcopter is rather simple, it can be difficult to visualize how it is able to accomplish three axis. While two axis movement can be accomplished by altering the angle of propellers, a third axis of movement must somehow be accounted for. One solution is by rolling the quadcopter on its longitudinal axis, causing the propellers to tilt in different directions in order to control movement in that direction. A normal helicopter has two rotor systems, which allow for this type of movement. Since a quadcopter has only one rotor system, we need another way of achieving this roll. This is done by applying a thrust force into the airframe itself that will cause it to roll based on inertia and resisting forces (lift). It's helpful at this point to recognize that there are actually two separate ways that we can alter the yaw and pitch of a quadcopter: Improving pitch and yaw with altitude hold In order to gain some intuition into how pitch and yaw work, let's examine what we see when an airplane pulls up or down into a higher or lower altitude. As with any aircraft, there are a number of forces acting upon it due to its weight and drag (air resistance). These forces include lift force on its wings, thrust force from the engine(s), drag force from air resistance on it body and possibly even some aerodynamic torque due to wingtip vortices. The sum of these forces must equal zero in order for the plane to stay level; otherwise we say that it experienced an unbalanced flight condition. You'll notice that these forces don't add up directly with each other but instead act at angles relative to each other based on their properties such as direction and magnitude (see diagrams below). So lets think about what happens when an airplane wants to climb or descend by pulling up or pushing back respectively. When we pull back on the yoke, we are essentially creating a force at the tail end of the aircraft that reduces its forward velocity. Furthermore, when we push back on the yoke, we reduce forward speed in the opposite direction (by pushing us into our seats). This may seem counter-intuitive until you realize that there's a very important reason for it: If a plane loses some of its lift through speed or reduced angle in the wings due to pitching up or down respectively, it will begin to drop from increased gravity forces. A pilot does not experience increased weight in an airplane since their body is supported by their seat. When pitching up or down, however, they are changing their perceived weight relative to the center of gravity inside of the craft (remember your high school physics class?) and must compensate for this change to stay level. In an airplane this means that pitch and roll are somewhat intertwined because they both attempt to maintain level flight; one is just altering lateral movement while the other is vertical. The same can be said for quadcopters. While a quadcopter will experience different roll motions based on each rotor system affecting its inertia differently, they all act together with pitch and yaw to maintain static balance. We'll revisit this concept as we think about how different settings affect pitch and roll of quadcopters later in this chapter! Improving pitch and yaw with basic controls Let's now do a quick rundown of how you can control your quadcopter using default mode 2 controls (which is still used by most hobbyists). Let's first examine how UAVs achieve upright static balance which allows them to hover: The four main components of controlling tilt angle via PID tuning In order to control tilt angle (yaw) in a quadcopter, an inward rotational force must be applied around its central axis (roll). If it was not already obvious, this is actually exactly why propellers generate lift based upon their angle! While an outward force would cause a plane or copter to lose altitude due to higher air resistance drag force, it would have no effect if thrust from its motors were kept constant (basically saying that you don't need heavy propellers when going fast!). However, this isn't true for UAVs since they use their motors for both lift balance as well as thrust balance; therefore an inward rotational force must be applied by the rotors to maintain balance relative to the center of gravity inside of the craft. The term thrust balance is used because each rotor blade produces a forward force that drives the quadcopter forward. In order for this force to exactly equal air resistance, our established lift must be equal in magnitude but opposite in direction to our thrust (see diagram below). This means that we can control the aircraft's angle simply by adjusting how far each rotor blade is tilted toward its respective axis (pitch) or adjusting how fast they are spinning around their axes (roll). Tip If you're worried about getting dizzy from examining all these images, don't be! Much like the pilot you really will begin to get an intuitive sense for whats going on after a little bit of practice. It also helps to remember that it's just pure geometry at play and nothing more complicated than that! So if we want our UAV to keep moving forward or backward without losing altitude, we need only tilt each motor blade appropriately so that the generated lift precisely balances out with drag (see diagram below): Balancing lift and drag forces with throttle input As discussed in previous chapter, there are two main components involved in maintaining static hover: lift generation and thrust generation. While it's possible to use different settings for each of these components as well as gain a finer level of control over fine adjustments, most hobbyists simply change their throttle levels in order to control their yaw using default mode 2 controls. The reason for this is due largely due to the fact that throttle input works directly on both propulsion systems simultaneously while attitude control inputs work on them individually; furthermore, any adjustment made via throttle input will affect your pitch as well as your roll which means you won't have complete separation between pitching up and down versus rotating left versus right. However, we still want our quadcopter to stay level based on what is happening relative to gravity; therefore we must compensate when altering our spin direction with joystick controls. Furthermore, depending upon which motors are receiving more power (via increased collective pitch), one side may rotate slightly faster than another which can be compensated for using small stick movements combined with basic throttle adjustments. When coordinating multiple motors however, even subtle differences in acceleration and deceleration times can cause significant problems when trying to remain stationary; this is why coordinated flight modes are essential in some cases such as setting up a camera shot or performing an autonomous approach.

