SRI VENKATESWARA INTERNSHIP PROGRAM FOR RESEARCH IN ACADEMICS (SRI-VIPRA)

Project Report of 2022: SVP-2224

"Investigation of Unmanned Aerial Vehicles (UAVs)"

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SRIVIPRA-2022

(Sri Venkateswara College Internship Program in Research and Academics)

This is to certify that this project on the **Investigation of Unmanned Aerial Vehicles (UAVs)** was registered under **SRIVIPRA** and completed under the mentorship of **Dr Neha Verma and Dr Hari Singh** during the period from **21st June to 7th October 2022.**

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SRIVIPRA PROJECT 2022

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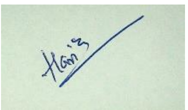

Dr Neha Verma **Dr Hari Singh**

Certificate

This is to certify that the aforementioned students from Sri Venkateswara College have participated in the summer project SVP-2224 titled **"Investigation of Unmanned Aerial Vehicles (UAVs)"**. The participants carried out the research project work under our guidance and supervision from 21 June 2022 to 07 October 2022. The work carried out is original and carried out in an online mode.

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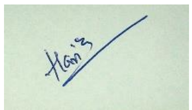

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We are grateful to the Department of Electronics for encouraging us to widen our academic perspectives. We owe a deep sense of gratitude to our mentors Dr Neha Verma and Dr Hari Singh for their constant support and guidance. It was their encouragement and assistance which made this work possible. During these weeks, we learned about the functioning of Unmanned Aerial Vehicles (UAVs). The project was divided into various sections wherein we learned about the basic body design and functioning of various parts of a Quadcopter. We got an insight into the MATLAB Simulink as a part of the software study, explored the UAV toolbox and tried modelling the working of motors (brushless). For hardware study, an attempt at an Ornithopter was made, which was based on the basics of what we have learned about UAVs. It was an enriching learning experience for all of us.

Lastly, we would like to thank all those people who have been associated with this project and have helped us with it. Immeasurable appreciation and deepest gratitude to all of you for your help and support.

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CHAPTER 1

INTRODUCTION OF UAVs

An Unmanned Aerial Vehicle (UAV), commonly known as a Drone, is an aircraft without any human pilot, crew, or passengers on board. UAVs are a component of an unmanned aircraft system (UAS), which includes adding a ground-based controller and a system of communications with the UAV. The flight of UAVs may operate under remote control by a human operator, as remotely-piloted aircraft (RPA), or with various degrees of autonomy, such as autopilot assistance, up to fully autonomous aircraft that have no provision for human intervention. Unmanned Aerial Vehicles (UAVs) have been widely adopted in the military world over the last few decades and the success of these military applications is increasingly driving efforts to establish unmanned aircraft in non-military roles [1].

1.1 NOT-SO-SHORT HISTORY OF UNMANNED AERIAL VEHICLES (UAVs)

It is easy to see how Unmanned Aerial Vehicles (UAVs), or Drones, can be seen as a modern invention. If we could travel back in time to just ten years ago, the idea of ordering a reliable flying camera online would seem more science fiction than science fact. This is especially true for easily accessible drones with payloads capable of producing thermal, multispectral, and LIDAR (Light Detection and Ranging) based imagery. You might be surprised to learn the first UAV dates back to the year 1783. Modern technology moves at a somewhat rapid pace. It is easy to forget the building blocks that brought the UAV industry to where it is today. An appreciation for the past achievements that helped to give birth to the modern drone era is essential.

In this section, we'll review some of the most significant historical events related to the history of Drones. In some cases, historical firsts were not specific to the UAV industry; however, they are relevant technological advancements.

1.2 HISTORICAL TIMELINE OF UAV TECHNOLOGY

1783 – The First UAV

When we think of UAVs, hot-air balloons are typically not part of the discussion. From a technical standpoint, these crafts were the first aircraft to not require a human pilot. Joseph-Michel and Jacques-Étienne Montgolfier hosted the first public demonstration of an unmanned aircraft, a hot-air balloon in Annonay, France.

1849 – The First Military Use of UAVs

Austrian Artillery Lieutenant Franz Von Uchatius invents the balloon bomb. Field Marshal Von Radetsky used the balloons to attack Venice, but they were mostly ineffective.

1858 – First Aerial Photograph

Gasper Felix Tournachon takes the first aerial photograph from a hot-air balloon in Paris, France. Unfortunately, the photograph has been lost in history.

1896 – First Camera on a UAV

Alfred Nobel, famous for the invention of dynamite, launches a rocket with a camera on it. Nobel's experiment marks the first time cameras were placed on an unmanned system.

1898 – The First Radio-Controlled Craft

Nikola Tesla displays his radio-controlled boat for a crowd in Madison Square Garden. The craft could respond to directional signals sent to it by Tesla and could also flash its lights. Some of the audience members thought Tesla was a magician or had the power of telekinesis. Others believed a trained monkey was inside the small boat. It was a compelling demonstration of what would evolve into radio-controlled aircraft.

1915 – British Use of Aerial Reconnaissance Photos

During the Battle of Neuve Chapelle, British forces used aerial photography to build a map of the German front. The photographs were laid on top of one another and are one of the earliest examples of an orthomosaic.

1917 – First UAV Torpedo the Kettering Bug

Charles Kettering invented the unmanned Kettering Aerial Torpedo, nicknamed the "Bug" in Ohio. The Bug used a system of pre-set internal pneumatic and electrical controls to stabilize the aircraft. When the Bug reached a predetermined distance, the engine would stop, the wings would detach, and the Bug would fall from the sky. It carried 180 pounds of explosives.

1935 – The First Modern Drone is developed

When the Royal Air Force commenced in 1918, the United Kingdom (UK) needed effective methods for training pilots. Target practice was typically accomplished by towing gliders behind crewed aircraft. However, that method failed to provide a realistic simulation for engaging enemy fighters in live combat. In response, the De Havilland DH.82B Queen Bee aircraft was used as a low-cost radio-controlled drone developed for aerial target practice. It is considered by many to be the first modern drone.

1936 – US Drone Program Begins

U.S. Admiral William Harrison Standley witnessed a test flight of the Queen Bee in 1936. After returning to the U.S., he placed Lieutenant Commander Delmar Fahrney in charge of developing a program similar to the UK's. It is believed that Fahrney first used the term "Drone" for the U.S. platform as a tip of the hat to the UK's Queen Bee.

1937 – U.S. Navy Develops a Radio-Controlled UAV Torpedo

The first radio-controlled UAV was the Curtiss N2C-2. The N2C-2 received its commands from an operator located in a crewed aircraft that flew alongside the Curtiss. While this limited the UAV's effectiveness, it was a significant step in the development of radio-controlled UAV technology.

1941 – Actor Reginald Denny invents the Radio Plane

The Radio Plane was a radio-controlled target plane. After forming his company, Denny produced target drones for the military and was responsible for numerous drone technology innovations. By the time the Northrop Corporation bought the company in 1952, Denny's company had produced almost 70,000 target drones for the US Army.

1943 – The Beginnings of First-Person View (FPV) Flight

Boeing and the U.S. Airforce developed the BQ-7, which operated on a crude FPV system. Old bombers were effectively stripped of non-essential equipment and loaded with explosives. A human pilot would fly the aircraft towards the designated target. Once the target was in view, the autopilot was engaged, and the pilot bailed out of the plane. The BQ-7 would then fly to the target on its own. The BQ-7 was virtually ineffective in war, and the pilots that bailed out had a high rate of death or capture.

1973 – Israel Develops UAVs for Surveillance and Scouting

The Mastiff and the IAA Scout series of UAVs represented a leap in the capabilities of drones. Military commanders were able to increase their situational awareness with these platforms significantly.

1982 – Battlefield UAVs

The Battle of Jezzine represented the first battle where drones made a considerable difference in the engagement's outcome. Israel employed their drones to outmanoeuvre the Syrian Air Force and win the battle with minimal casualties. The legitimacy of UAVs in warfare was established.

1985 – US Significantly Scales Up Drone Production

By the conclusion of the Vietnam War, the U.S. was ready to scale up its drone program. The successes of Israel's UAV program in the early 1980s made it clear that drones would have a growing role on the battlefields of the future.

1986 – The RQ2 Pioneer Drone is developed

The U.S. and Israel jointly develop what will become one of the most successful UAV platforms to date. The system was an upgraded IAI Scout drone and featured significant payload improvements. During the Gulf War, some Iraqi forces even surrendered to a Pioneer UAV.

1991 – UAVs Fly 24/7 during the Gulf War

For the first time in a major conflict, at least one drone was airborne from the conflict's start until its conclusion.

1996 – The Predator Drone is developed

With the help of UAV giants like Abraham Karem, the U.S. develops the Predator drone. This platform brought weaponized drones to the battlefield like never before. Probably more than any other UAV, the Predator created the public image of drones striking targets around the world.

2006 – UAVs Permitted in US Civilian Airspace for the First Time

Following the devastation caused by Hurricane Katrina, the FAA allowed UAVs to fly in civilian airspace for search & rescue and disaster relief operations. Predator drones with thermal cameras were able to detect the heat signatures of humans from up to 10,000 feet away. Around this time, the consumer drone industry began to really take shape.

While DJI had yet to become the marketplace giant it is today, companies like Parrot, DJI, 3DR, and many others were looking to take military UAV technology and repurpose it. The potential for industrial and consumer UAV markets was more than enough for many businesses to invest in the technology.

2010 – Parrot Controls a Drone with a Smartphone

At CES, French drone manufacturer Parrot unveiled its AR Drone. The UAV was a small quadcopter fit for consumer use. An app on a smartphone was all the pilot needed to operate the drone safely.

2013 – DJI Produces the First Phantom Drone

While the company was founded in 2006, the iconic Phantom series was not released until 2013. This drone began the modern camera-equipped drone craze. Within just a few years, DJI would hold a commanding position in the consumer drone market, with almost 80% of consumer drones in operation manufactured by DJI or one of its subsidiaries.

2013 – Major Companies Look to Start Drone Delivery

FedEx, UPS, Amazon, Google, Uber, and countless other delivery companies recognize drone benefits as a delivery platform. Testing of various UAV concepts and work with regulatory agencies around the world begins.

2014 – Use of Drones Rapidly Grows in Industry and with Consumers

Since 2014, UAVs have continued to expand in capabilities and use cases. As more industries explore how drones can make their work safer and more cost-effective, growth is expected to rapidly surge in the coming years. By 2030, the entire UAV market is set to be worth $92 billion.

2020 – Pandemic Alleviation

From quarantine & social distancing enforcement to mass disinfection and medical supply delivery assistance, drones have been a staple during the coronavirus outbreak.

Now, more than ever before, regulations are being adjusted to provide fast-track authorizations for promising use-cases. It’s impossible to predict the long-term impact of these developments, but one thing is certain: the pandemic has helped countries around the world imagine the potential that drones hold for society.

CHAPTER 2

CASE STUDIES ON DRONES FOR COMMERCIAL DELIVERY

A delivery drone is an unmanned aerial vehicle (UAV) used to transport packages, medical supplies, food, or other goods. The delivery drones are typically autonomous. In November 2020, the Federal Aviation Administration (FAA) proposed airworthiness criteria for type certification of delivery drones with the intent to initialize commercial operations. Zipline, Wing copter, and Amazon Prime Air were among the ten companies selected for this type of certification.

2.1 AMAZON AND OTHER BIG TECH COMPANIES [2], [3]

In 2013, Jeff Bezos introduced the world to a concept that promised to revolutionize delivery—within a matter of years, autonomous drones would engulf cities, sweeping across skies, delivering packages to front yards just thirty minutes after their order. The announcement floored America—grabbing headlines for weeks and setting off fiery debates about just how disruptive the disruptive technology would be. The drones would offer urban and suburban consumers a clean, quick, convenient delivery option for food, medicine, or whatever else in just five-pounds-or-less without burning fossil fuels, without getting stuck in traffic, and without making them wait. The idea was far-fetched, it was exciting, it was the future arriving in front of our very eyes, and it signalled that the race to take delivery drones to market was on.

By the time Amazon landed its first package, Zipline was already delivering medical supplies in Rwanda, SkyDrop had flown a 7-Eleven Slurpee and a Domino's pizza straight to consumers and Google's Project Wing had air-dropped burritos to hungry college kids. A wave of startups sent their maiden drone deliveries skyward to much media fanfare while major parcel couriers- DHL, UPS, and FedEx—substantiated the hype by partnering with the budding tech companies set to help solve their last-mile problems. Inventors, investors, eccentric billionaires, and the world's biggest companies were all pulling the same rope. Anything, anywhere, anytime: the dark days of two-day delivery were over; the drone delivery era was coming… or so it seemed.

It's now 2022 and saves for the smallest fraction of a per cent of people, it's not automated dropping off your small packages and food orders. The world TV show 60 Minutes introduced in 2013, the world that felt closer and closer to reality with every inaugural delivery, is just not here. Fundamentally, the fast delivery niche still exists. The last mile still counts for 40% of parcel shipping costs, roads are still increasingly clogged with traffic, green shipping alternatives are still desperately needed, and consumers want products as cheap and fast as possible. Outside of a few specific locations, drone delivery has yet to take off and in those few specific locations, it's hardly more than a proof of concept. Certainly, delays are understood- expected even- when it comes to the acceptance of disruptive technology. Delayed acceptance though, is the very only part of the story.

