Keys of UAV technology

How to build your drone

Treball de recerca

ISAAC

Bassas Batista

La Salle Tarragona

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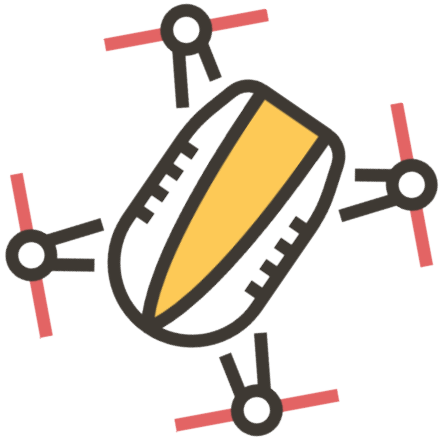
Curs 2018 – 2019

1 Index



2 Introduction

"Keys of UAV Technology – how to build your drone" is the title of my research project. There are many reasons why I have chosen this as my research subject, but the main one is I wanted to learn as much as I could about UAV technology

I LIKE IT

I've admired RC vehicles since I was a very young child, and it's something I just love to learn about. I have had many Radio Control cars and trucks when I was a kid, and I even built a Lego one myself. Now that I'm older, and I have access to more advanced components than Lego pieces, and hard to use tools, I decided it was time to go a step beyond: instead of creating a land vehicle, why did I not build a drone myself?

When I discovered drone technology back in 2014 (a bit after the DJI Phantom 2 release), I was first really curious and fell in love with it. But by that time drones were really expansive, and most UAVs available on the market were photography drones, so I eventually lost hope on having the chance to buy one for me, although I did continue watching videos on several social media platforms such as YouTube.

The turning point to this situation was on 2016, when I first discovered the racing world. From there I started watching many videos about drone races and I instantly go hooked, but I wasn't brave enough to try it myself, as I thought it was too expansive. Despite that I always had regretted not having bought a drone so when I was told I had to do this project, I instantly knew what I wanted my work to be about.

Also, another thing that has fascinated me about drones is the aerodynamics. Apart from being a tech lover, I have also been a sailor for almost ten years, something that has teched me a lot about aerodynamics, and about how wind interacts with a sail. Due to this, I also was, since the very beginning, very interested in learning how these same principles that are used in sailing are applied to the aerodynamics of planes and aircrafts. After following drone races and championships since the very beginning of the Drone Racing League, and I've always wanted to participate in some of these major events, and now that I have my drone all built and programmed, I hope I will soon have the chance take place in one of these competitions. But just like this one there are many other reasons why I have chosen drones as my research project.

FUTURE STUDIES AND PROFESSIONAL FIELD

Electronical engineering and programming have always been two topics that I have admired since I was a kid, and I have always dreamed of studying and working on something related to these fields in the future. Now, with college just around the corner, I know for sure that's what I will study, not only because of my passion towards these areas of knowledge, but also because they both are fields that are gaining a lot of momentum, and with the introduction of new technologies, they are having an exponential growth and are gaining new applications in many sectors.

Drones are one of those innovative applications which are now starting to be introduced into the businesses, but are drone skills valuable enough to

get paid for them? Can someone work as a drone pilot, or is it still a job which is in development?

Other great question come up when we start talking about drones as an entertainment source. Nowadays we have many sports and activities that are sponsored by massive corporations and are watched by millions of spectators. Drone races are still not quite there, but can a professional drone pilot earn enough money to live just by racing? We've seen that happen in many other sports such as soccer, where players are payed gigantic amounts of money to play, but when will drone races be influential and popular enough for that to happen?

TECHNOLOGY IN CONSTANT DEVELOPMENT

Drones are also a technology that is expected to have a huge market opportunity, and for instance, Goldman Sachs Research forecasts a $100 billion (BN) market opportunity for drones between 2016 and 2020. And although defense will still be the largest market consumer, the ludic drone market is growing fast and will be a $17 billion market in the same period, while commercial/civil government will be $13 BN.