**While this process may sound complicated, it's really not! Remember that the goal is to achieve static balance by adjusting how far each propeller blade is tilted relative to its respective axis. For example, if we want the left side of our quadcopter to go faster than the right, then we will want the propellers on the left side to be extended slightly more than those on the right. This will increase their lift force and compensate for drag; however, it will also cause our craft to tilt slightly to one side due to moments of inertia due to angular velocity around its central axis (roll). On a quadcopter however, there are four different motors that can be individually adjusted via roll control from -100% all the way up. Since their rotors are spinning in alternating directions around a shared central axis, any simultaneous changes in angle will sum together vectorially which means each motor only needs to adjust its pitch slider independently relative to the others by 100%. As long as we keep these adjustments at relatively small percentages (10-20%), we can easily account for minor differences in acceleration and deceleration times between motors. Tip Take some time now and practice controlling your quadcopter using only throttle input before attempting any other maneuvers. It will help you understand exactly what is going on when you add other controls later on! Remember that we discussed earlier that there are two main components involved in pitch and roll: attitude control and thrust balance. We'll begin by examining how attitude control affects each rotor system individually so that we're able better understand the process behind setting up a fully stabilized flight mode (stable): The four main components of controlling pitch via attitude control As discussed earlier, attitude control refers to adjusting how far each rotor blade is pitched toward either its x or y axises respectively which can be accomplished using two different settings: Attitude Mode and Rate Mode . If you recall from previous chapters, ATTITUDE mode simply alters each motor at a constant rate while RATE mode allows us to alter how fast they rotate based upon joystick input. While changing a single motor's rotation rate can cause some interesting effects since it affects both lift and drag components simultaneously depending upon if it's pitched up or down respectively (remember that it actually adjusts both axes simultaneously), changing them all together has an effect similar to increasing/decre**asing the rotor's diameter instead. For example, if we wanted to increase the lift force of a single rotor without altering its drag, then we would pitch it up (rotate it further from its axis) which would decrease its effective angular velocity and reduce our thrust accordingly thus causing the quadcopter to ascend. If we wanted to decrease the lift force and increase our overall speed, then we would simply pitch that same rotor down which would cause an increase in its angular velocity due to conservation of angular momentum which will lead to increased thrust hence increasing our overall forward speed. By changing the pitch angle of each motor independently, we can achieve static balance (a constant hover) by matching all rotor speed and acceleration/deceleration times precisely which is exactly what happens by default for all aircraft when flying in ATTITUDE mode. Now consider how this system works on a quadcopter; given that there are four separate rotors spinning in opposite directions around a shared central axis, any simultaneous changes will sum vectorially so as long as they are not added or subtracted together, then they will not cause any net change in direction! Therefore if we were using only attitude control such as LEVEL mode (the one currently active in the DJI software), then we could adjust each propeller shaft independently to obtain static balance simply by making changes based upon each motor's rotation speed alone: The main components of controlling pitch via rate control Rate Mode , on the other hand, allows us to set individual rates for each motor based upon how fast it needs to rotate in order to produce enough lift or thrust to keep our craft at a particular altitude. This means that under rate control, each motor is assigned a specific x or y value respectively known as "throttle" values . Since there are multiple rotors, changing their respective throttle settings simultaneously has no effect since their x values sum together while their y values cancel out resulting in no net change in rotation direction (remember that x represents roll while y represents pitch): Tip While Rate Mode allows for very fine-grained control over motors individually , it also becomes more difficult to obtain dynamic balance since any movement by one motor tends to affect others directly via moments of inertia around their respective axes. However, many professional drone pilots still prefer Rate Mode because they feel it better matches how humans fly drones naturally using their thumbs (). However because Rate Mode requires us to set an individual x and y value for each motor, we'll need to adjust each one only slightly in order to produce sufficient thrust/lift at any given altitude. This is accomplished by matching all rotors' lift or thrust force together either directly via a pitch curve or indirectly via throttle curves which will be discussed later on. We'll then cover how this combined thrust/lift can be used to obtain dynamic balance using a combination of roll and thrust control: The main components of controlling roll and pitch with direct control As discussed earlier, the main goal of roll control is to synchronize the rotation rates of each rotor system with respect to its individual axis while the other main goal of pitch control is to keep our craft's center of mass directly over its central axis so that it doesn't fall due to gravity or tilt excessively due to moments of inertia caused by angular velocity around it. While attitude control simply sets each rotor blade's angle separately based upon a single rotation axis , roll and pitch control allows us to adjust both axes simultaneously (aka dual-axis ) based upon the distance between them directly as shown in the diagram below: Note that roll and pitch control are not available as separate modes within DJI GO; however, you can access these controls if you decide not use ATTITUDE mode and instead switch between RATE mode (where they are enabled by default) and LEVEL mode (where they are disabled). Now let's explore some common ways these controls can be used together in order to more effectively stabilize our craft: Adjusting both roll and pitch simultaneously using dual-axis controls The single most common means by which modern quadcopters are stabilized is via direct Centering Roll Control . As discussed earlier, centering refers to the process by which we modify both axes simultaneously until their values sum together exactly at zero in order for our craft's motors to start rotating from rest without any initial yaw rate causing it spin unexpectedly from side-to-side before actually taking off. If you've ever flown any type of modern remote-controlled aircraft before, then you have undoubtedly encountered this issue when learning how to fly models such as multirotor drones where their engines almost always tend to kick into gear after just a few seconds upon turning on their radio transmitter! Given that we have four independent motors on our drone though, we could potentially take advantage of this built-in delay by setting all four roll values to zero initially then adjusting the pitch of each motor accordingly in order to perfectly balance our craft dynamically. This would definitely prevent it from rotating undesirably as we lift off; however, since there is only one main axis involved (the roll), it is not very useful for other situations such as windy conditions or the drone just losing contact with the ground. Roll and pitch control at different rates of rotation As discussed earlier, dual-axis control refers to how we can individually adjust both axes of a rotor system simultaneously in order to ensure that the craft's center of mass stays directly over its central axis at any given time. This is accomplished using both roll control and pitch control which are collectively known as direct stabilization . Unlike ATTITUDE mode, RATE mode requires us to manually set each propeller shaft's x and y values based upon throttle input via two individual sliders; however, since there are four motors and two sets of axes involved, adjusting both simultaneously will require us to modify them independently via two sub-sliders found next to their respective value: Clicking on either of these sliders will make that parameter appear yellow while dragging them with your mouse will allow you to change their value relative to one another in order to match the angle of each rotor shaft relative to its respective axis. Since we want all four rotors spinning together without any sudden or unexpected changes in speed, we'll need to adjust each individually so that they equal whatever speed their maximum thrust/lift would be at if they were spinning alone without any propellers on the opposite side. For example, if we started out with our quadcopter hovering 30 feet above the ground then let go of its controls for a moment so that it had a chance to stabilize itself perfectly still (without any wind causing it rotate), then any adjustments made during this period would be valid! As an alternative, we could simply pick up our drone and carry it around while flying out back into a large open field where there was no disturbance from wind gusts or trees etc...and measure its blade angles using either a protractor or even just graph paper

### Throttle

### Roll

### Pitch

### Yaw

The main difference between roll, yaw, hover, and pitch in a quadcopter is based on what the main prop is doing. For roll, all 4 props are spinning, but the forward propeller spins faster than the rear one. This causes the quadcopter to bank in that direction. The amount of “banking” it does is directly proportional to how much faster one blade is spinning than the other.

When you fly a quadcopter that has a single motor in each blade, this is referred to as Pitch (since there are no roll). When all 4 motors are spinning and one prop stops completely, it will fall out of the sky. You can use this effect intentionally by arming only 3 motors instead of all 4 motors while flying acro. If you do this at exactly half throttle, 3 blades will spin while 1 blade will completely stop and the quadcopter will fall out of the sky (because 2 more blades would be counteracting each other). At any other point along the throttle range, pitch can happen and you can adjust your altitude with motor power levels.

Yaw happens when there is an imbalance in current between two rotor pairs of a multicopter. As seen in Figure 6-10 , when you apply yaw input (pushing stick left or right), it affects only 2 propellers equally because they are connected by opposite wires (propeller A goes up, propeller B goes down; if you push left joystick, both propellers on port side go up). The second pair is not affected at all because they have opposing polarity (port side–clockwise/starboard side–counterclockwise). So when applying yaw input to a multicopter, two opposing sets of blades will rotate differently compared to each other because they have opposite current flows.

Figure 6-10. Yaw using two different currents through motors and ESCs

Pitch and Roll are symmetrical events; when you move stick left or right for pitch/roll in either direction for multicopters having four sets of three identical rotors, all three rotors spin symmetrically. With all three propellers spinning with equal speed—this creates little net change in thrust force between front and back motors for pitch/roll/yaw axis rotations—these operations require more changes in net torque over a period of time across these axes compared to yaw axis operations where net thrust force equals zero; consequently making yaw operations much easier than pitch and roll for multicopters.

All flying and hovering movement in a quadcopter is achieved by asymmetric torque, which means that each propeller has different speeds, directions, or both. For pitch/roll/yaw to happen correctly, you must make sure all four propellers are spinning at the same speed; then apply different current levels to two opposing pairs of motors (port side–clockwise and starboard side–counterclockwise) through your ESCs. This imbalance will cause each set of motors to have slightly different thrust forces during rotation because one motor on each set will have more torque than the other. This slight difference will cause each pair of rotors to move slightly off-center from each other, thus causing pitch and roll movements in the airframe itself. Also note that when you push stick left or right for roll/pitch input on a quadcopter using brushless motors, it always affects both sets of two pairs equally because they both share common wires.

## Applications of Miniature Quad-rotor Helicopters

If you are considering purchasing one, make sure to consider the following applications:

- Surveillance: Miniature quadcopters have been used as surveillance tools by law enforcement agencies and private investigators alike. They are small enough to fly in tight spaces, stable enough to hover over an area without being noticed, yet responsive enough that they can quickly change position when needed. Most miniature quadcopters possess infrared cameras so they can record footage at night too!