In 2021, Amazon fired staff and closed its Prime Air offices in the UK. From the former centre of Amazon's drone delivery project emerged stories of mismanagement and disarray: employees drank beers at their desks, managers were given no direction, and executives ignored the stalling division aside from the occasional pizza party. While the company responded to these reports with a statement affirming its continued investment in drone delivery, Amazon hasn't released any promotional material for the project since 2016 and Prime Air's website doesn't seem to have been updated in years. The most generous possible interpretation is that Amazon's project is definitively on the back burner. Others weren't even there.

While Amazon remains quiet on its future intentions, DHL announced in the summer of 2021 that it was officially abandoning its parcelcopter project nearly eight years after its maiden flight. So, two of the most important drone delivery companies have their programs on ice, few companies are getting the investments they used to, and no company has yet realized the imminent future of widespread operations laid out a decade ago.

2.1.1 What went so wrong with drone delivery [4]?

Let's understand this with the help of the example of the city of Phoenix in Arizona, US Phoenix is a sprawling desert metropolis home to 5 million people. At first glance, Phoenix seems the perfect candidate for a drone delivery service: it is year-round sunny, and dry, still, the climate would make easy reliable flight conditions; its autonomous innovation-friendly city and state governments would welcome them with open arms; and its sprawling, low-density neighbourhoods would make for countless hungry and impatient residents lacking walkable dining and shopping options. This was supposed to be the low-hanging fruit. It was thought that surely, a drone delivery company could come in, connect any house with any product within minutes and demand would immediately outstrip supply. But the concept of drone delivery didn't work here too.

Connecting any house with a drone delivery provider doesn't quite work because in the centre of the city is Phoenix Sky Harbor International Airport. To assure the safety of arriving and departing aircraft at the busy hub, the FAA restricts the use of drones within a particular area. It could also not operate around Luke Air Force Base and Phoenix Goodyear Airport and a bunch of other airspaces. It's not entirely impossible to operate drones within restricted airspace, but, from a legal perspective, it ranges from somewhat to extremely difficult—enough that it probably wouldn't be worth pursuing a drone delivery company, at least at the start. The rest of Phoenix is also subject to these deliveries only to an extent.

Drones need someone to deliver to and it has to be safe. When the concept was first introduced, the vision typically presented was of a drone flying down, landing on one's lawn, releasing its delivery, and then taking off and flying away. But that didn't work.

Drone delivery is a novel technology and, like any novel technology, the public views it with an air of distrust- the worst thing the industry could do is prove that the distrust warranted a series of high-profile accidents at launch.

The first instance of a delivery drone injuring a customer will inevitably ignite a media firestorm, which could lead to a legislative clampdown, so manufacturers naturally must strive for perfection. Perfection is tough to scale though. Delivery drones must act autonomously to be cost-competitive, and autonomous operations require computer vision and artificial intelligence able to identify a clear landing zone. Determining whether someone is behind or in front of a window, noticing when a dog is running towards a drone, and knowing what a pool is and what's dry ground-these are all challenging for a computer to tackle on its own, and so attaining perfection proves rather difficult. Therefore, the logistics field generally considers the last mile of delivery the most difficult- once the economics of scale are gone- drone delivery is the last mile solution with its last foot problem.

It's fairly straightforward to get a drone to a couple of dozen feet above the ground- getting a package safely to the ground has proven more challenging. Some solutions have emerged, Zipline, focusing on longer-distance delivery to a set number of facilities with dedicated delivery zones, drops its payload in packaging with an attached parachute that carries it to the ground. Matternet also uses dedicated zones for delivering to commercial facilities, while they've developed a system of delivery stations for use by urban consumers. Uber Eats, meanwhile, implemented a scrappy yet inefficient system where delivery drones would land on top of delivery drivers' cars, and then those delivery drivers would walk the food to the customer's door.

Most solutions for the last foot problem, however, have gravitated towards one method. Wing, SkyDrop, Flytrex, Wingcopter, and others have developed systems where their drones hover above the destination at a safe height and lower their payloads to the ground using cords—far less risky than landing a heavy drone propelled by fast-moving rotors. What all these solutions have in common is that they require a roomy, controlled, obstruction-free area to make their final deliveries. However, in the places where people live, that's hardly a given.

Yards are the best delivery zones that are widespread, but not everyone has a yard. While it's a safe bet for single-family homes in an area like Phoenix, it can be hit or miss whether multi-family homes and apartment buildings have a big enough yard and, even when they do, their communal nature means that the customer couldn't necessarily guarantee that the landing area would be free from obstruction as would be the case with their own, private yard. So, at least for an early drone delivery service, it probably wouldn't work in restricted airspace and probably not for anything single-family homes either. These and other legal, technological, and practical constraints combined mean that the scope of what works in terms of drone delivery is narrow.

It's pretty easy to start crossing off cities—some have harsh winters, some of them have high densities that inhibit yards, some have very restricted airspaces, some have a landscape that's too hilly, and so on. While it varies by company, most delivery drones tend to be able to fly to deliveries as far as about six miles away. So, assuming early operations would base out of a single location to capture economies of scale, meaning their drones would have to return to the said location to charge after each delivery, that means a viable first delivery zone in Phoenix—optimizing for a large area, free of airspace restrictions, centred on wealthier neighbourhoods is fairly small. 310,987 people live in this zone- a small chunk of the metro area's 5 million. However, in Phoenix, only 63.2% of housing units are single-family which are likely to have the private yard necessary for delivery and only 92% are occupied meaning, in this prime zone, at least extrapolating using city-wide data, which is the most precise available, there are only 180,820 possible users of a drone delivery service.

While not a very precise methodology, it's indicative of how the prospect of drone delivery—the prospect of anything, anywhere, anytime— is getting diminished down into a niche service for a lucky few. A small system linking a strip mall to the neighbourhood behind it, a fixed route flying COVID vaccines from a distribution centre to vaccination sites, six shops delivering to a small part of a small town in Virginia— drone delivery has hardly moved beyond proof of concept, and it's not even clear that they've proved the concept.

2.1.2 Low-tech Companies' solutions for the last mile problem

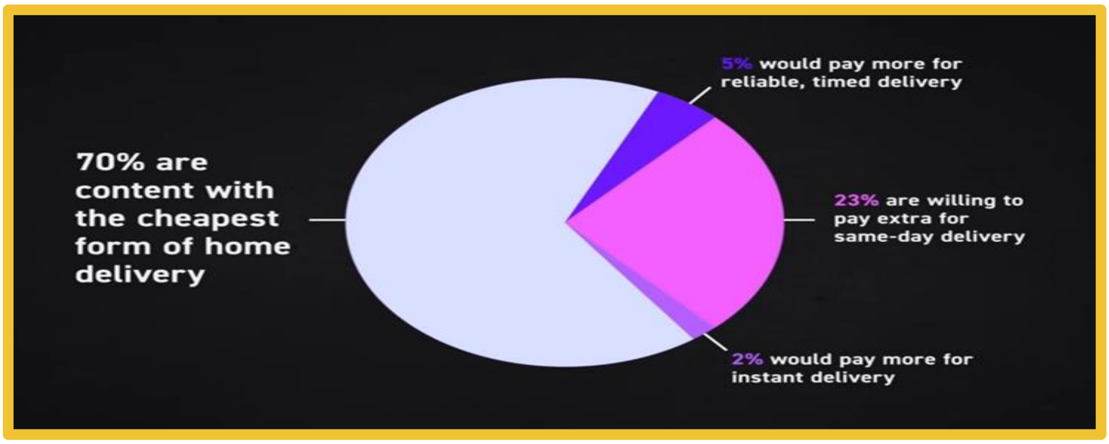

Figure 1 Division of customers market based on the type and pricing of deliveries.

In 2016, when asked about same-day delivery, 70% of respondents said that they were content with the cheapest option while just 23% of respondents said they'd pay more for same-day. For drones to prove commercially viable, they'd need to decisively corner that quarter of more willing consumers and to become ubiquitous, they'd likely need to operate at no extra charge from ground delivery at all. Most people, it turns out, are simply okay with waiting a day or two for their packages, while all want them delivered as quickly and as cheaply as possible.

When the drone delivery hype hit the fever pitch, one bit of nuance went overlooked. Consumers simply don't care about how a package gets from b to c, so long as it's quick, cost-efficient, and reliable- they'd opt for a new technology once for the novelty, but by the 100th time that wears off. Eventually, rationality will return. When surveyed in 2020, consumers

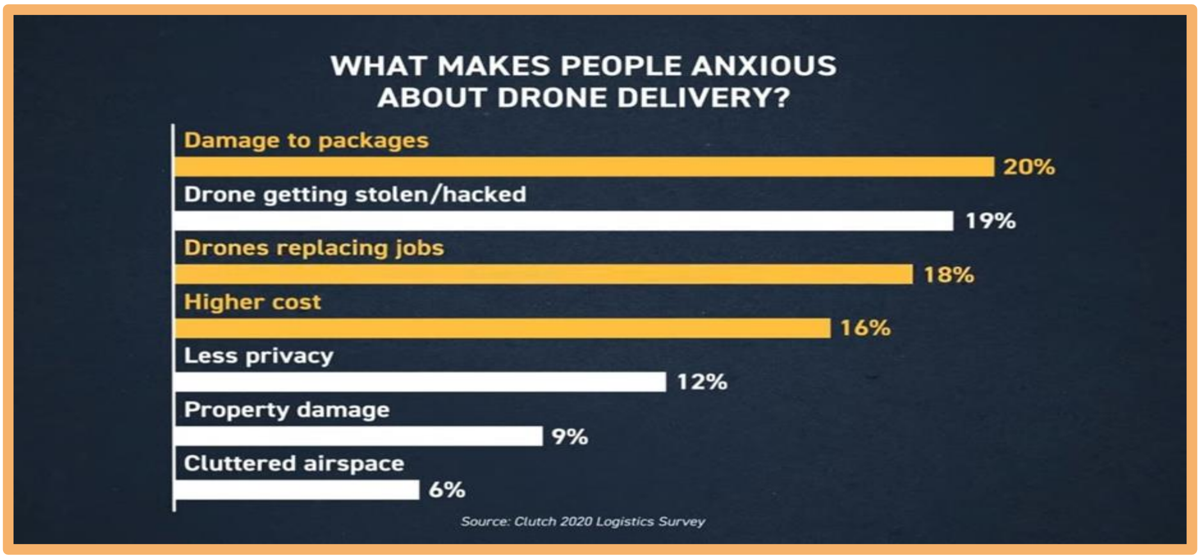

Figure 2 what makes people anxious about drone delivery?

perceived drones to potentially threaten those most factors for delivery— they said they were uncertain about drones' reliability, and cost and were worried about the job loss they could incite. Meanwhile, competitors have figured out some low-tech solutions that fulfil these consumer desires: look no further than food delivery apps. Since 2017, the very moment when drone delivery hype hit the fever pitch, the food delivery industry has tripled in size, ballooning into a $150 billion sector globally. In this, speed matters, and consumers expect to pay for the delivery cost- facts that seemingly pave the way for drone delivery. But between Uber Eats, Grubhub, and Doordash, the power players are already established and the competition is already fierce.

These comparatively low-tech companies don't even tell the consumer whether to expect their burger to come by car, moped, bike, or foot; they just prioritize getting food to doors quickly, pleasing the consumer regardless of the method, and undercutting drone delivery in the process. By and large, food delivery apps closely match the upside of drones within urban and suburban areas without the hassle of complying with FAA guidelines and figuring out the last foot problem. Adding to the competitive problems facing drone startups, these companies and others have since expanded into grocery, medicine, and good deliveries. Put simply, from the consumer perspective, the problem drone delivery was designed to address had already been solved without building out a massively complicated aerial delivery network. The current low-tech, gig economy model isn't perfect, though. For consumers and restaurants alike, the usage fees are expensive, for those delivering the pay is minimal; and for the big players, profit has proved elusive. One partial solution is automation. Here still, drones are likely to lose out. Ground-based autonomous and semi-autonomous robotics have begun popping up in test markets and partnering with the likes of Uber Eats and Grubhub to expand their reach. While a recent partial ban on sidewalk-wandering robots in San Francisco points to the hurdles the technology faces, these hurdles just won't be as numerous as those facing drones. Automation and technological advances may well help smooth out food and last-mile delivery. Soon, your prescription, your lunch order, or your afternoon coffee might be showing up at your front door courtesy of an autonomous vehicle- you'll just need to reach down and grab it from a robot instead of unclipping it from a drone above.

2.1.3 Gartner's Hype Cycle

Now, many probably look at drone delivery in retrospect and find it unsurprising that the bombastic claims of the 2010s failed to pan out, but far fewer would have expressed a dissenting opinion just five years ago. That's because this is a rather classic story: that of a hype cycle.