With this project I would also like to learn what experts in the field think about drones, and where the technology is heading. "What sectors is this technology being developed at a higher rate", or "how much potential do you think this technology has" were two questions I kept asking to many of the professionals that I contacted who are currently working with drones.

LEARN ABOUT NEW DRONE APPLICATIONS

One more purpose I had when I decided to research about drones was to learn all the new ways and applications this new technology is used for. Drones are a great tool, with a lot of potential, which are now starting to be used for many things, and sooner than we expect they will be all around us. One of my aims when I decided to research about drones was to know what are drones currently being used for. What fields are drones being used at or what benefits drones provide over more conventional technologies where questions I frequently asked myself before researching about this topic. Since the very beginning I wanted to determine what were these innovative projects and how frequently drones were used in each sector to provide benefits over more spread around and more common technologies. I also wanted to know what uses drones are being used for, and if possible, get in contact with the people and companies who are part of this projects, in order to learn more about it, and to be able to ask professionals in the field what they think about drone technology.

PROMOTE THE USE OF THIS NEW TECHNOLOG & SITUATION IN CATALONIA

One of my ideas was to make this research project an introduction to the drone technology, so people can realize how useful it can be, and companies start investing more in this technology. I also wanted to know how drones are being used in Catalonia, the region where I live. So far I

have only been talking about drones in a worldwide context, but during my research I also wanted to learn what the situation is in Catalonia. Are many projects currently going on? And if so, what companies are investing and taking part in these projects? I also wanted to know if these projects were being leaded by important tech companies in Catalonia, or if they were just startups addressed by minor companies.

LEARN HOW EVERYTHING WORKS

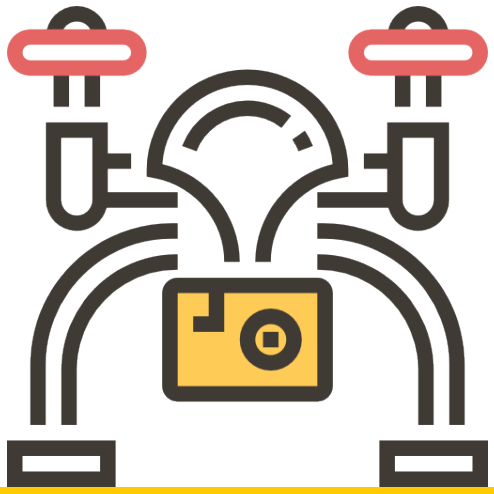
Despite all the knowledge I have about drones has been acquired through the use of RTF (ready to fly) drones and DJI photography drones such as the DJI Phantom 4 or the DJI Spark, with this project I wanted to learn more about how each different component inside the drone works, and how it interacts with all the other parts of the drone in order to make the aircraft capable of flying.

I also wanted to determine what different drone parts are available in the market depending on the type of drone you want to build (a racing drone, a photography drone…). For this reason, one of my goals was to not only research about all the components, but also to buy some of them and build a drone myself to test them.

In order to be able to do this practical part, I first will have to research and learn the answers to some questions such as what are the basic components that a drone needs, and what other components can be added in order to include new features (such as cameras or sensors, which are not necessary components in order to fly, but can provide the drone with many

more advanced features). While doing my research other questions came to my mind, such as how all these pieces interact between each other, or how expensive was to build a drone.

I hope after doing all my research all the questions asked above are clearly solved along this project pages. It's been really interesting for me to learn a lot about this topic, and I've had a lot of fun doing it, so I hope you all feel the same while reading it, and you learn a lot about this awesome new technology.



3 What is a UAV

A UAV (Unmanned Aerial Vehicle), commonly known as drone, is an aircraft that is piloted by a remote control, or with onboard computers.

UAVs (the aircraft itself) are just part of a more complex system, the UAS (Unmanned Aerial Systems) which include the drone, a remote controller on the ground, and a communication system between the two of them.

UAVs were first created to complete hard military missions that were just too dangerous for humans.