- Racing: Although not all racing drones are designed to fit inside the definition of a "mini" drone (i.e., those weighing under 0.55 pounds), there is a growing interest in them due predominantly to their speed and agility on short courses like football fields or basketball courts . Because they fly relatively low off the ground , racers must always pay attention in order not to crash into obstacles during competition; however, this also makes it much easier for competitors with large bodies - such as tall teenagers - to use them effectively! The best miniature quadcopter helicopters come with multiple channel controls which allow users more control over each individual rotor blade's pitch angle than would otherwise be possible using just one or two channels; thus making these devices ideal for competitive fliers who demand precision from their equipment while still retaining its maneuverability . This also allows users greater ability than ever before when flying indoors where space often prohibits true micros from achieving optimal height capabilities ! However, although some mini-quads do incorporate brushless motors , most current models still utilize brushed ones which become less efficient the colder it gets outside (-15 degrees F). In addition, many mini quads cannot handle winds above 20 MPH very well because of how light they tend to be built compared to larger models featured on our site . For pilots looking toward long term investment potential , we recommend Dromida Vista FPV Quad Copter 2+2 Channel RC Helicopter instead because it uses brushless motors similar those found on larger scale models such as Hubsan H107L X4 Micro Quad Copter With Camera & 4GB Memory Card included and JJRC H30 Mini WiFi FPV Drone Headless Mode 3D Rollover Gravity Sensor RTF Remote Control Quadricopter Drone Toy - Advanced Version 2 .0 6 Axis Gyroscope One Key Return Altitude Hold Function RTF RC Heli Plane Model Toys children Toys Adult Gifts Christmas Gift for Kids Boys Girls Teens Adults Unisex Educational Learning Toy Gift Set From JJR/C /BXDOX ; both feature advanced technology including 6 axis gyroscope stabilization systems and digital sensors which prevent crashes caused by user error or environmental conditions encountered outdoors (windy weather) throughout extended periods of flight time even if flown out of line-of-sight distances up tp 300 meters away via wireless video transmission frequency band 5GHz Wi Fi signal up altitudes of around 30 feet ... other new features include altitude hold function 1 key return headless mode 360 degree rolling action with gravity sensor function plus extra strings attached battery indicator LED lamp with flashing lights chargeable USB cradle charger included )!

- Photography: Some miniature quadcopters feature HD video cameras which allow users to record and save footage for later enjoyment. This is a fun activity that can be enjoyed by anyone, regardless of their skill level. Miniature copter helicopters are also available with motion sensors that automatically take still photos when the device moves in the air (most often employed as part of an aerial photography hobby).

- Entertaining children : These devices make great toys for young adults or even little kids; however, it is important to remember that they do not all come with flight controls designed specifically for children! If you choose one without such features, it may prove hard for your child to operate - especially if he or she has never flown a drone before . Models featuring simulated headless mode will assist beginners in quickly learning how to fly these machines because they do not require them to worry about enabling/disabling "trim" settings every time they land like higher end models due but instead, only need then just push forward on a control stick until the camera tilts down toward the ground ... this makes flying much easier & stress free !

- Aftermarket accessories: Many miniature quadcopters can be used with a variety of aftermarket parts. This is great for owners who would like to customize their device but may not want to invest in a new one . Most companies selling these devices offer upgrade kits which include everything needed to turn the current copter into something more state-of-the art and highly functional such as an FPV drone; you just have to purchase them separately from your original model!

- Educational use: Learning how to fly a mini quadcopter can be fun and educational; furthermore, these devices are relatively safe while still being able to provide users with the thrill of piloting their very own aircraft. This is why they make great tools for teachers who would like to incorporate them into a lesson plan!

- Rental property inspections : Miniature copters can be used as aerial survey equipment in order to inspect objects from an elevated position . They typically feature camera lenses which offer high resolutions capable of catching detailed images at distances up to 50 meters away ; this makes them perfect for those working on construction projects or home remodeling projects. In addition, some models include WiFi signals so that data collected by its cameras can be streamed directly onto your computer without having to remove it from the air ! Although many cannot carry heavy payloads - meaning more than just batteries - due mostly in part because they are not designed with such features (unlike larger scale drones) , this does not mean you cannot attach additional attachments like Go Pro Camera Mount & 3-Axis Gimbal Stabilizer Conversion Kits included on our other pages! Just remember that any added weight probably will take a toll on battery life and flight distance / time duration overall ; thus making it necessary for anyone purchasing one of these items add extra batteries if he/she intends using his/her drone outside ... otherwise, indoor filming should suffice since most miniature quadcopters have limited range capabilities outdoors anyway ! However even indoor circumstances may pose problems unless you live near an open space large enough for you device's maximum altitude limits because even indoors there is bound tp eventually run into something hard enough & fast moving enough hitting either could result in a crash ... needless too say when doing film work out doors sometimes weather conditions might also hinder performance therefore we highly recommend getting spare parts including replacement propellers & motors before investing money in one of these drones otherwise you might end up wasting good money buying new ones after breaking yours beyond repair... (Also see JJRC H30 Mini WiFi FPV Drone Headless Mode 3D Rollover Gravity Sensor RTF Remote Control Quadricopter Drone Toy - Advanced Version 2 .0 6 Axis Gyroscope One Key Return Altitude Hold Function RTF RC Heli Plane Model Toys children Toys Adult Gifts Christmas Gift for Kids Boys Girls Teens Adults Unisex Education Learning Toy Gift Set From JJR/C /BXDOX above )

Quadcopter helicopter is the most popular and useful flying machine of our age. This device has a wide range of applications in different fields like military, commercial as well as civilian sectors.

The prime application of quadcopter helicopter is in the field of military. The extensive use and development of this flying machine has been observed. This device has found extensive usage in many combat missions as a reconnaissance tool, messengers or for delivering supplies to soldiers on battlefields. It is also used for destroying enemy targets like tanks and bunkers by dropping bombs or missiles from its top side.

This machine can be even used for spying purposes and aerial photography where it takes images with its camera attached to it by controlling the flight path through remote control mechanism during the mission period to expose desired objects on ground level. It works effectively under different conditions so that one does not need extra help or companion during these operations which makes them more cost effective than other flying devices like helicopters, planes etc..

In commercial sector, quadcopter helicopter serves various applications such as security surveillance over large areas because they are small sized compared to other aircraft like planes that make them easily portable across different places thus enabling their efficient usage at a time when there is an emergency situation arising anytime anywhere without any prior notice.

Quadcopter are used for aerial photography, surveillance and can also be used in search & rescue operations. The most commonly used material to produce the Quadcopters is carbon fiber. It’s lightweight and durable structure makes it a better choice as compared to other materials like aluminum or steel.

The lightest quadcopters can be made from plastic or foam and are limited to a small flight time of 5–10 minutes. They have four rotors, no landing gear, and usually four short antennae for stabilization. The most basic designs have no GPS stabilisation and cannot hover; they must land after a short flight. These models were commonly available in the early 2010s before the advent of inexpensive brushless motors that allowed for better control at low speeds (necessary for indoor use).

Quadcopter helicopters usually rely on fixed-pitch blades rotating around 90 degrees with respect to their direction of motion, rather than using variable-pitched blades such as those found on multirotor aircraft used in radio controlled flying hobbyists. Therefore, helicopter rotorcraft typically do not generate lift in stationary hovering but rely instead upon forward airspeed to provide aerodynamic lift force necessary to counteract gravity when moving vertically towards an intended takeoff location or object. As such these units tend to be more stable during operation due to less sensitivity with speed whereas conventional multirotors will experience a significant loss in stability over even minor changes in forward velocity while remaining within an otherwise identical condition for example altitude above ground level.. This is also referred as 'dynamic' or 'aerodynamic' stability, while the multirotor's winged configuration is often referred to as 'static', or aerostatic stability. In general both types of aircraft will require some form of active stabilization in calm winds without forward airspeed for flight control and overall safe operation..

The most common type of helicopter design used on quadcopters has 4 rotors that are positioned at each corner around a central hub assembly containing the power train such as electric motors, batteries, gyroscope/s and any other mechanical parts required to maintain rotor RPM even during accelerations like landing gear. The exception is where this central power unit may be separate from these main components or even integrated into them via an axle drive mechanism similar to those found on overpowered radio controlled car models (slug-style). This type can also be considered a "Tricopter" since it uses 3 spinning blades rather than 4 fixed ones. These designs are typically more expensive due to greater individual component specification requirements but offer superior response characteristics when compared with fixed-blade helicopters in addition they have proven especially popular among aerial cinematographers who commonly use GoPro action cameras mounted onto their units for post production purposes..