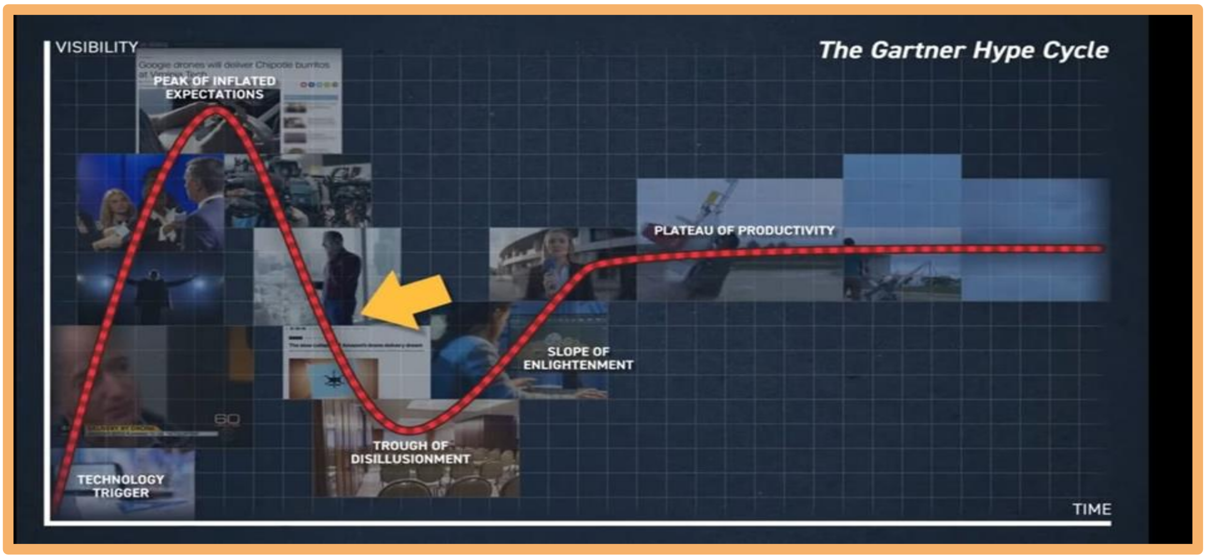

Figure 3 The Gartner Hype cycle.

A new idea comes around, a few early players start development, and then something— a launch, a demo, or even just a domino effect— sets off a media firestorm painting a rosy picture of a future revolutionized by this new technology. The story is so archetypal in tech that there's even a theoretical framework defining the process: Gartner's Hype Cycle. According to this, after that media firestorm, the peak of inflated expectations results slow and sentiment starts shifting downward. Investors complain and the public's memory fades until the media begins coverage of the purported failure. The public grows disappointed, but then grows silent, and in the silence, first generations are adapted into seconds, failures inform potential success, and slowly something meaningful— albeit minor compared to the original vision— starts to work.

We are here. While what's happening may be drowned out in the media by what's not, some applications are starting to work. Three years ago, Zipline was a small Silicon Valley startup operating a few dozen drone delivery flights a day in one region of Rwanda. They relied on the principle that many medical products are crucially important when used, but not used regularly, and often have short shelf lives, making them tough to economically and efficiently stock at smaller clinic operations. In less developed regions, poor road infrastructure makes many remote clinics many hours or days away from a distribution centre, despite being in relative proximity as the crow flies. Therefore, Zipline's drones act as a quick, low-cost distribution system for necessary medical products to remote areas dotting Rwanda's rolling hills.

Far more places than Rwanda fit this description; nowadays, Zipline operates similar systems in the country's Eastern Province, four regions in Ghana, the US, and some other locations are in active development. Excitingly, the news of Zipline's impending expansion to the Ivory Coast hardly made news, just a simple press release and some industry and regional coverage. This is progress. This shows that Zipline's deployments aren't proofs of concepts, they aren't publicity stunts, and they're actual, real, commercial implementations. Crucially, Zipline didn't find a use case that drones could fulfil- they found a use case only drones could fulfil. Matternet and Wingcopter are now placing heavy emphasis on their medical potential as well. As the early use-case matures, the cost will come down, acceptance will rise, and innovators will find more uses that only the novel technology can fulfil.

Eventually, everything will creep closer to that idealistic vision first presented at the peak of the hype, and then, just slightly delayed behind expectations, the new technology will finally have changed the world.

2.2 ZIPLINE [5]–[7]

Zipline is an American company that designs, manufactures, and operates delivery drones. It uses autonomous planes to deliver medical supplies—vaccines, pharmaceuticals, whole blood, platelets, frozen plasma, and cryoprecipitate —to hard-to-reach places.

It runs the only nationwide drone delivery network in the world, powered by the fastest and most reliable long-distance delivery drone. The company started its first project in the Sub-Saharan country of Rwanda in 2016 for drone delivery of blood for blood transfusion.

Blood delivery systems all around the world need to be specifically efficient as the shell life for RBCs is about a month while platelets and some other blood products such as plasma last for less than a week. Therefore, speed and logistics play a crucial role in blood transfusion. Despite the modern technological advancements and innovations in logistics, there's ample blood that gets wasted every year, even in developed nations like the United Kingdom.

But, in the year 2019, the poor country of Rwanda became the first country to not waste a single drop of blood. Rwanda, which is also known for its willingness to embrace innovation such as in the field of healthcare, boasts of a universal healthcare system where everyone has access to hospitals at an affordable or no cost. This also brings out some interesting observations in various reports such as the fact that despite being the 17^{th} poorest sub-Saharan African nation, its 67 years of life expectancy is better than that of some far richer African nations such as South Africa (63 years).

One of the most visible innovations has to do with how the country's hospitals get their blood. Most of the country's blood delivery is outsourced to a company called Zipline. This is also one of the first applications of commercial drone delivery. While companies like Google and Amazon are testing drone delivery in developed countries, Rwanda, a developing country, already has a full-scale, nearly country-wide drone delivery system in service.

2.2.1 How does it work?

The Drones currently service several hospitals throughout the country. The closest is just 4 kilometres from Zipline's facility in Muhanga with the furthest being about 80 kilometres away. Any of these hospitals can place an order with Zipline in almost any way they can- email, text, phone or WhatsApp. Zipline's products are delivered to them by road from the Rwandan health system (in Kigali) so they have a supply on-hand.

Medical staff at remote hospitals and clinics place orders with Zipline, a fulfilment operator receives this order and prepares the medical products into a special delivery package with a parachute. A Zipline flight operator then packs the medical products into a drone and performs pre-flight checks. The drone is then launched with a supercapacitor-powered electric catapult launcher and accelerates to 0 to 70 miles per hour (0 to 113 km/h) in 0.33 seconds.

Once in flight, the drone follows a pre-set flight path. Now, the drone is autonomous, it flies itself, but it has no decision-making authority. It flies high enough that it doesn't require any obstacle avoidance ability and, if it needs to hold for a minute to wait for air traffic to clear, it's told by the controller to enter a pre-set holding pattern. There are few weather conditions these drones can't fly through. They can handle severe wind, rain and lightning but if they can't make it to their destination, they can also use these pre-set holding patterns to turn around. While drones have improved greatly since a few years ago, a critical fault does happen every few hundred or so flights. In this case, the drone has a built-in parachute that triggers itself to safely fall back to the ground. Crucially, no one has ever been injured by a Zipline drone. If for any reason, a drone needs to stop flying immediately, such as if Zipline were to receive an order by air traffic control to immediately get out of certain airspace, the controller back at the base could also manually trigger the parachute to deploy. From there, operators would go out by the road and recover the drone.

The drones fly at 100kmph so they reach the nearest hospitals in mere minutes or the furthest hospitals 80 kilometres away, requiring about a 50-minute flight to reach. As a drone reaches its delivery point, the individual in charge of communication will message the hospital to let them know.

The drone will reach the delivery point, circle to lose altitude, then fly a few hundred feet over a predetermined landing spot, open its belly doors, and drop the package. The parachute will slow its fall but the impact is also softened by the bubble wrap inside. From there, the blood product arrives and the hospital staff just walks outside to collect it. For the nearest sites, these blood deliveries arrive in about 15 minutes ready to be transfused to patients critically in need. Now, the drone gains altitude, flies back towards the Zipline site, then circles again to lose altitude, and finally lands by catching an arresting gear.

Rwanda

Global Health researchers have found that Zipline's drone delivery service in Rwanda: shortened blood product delivery times by 61%; reduced blood unit expirations by 67%; and was frequently used in response to medical emergencies, with 43% of orders being emergency orders. As of September 2021, more than 75% of blood deliveries in Rwanda outside of Kigali use Zipline drones.

This specific solution worked for Rwanda due to other reasons as well. Rwanda is called the land of 1000 hills. Therefore, due to its mountainous geography, drone delivery is more cost-effective. Rwanda also gets heavy rainfalls and landslides and so the cost of maintenance of roads is very high. Due to the lower budget of the country, most of the roads in Rwanda are not developed enough to rely on for the transportation of blood in regular situations much less, emergencies. In addition, as Rwanda is a developing nation, its air space is not as busy and clearance for the drones to fly is much easier to attain than in developed nations.

Zipline started operating in Rwanda in 2016 and took some of its first flights in the same year. As the success story of its model spreads, they plan to expand in different countries.

Ghana

They opened their first distribution centre in Ghana in 2019 and played an essential role in supplying yellow fever vaccines and in another scenario, ORS to high school students suffering from acute diarrhoea within 20 minutes. Zipline has transported COVID-19 vaccines everywhere it operated since April 2021. The independent study of Zipline’s impact was conducted by ID insight and analyzed health facilities served by three of Zipline’s distribution centres in Ghana. The results indicate that Zipline meaningfully contributes to the Ghanaian government’s work to expand healthcare across the country, with a statistically significant impact on inventory availability and supply chain performance. Select findings show the Zipline system:

- Shortened vaccine stock-outs by 60%, and decreased inventory-driven missed vaccination opportunities by 42%
- Decreased days facilities were without critical medical supplies by 21%
- Increased the types of medicines and supplies stocked at health facilities by 10%

Today, Zipline Ghana is a central part of the Ghanian medical supply chain, operating 4 distribution centres serving 2,000 health facilities with routine medical supplies and emergency blood and essential medicine.

US

During COVID-19, the company worked with the government to deliver vaccines to the state of North Carolina. Moving forward, Zipline started its trail services for drone delivery for e-commerce shopping. In June 2022, it received the license for "Package Delivery by Drone (Part 135)".

Japan

In April 2021, Zipline started working on a partnership with Toyota Tsusho to deliver medical products in Japan. As the construction of its first distribution system was completed earlier this year, it will now supply medical products to Goto Islands. The use of drone delivery to assure the routine distribution of medical products is expected to cut current sea and air transport options from several costly hours down to 30 minutes.

2.2.2 Other Developments

In September 2019, the Govt. of Maharashtra announced its plan of establishing 10 Zipline distribution centres with the help of SII (Serum Institute of India). Similar plans to establish distribution centres in the Philippines, Cote d'Ivoire and Kenya have also been announced by Zipline.

Zipline as a company can effectively combine cutting-edge technology with innovative logistics to make the concept of aerial delivery a reality in the modern world.

CHAPTER 3

CLASSIFICATION OF UAVS [8], [9]

Based on aerial platforms, there are generally four types of UAVs (Drones):

1) Single Rotor Drone (SRD)

2) Multi-Rotor Drone (MRD)

3) Fixed Wing Drone (FWD)

4) Fixed Wing Hybrid Vertical Takeoff Landing Drone (VTOL)

3.1 SINGLE-ROTOR DRONES

A Drone having only one rotor is known as a single-rotor drone. Single-rotor drone types are strong and durable. They look similar to actual helicopters in structure and design. A single-rotor has just one rotor, which is like one big spinning wing, plus a tail rotor to control direction and stability.

Figure 4 Single Rotor Drone

3.1.1 Advantages of Single-Rotor Drones

- Greater efficiency over a multi-rotor.
- Allows for very long blades, which are more like a spinning wing than a propeller, giving great efficiency.
- If you need to hover with a heavy payload (e.g. an aerial LIDAR laser scanner) or have a mixture of hovering with long endurance or fast-forward flight, then a single-rotor helicopter is your best bet.
- They are built to be strong and durable.

3.1.2 Disadvantages of Single-Rotor Drones

- Single-rotor drone types are complex and expensive.
- They vibrate and aren’t as stable or forgiving in the event of a bad landing.
- They also require a lot of maintenance and care due to their mechanical complexity.
- The long, heavy spinning blades of a single rotor can be dangerous.

3.1.3 Technical Uses of Single-Rotor Drones

- Aerial LIDAR laser scan
- Drone surveying
- Carrying heavy payloads

3.2 MULTI-ROTOR DRONE (MRD)

Multi-rotor drones are the easiest and cheapest option for getting an 'eye in the sky.' They also offer greater control over position and framing, and hence they are perfect for aerial photography and surveillance. They are called multi-rotor because they have more than one motor, more commonly tricopters (3 rotors), quadcopters (4 rotors), hexacopters (6 rotors) and octocopters (8 rotors), among others. By far, quadcopters are the most popular multi-rotor drones.