Although the first drones were only used for military applications, nowadays the drone technology is gaining a lot of momentum, and it's rapidly expanding to other applications such as agriculture, police, surveillance, product delivery and transport, mapping and aerial photography in between others.

Depending on their use, UAVs can be classified into many different types:

1. MILITARY purposes, which was the initial use they were designed for:

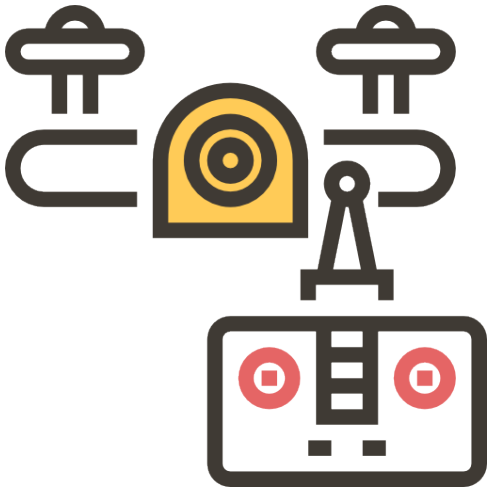
- Target and decoy: their purpose is to simulate aircraft or enemy attacks in the systems of defense of both land and air.
- Reconnaissance: gathering military information. This category ranges from HALE UAVs (High Altitude Long Endurance UAVs) to MUAVs (Micro UAVs), which are usually carried by soldiers in the field.
- Combat: for air combat and dangerous missions which are too risky for soldiers.

2. OTHER USES, which have been developing since drones stared to be introduced in the civil sector.

- Logistics: drones designed to carry and ship commercial products

- Commercial UAVs: designed to fulfill many purposes such as videoing, taking pictures, or other ludic purposes (freestyle, racing, etc.). With also many more technical applications, such as agriculture.
- Research and development (RD): this type of drones are created and tested in order to be able to develop new UAV systems or to improve its components.

In the next chapter, we will go in deep with the most common and innovative UAVs, exploring projects and initiatives in UAV technology that have been created to make business and make our lifes easier.



4 UAV History

4.1 Drone predecessors

4.1.1 The Austrian Balloons (1849)

The earliest documented use of an UAV dates to 1849, when the Austrians bombarded Venice, in Italy, using unmanned hot air balloons loaded with explosives. Even though those are very basic UAVs, and would not be considered as so nowadays, they were a huge technological advancement back in the 19th century.

4.1.2 First Aerial Pictures (1915)

During this battle the British army used really basic planes to take more than 1500 aerial pictures of the battlefield, and they used that information to create maps of German trenches and fortifications in that area.

4.1.3 First Radio Controlled Aircrafts (1930)

In the 30s the Us Navy created one of the first radio controlled piloted planes, the Curtiss N2C-2. This plane was a variant of the trainer aircraft, the Curtiss Fledgling.

4.2 First Recognizance Drones

4.2.1 The radioplane (1941)

The radioplane was the first remote controlled aircraft to be massively produced. It was developed and manufactured by the Radioplane Company, a US corporation that developed this technology to use it in WW2. Throughout World War II they produced over 9.400 OQ-3 Radioplanes, a propeller-powered monoplane primarily used as gunnery targets.

4.2.2 Mastiff UAV and IAI Scout (1973)

The Israeli Air Force's victory over the Syrian Air Force in 1982 with the use of the Mastiff drone made the investment in this new technology skyrocket. Both the Mastiff and the IAI Scout were recognizance drones that gathered information about the enemy.

4.2.3 Pioneer UAV program (1985)

The U.S created the Pioneer UAV Program to fulfil the demand for low-cost unmanned aircraft for fleet maneuvers. With the help of Israel, in 1986 the Us created a new drone known as RQ2 Pioneer, which was an average sized reconnaissance and exploration aircraft.