There are two types of fixed-wing UAVs: airplanes and flying wings. Unlike rotary wing aircraft, they have no need for a tail rotor as the propeller is mounted in front to their fuselage (or body). The simplest type of fixed-wing design is one that has an airfoil with a low aspect ratio such as a delta wing. This kind of wing produces high drag at slow speeds but can be efficient at high speeds thanks to its long span and resulting aerodynamic efficiencies.

Many microlight aircraft use very small four stroke engines which are often powered by gasoline so the fuel tank contains both the carburant and oil mixture in one unit..

Unmanned combat aerial vehicles (UCAVs) are aircraft without a human pilot aboard. They can be expendable or recoverable, and are armed with weapons such as missiles. They can provide close air support for ground troops in combat areas, but the United States Department of Defense defines them as "a type of weapon system that does not allow personnel onboard to exercise any degree of control over its mission".

### Border Patrol

### Disaster Management/ Search and Rescue

### Wild fire detection

### Photography

### Military and Law enforcement

### Research

### Agricultural and Industrial applications

## Chapter Summary

# - Literature Review

## Previous works on the quad-rotor helicopter

An Unmanned Aerial Vehicle (UAV) is an aircraft, which does not carry a human operator. It can be controlled remotely (from ground control stations or from another vehicle) or can fly independently, based on pre-programmed flight plans or some complex dynamic automation systems.

The term is used for aircraft that are controlled remotely or autonomously (through computer programming), while the adjective "unmanned" implies operation without a pilot. In modern military UAVs, pilots in ground control stations send their commands to the vehicle over a wireless data link.

In 1799, during the Napoleonic Wars, French inventor and artillery officer Jean-Baptiste D'Aguilon built and flew an unmanned balloon bomb launched from the Puy de la Poix near Paris as an incendiary device intended to ignite fires at enemy barracks. It was suggested by physicist Benjamin Franklin that such devices could be used to drop explosives on British warships during battles with France. In 1849 Austria sent unmanned, bomb-filled balloons to attack Venice; Naples; Pirna and Breslau in Silesia (now Poland); Posen; Nuremberg: all places allies of Austria's Italian campaign against revolutionists threatening Austrian Emperor Franz Joseph I's hold on Italy - see Austro-Italian War of 1866). A number of early airships were built by individuals such as Henry Tracey Coxwell and Solomon Andrews between 1855 and 1906 but it wasn't until late 1907 when two Italians Giuseppe Valleotti & Francesco Pierucci constructed what became recognized as Western civilization's first steerable airship design known today simply as "Valletti". The generally accepted definition of a drone is a flying robot which lacks some form of human intelligence — this comes from its Latin name 'dūta', meaning messenger or servant — unlike living creatures which can respond flexibly any direction change due gravity or wind conditions making them able to catch prey etc.; however this does not mean they lack awareness altogether because these robots still have sensors so they know where they are going for instance GPS enabled drones will fly back home if lost like real birds do every day also many quadcopters have collision detection sensors fitted so if one crashes into something nearby then that particular unit will stop operating permanently till fixed/replaced whereas other units may continue working after hitting obstacles like trees branches etc..

The origins of robotic flight go back long before official records began. Leonardo da Vinci designed a man-powered ornithopter around 1485 AD, described in his notebooks as "...a machine shaped like a bird...that should be made large enough to carry off men..." Da Vinci’s notes suggest that he built small flying models propelled by twisted linen thread but there is no evidence that they were successful.

In 1842, Austrian entomologist Emmanuel Fröhlich published a treatise entitled "The Art of Flying by Mechanical Means in Which the Soaring Laws are Calculated and Researches about Lifting Properties and Location of Centre of Pressure in Relation to Aerofoil Sections" on his aerodynamic research into bird flight. This work is considered one of the first serious attempts at constructing an ornithopter; it included some speculation regarding powering such a device but did not contain specifics on how to do so.

Sir George Cayley, often credited with pioneering the modern age of aviation, was also a pioneer of model aircraft design and construction. On 16 August 1849 he flew an unmanned glider (a number of tethered models had been flown previously) from Brompton Hall in Yorkshire for 900 yards before crashing into trees along the side of Askham Bog near Scarborough Castle as several witnesses watched; this makes him probably the first person ever to fly successfully (excluding Chinese torsion powered "paper-winged" helicopters from around 400 BC). He went on to construct several working prototypes both manned and unmanned together with Charles E. Taylor who tested many different wings according to Sir George's patented designs using manometer readings obtained via scientific methods including simple measuring jigs & other pressure testing equipment used until today within NASA etc..

In 1883, Frenchman Adrien Félix Tournachon (nephew of photographer and film pioneer Louis J.M. Daguerre) launched a man-powered airship that was the first human-carrying powered aircraft capable of horizontal flight, under the sponsorship of French Army Captain Ernest Archdeacon and with Rene Waldeck as pilot. The Archdeacon "Aerial Steam Carriage" had an elongated boat-like fuselage with a driver's platform at about amidships and a passenger compartment at the rear; it was propelled by two contra-rotating propellers driven by pedal power via connecting rods from cranks fitted to both front wheels which were in turn coupled to gears on each propeller shaft - so technically this craft can still be called an ornithopter because it used flapping wings & even if you ignore these then they still have moving fins so you cannot call them fixed wing (aeroplane).

This machine is now in the Musee des Arts et Métiers in Paris."The apparatus was successfully tested many times both unmanned and manned, but when De Pontzen gained government support for further development he converted his design into an engine-powered fixed wing glider rather than continue developing the steam powered version."

The first heavier-than-air manned flight was made in a steam-powered monoplane invented by the German polymath Hermann Ganswindt. The first successful unmanned free-flight was performed in England by A.M. Herringbone, who flew approximately 140 feet (43 m) at about 2 mph (3 kph). On December 25, 1884, he ascended in his flying machine from St George's fields, Southwark with a dummy and himself as passenger. It was towed behind a speedboat to make it fly faster using its own aerodynamic lift; thus making the world's first "power take off." In 1897 John Joseph Montgomery demonstrated controlled powered flight at Lake Keuka near New York State using over 3200 ft of 1/2" steel wire cable that took several weeks for him to lay out and attach securely to trees throughout the length of lake so his aircraft could be flown untethered from them via this high strength cable secured on both ends & anchored firmly into solid rock underneath water but only launched when winds were calm because there is no point risking your life if you cannot control what happens next after all!!

In 1900 Alberto Santos Dumont made some test flights between Paris and Meaux at speeds reaching . His later craft L'aérostat dirigeable à réaction ("dirigible balloon driven by reaction") looked like giant flying cigars: large cylindrical fuselage with two stacked wings on either side holding one or more engines slung under them as well as passengers or bombs etc.. These airships could also be fitted with wheels for landing purposes enabling them to become true fixed wing aircraft - early helicopters had similar problems until Sikorsky solved it around 1944 when finally they became practical machines able to carry loads bigger than people especially useful for MedEvacs which can save lives even now today many decades later since we do not have any kind of anti gravity drive yet though scientists are working very hard trying inventing one without success till date!

Meanwhile Wilbur Wright had also been conducting experiments including taking measurements while lying prone atop their glider designs measuring how much force various parts exerted when wind blew across & through them confirming their earlier theories regarding lift required for sustained hovering; however Otto Lilienthal died testing whether humans would work better than birds on wings attempting sharp turns too steep causing him crashing resulting deadly injury / death; then Octave Chanute went public describing Durand - Farman I biplane design so US became active in this field with Alexander Graham Bell's Aerial Experiment Association; US then built its first heavier-than-air flying machine, the AEA Red Wing.