3.2.1 Types of Multi-Rotor Drones

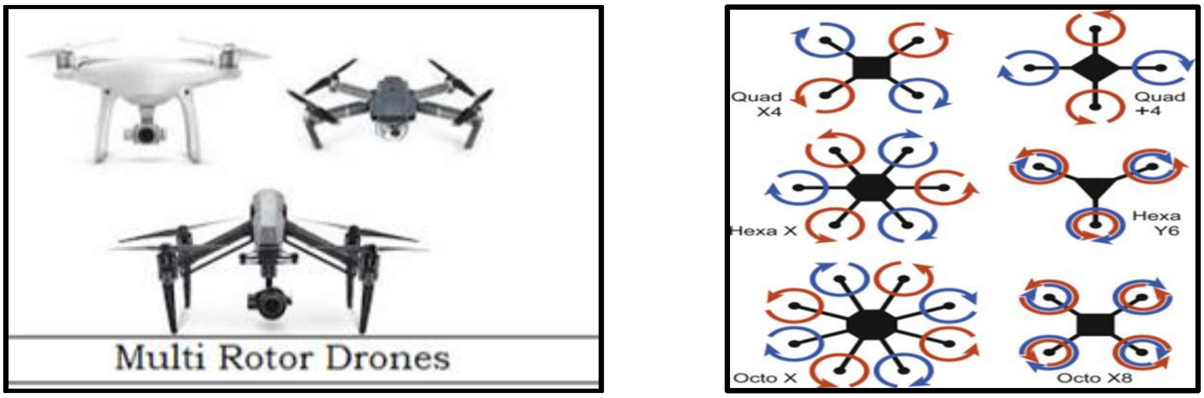

Figure 5 Types of multi rotor drones.

- Tricopter: As the name suggests it has 3 rotors and is generally more difficult to build.
- Quadcopter: One of the most stable designs
- Hexacopter: This type and more like it, with higher rotors like octocopter, usually used for the higher payload.

3.2.2 Advantages of Multi-Rotor Drones

- Better control; increased manoeuvrability, can move up and down on the same vertical line, back to front, side to side and rotate in its axis.
- Ability to fly much more closely to structures and buildings.
- Ability to take multiple payloads per flight and reduces the time taken for inspections.

3.2.3 Disadvantages of Multi-Rotor Drones

- Limited endurance and speed; unsuitable for large-scale aerial mapping, long-endurance monitoring and long-distance inspection.
- Fundamentally very inefficient and require a lot of energy just to fight gravity and keep them in the air.
- With the current battery technology, they are limited to around 20-30 minutes when carrying a lightweight camera payload. However, heavy-lift multi-rotors are capable of carrying more weight, but in exchange for much shorter flight times.

3.2.4 Technical Uses of Multi-Rotor Drones

- Visual inspections
- Thermal reports
- Photography & Videography
- 3D scans

3.3 FIXED-WING DRONES

A fixed-wing drone has one rigid wing that is designed to look and work like an aeroplane, providing lift rather than vertical lift rotors. Hence, this drone type only needs the energy to move forward and not to hold itself in the air. This makes them energy-efficient.

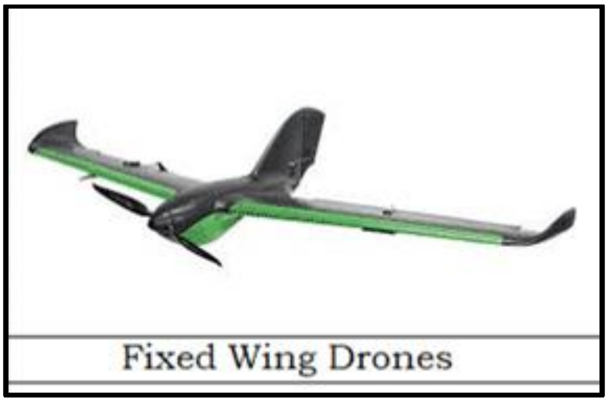

Figure 6 Fixed Wing Drones

3.3.1 Advantages of Fixed-Wing Drones

- Cover longer distances, map much larger areas, and loiter for long times monitoring.
- The average flight time is a couple of hours. With a greater energy density of fuel can stay aloft for 16 hours or more.
- This drone type can fly at a high altitude, carry more weight and are more forgiving in the air than other drone types.

3.3.2 Disadvantages of Fixed-Wing Drones

- Expensive.
- Training required to fly. Always moving forward, and move a lot quicker than a multi-rotor.
- A launcher is needed to get a fixed-wing drone into the air.
- The hundreds and thousands of captured images have to be processed and stitched together into one big tiled image. There is a lot more to be done after this, including performing data analysis, such as the stockpile volume calculations, tree counts, overlaying other data onto the maps, and so on.

3.3.3 Technical Uses of Fixed-Wing Drones

- Aerial Mapping
- Drone Surveying – Forestry/Environmental Drone Surveys, Pipeline UAV Surveys, UAV Coastal Surveys
- Agriculture
- Inspection
- Construction

3.4 FIXED WING HYBRID VERTICAL TAKEOFF LANDING DRONE (VTOL)

Hybrid VTOL drone types merge the benefits of fixed-wing and rotor-based designs. This drone type has rotors attached to the fixed wings, allowing it to hover and take off and land vertically. This new category of hybrids is only a few on the market, but as technology advances, this option can be much more popular in the coming years. One example of a fixed-wing hybrid VTOL is Amazon's Prime Air delivery drone.

Figure 7 Fixed Wing Hybrid VTOL

3.4.1 Advantages of Fixed Wing Hybrid VTOL

- The autopilot can do all the hard work of keeping the drone stable, leaving the human pilot with the easier task of guiding it around the sky.
- Hybrid VTOL drones offer you the best of both worlds – fixed-wing & rotor-based designs.
- They are perfect at either hovering or forward flight.

3.4.2 Disadvantages of Fixed Wing Hybrid VTOL

- Only a handful of fixed-wing hybrid VTOLs are currently on the market
- The technology used in these drone types is still in the nascent stage.

3.4.3 Technical Uses of Fixed Wing Hybrid VTOL:

- Drone Delivery

3.5 DETAILED CLASSIFICATION OF DRONES

Based on shape, design and usage, drones have several types

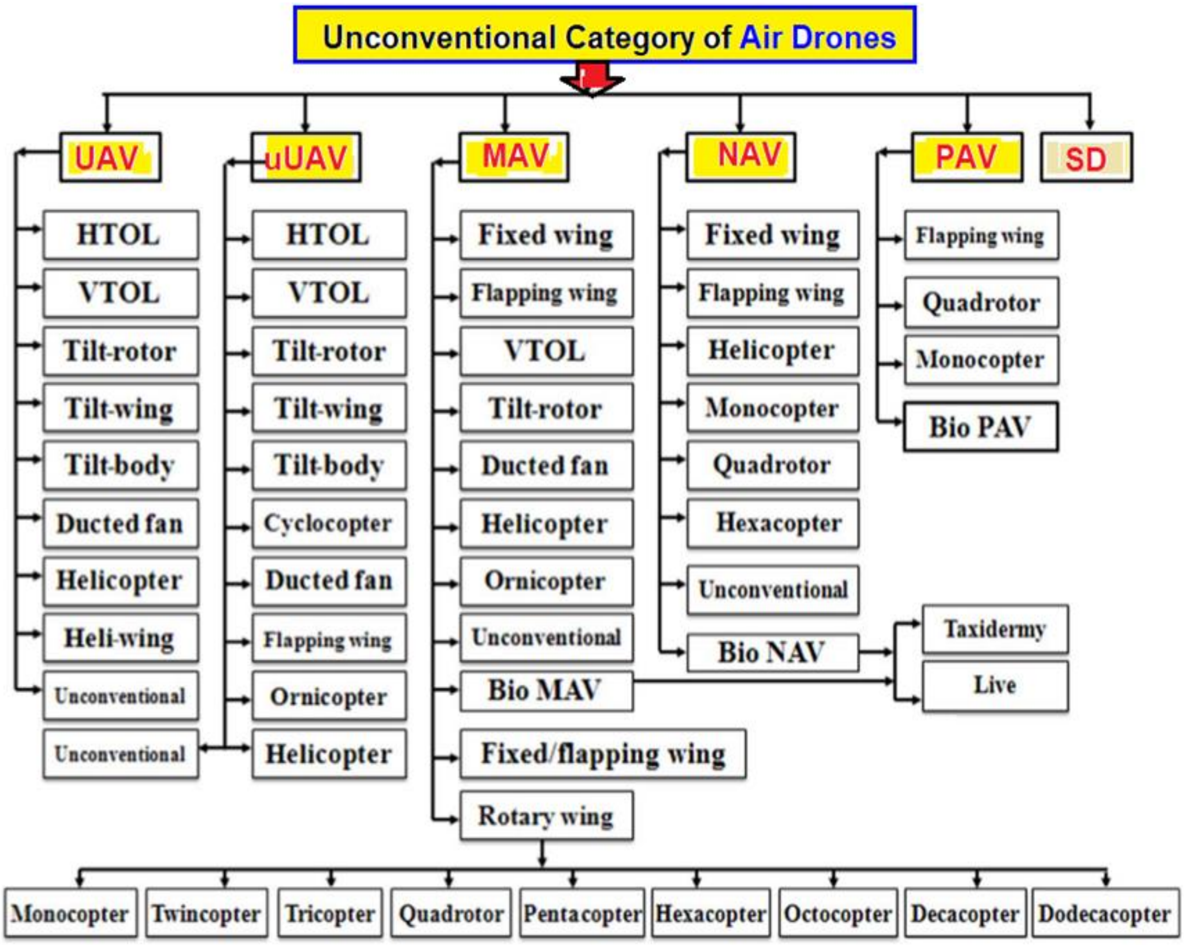

Figure 8 Unconventional category of Air Drones.

CHAPTER 4

COMPONENTS OF UAVS

4.1 FRAME

Frames made up of various materials are present out there like Plastic, Glass Fiber and Carbon Fiber. The type of frame to choose depends upon the application of the quadcopter.

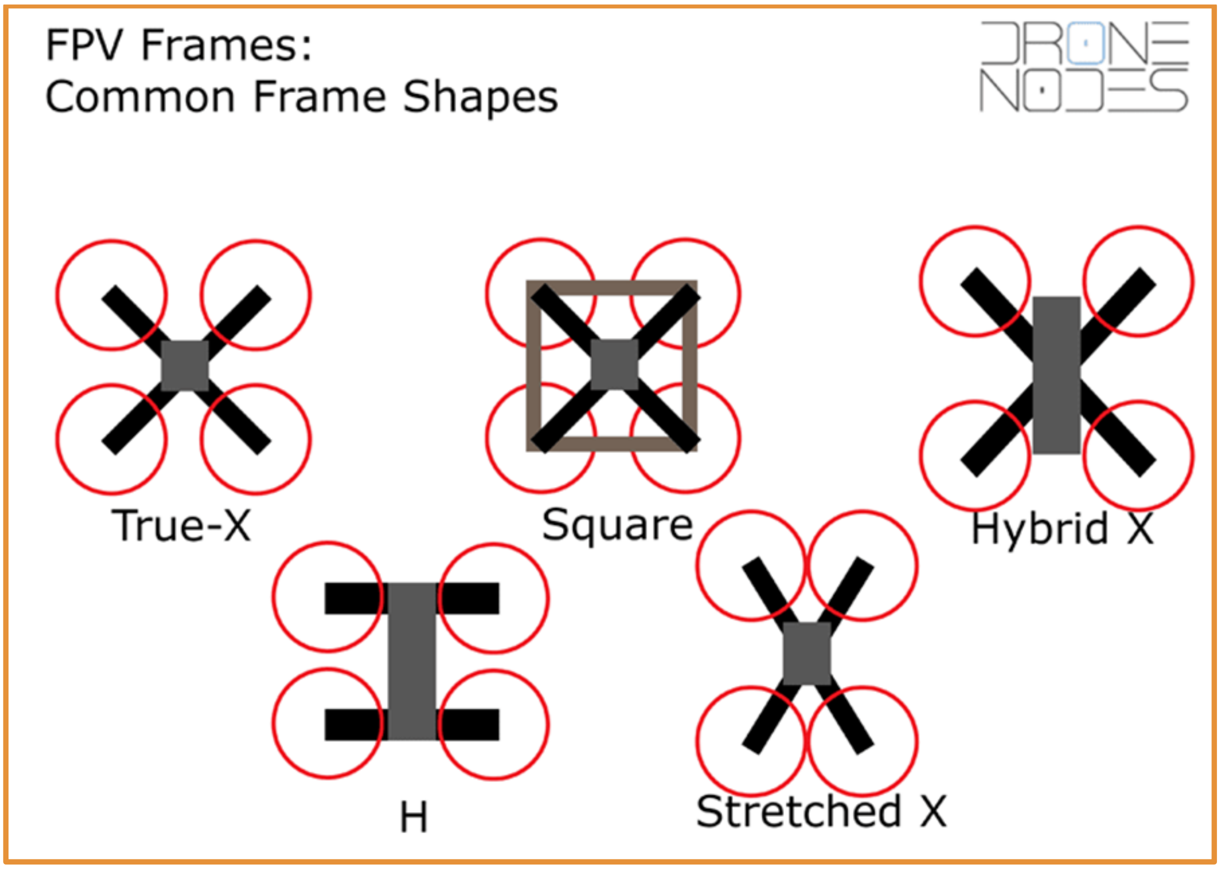

Figure 9 types of common FPV frames.