4.2.4 Miniature and Micro UAVs (1990)

Another growth field in UAVs are MAVs, or Micro Aerial Vehicles. This kind of drones were first designed and produced in the 90s, mainly for military purposes, although nowadays they are becoming a really popular technology for civil uses due to its low price and resistance.

4.2.5 Predator Drone in Afghanistan (2000)

The GM MQ-1 Predator was the first combat drone. It was developed by General Atomics, an American country, and it was first used for both recognizance and combat missions during the Afghanistan war.

4.2.6 Delivery and commercial Drones

DJI, the world's biggest drone company released its first commercial UAV, the DJI Phantom in 2013. Since then, many new models have been created, and the technology is being developed and improved every day.

In 2014 Amazon announced they were planning to introduce drones in for delivery purposes.

4.3 Drone sector in Catalonia

Nowadays, the situation for drones in Catalonia is really good. Catalonia has some of the most important companies in the sector, some of them competing in an international level. Thanks to the commitment of the Generalitat for this sector, in 2015 a drone Working Group was formed. Since then, the sector has had several initiatives that have allowed it to be enhanced. According to Jordi Puigneró, General Director of Telecommunications and Information Society of the Generalitat de Catalunya at that time, "the drones will be the Catalan aeronautics industry of the 21st century, but what will bring value and benefits to our economy will be, above all, the smart services associated with drones ".

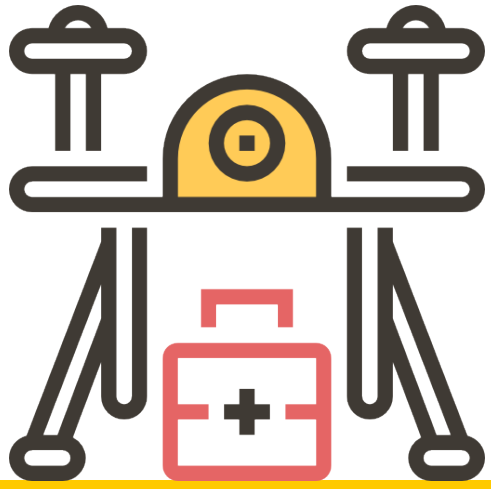
The presence of the Mobile World Congress (MWC) in Catalonia, and other conferences of great importance to the sector such as the Smart City Congress, contribute to this good health in the sector.

INTERVIEW BOX - Interview to Carme Prados, Seidor

Carme Prados, who is a Seidor employee, has a 20-year labor experience in the Catalan technological sector. She works as a consultor, helping companies from many different sectors to define and improve their digital strategies. Seidor, a Catalan company with more than 4,000 workers and with presence in 28 countries is one of the most important technological companies in the Catalan market.

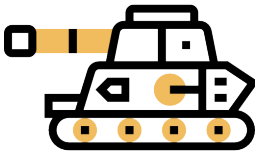
Drones in Catalonnia

According to Prados Catalonia has been able to position itself very well in the technological sector, thanks in part to the MWC, and all the big companies that this event gathers. In this sense, the great development of companies that have grown under this umbrella has been highlighted, and all those companies have also enhanced services around the drones: "Catalonia has the Catalonia Smart Drones, an association that groups almost 90 members and intends to increase the competitiveness of the industry and promoting projects and employment around the sector".



5 What are they used for?

5.1 War



Drones have been used for war purposes since WWI. Although the first models were really basic, and most of them were basically controllable missiles (which made them 1 use drones), throughout the years they have evolved to the point where they form part of every major world army. This war drones can be separated into two types: ISR drones (Intelligence, Surveillance and Reconnaissance) and UCAVs (Unmanned Combat Aerial Vehicles). Nowadays most of the drones used by the military are ISR, as they are much cheaper than UCAVs, and secondary world powers can only afford this type of drone.