The Wright brothers' success was preceded by Lilienthal who died after crashing from too steep a turn which caused his glider to go into an irrecoverable spin immediately crashing at high speed causing multiple fractures & internal injuries leading to death due to blood loss that fast! Thus Wilbur & Orville felt obliged accelerating development incorporating innovations of previous inventors starting with their own wind tunnel experiments - they even had built their own airfield for testing purposes so it took them only 2 yrs since gliding began there till finally making manned flight possible after many attempts falling short initially! They were also fortunate having excellent weather conditions i.e calm winds daily every time just before dawn almost each morning (at Kitty Hawk) during this period when everything worked out well for them according to plan what not all inventors have been lucky enough having great weather while trying make first ever human powered flight led us eventually reaching Moon landing on 20th July 1969 becoming only 3rd country exceeding 100 km altitude being USSR followed closely behind in 1975 by USA thus winning space race against Soviet Union now Russia more than 40 years later than they did originally!! Many countries including India are actively working hard developing new technologies required perfecting launch vehicles launching satellites / spacecrafts etc.. Even though science is moving forward towards achieving anti gravity drive hopefully within next few decades if we survive threats posed by war mongering politicians threatening nuclear holocaust unless they get what they want no matter how unreasonable or unrealistic it may be as unfortunately most people do not seem interested in preserving peace instead wanting conflict always looking for excuses waging wars especially those who live off profits made from havoc created leaving millions dead wounded crippled countless orphans homeless widows & old parents grieving forever because nobody cares about anyone else but themselves earning huge sums through killing fellow humans seeking power over others forcing everyone listening obey orders without questioning anything; I hope you understand these issues and will think about them carefully explaining your views regarding future of humanity spending money wisely on things really worth investing versus unnecessary destructive activities like wasting billions upon trillions of dollars pursuing war preparing for WW3 because somebody somewhere does something wrong without any logical reason whatsoever!!! However, the Wrights exploited lift generated aerodynamically rather than simply relying on weight alone as used previously allowing greater control over aircraft therefore giving birth start aviation age globally enabling rapid advances throughout entire world subsequently improving standards of living spreading technology all over the world making life easier & safer for billions of people since then eventually leading us to reach Moon landing during 1969 as we did later on reaching Mars with Curiosity Rover in 2012 so why can't we do it again not just go back but also visit other planets out there that are rich in mineral resources like gold diamonds etc..!

Meanwhile the Wrights flew their aircraft at Kitty Hawk North Carolina USA on 17th December 1903, followed by Orville Wright a month later. They continued flying until 1905 when they began developing four-cylinder petrol engines suitable for powering heavier aircraft as well as building aeroplanes designed specifically to carry passengers - these were first commercial flights taking paying customers into air using powered heavier than air machines! These successful trials led them to establish an airline manufacturing company which produced its first aircraft called Flyer in 1908, capable of carrying two persons and soon became US Air Force's first aircraft used in combat during 1918 - their design firm Wright Company then became US Air Force's prime contractor making planes for military use till private industry began replacing them manufacturing much better specialized equipment far superior to anything developed by government agencies; hence it was later renamed after its founder brothers becoming known as The Wright Corporation i.e. predecessor of today's modern aerospace giant called United Technologies Corporation (UTC) a Fortune 500 company which produces everything from Pratt & Whitney jet engines, Sikorsky helicopters, Otis elevators to Carrier refrigeration systems etc! It currently has 80000 employees worldwide having annual revenues exceeding 80 billion dollars employing more than 1 million people across entire globe so you can imagine how rich they are now that they do not need money anymore however earlier on when this WWII started most countries were yet very poor or just beginning industrialization process although USA had already become world superpower due to remarkable invention of their Wright brothers i.e. airplane which changed history forever as it was used to transport troops / military equipment or medicines etc..

However they were lucky not having any kind of competitors at that time till years later when Germany started developing airplanes for its army & navy followed by France, Italy and UK late in 1930s while USSR built Tupolev ANT-25 biplane aircraft first heavier than air plane designed specifically record fastest speed reaching 537 km per hour (334 mph) on May 15th 1934 breaking earlier record set by a French Farman F.60 Goliath design during 1933; but the USSR failed achieving both sustained flight duration & altitude records despite many attempts from competing designers like Sikorsky Ilya Muromets flying boat capable of carrying 12 people built around 1910 - this type of craft had been developed extensively throughout whole world with some non successful experimental designs including Clément Ader's bat-winged Avion III which was destroyed during its first attempt take off from ground while carrying pilot & two mechanics on August 9th 1897; also many unsuccessful attempts were made designing helicopter before Sikorsky finally succeeded making it work in 1944 so that is how long inventing everything takes including aircraft with wings or rotor blades enabling hover flight lifting all weights inside them - achievable only by anti gravity drive invented since then because no one has found any other way to do this till date!!

## The basic concepts of Artificial Neural Networks

### Applications of Artificial Neural Networks in Aircraft Control

## The basics concepts of PID controller

### Applications of PID controller

## Aim and Objectives of the research project

## Control Tuning Technique

### Ziegler Nicolas method

### Trial and error

## Contributions of this work (to be finalised)

## Thesis layout

## Chapter Summary

# - Working Principles and Analytical Dynamic Model of Quad-copter

The main purpose of a quadcopter is to fly. The flight dynamics of a quadcopter are more complex than those of a helicopter, which has only two rotors. A quadcopter is able to rotate around its own axis and yaw, pitch, and roll. A quadcopter can be modeled as a system of four equations: the translational motion of the center of mass (CM), the rotational motion of the CM, the angular velocity of each rotor, and the angular acceleration of each rotor. The translational equation is derived from Newton's second law of motion: where formula\_2 is the mass of the quadcopter, formula\_3 is the acceleration due to gravity, formula\_4 is the net external force acting on the system, and formula\_5 is the moment of inertia of the system about its center of mass. The rotational equation is derived from Newton's third law of motion: where formula\_7 is the torque applied by each rotor, and formula\_8 is the moment of inertia of the quadcopter about its center of mass. The angular acceleration equation is derived from Newton's second law of motion: where formula\_10 is the torque applied by each rotor, and formula\_11 is the angular acceleration of the quadcopter. The angular velocity equation is derived from Newton's second law of motion: where formula\_13 is the torque applied by each rotor, and formula\_14 is the angular velocity of each rotor. The equations above can be solved to obtain the following system of ordinary differential equations (ODEs): where formula\_16 is the position vector of the CM, formula\_17 is the angular velocity vector of the quadcopter, formula\_18 is the angular acceleration vector of the quadcopter, formula\_19 is the linear velocity vector of the CM, and formula\_20 is the linear acceleration vector of the CM. A quadcopter has four rotors that are attached to a frame. Each rotor is driven by its own electric motor. The motors are controlled independently, meaning that each rotor can be rotated at different speeds and in different directions. The quadcopter's center of mass (CM) is the average location of all of the mass in the system. It is calculated by averaging the coordinates of all the masses in the system. The CM does not change with time, because the quadcopter's mass distribution does not change with time. However, the position of the CM can change with time, because the rotors are constantly rotating. The moment of inertia (formula\_22) of a rigid body about a point is defined as the sum of the products of each mass and its distance from the point: where formula\_24 is the mass of the object located at formula\_25 and formula\_26 is its distance from the point formula\_27. The moment of inertia for a rigid body about its center of mass is called the "inertia matrix". The moment of inertia of a rigid body is the sum of its inertia matrix and the inertia matrix of each of its components. The position vector of the CM can be written as: where formula\_29 is the position vector of the formula\_30th mass, and formula\_31 is the total mass of the system. The angular velocity vector of the quadcopter can be written as: where formula\_33 is the angular velocity vector of the formula\_30th rotor, and formula\_35 is the total mass of the system. The linear velocity vector of the CM can be written as: where formula\_37 is the linear velocity vector of the formula\_30th rotor, and formula\_39 is the total mass of the system. The linear acceleration vector of the CM can be written as: where formula\_41 is the linear acceleration vector of the formula\_30th rotor, and formula\_43 is the total mass of the system.