4.2 WHAT IS ELECTRONIC SPEED CONTROL OR ESC? [10]

Electronic speed controllers (ESCs) are one of the main components of a drone that allow drone flight controllers to control and adjust the speed of the drone's brushless motors. A direct signal from the flight controller causes the ESC to raise or lower the voltage to the motor as required, Thus changing the speed of the propeller. There are two kinds of electronic speed controllers based on specific requirements, i.e. brushed ESC and brushless Electronic Speed Control. period. Brushless ESC is a bit more costly than brushed ESC. Connected to a brushless motor, it carries more power and higher performance as compared to the brushed ones. It can also last a longer

Figure 10 Brushless Electronic Speed Controller

Figure 11 Brushed Electronic Speed Controller

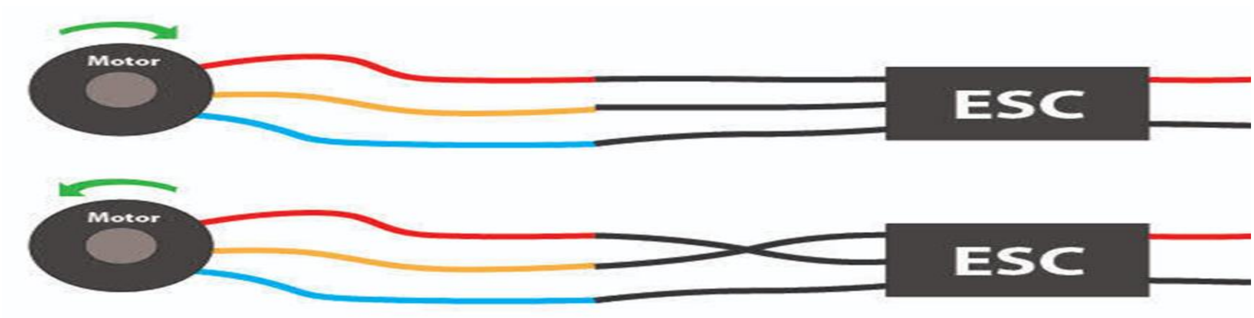

Figure 12 Clockwise and anti-clockwise rotation of motor with an ECS

To make motors rotate in an anti-clockwise direction just Swap any two wires of ESC (as shown in the above image) and connect them to the brushless motor. This will make the motor spin in an anti-clockwise direction.

4.3 Transmitter [11], [12]

Figure 13 Transmitter

A drone radio transmitter is a wireless device that uses a radio signal for the transmission of commands, it works by setting a distinct radio frequency over the radio receiver, which is connected to the drone being remotely controlled.

Layman instructs the drone for performing a variety of movements and each movement will require different channels.

4.3.1 Types of Movements

- **Roll**: It can move your drone left or right in the air and for a moment it rolls until you leave the gimbals (sticks) from one side.
- **Pitch**: It just tilts our drone forward and backwards to change the height of the drone.
- **Yaw**: It helps to rotate our drone clockwise and anticlockwise which simply allows us to make circles or patterns in the air.
- **Throttle**: It controls the amount of power sent to the drone that directly correlates with the speed of the drone i.e. more power higher speed and vice-versa

Factors to consider while selecting a transmitter:

- **Modes**: If you are a regular mini quad pilot then the configuration changes may challenge your brain muscles as according to you throttle will be on left and if changes then coordination may be hampered.
- **Gimbals**: These are the sticks on the left that controls the throttle and yaw and the stick on the right controls the pitch and roll, now good gimbals adjust your size, tension and some prefer to pinch and thumbs that knowledge gives you more concise flight experience.
- **Switches**: Transmitters contain switches for arm changing and flight modes we don’t need them in general but will be effective for professional work and projects
- **Battery Life**: Battery life consideration is worth it as the cost can increase in the long run while higher-end radios contain built-in Li-ion batteries with charging circuits.
- **Flexibility**: The best-built quality of transmitters can be determined by their flexibility in responding with highly programmable logical switches and performing special functions.
- **Module Bay**: Many radios come with an external module bay which allows us to place a large array of standard RC-sized modules in a completely different radio while multiprotocol modules are also available which allow one radio to control nearly everything and depends upon the work adaptation.
- **Range**: A range of transmitters is viable according to your function with drones as it depends upon the output power and sensitivity and quality of antennas of transmitters.

4.3.2 Pin Diagram Of A Transmitter

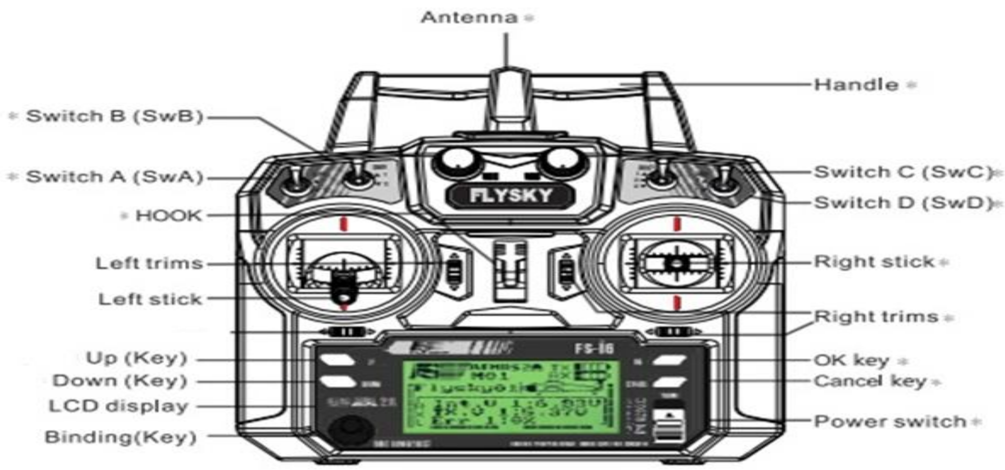

Figure 14 Pin diagram of a transmitter

4.3.3 Availability of Transmitters

Different kinds of transmitters according to your suitability are:

- **Taranis X9D+ SE**: It is a special edition of X9D+ with readily available popular mods, its gimbals allow it to use a better range and higher gain on the antenna. This is a premium transmitter for mini quad pilots.
- **TBS Tango 2**: It is equipped with sensor gimbals, gives lower tension in the gimbal and its strokes and allows better flexibility, its claiming range is 30km
- **Radiomaster TX16s**: It is equipped with gimbals with 2.4GHz frequency with 16 channels and its touch screen, known for its durability and versatility.
- **Taranis X-lite**: It's one of the most affordable transmitters, it has a bay of X9 lite and it looks like a game controller. You can notice its smooth feel on your palms and its light weight is apparent.
- **FrSky Taranis QX 7**: This is the most popular and cheapest radio in the mini quad world and is used by the majority of pilots.

4.4 BRUSHLESS MOTORS [13]

Figure 15 Brushless DC motor

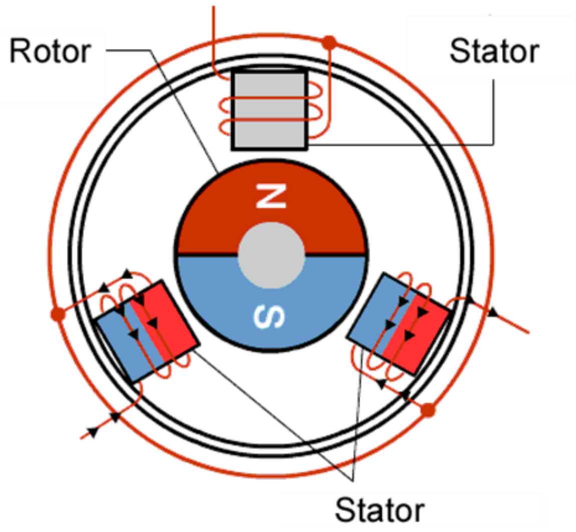

Figure 16 Circuit of brushless DC motor

It is a motor that converts electrical energy to mechanical energy but it does not contain brushes like a basic motor, instead, it has two components **Rotor** and **Stator.** It has a variety of applications because of its high efficiency and less wear and tear.

Stator: Stator is a design that consists of coils and its stationary part but configured with the rotor higher the amount of coil more efficient will be the BLDC.

Rotor: Rotor is a permanent magnet with the same facing and is also a moving part that is directly and indirectly with the propellers.

4.4.1 How Brushless DC motor work

Brushless DC motors do not use brushes. With brushed motors, the brushes deliver current through the commutator into the coils on the rotor. So how does a brushless motor pass current to the rotor coils? It doesn't—because the coils are not located on the rotor. Instead, the rotor is a permanent magnet; the coils do not rotate but are instead fixed in place on the stator. Because the coils do not move, there is no need for brushes and a commutator. If we apply the appropriate current, the coil will generate a magnetic field that will attract the rotor's permanent magnet. Now if we activate each coil one after another the rotor will keep rotating because of the force interaction between the permanent and the electromagnet. It forms a star connection and increases the rotation with the same current.

4.4.2 How to connect to a Drone

If we have a quadcopter then we require four brushless motors and along with that we need four ESC (electronic speed controllers) i.e. these are the devices which allow the flight controller to adjust and control the speed of an aircraft by raising or lowering the voltage signals to change the speed of propellers. The real issue may arise if we have the incompatibility of either motor or ESC, so to avoid that make sure to check their specifications before. Three pins of the brushless motor will be connected to either end of consecutive pins of ESCs. We need to make sure the adjacent Dc brushless motor will be opposite in rotation to each other and this can happen by changing the wire in Escorts. Then this ESC will be connected to the flight controller and which is called the brain of the drone.

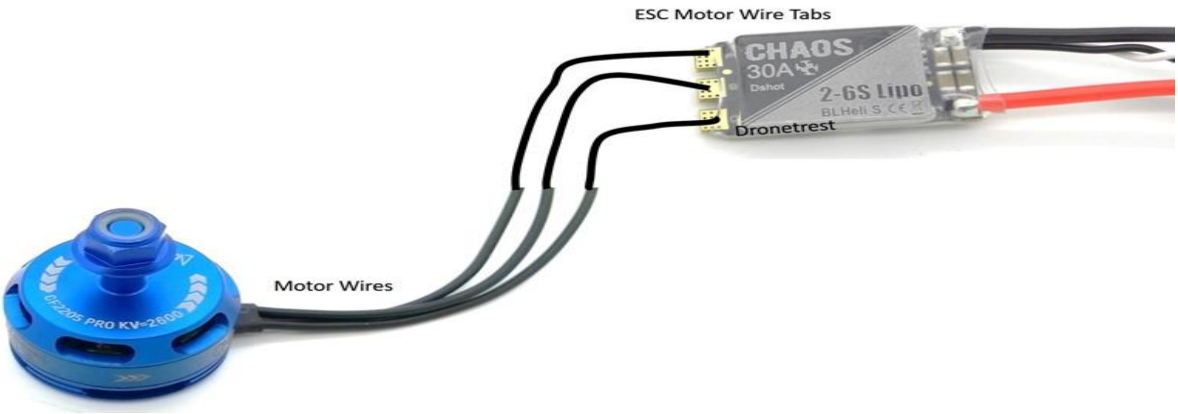

Figure 17 Connecting motor with an ESC

4.5 PROPELLERS

Figure 18 two bladed propellers

Figure 19 three bladed propellers

The propeller acts as the wings of the flight. It pulls the air downwards and makes your drone fly.

4.6 FLIGHT CONTROLLER

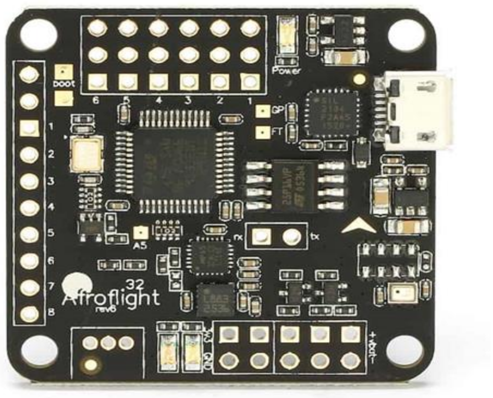

Figure 20 Basic flight controller circuit

Flight controllers are circuit boards that have particular sensors such as gyroscopes (help to determine the angular orientation) and accelerometers (help to measure the vibrations of motors) and several other insignificant but useful sensors such as barometer (altitude of the quad can be found), compass (provides orientation in relation to earth's magnetic field) etc..,

But the functions of the flight controllers do not end there. One of the major functions of a flight controller includes receiving and processing the input signals from the receiver and executing appropriate commands given by the users. Simply put, flight controllers might be compared to the human brain. The human brain tells us how to walk, in the same way, flight controllers are the brains on a quad that tell the quads how to fly.

Quadcopters can also use more advanced technologies such as GPS for auto-pilot or fail-safe modes.

4.6.1 Block diagram of Flight Controller

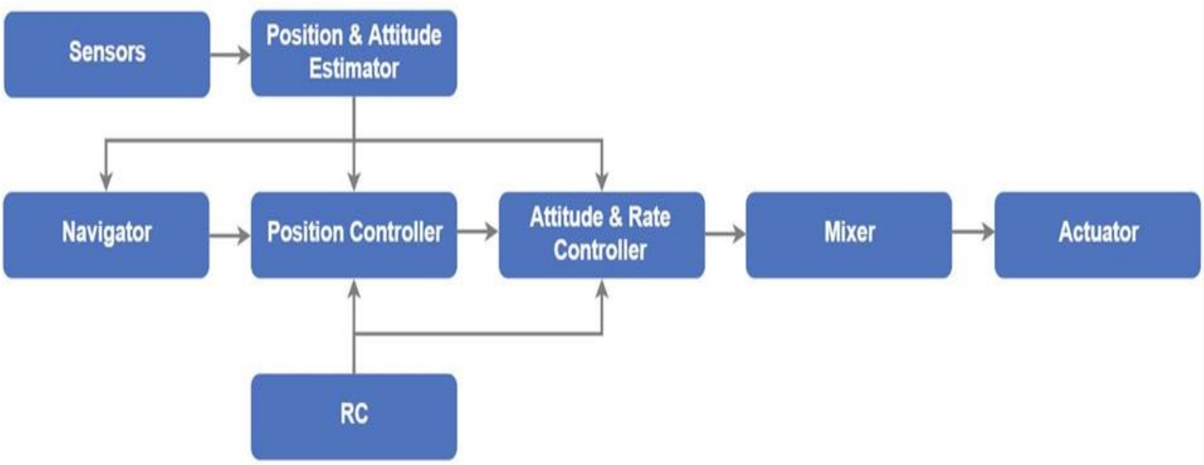

Figure 21 Block diagram of the flight controller

4.6.2 Some Common Components of Flight Controllers

1. STM32 Processor Barometer
2. Gyroscope
3. Magnetometer
4. Accelerometer
5. Boot Button/Jumper
6. Flash Memory
7. UART Ports
8. Infrared Transponders
9. Black Box Data Logging
10. Video Transmitters
11. On-Screen Display (OSD)

STM32 Processor -

Based on operating frequency, flight controllers had different types of processors such as F1, F3, and F4 etc. F3 is the successor of F1, F4 is the successor of F3 and the same is on F7. All these 4 processors are based on STM32 architecture which uses 32-bit processing rather than 8-bit on KK2.x boards.