The ISR drones can be launched both from long, medium and short distances. First, the long distance ISR drones (launched and controlled from a remote safe location) are the most effective ones but need much more gear and preparation before getting one in the air. The NG RQ-4 Global Hawk, for example, needs a landing track, but once on the air it can fly for up to 32 hours straight, and can surveil 100.000km² in one day, a piece of land equivalent to the size of Iceland, or three times the size of Catalonia. Medium distance ISR (launched from trailers with pneumatic catapult systems) such as the AeroVironment Ravens, the AeroVironment Wasp and the RQ-7 Shadows have a much shorter range, as their flight time is, on

average, in between one and two hours, and their maximum range[1] is around 10km. This huge decrease on flight time, is due to the fact that most mid-range ISR are powered by electricity, and even with the best Lithium-ion batteries, the energy density[2] of gasoline is 45 times greater than the energy density of a battery. This makes electric drones worse on some aspects, but it also means they are smaller, and easier to transport and launch.

Last of all, short distance ISR drones (which are hand-launched by a soldier in the field) such as the AeroVironment Pumas or the Honeywell T-Hawk can be carried by a soldier while on a mission and launched at any moment. They also use batteries, so even if the drone runs out of energy, soldiers just need to swap the battery to continue flying it. This kind of drones are the smallest and lightest of al types, as they are meant to be carried easily. They also have the shortest flight duration (usually less than an hour) and the shortest maximum range.

On the other hand, we have UCAVs, more advanced drones which only the world powers (such as the US, Russia or China) have access to, as they are more expensive. This kind of drones can not only provide information about their enemies but can also attack and perform combat maneuvers. These vehicles are mainly represented by the GA Reaper, the GA Predator and the GA Gray Eagle. This kind of drones can fly for around 24h with and average range of 1.500 km. They are capable to carry inboard weapon stations (high

[1] Maximum distance the drone can go before losing the signal with the remote controller.
[2] How much energy can provide a kg of a certain material, or, in this case how much energy can provide a fully charged 1kg battery.

caliber machine guns), and many different types of missiles, such as a Hellfire, and ASM (Air-to-surface missile), Stingers (Air-to-air missiles) and even PG AGM (Precision-Guided Air-to-ground missiles). With all this equipment this kind of drones are well prepared to do jobs such as airstrikes, SEAD (suppression of enemy air defenses) and even electronic attacks (used to trick enemy radars and other defenses).

5.2 Agriculture

An agricultural drone is a UAV that is specifically designed to help increase crop production, but also to surveil and monitor crop growth. They have a wide range of sensors that provide farmers with a lot of information that helps them decide on what to do. This kind of drones are capable of doing two different tasks: providing information about the crops and the field in general, and actually doing some specific jobs, like irrigate water on the crops, or spraying insecticides.

5.2.1 Information and data gathering

Although many people think this is not as important as crop irrigation, and it's just and add on to agriculture drones, it really is the most important jobs that the UAV does for the farmer. Total field, in-season, up-to-date condition data is one of the most valued pieces of data in a precision program. With these statistics a farmer can spot problems prematurely, and

rapidly select proper interventions. Spot-checking, which is the main technique used nowadays, is not accurate, as with this technique the farmer only checks the health of certain spots within the field, which sometimes is not a good representation of how healthy the whole field is. Also spot-checking is a slow process, especially when dealing with large amounts of acreage.

The solution to this problem has been, for the last decade, using manned surveillance flights or even using satellites with NIR cameras (Near InfraRed cameras). The problem with these technologies is that only massively big companies can afford them, as the solutions are really expansive. With the introduction of drones in the sector, regular farmers get this kind of sensors on the air in a much more affordable way.

Agricultural drones represent a new way to gather field-level information. The most captivating reason for using drones is that the results are on-demand; whenever and wherever needed, the UAV can be easily and rapidly deployed. Only drones offer this kind of immediacy and convenience when it comes to data collection. Nowadays, drones are affordable for everybody, and compared to most farm equipment they represent a really small investment. They are also quite easy to operate and fly, and most important, they are a safe and reliable tool.