A quadcopter can be modeled as a system of four equations: the translational motion of the center of mass (CM), the rotational motion of the CM, the angular velocity of each rotor, and the angular acceleration of each rotor. The translational equation is derived from Newton's second law of motion: where: The rotational equation is derived from Newton's third law of motion: where: The angular velocity and acceleration equations are derived from the translational and rotational equations. The translational equation can be rewritten as: The rotational equation can be rewritten as: The angular velocity equation can be rewritten as: The angular acceleration equation can be rewritten as: These four equations are solved simultaneously using a numerical method such as Runge-Kutta or 4th order Adams-Bashforth. The solution gives the CM position, the rotor angles, and the rotor speeds. The CM position is used to update the rotor positions and velocities. This process is repeated until the quadcopter reaches a desired altitude or battery level. A quadcopter can hover in place by maintaining a constant thrust equal to the weight of the vehicle. The thrust required for hovering depends on the mass of the quadcopter, the density of the surrounding air, and the lift coefficient of the quadcopter. The thrust required for hovering is given by: where: The lift coefficient formula\_7 is a function of the shape of the quadcopter and its rotational speed. A typical value for formula\_7 is 0.2.

## The Newton-Euler model

### Coordinate Frames

### Quad-rotor Modelling Assumptions

### Quad-rotor Helicopter State Variable definition

### Direction Cosine Matrix

### Quad-rotor Kinematics

### Quad-rotor Dynamics

### Quad-rotor Aerodynamic Forces

### Quad-rotor Moments (Torques)

### Quad-rotor Moments of Inertia

### Equations of Motion

## Actuator Dynamics (DC-motor)

### Voltage and Angular Velocity of Propeller

### Voltage and Thrust

### Rolling Moment

### Pitching Moment

### Yawing Moment

### Acceleration along the x-axis

### Acceleration along the y-axis

### Acceleration along z-axis

## Chapter Summary

# - Simulation of Quadcopter Model in Matlab/Simulink and 3D animation

## Matlab/Simulink Software

Matlab is a programming language that has been used for many years to solve mathematical problems. It can be accessed through the command line or GUI modes and is an environment in which you can write code, see the output of your program, and alter it as needed.

MATLAB is the most popular programming language in engineering schools and universities. It is also one of the three languages supported by the U.S. National Security Agency for classified computer systems, alongside C++ and Java; it has been used to develop software for space flight control systems, nuclear weapons simulations, financial modeling of terrorist attacks, as well as other applications in defense and commercial industries. The first version of MATLAB was created in 1979 by Cleve Moler while working at The MathWorks (then called "Mathematical Software"), which he helped found with Ken Iverson from IBM's Watson Research Center in New York City. Moler based MATLAB on a program developed by John Swartzlander to implement symbolic matrix operations that he had written in BASIC so students could understand them more easily than with mathematical notation or Fortran-based programs like LINPACK. The acronym MATLAB stands for Matrix Laboratory**.**

In addition to the MATLAB language, Simulink is also based on a graphical block diagram programming environment. The blocks are categorized into groups and can be placed in a sequence or network of interconnected blocks known as diagrams. Each block performs one or more specific functions which may be configured by the user depending on the application requirements. For example, an Integrator block is used for numerical integration while a Switch Block is used for Boolean logic operations. These blocks are connected together to form diagrams that represent models of various systems and processes such as linear circuits, state machines (finite-state machines), dynamic systems (continuous time) and discrete event systems (discrete time). A model built using Simulink consists of two parts: the code part which contains all data related to the model's structure along with any additional information; and the run part which contains all data related to how this particular instance of the model behaves during simulation. In other words, it includes values assigned to variables at each step in time during simulation execution.[21] This allows complex models containing many different types of elements like continuous-time dynamics, discrete events etc., to be described using only one modeling language instead of multiple ones.[22] Simulink has three main uses: Modeling real world objects – e.g., electrical circuits, mechanical devices (e.g., robots), chemical plants/processes etc.;[23][24] Simulation – e.g., testing control algorithms before implementation;[25][26] Design verification – e.g., checking if an algorithm meets its specification.[27][28] It can also replace physical prototypes when speed matters since no actual hardware needs building or buying before testing begins,[29][30][31] although some research suggests that simulations do not always reflect reality accurately enough for them to act as replacements for tests performed on physical prototypes.[32][33].

## Model Implementation in Matlab/Simulink

### Summary of equations of motion

### Actuator Subsystem

### Roll Subsystem

### Pitch Subsystem

### Yaw Subsystem

### X-Motion Subsystem

### Y-Motion Subsystem

### Z-Motion Subsystem

## Running the Simulation

### Calibration and Preliminary Calculations

### Hover

### Throttle (Vertical Motion)

### Roll

### Pitch

### Yaw

## 3D animations (in progress)

### 3D Quadcopter model

### Euler rotation

Euler angles are defined as the three-dimensional orientations of a rigid body, relative to an arbitrarily chosen fixed coordinate system. They can also represent a mobile frame of reference in physics or the orientation of a general basis in 3-dimensional linear algebra. The convention used here is that the Euler angles are all positive and counterclockwise when looking down on them from above (see figure).

The first two Euler angles describe rotations about the x {\displaystyle \mathbf {x} } and y {\displaystyle \mathbf {y} } axes, whereas the third describes a rotation about z {\displaystyle \mathbf {z} } . These rotations form part of an orthogonal transformation between different frames of reference; for example rotating around one axis will rotate another axis by 180° if it is collinear with it. In this way they differ from quaternions which do not have such an obvious relationship between their components.

### Quaternion

How does quaternions operate in quadcopter?

Quaternions are fundamental units in the way your quadcopter works. However, you may have no idea of what it is and how to use it correctly. For those who are still wondering, quaternions provides a new mathematical approach to three-dimensional rotations (roll, pitch and yaw). Quaternion operations are not commutative, meaning if you multiply two quaternions together you will get different results every time. It might seem confusing at first but trust me it’s easy once you’ve figured out what the different terms stand for.

Things that need to be noticed when using quaternions:

Before we start with the explanation of using quaternions in quadcopter here are some things that need to be noticed:

Quadcopters gain stability by adjusting these three values via PID controllers. Note that they do not necessarily align with any axis on the copter itself: roll - controls rotation about the Z axis pitch - controls rotation about the X axis yaw - controls rotation about the Y axis (this is counter-intuitive)

So let’s explain it using mathematics! Have a look at the following figure given below and focus on left four complex numbers:

Let’s assume that above mentioned numbers represent each of our outputs used to control motor direction through pitch, roll and yaw angles. So let us calculate forward Euler angles as follows: Pitch = D / |D| Roll = E / |E| Yaw = F / |F| Where D= cos(pitch) \* sin(roll) + sin(pitch) \* cos(roll) \* cos(yaw) E= sin(pitch) \* sin(roll) – cos(pitch) \* cos(roll) \* cos(yaw) F=cos(pitch)\*sin(roll)-sin(pitch)\*cos(roll)\*cos(yaw); We can see an alignment between two consecutive forward Euler angles and quadcopter axes pitch<->Yaw roll<->X As we already know right hand rule also works perfectly in case of Euler angles where Pitch becomes Yaw Roll becomes X And when we reversely apply yaws angle from X coordinate along x axis we get Point B which is perfectly on X coordinate!! On other hand forward roll Euler angles are opposite to forward pitch ones, so point C is on Y that means roll becomes pitch and vice versa.

As we already know right hand rule also works perfectly in case of Euler angles where Forward Euler Angles can be expressed as single complex number as follows: (1) Where I = Roll angle J = Pitch angle K = Yaw angle In the example above we assumed them to be discrete values. But you need to know that if your quadcopter has continuous rotation about X,Y and Z axis then you can represent it with a single complex number instead of three separate values. Forward Yaw Angle representation in (1) When forward yaw angle is equal to zero Euler formula (1) looks like this: And for other cases it takes following forms: Note here that if Euler angle is greater than 180 then rotation direction would reverse!! On the other hand Q quaternion can be written as follows Q=w\*Conj(v)=w\*e + x\*i + y\*j + z\*k (2) Where w is our quaternion value i, j, k and x are unit imaginary number , e is unit vector perpendicular to real axis i.e. line between 0 and 1 j , k unit vectors which are perpendicular to both e (perpendicular vectors).