Processors	**Operating Frequencies**
F1	72(MHz)
F3	72(MHz)
F4	168(MHz)
F7	216(MHz)

Table 1 types of flight controllers based on processors and their operating frequencies

F1 Processor: F1 processor is the oldest processor and has the lowest processing capability of all the above processors. It is actually an outdated processor with Beta flight ending support to F1 FCs in 2017.

Figure 22 F1 processor

F3 Processor –

F3 was essentially an F1 FC with an increased number of UARTs (It is discussed in detail below) and increased flash memory (memory used to store the FC's firmware codes). Some smaller FCs use this processor even now because of its compact size and exceptional processing power. With developments in Beta flight optimizations taking place constantly, F3 processors are having a hard time keeping up.

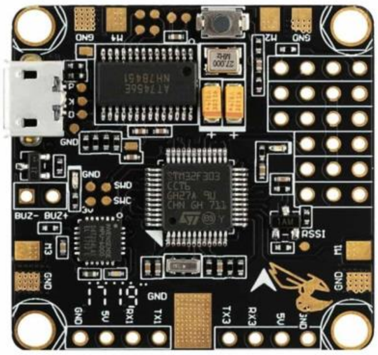

Figure 23 F3 processor

F4 Processor –

F4 was a giant leap in mini quad processors with more than double the processing power of an F3. But there are limitations with F4 processors with no support for smart audio natively which is not a big deal for most people. Still, F4 FCs are the most popular choice for their functionality and affordability.

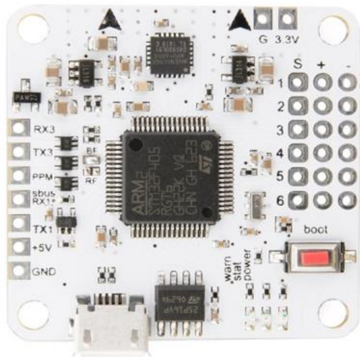

Figure 24 F4 processor

F7 Processor –

The F7 processor is the big daddy of mini quad FCS. F7 FCs became available in mid-2018 and these are the most recent processors. F7 FCs are packed with up to 8 UART which can be used for telemetry, GPS, camera control etc.., F7 FCs come with dual Gyros (MPU6000 which is noise resistant and ICM20602 which can run 32K gyro sampling).

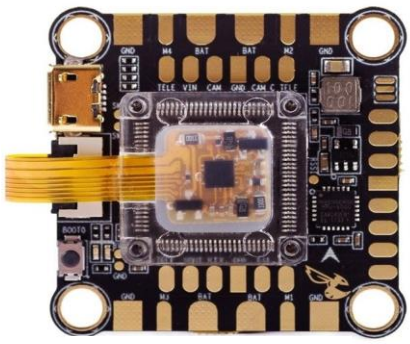

Figure 25 F7 processor

The processing power is predominantly used for a concept known as loop time. There are two main principles related to loop time:

1. Sampling Rate (Gyro) – This is how frequently the processor reads gyro sensor information.
2. Loop time – This is how frequently the control loop processes the sampled data from the gyro to execute infinitesimal corrections.

For these two parameters, the industry has settled on a common naming convention written as 4 kHz/2khz, 4 kHz/4khz, 8 kHz/8khz, or 32 kHz/32khz. The first number is the gyro sampling rate and the second is the flight controller PID loop time. Below is a table displaying frequencies.

- 1khz = 1 milliseconds (ms) = 1,000 times per second
- 2khz = 0.5 milliseconds (ms) = 2,000 times per second
- 4khz = 0.250 milliseconds (ms) = 4,000 times per second
- 8khz = 0.125 milliseconds (ms) = 8,000 times per second
- 32khz = 0.031 milliseconds (ms) = 32,000 times per second

For example, 4K/2K means the processor is sampling gyro data at a rate of 4,000 data points per second. The second number indicates that the PID loop runs 2,000 complete control loops per second. It's important to note that it's a waste if the PID loop time is faster than the gyro sample rate. When you set a new loop time in your FC, always check CPU usage via the CLI command "status", the general consensus suggests it's best to stay under 30% CPU usage in BF, though some boards might handle a bit more. The drone flight controller typically isn't the most limiting element and other components tend to run slower. Here are some examples:

- Some receivers have a frame rate of 5-10ms which means they process data at 0.2 kHz which is much slower than FC speeds!
- ESC and brushless motors have a lag between the time when power is applied from the ESC and when that power setting actually generates the appropriate amount of thrust at the motor
- Props aggregate the response latency

The general opinion is that F4 processors have about the same performance as an F3 controller. Although, we have seen that some people are unable to use Beta flight's new dynamic filtering feature in conjunction with fast loop times. In short, dynamic filtering is an algorithm that continuously analyzes gyro data and automatically filters signal noise between 200-400 Hz, which is where most of the motor signal noise occurs. This range can be adjusted, but we recommend analyzing black box data to refine the filter.

Barometer –

The barometer allows the FC to read accurate altitude information. It can accomplish this because the pressure sensors are very sensitive and can detect slight changes in air pressure when the drone changes its altitude. Barometers aren't incorporated in all flight controllers. Flight controllers identified as "Acro" models generally do not have a barometer. Normal or Plus flight controllers are equipped with a barometer and sometimes a magnetometer (i.e. compass). This can be helpful when making your quadcopter semi-autonomous; however, if you're simply interested in FPV flight, we suggest you stick with the Acro model.

Gyroscope –

This is the sensor that generates continuous pitch, yaw, and roll data for the flight controller to process. It's the most important part of the flight controller! The concept for achieving optimal performance is to record as many accurate gyro readings as quickly as possible so the flight controller has the greatest amount of data on which to base its computations. Gyros with a digital interface typically use either the SPI or I2C communication protocols. The fastest readings are accomplished by those connected to the processor via SPI. As of 2018, most flight controllers use the MPU6000 gyro and we recommend purchasing a flight controller with the MPU6000 gyro or greater.

Popular Gyro Chips:

- MPU6000
- MPU6050
- BMI160
- ICM20602
- ICM20608

Magnetometer (Compass) –

The magnetometer, or compass, is a sensitive device that measures magnetic forces. This sensor is not important for FPV flight. Instead, it is much more suitable for other drone applications such as aerial photography. Since the accelerometer and gyroscope sensors don't provide directional heading information the onboard compass fills this void.

Boot Button/Jumper Boot Pads –

Boot buttons or boot pads are simply a means to force the flight control board into bootloader mode. In bootloader mode, the flight controller can receive firmware updates (e.g. Beta flight, clean flight). This is done by powering on the flight controller while bridging/shorting the connection between pads or holding the boot button down if your flight controller is equipped with one.

Flash Memory –

Flash memory allows pilots to store performance data directly on their quadcopters. Similar to the flight recorder on an aeroplane, newer flight controllers have built-in data-logging capabilities that store black box information. This is particularly useful if something is not working properly and the black box log will allow others to help you diagnose issues much more quickly. It's also an effective means to help you collect and subsequently analyze the data for tuning the PIDs on your quadcopter. These days most flight controllers onboard flash memory for data logging or use a removable SD card.

UART –

UART stands for Universal Asynchronous Receiver/Transmitter and is a digital communications protocol that allows your flight controller to communicate with external devices. Think of a UART as a USB port for the flight controller. It's the external port devices can communicate through. UART 1 is used to control the USB port used to connect to your computer on most flight controllers. The number of available UART ports largely depends on the generation of the processor.

Processors	**UART Ports**
F1 (STM32F103CBT6)	2
F3 (STM32F303CCT6)	3
F4 (STM32F405RGT6)	3
F7 (STM32F745VG)	8

UART Ports Use 4 Wires:

- **Ground:** Electrical ground reference that must always be plugged into the ground port on each device.
- **Power:** This wire can feed power from one component to another
  - Can send power (usually 5V) to other components or receive power from other components.
  - You do not need to connect this wire for the UART to work.
  - It is required to power external accessories.
- **TX:** The transmit line (TX) is the wire the device uses to send data out. It's important to note that it must connect to the RX port on the other device.
- **RX:** The receiving line (RX) is the wire the device uses to receive data. It's important to note that it must connect to the TX port on the other device.

Accessories that use UART communications

1. Serial Radio Control Receiver
2. Telemetry
3. OSD (Not including Beta flight OSD)
4. VTX Control
5. GPS

6. Race Transponders
7. External Blackbox loggers

Infrared Transponders –

A racing transponder allows your drone to be tracked and timed around the course using infrared technology. Each transponder has a unique 7-digit ID number to track the drone. This is a nice feature that's standard on some FC boards and if you're eventually going to engage in FPV flight this is a must! They can be programmed directly from Beta flight or the transmitter if the flight controller supports Beta flight on-screen display (OSD).

Quadcopter PID Tuning Explained –

Flight controllers are configurable and programmable devices, thus allowing for adjustments based on varying configuration settings. These adjustments are referred to as loop tuning and are performed in the PID Tuning section in FC firm wares.

A proportional–integral–derivative controller (PID controller or three-term controller) is a control loop feedback mechanism widely used in industrial control systems and a variety of other applications requiring continuously modulated controls. Tuning a control loop is the adjustment of its control parameters (P, I, and D) to the optimum values for the desired control response. Achieving a crisp response and smooth flight stability without crazy oscillations is the end goal in most cases.

Proportional (P)

This is how abruptly your quad responds to pilot inputs. You get the most impact adjusting the P gain and you can think of its impact as similar to the volume knob on your radio.

Integral (I)

It is a little trickier because it's a calculus-based principle, but in the end, it's the principle that helps reduce the wobble errors. The integral term aspires to eliminate the residual error by adding a control effect due to the historic cumulative value of the error.

Derivative (D)

D is another calculus principle that represents a change in a variable over a change in time. It is sometimes called "anticipatory control" and what this means is the more rapid the change, the greater the controlling or dampening effect.

Throttle PID Attenuation (TPA)

TPA isn't used that often but when all else fails it helps reduce the wobble by tampering down the PID values when the throttle is raised passed a specified point.

Tuning Methods

The Ziegler–Nichols tuning method is a commonly used method of tuning a PID control loop. It is performed by initially setting the I (integral) and D (derivative) gains to zero. However, most of the flight controllers are pre-configured to fly somewhat stable out of the box, but they certainly need to be tuned and adjusted for smoother flights. I have written a simple-to-follow process flow to help you program PID loops.

Here is a table of what happens to your multirotor as you increase P, I, or D by itself:

	Rise time	**Overshoot**	**Settling time**	**Steady-state error**	**Stability**
Proportional	Decrease	Increase	Small change	Decrease	Degrade
Integral	Decrease	Increase	Increase	Eliminate	Degrade
Derivative	Minor change	Decrease	Decrease	No effect in theory	Improves if the Derivative is small

There are a variety of flight controllers that have been used over the past few years. The most common is the STM32 series flight controllers. There is a series of ten generations of the STM32 MCU processors. We have arranged them from the slowest to the fastest processing speeds: L0 -> L1 -> L4 -> F0 -> F1 -> F2 -> F3 -> F4 -> F7 -> H7.

4.7 RECEIVER

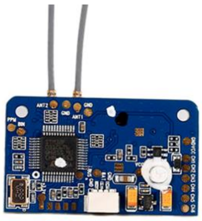

Figure 26 Receivers.

The radio receiver receives radio signals from an RC transmitter and converts them into control signals for each control channel (throttle, yaw, roll & pitch). Modern RC receivers operate on a 2.4 GHz radio Frequency, while older Rx units often used 72 MHz frequencies.

Rx units may have as few as 4 channels, but many have more channels for additional control options. We selected a HobbyKing orange Rx 6 channel Receiver for this project.

4.8 BATTERY

Finally to power on your quadcopter, you need a Lithium polymer (LIPO) battery. The flight time of your quadcopter depends on the battery capacity. But a heavier battery doesn't mean greater flight time.