5.2.1.1 Choosing a drone for agricultural tasks

When choosing a drone type for agricultural tasks we have two different options: multirotor and fixed-wing drones. On one hand, fixed-wing drones have a much larger flight range capacity, which make them useful for big fields. The problem with this kind of drones is they usually need a small

landing track to take off, and they need to take off facing always the wind, which is a problem when the wind comes from one of the sides of the track. Fixed-wing are much more energy-efficient, and can usually carry a heavier payload, but the landing and setting off requirements are huge setbacks.

On the other hand, multirotor are much easier to set up, and take off, and are more suitable for unexperienced pilots. There is no need to plan landing and takeoffs with this kind of UAV, as it can land vertically anywhere you want. Multi-rotors have many advantages over fixed-wing drones: they're easier to operate, require no advance wind planning, and have the ability to fly more precisely. Furthermore, range is no longer a practical issue, as under the new drone legislation in Spain (and in most UE countries and the USA), operators can only fly to edge of line of sight, which makes long range fixed-wing drones not as useful.

5.2.1.2 Adding sensors: a key element for agriculture

Inexpensive consumer drones can be used out of the box to take photos from above a field, which may spot some problems, but to really obtain value from an agricultural drone other types of sensors must be considered. Here is where NIR cameras and NDVI (Normalized difference vegetation index, a program capable of detecting how healthy a plant is by analyzing the light spectrum that is reflected on its leave) take an important role. With these sensors, the farmer can quickly identify which sectors of the field are in worse condition and consider this information to act appropriately.

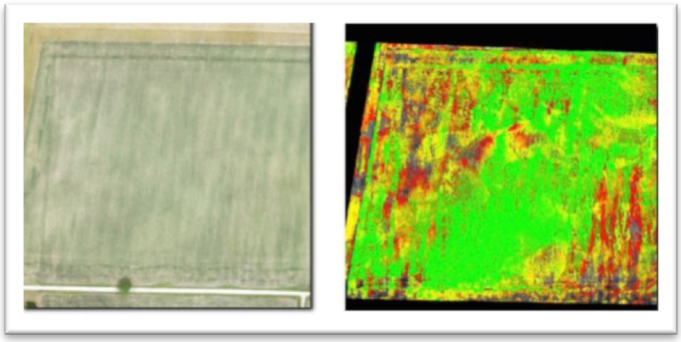


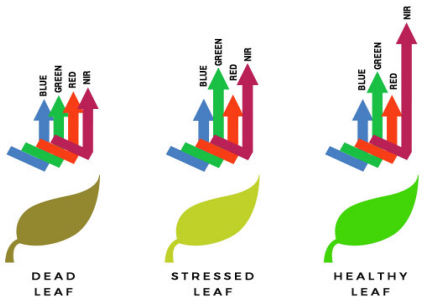
FIGURE 1. RGB picture vs NDVI picture

SOURCE: AGRIBOTIX: AGRICULTURAL DRONES

Here we have two images of the same field, one taken with an RGB camera (normal color picture) on the left, and one taken with an NIR camera, on the right. Thanks to the NDVI, we can clearly see which sectors of the field are not as healthy (red and orangish) and what parts of the plantation are healthy (green). This information is not something that can be identified in the RGB picture. Thanks to this data farmers don't have to waste time spot-checking the field. Instead, the UAV provides a much more accurate information within a shorter period.

IN DETAIL BOX: So, how are this kind of pictures taken?

Healthy plants absorb RGB light to be able to do the photosynthesis, and reflect NIR light, as they do not need it to perform photosynthesis, and absolving it would cause the plant to overheat its tissues. On the other hand, dead plants do not reflect as much NIR light, because they don't do photosynthesis, and therefore they act like inanimate objects, which absorb and reflect all kinds of light equally.



Normal (RGB) cameras only gather the three main colors in the light spectrum: Red, Green and Blue, and all the other light frequencies (each frequency is equivalent to a color) we can see in a picture are just a mix of those three elemental colors. On the other hand, NIR cameras use a special silicon filter that is sensible to near infrared light, in order to gather information about this kind of light that is not visible to the human eye.