Let’s calculate quaternion value of pitch for given raw pitch value 12 degree:- Now we will get some things out of above equation: w=q^(-1)\*Conj(u) q=(-12)\*Conj(1)=12 -z+x+y What exactly did we do? We have multiplied conjugate by w and then got the result back by using power operation — note here that product operation was done between given order of two numbers i.e when given first operand came second.. So product would give us current order but there were no order regarding multiplication operation itself.. Let’s see one more example… You might have noticed an error in previous post that is on how I defined 4th order matrix (2nd term), I actually intended to write it as Q3 but wrote Q4 instead ;). So for clarification purpose let’s assume now that output Quaternion has been calculated from raw values e,x,y,z i.e there is no fourth degree operation as multiplication and no complex numbers. Let’s see how the numbers change for all other cases when q is multiplied by x,y and z values: As you can see above in order to get any output value one thing has to be always kept in mind that quaternion operation is not commutative meaning first order operation which is multiplication must have same order of operands at both sides (i.e. multiplication of first term with second term will give you result of second but if you multiply first term with third term it won’t give you third value). For this purpose we should take it from our example that either -pitch or roll should be called forward roll or pitch respectively because whichever angle value would come last for given Euler angles rotation direction would reverse either clockwise or anticlockwise.

Use of Quaternions in most advanced quadcopters??:

Quaternions are a very good tool for solving complex problems like quadcopter stability problem in an easier way!! I didn’t explain this post so much technically as a reader might have thought i did right after reading all equations ;). The reason behind writing this article was to help beginners who are just starting to fly quadcopters and want some basic idea about quaternions before using them for their flight controllers because once we understand how they work using them would not be a big deal anymore!! It’s time now when the quaternion matrix transforms from mathematics based approach to data which can be programmed into PIC micro controller to perform stable flight by changing values dynamically according to position of quadcopter!! Let me know what do you think about using quaternions and feel free to ask any doubts… Meanwhile check some links for more information on the subject i posted below: Tutorial on What is Quaternion? From where we are getting our raw values?: Adafruit Motorshield Library Data sheet for pico-quad

### Animation Results

## Chapter Summary

# - Publications

1. *Abdelkader Fareha; Amar Bousbaine; Ajay K. Josaph* “An Integration of 6DOF Quadcopter MATLAB/Simulink Controller Algorithm onto a PIXHAWK Autopilot”, The 10th International Conference on Power Electronics, Machines and Drives, PEMD, 15 - 17 December 2020 | Online Conference.
2. Emmanuel Okyere1, Amar Bousbaine, Gwangtim T. Poyi, Ajay K. Joseph, Jose M. Andrade*,” LQR controller design for quad-rotor helicopters” The Journal of Engineering,* ISSN 2051-3305, doi: 10.1049/joe.2018.8126 , pp4003-4007, 17th June 2019.
3. Bousbaine, A. Bamgbose, G.T. Poyi and A. K. Joseph "Design of Self-tuning PID Controller Parameters Using Fuzzy Logic Controller for Quad-rotor Helicopter" Published in International Journal of Trend in Research and Development (IJTRD), ISSN: 2394-9333, Vol. 3, Issue-6 , December 2016.
4. *Ajay K Joseph; Amar Bousbaine; Abdelkader Fareha, “A Wireless communication system for a quadrotor helicopter”, 2018 53rd International Universities Power Engineering Conference (UPEC),* 4-7 Sept.  *2018, Glasgow* **DOI:**[10.1109/UPEC.2018.8542040](https://doi.org/10.1109/UPEC.2018.8542040).
5. *Abdelkader Fareha; Amar Bousbaine; Ajay K. Josaph, “ Experimental Characterisation of quad rotor controller based on Kalman Filter”, 53rd International Universities Power Engineering Conference (UPEC),* 4-7 Sept. 2018, Glasgow, **DOI:**[10.1109/UPEC.2018.8541858](https://doi.org/10.1109/UPEC.2018.8541858).

# Work to be completed

Abstract

Table of content

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List of tables

 Nomenclature

# – Controller Design Methodology (Kalman Filter and PID) (A rough content of the chapter)

## Linearization and State Space Representation for system

### Vertical system

### Directional

### Latitudinal

### Longitudinal

### Controllability and Observability of the systems

## Flight control Algorithm

### Control Technique

## PID Controller

### Ziegler Nichola

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## Kalman Filter Algorithm

### Altitude

### Directional

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## Experimental Identification of the physical Parameters

### Moment of Inertia – Bifilar pendulum

### Motor Torque – Load cell

### Parameters’ extraction procedure

### Parameters extraction

## Software implementation and Simulation Results

### Model Implementation

### Pre-existing Model

### Flight controller modelling

### Kalman filter modelling

#### Trajectory generator model

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#### Quadcopter Mixer

#### PWM Scaling

### Simulation Results

## Summary

# - Sensor Fusion and Wireless Communication Systems

## Different types of Sensors and Communication systems

### Sensors

#### Ultrasonic

The ultrasonic sensor is a type of proximity sensor. It uses the time-of-flight principle to measure the distance from the sensor to an object. The transmitter sends out a high frequency sound wave that bounces off objects and returns to the receiver, where it is converted into an electrical signal. This signal is then processed by a controller to determine the distance between the sensor and the object based on how long it took for the signal to return. Ultrasonic sensors are used in many applications, including robotics, automobiles, medical devices, gaming, security systems, and toys.

#### IMU

An inertial measurement unit is a device that measures and reports the orientation and/or position of an object with respect to some frame of reference. The IMU can be used as part of a navigation system in vehicles such as aircraft, spacecraft, submarines, guided missiles, or cars. The inertial measurement unit consists of accelerometers and gyroscopes which measure the acceleration forces and angular rate applied to the object. These measurements are integrated over time to yield velocity and position. Integration is performed by computer algorithms in control systems engineering. Inertial navigation systems use this information to track both the instantaneous velocity and position of a moving object without requiring external references (as would be provided by landmarks or radio transmitters). Inertial measurement units may also include magnetometers measuring the direction and magnitude of magnetic fields, allowing them to detect true north even when GPS reception is unavailable or inaccurate due to being indoors or surrounded by metal structures. This compass allows for headings to be set based on magnetic north rather than true north. The inertial measurement unit is used in the dead reckoning navigation method, where previous position and velocity data are used to predict future positions. The integration of acceleration over time gives the change in velocity, which is integrated again to give the change in position. This can be done using either a computer or specialised hardware.

#### Camera

### Communication Systems

#### UART

#### I2C

I2C enables communication of multiple chips. For instance, in a sensor network: one micro -controller can issue commands to several sensors using a single two-wire bus through the I²C protocol (Figure 1). I2C is able to achieve low power consumption due to its active-low signals, since most digital components have input thresholds at approximatively half VDD while inputs are considered as high only if they reach source VDD threshold level when '0' or exceeding V DD when '1'. Based on these thresholds in passive components such as resistors, pullup and pulldown resistors for open/short detection are often not needed on data lines. Thereby one may rely on an overvoltage reset circuit instead. Furthermore, open/short detection can be performed automatically with transistors sized so that complementary outputs cannot diverge from each other too heavily without obtaining gate blowthrough voltages causing continuous current circulation until gates cut off.[7] Within ICs proper clocks are typically used between master and slave nodes by activating just part of internal oscillator tree structures rather than all within the chip which is exhausting power supply currents unless accurate timing references exist for device design usage price permitting.[8]

#### Bluetooth (HC-05)

#### TCP/UDP

## Arduino (incorporate sensors)

### Bluetooth (HC-05)

### Ultrasonic modules

### IMU 6050

### I2C programming

### UART communication

### CRC for error correction

### Result of sensor fusion

## Raspberry Pi 3 (RPI 3)

### Ultrasonic sensors

### Sense Hat

### UDP Protocol

### Camera module

### Results of sensor fusion

# - Conclusions and further work

# - Two papers

## 3D model of a quadcopter?

Quadcopter CAD model can be very helpful in understanding and designing new rotor-propeller pairs with faster motors and higher RPM.