Figure 27 LI-PO battery

Then the circuit diagram is to be followed

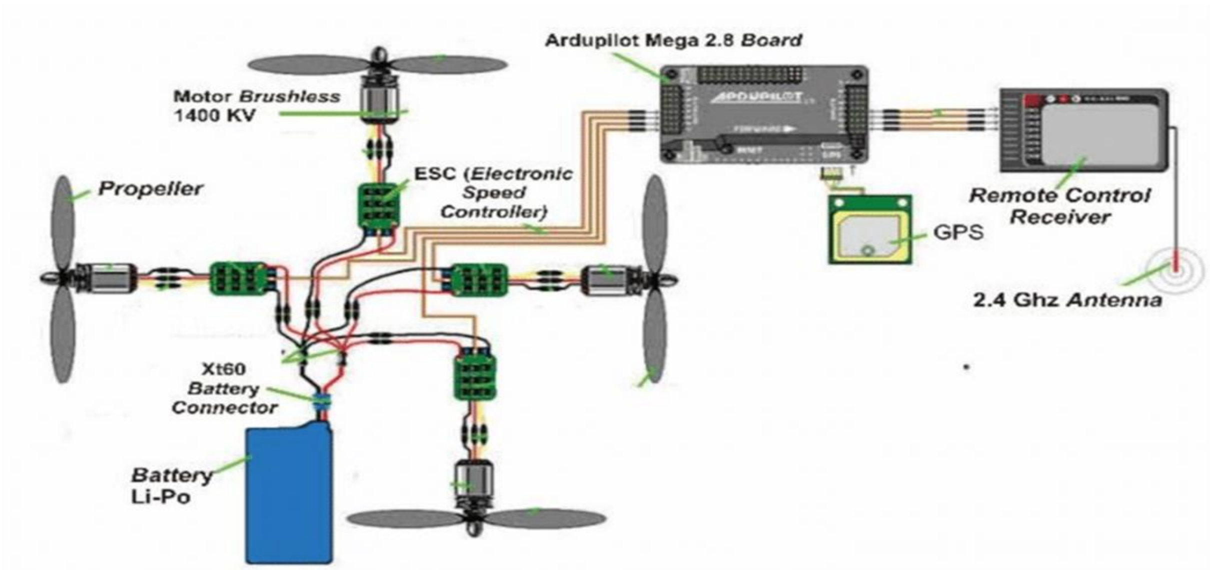

Figure 28 Circuit diagram for a quad-copter

CHAPTER 5

SOFTWARE STUDY

Software use has been done in our project for knowing the internal mechanics and electronics of systems used in our project study. Moreover, this helped us in some real-time simulations and visualize better.

5.1 MATLAB SIMULINK SIMULATIONS [14], [15]

Simulink provides a graphical editor, customizable block libraries, and solvers for modelling and simulating dynamic systems. It is integrated with MATLAB, enabling you to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis.

5.2 THREE-PHASED BLDC MOTOR

In this part, a simple model to simulate a three-phase BLDC is created and its back-EMF profile is investigated.

5.2.1 Circuit Diagram

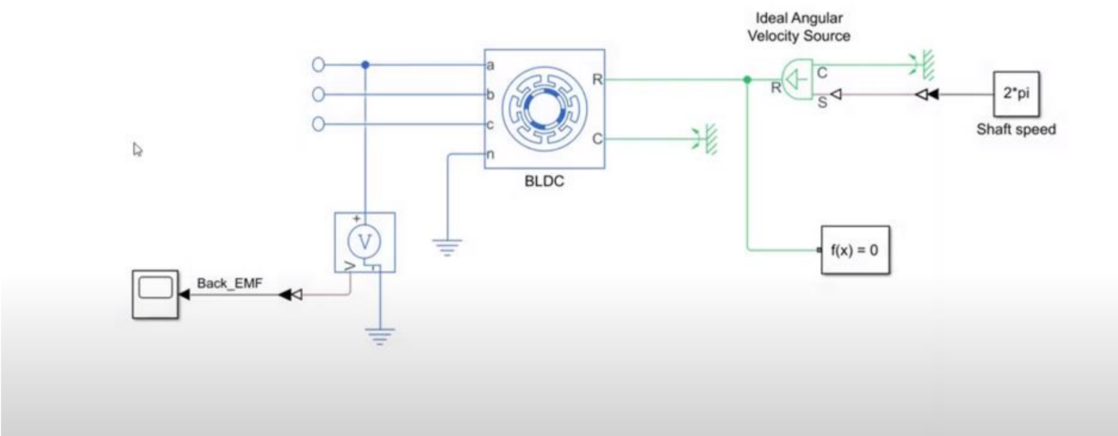

Figure 29 Circuit diagram for three-phased BLDC motor

5.2.2 Simulation

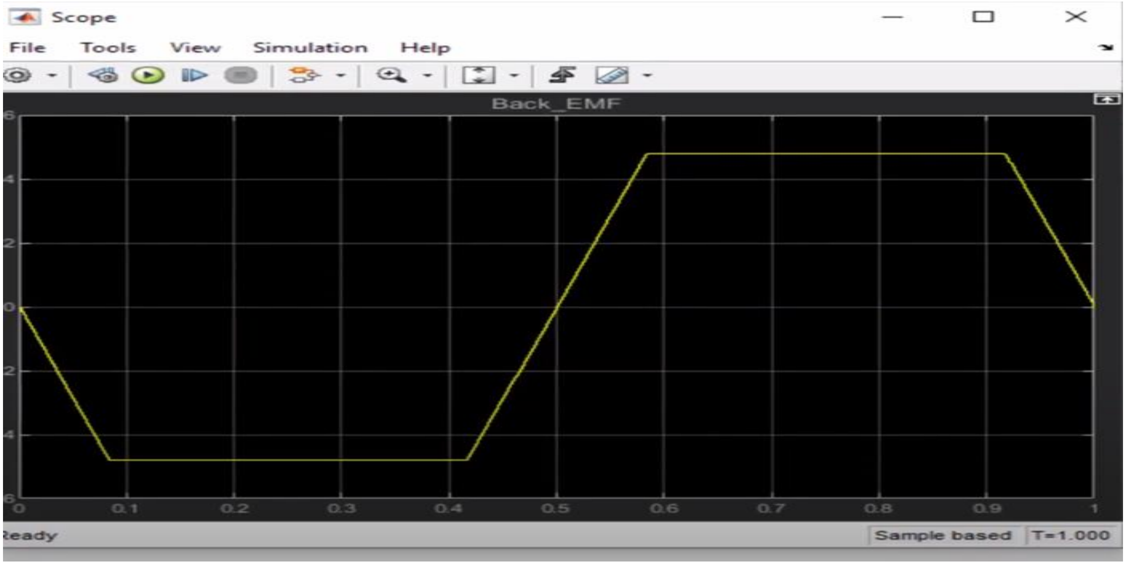

Figure 30 Back emf of BLDC motor

5.2.3 Description

In Simulink, we'll create a scenario where we turn the motor shaft while having open terminals at all three phases and then measure the voltage produced at one of the phases to observe the back-EMF.

This physical model is created using Simscape Electrical. In the Simulink library browser, we first navigate to the Permanent Magnets and drag the BLDC block to the canvas. This block represents a BLDC with a trapezoidal back-EMF profile.

You can use your motor's data sheet to set the values of the block parameters under the rotor, stator and mechanical tabs. The ports at the left-hand side of the block are for electrical connections and the ones on the right are for mechanical connections.

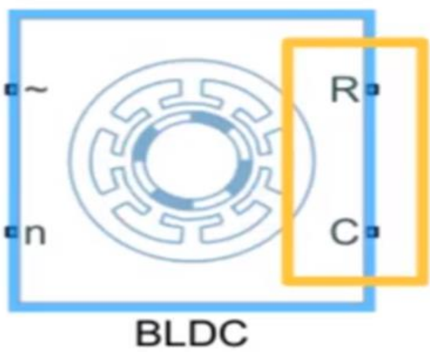

Figure 31 right side mechanical connections

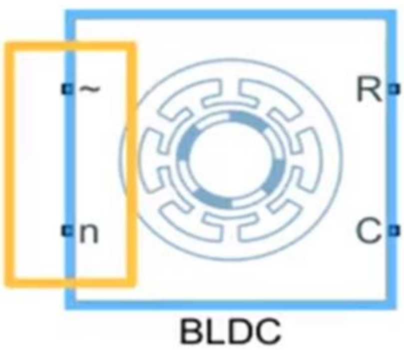

Figure 32 left side mechanical connections

To create open terminals, first, the composite port is expanded to three phases and then an open circuit block is connected to each of the phases.

To connect the motor's neutral phase to the ground, the electrical reference block uses the mechanical connections of the motor.

To make the motor shaft turn, the motor is driven by using an ideal angular velocity source block. A mechanical reference is connected to the ports labelled with C. The velocity source block has a second input, which is a physical signal. To make the motor rotate at a constant speed, a constant value is an input to the block. This block outputs a Simulink signal. Now, this Simulink signal is then converted to a physical signal using the Simulink PS converter. To solve the Simscape model a solver block is used, where we choose to use the local solver and also set the sample time. Now simply one of the three phases is picked and the back-EMF is measured. A voltage sensor is connected to phase A to measure phase A's back-EMF voltage. The output of the voltage sensor block is a Simscape signal. To convert it to a Simulink signal, this time PS Simulink converter is used and connects the signal to the scope for visualization. Then this model is simulated and views the back-EMF voltage of phase A.

Result: We observed that the back-EMF exhibits a trapezoidal shape, including regions where the voltage remains flat.

5.3 MOTOR CONTROLLER

5.3.1 Circuit Diagram

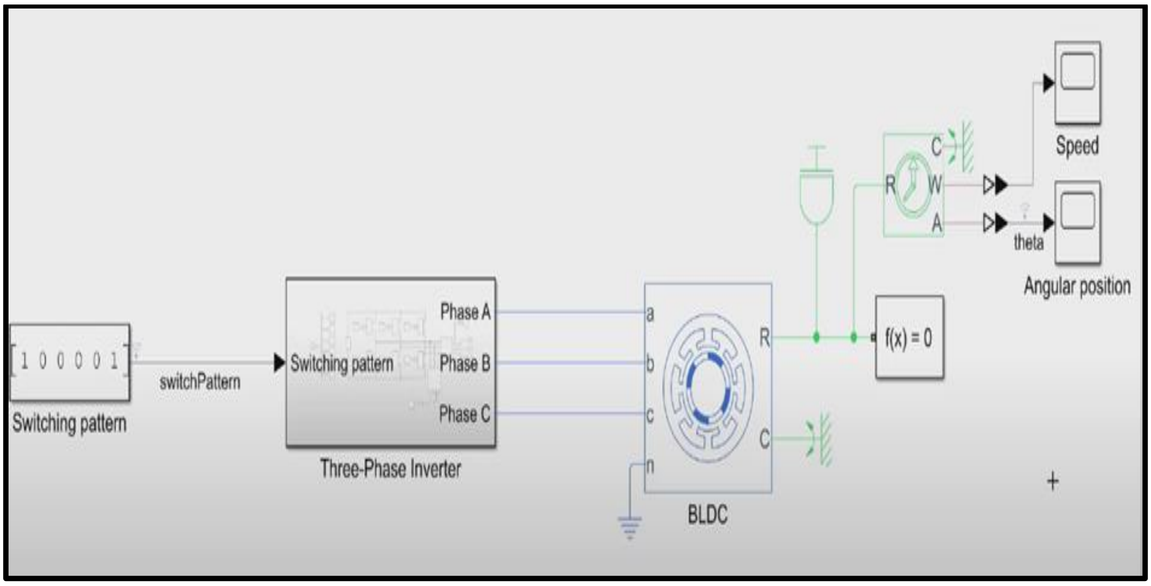

Figure 33 MATLAB circuit diagram of Motor Controller

A Three-phase inverter is used to convert DC power to a three-phase current to control the BLDC motor. The input to the three-phase inverter is a switching pattern that controls the on and off states of the phase pairs of the motor. A static switching pattern is used to energize phases A and C and observe that the rotor is aligned with the stator magnetic field at 30 degrees.