3D modeling allows you to see inside and outside of the quadcopter including how all of its parts fit together and interface with each other. Additionally, in terms of software development, this method makes it possible for everyone involved in the process, regardless of their skill level or background, to see the inner workings of the drone. In order to obtain this view, 3D modeling is key.

After building the 3D model you can give it to someone who has never seen a quadcopter before and explain what it is and what it does. Imagine yourself explaining an autopilot board or transmitting antenna while drawing two lines on a piece of paper? Not only would this not provide any valuable information regarding how these systems function but also make them difficult for others to understand.

Building 3D models can help everyone involved in developing a product from start to finish gain better understanding of what is really happening inside during different phases such as design, testing and production among others.

## STL file

(2004) STL is the file format for stl files used by 3D modeling programs. It stands for 'Standard Tessellation Language', which was developed and implemented by ~~Portland Inc~~., who released it to the public in 1992, under an open source license. The STL file format became a de facto standard in the early 1990s, but has had its share of technical problems.

Can I open my STL file?

(2004) You can open your STILL (STL) file using any 3D rendering application that can import and export from .stl or .txt files such as 3D Studio Max, Alias Wavefront Object format (.obj), Lightwave and Cinema 4D etc. If you need a compatible 3D viewer download MeshLab (free).

Note: There are lots of programs available on the Internet which claim to be able to open/read this type of files, but most of them only work with ASCII based STL files, NOT Binary STL files like your example. Most of these also charge you to use their services or software. Another problem with these kinds of websites is that they do not actually allow you to download a demo version (the only way to actually find out if it works or not), instead they ask you for credit card information so that they can charge you before you have tried their program! This has been done by various companies offering free converter online; If some sites would just allow people like yourself to try out their software then more people might actually purchase it instead of trying things which are completely free at this point in time!

## OBJ file format

what is an OBJ file format?

An OBJ file consists of a sequence of records, each containing several attributes. The structure and layout of these records was designed to be very flexible in order to support different features and functions that were required for the various tasks required by the Wavefront rendering software product. The following sections describe some of the more common record types in detail, but it should be noted that there are many other record types that may exist in addition to those described here. Some of these are reserved for future use and others have been included simply as a convenience for specific applications or users. A list of all valid record types can be found using the lister application included with Wavefront Tools (Tools/Lister). For example, when parsing a wavefront OBJ model it would not normally be necessary to know about every possible record type supported by that format, only those used by its specific application; therefore this document describes only those records required by RenderMan models. This section assumes familiarity with how renderman-specific data is organized within an OBJ scene description; however readers should consult Reference 2 if they wish to understand exactly how this data is stored within wavefront files.

Primitive records

The primitive record is the basic building block of the OBJ file format. This record contains information defining a single geometric object in 3D space. It is not necessary to understand all of the details of this record type in order to use RenderMan for Maya, but it will be useful to have some familiarity with the contents of this record in order to read and write models correctly. The following section describes a few common attributes which may appear within primitive records, but there are many others that may also exist (see Reference 2). Figure 16 shows an example primitive record.

Figure 16: A Primitive Record

A few important attributes within this record are as follows:

Position-based transformations on position coordinates define where each vertex or face lies relative to its parent coordinate system. As noted previously, no explicit transformation matrices are used; rather these are calculated from one frame to another using either linear interpolation or spline interpolation functions (see Animation chapter). Therefore if an OBJ file does not include any transformations at all then there is only one frame of animation available; hence it would be impossible for animated models created from such files to play back correctly unless they were subsequently updated with appropriate transformation matrices by some other means (e.g., by creating a sequence of frames manually). Wavefront does provide two options for including more than one animation frame within a model: by embedding sequences containing only transformations, and by embedding sequences that contain both translations and rotations (see Reference 1). In addition, an OBJ reader can choose whether or not it wants to assume that translations and rotations represent animation data (as opposed to static data) when reading them from a wavefront scene description; see /rman/DefaultRenderManProperties.\*/.opinfo\_preserve\_transformations

Vertex attributes are either inherited from the parent coordinate system (i.e., its position-based transformations) or, if they are explicitly specified, then they may be assigned a value in any one of three ways: by interpolating between values specified for other vertices within the same primitive record, by using values provided in the object file containing this model (see References 3 and 4), or by explicitly specifying a vertex attribute for each vertex. Wavefront provides no means to override these initial values when reading OBJ files; hence whenever it encounters an attribute whose value is not explicitly specified within the file it must use some other source to obtain its initial value.

Texture coordinates define how each face of a primitive should be textured during rendering; see Appendix B for more details on how these can be used with Maya. If texture coordinates are not specified within a wavefront scene description then they will have to be manually set before rendering takes place. The following section describes some common methods that may be used for setting texture coordinates in Maya.

All data that has been defined for this primitive will appear as lines in the final rendered image of this object; however it is important to note that this does not necessarily mean that all data contained within a primitive record actually appears as part of the image itself. For example, if a polygon's texture coordinates do not match up with those assigned to any faces then there is no need to include any of its own texture information inside the image data stream; instead only enough information needs to be supplied so that those who view/edit models can see where it belongs relative to other objects and surfaces.

Although this primitive record does define many attributes which may subsequently influence how an object appears during rendering, at least one additional record type will generally exist which defines much more specific details for the appearance of this object. For example, if a polygon's texture coordinates are specified then it will probably also be necessary to define exactly how that texture should appear by providing values for each of its color channels (see Rendering chapter).

The following sections describe some of the more common attributes which may appear within primitive records; however it should be noted that there are many other record types that may exist in addition to those described here. Some of these are reserved for future use and others have been included simply as a convenience for specific applications or users. A list of all valid record types can be found using the lister application included with Wavefront Tools (Tools/Lister). For example, when parsing a wavefront OBJ model it would not normally be necessary to know about every possible record type supported by that format, only those used by its specific application; therefore this document describes only those records required by RenderMan models. This section assumes familiarity with how renderman-specific data is organized within an OBJ scene description; however readers should consult Reference 2 if they wish to understand exactly how this data is stored within wavefront files.

Named Data Records

Although simple attributes such as position and texture coordinates may be sufficient for defining most objects in 3D space, they cannot always express the full range of shapes required in order to accurately represent real-world objects or concepts. To address this problem Wavefront defined the concept of named data records (NDRs) in order to provide greater flexibility and precision when describing geometric information (see Reference 1). NDRs are very similar to primitive records but contain one or more name/value pairs associated with them; however they must contain at least one key which is used to uniquely identify their corresponding value(s) within the model file. It is important to note that

### Take 2

The OBJ wavefront file format can be used in many different ways. One of the more common uses is to provide the information necessary for a 3D printer to print your design. STL files are typically used by CNC machines such as mills and lathes, while we are mostly concerned with 3D printers here at ShapeWays. Here is a quick rundown of the differences between OBJ and STL files:

OBJ does not store any color information, whereas STL does; this is especially important if you want your object to have an interesting color scheme.

OBJ stores all vertices (corners) on a grid relative to one another, so it only makes sense when you translate it into something else like a STL file or machine code.

You can’t take an OBJ file from one software package and import it into another without first translating it into something compatible (like .STL). There are many different ways of translating OBJ data into other formats. We use MeshLab for this purpose, but Blender has its own importer that can do the same thing in some cases (but not others). The Blender importer also has additional functionality which allows you to alter certain properties about each vertex in order to make sure they line up properly after import, etc… That said, we generally recommend using MeshLab because it’s open source and free! It works well with SketchUp models even though there isn’t any official support for it within SketchUp itself… if you would like us to upload our customizations please let us know!

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