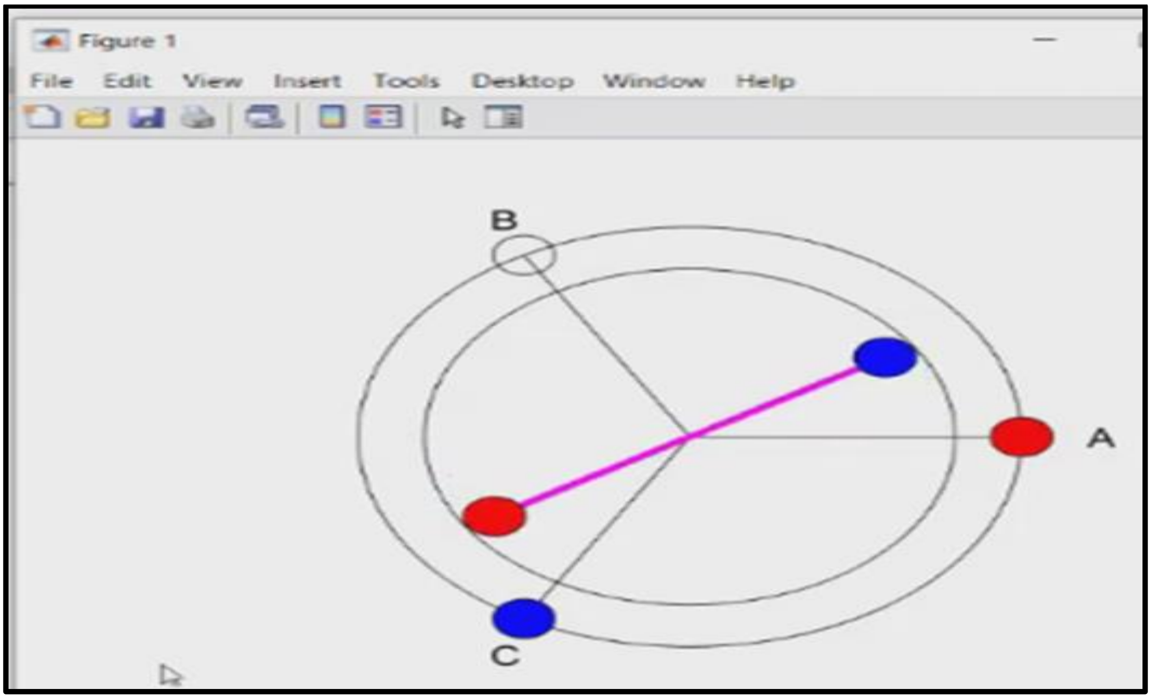

Figure 34 MATLAB simulation of rotor aligned with the magnetic field

For a continuous rotation of the rotor, a Hall Effect sensor is needed to determine which sector the rotor is in. Commutation logic then uses the current sector to select the corresponding switching pattern. In practice, Hall Effect sensors sense the magnetic field around each phase to determine the current sector. For simulation purposes, however, the angular rotor position is presumed from which the sector is computed. The logic for the Hall Effect sensor model should be the following:

If the rotor is between 0 and 60 degrees, then it means the rotor is in the first sector, so the output is 1. Similarly, there are five more cases when the full rotation of the rotor is completed. Let's keep this table here and try to model the same logic in Simulink.

The angular position theta is always between 0 and 360 degrees, which means that after every full rotation of the rotor. Theta is reset to 0 degrees. For each case, two conditions are needed to check for.

To implement the first check, a Constant block is added, which is set to 0. A Relational Operator block is grabbed and the right operator is chosen to use for comparing theta with 0. Similarly, the second condition is modelled. When both of these conditions are met, we want to set the sector to 1.

This is done by using an AND gate along with a gain representing the sector number. Note that the logical operator outputs a Boolean value, which is needed to convert to the same data type as the gain.

This is done with the Data Type Conversion block, which takes the Boolean value and converts it to the data type that it inherits from the Gain block.

According to this logic, when both conditions are met, the AND operator will return 1 and the sector will be set to 1. If either or both of the conditions are not met, the output will be 0, as this will mean that the rotor is in another sector. To implement the rest of the conditions, the same logic is used.

Now the sum of resulting values will give the sector number. Note that at each time only one of these outputs will be positive and the rest will be 0. This part is selected and a subsystem is created that is called a sensor.

The commutation logic is basically like a table containing all of the possible switching patterns and outputs them in the right sequence for properly rotating the rotor based on the sector information. The first switching pattern. To choose a pattern based on the sector, we're going to use a switch.

CHAPTER 6

HARDWARE STUDY

Electronic hardware consists of interconnected electronic components which perform analogue or logic operations on received and locally stored information to produce as output or store resulting new information or to provide control for output actuator mechanisms. In our hardware study, we have used a few electronic components and some mechanical mechanisms like gear systems.

6.1 ORNITHOPTER [16], [17]

An ornithopter is a device that imitates the flapping-wing flight found in nature. The word "ornithopter" (c.1908) combines the ancient Greek words for "bird" and "wing". An ornithopter doesn't need to have feathers, though. What makes it birdlike is the flapping motion! Aeroplanes have a rotating propeller. Helicopters have a rotary wing that provides both lift and thrust. Those machines are driven by rotating airfoils. Instead of rotation, the ornithopter wing imitates the reciprocating motion of a bird's wing. The flapping wings of the ornithopter don't have to supply all of the lift. Even in real birds, the body and tail provide a significant portion of the total lift.

Some applications for ornithopters have been implemented. Like other types of radio-controlled aircraft, ornithopters can be used to carry cameras. Ornithopters can be made to look like real birds or insects, so they could be used for covert spying. Ornithopters have also been used in studies of wildlife where an aircraft resembling a real bird was needed. Another application that has been tested is the use of ornithopters to chase birds away from airports. Bird control specialists use a variety of methods to keep birds away from runways. If an aeroplane runs into birds, it can receive damage causing it to crash, so this is an important part of airline safety.

6.2THE PROTOTYPE

Looking at the scope of the project and how far the team had come with the literature survey and a few simulations, it was very natural to try something hands-on and something that actually could fly physically from a distance.

The team decided to make a remote-controlled ‘Ornithopter’ as it was the most feasible and on-budget idea. Moreover, it seemed quite fascinating and simple at the same time.

6.3 MATERIAL USED

1. Thin wood cutouts
2. Thin Bamboo sticks
3. Steel paper clips
4. Thread
5. Adhesive
6. Instant adhesive
7. Thermocol sheet
8. Polythene sheet
9. Gears with axle
10. RC helicopter Receiver
11. Transmitter (Infrared) and
12. LI-PO battery
13. Coreless Motors

6.4 DESIGN

Frame

For the frame, a thin light wood frame was made as per specific dimensions and was held together by adhesive, instant adhesive and thread windings. Four plastic tubes were also fitted in the frame for attaching wings afterwards. For the wings and tail frame, thin bamboo sticks were used by tying and sticking them together in the required structure. The tail angle was around 45 degrees to which a very thin thermocol sheet was attached.

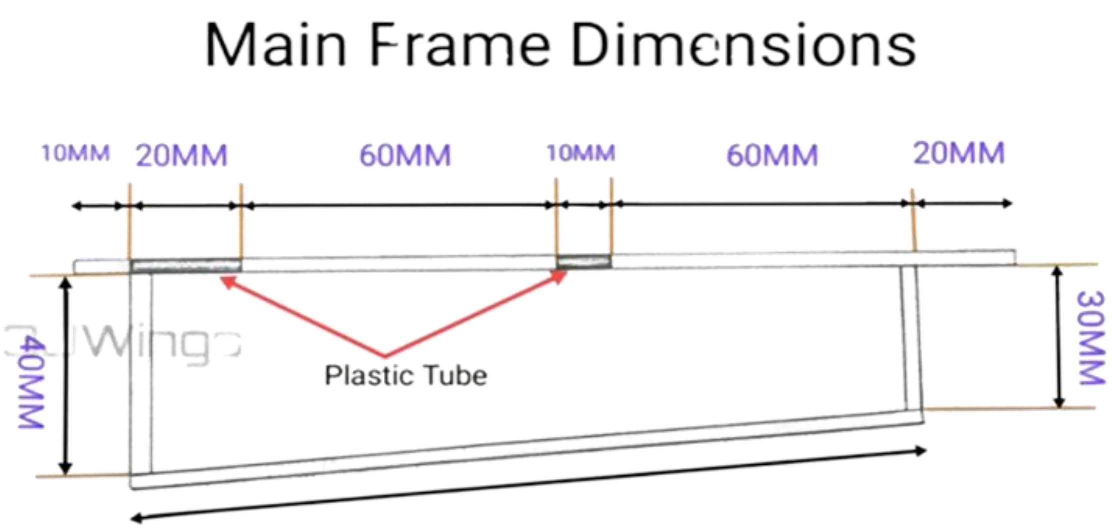

Figure 35 Main Frame dimensions

Figure 36 Main frame design

Figure 37 Main Structure

6.5 CONTROLLER AND BATTERY

The RC helicopter has a controller connected to the receiver which sends a signal to the motors, light etc. to work according to the transmitter's instructions. Only the wires connected to two motors, which accelerated the helicopter and made it turn were left connected along with an LED light, the rest were disconnected as we required only these two motions for the Ornithopter. The LiPo battery of 3.7V was kept attached to the controller, it was desirable because of its lightweight and reasonable fight time.

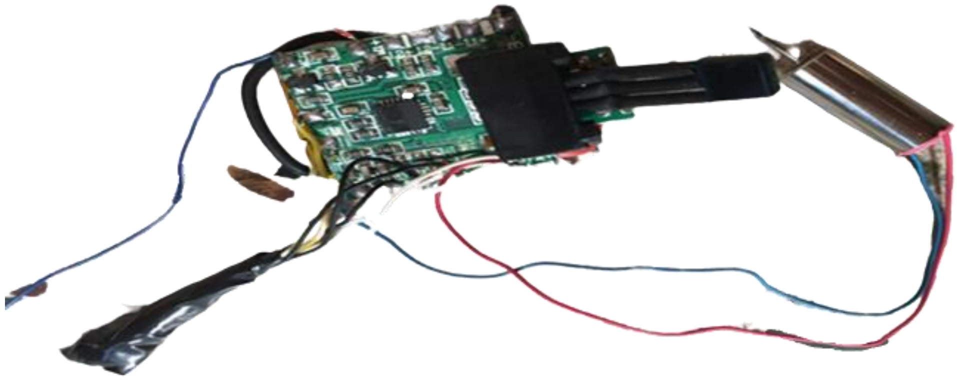

Figure 38 Controller and Battery

6.6 TRANSMITTER AND RECEIVER

The transmitter and receiver of the RC helicopter were used. The remote was four-channelled and was capable of producing four motions from the helicopter that are throttle, pitch, yaw, and roll. For the Ornithopter, we used only the throttle control for wing speed and roll control for the tail fan to manoeuvre. The transmitter was an Infrared control signal and thus had a shorter range than a radio transmitter, it was controllable only to about 5-6 meters.

Figure 39 Transmitter and Receiver

6.7 GEAR SYSTEM

The motors that were used were high-rpm coreless motors. So, to reduce the rpm and have more torque for the wings to flap two bigger gears were attached to the smaller gear of the motor. The green-coloured gear is loose on the axle and just transfers the motion of the motor onto the bigger white gear which is tight on the axle and is responsible for the movement of wings by converting cyclical motion into linear up-down motion with help of certain connectors.

Figure 40 Gear system.

6.8 STREAMLINED BODY

To make the frame less susceptible to damage and make the body which provide the least resistance from the air a thermocol was pasted to the frame.

Figure 41 Streamlined body

6.9 WINGS

For the wings to provide lift by their flapping motion a polythene sheet was attached to the wing frame.

Figure 42 Ornithopter

6.10 FLIGHT TESTS

For the flight test, we tried to glide the ornithopter to a gallery but because of the thick and heavy polythene the wing speed was reduced substantially and the prototype couldn’t stay in the air and crashed at just a few feet, moreover it just backflipped because of less weight in the front.

For the second flight test, we changed the thick polythene with a very thin sheet of polythene which did increase the fapping speed a bit and reduced the weight in the rear part. This time the Ornithopter glided for a couple of meters but the wing speed was still not enough to keep it in the air and give it a full lift.

Our tests with this prototype were stopped after this and left for future modifications.

FUTURE SCOPE

To make the Ornithopter flight a real success there are a few modifications that can be done. The main issue that we faced, which led to less lift force, was low flapping speed. The flapping speed can be substantially enhanced if we use a more powerful motor and bigger gear system which will in turn increase both speed and torque resulting in a smooth and fast flapping of wings. Moreover, the wings were a bit imbalanced, this can be sorted out by redesigning the wings.

Few other plans can turn into a reality if our project receives some reasonable amount of funding and infrastructure. As one might expect, weight reduction is extremely important in ornithopters. This is true, in part, because ornithopters are mechanically complex. The weight of the flapping mechanism is a necessary burden that airplanes don’t have to contend with. At the same time, most ornithopters don’t live up to the potential efficiency demonstrated by real birds, so the weight must be less than that of a bird or airplane to achieve comparable performance. The effect of weight is dramatic. It’s best to design your ornithopter so that it can survive a crash. With very small and light ornithopters, this is easily achieved by using a fibreglass or plywood plate for the body, instead of an open-frame wood structure. Carbon fibre rods make a flexible wing spar that resists breaking. Adhesive joints tend to fail in an impact so using screws instead is an important part of crash-proofing the bird. A foam head offers a lot of protection from impacts. Brushless motors can achieve efficiencies as high as 80%. However, the actual efficiency depends on the loading of the motor. With ornithopters, we strive toward the maximum efficiency speed by adjusting the gear ratio, the size of the wings, or the flapping amplitude. There are several types of batteries on the market. None of them is very good, compared with the fat birds that use to store energy. The amount of energy stored in fat is about 10 watt-hours per gram. Can you imagine a 1-gram battery putting out ten watts of power for a whole hour? Probably not, because the best batteries on the hobby market today supply something like 0.14 watt-hours per gram or seventy times less than fat. These are the lithium-polymer batteries, abbreviated as "Lipo". There are some other drawbacks to lithium-polymer batteries, such as safety, and relatively short life in terms of the number of charge cycles they can endure. However, they offer the best solution available at present. Spur gears, as shown, are the best choice for ornithopters because of their low friction. The vast majority of successful ornithopters have used spur gears. Transverse drive shaft, with cranks at either end. This simplifies the design and saves weight. Since the cranks are not operating in the same plane as the flapping arc, the connecting rods must have ball joints at their ends. This results in more friction compared with ball bearings operating in a single plane. Instead of using infrared for the transmitter, radio control will be more effective as it would provide a longer range for flight. All these advancements can help in making an Ornithopter that has good flight time, longer range, battery efficiency and in overall a better prototype.

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