The NDVI has no units and uses values from -1 to 1 to determine whether a plant is healthy or not. Values in between -1 and 0 are all inanimate objects, including dead plants. These values are represented by red in the maps. Values from 0 to 0.33 means the plant is still alive, although is not very healthy. Orange is the color that characterizes these values in a map. Values between 0.33 and 0.66 are signified with yellow on the map, and they represent fairly healthy plants. Last of all, values from 0.66 all the way up to 1 embody healthy plants, and they are represented with a bright green on the NDVI maps.

5.2.2 Crop fumigation, irrigation and seeding

Now that we now how important drones are to gather infield information and data, we can also learn other more basic tasks drones are capable of doing.

After data gathering, the second thing drones are most used for is fumigation. Having to spread the insecticides all over the field is a rough task both for small farmers, who sometimes do it manually (with a small insecticide deposit on their back and a hose to aim the liquid towards the plats) and for big land owners, who spend a lot of time on a tractor driving around the field.

With the introduction of farming drones, this process can be done automatically by the drone. These devices can spray pesticides between 40 and 60 times faster than manual spraying operations[3]. These drones can usually fly for around 25 minutes and can carry a payload of about 10 kg. This is the case of the Agras MG-1, a drone designed by DJI which can cover up to 36.000 m² of terrain in an hour, which means an average size field[4] can be fumigated in 2 days, a breakneck speed compared to what it takes to fumigate manually.

3 According to DJI

4 According to the 2012 USDA Census of Agriculture data and average field in the USA is 1,756,335.6873 m²

Also, for the drone to fumigate, all the farmer needs to do is just loading it with pesticide, quickly program the path the drone is going to follow and swap the battery when this one gets discharged.

FIGURE 2. DJI Agras MG-1

SOURCE: DJI OFFICIAL WEBSITE

Another thing this kind of drones are used for is water irrigation, although it is still a technology only available for small sized fields, because drones are not powerful enough to carry the massive amounts of water that big crop fields need.

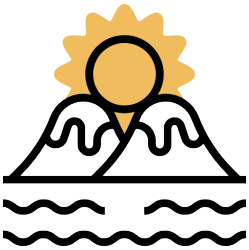
Last of all, seeding is also a really common thing drones are used for in agriculture. This technique is not as spread as the fumigating since is still a technology in development, and there are not many drones capable of seeding. This makes UAVs capable of seeding a bit more expansive, which means most small farmers don't tend to go for these models, but it is definitely a technique that is helping farmers with huge pieces of land seed much faster.

One of the most common seeding drones is the DJI Matrice 600, a frame which can be modified to fulfill many different purposes such as professional photography, terrain mapping, or even payload transportation.

FIGURE 3. . DJI Matrice 600 Pro

SOURCE: DJI OFFICIAL WEBSITE

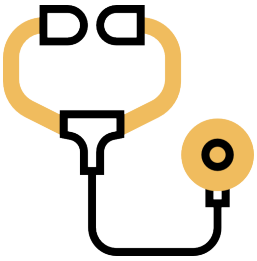
5.3 Topography



One of the many things that drones have been designed for recently is to precisely map terrain using a variety of sensors and cameras that allow the vehicle to get different types of data that can then be used to create many sorts of maps, such as 3D maps or heat signal maps. This kind of data is then used to make our lives easier by making apps that we use on a regular basis (like google maps) more precise. Topography drones are also starting to be used to accurately map an area where something is going to be constructed, such as a building or a road. These drones are not only used to gather data form large areas rapidly, but also to map hard access zones such as steep mountains.

5.4 Emergency Services

5.4.1 Ambulance



Ambulance drones are the future of EMS (Emergency Medical Services), as these UAVs are capable of reaching the accident area much quicker. Cardiac illnesses could be a good example of that. Around 800,000 people suffer from a cardiac arrest in Europe every year, and chances of surviving one of these heart attacks is 8%[5].

Many professionals on the field agree that the first moments after one of these cardiac arrests are crucial, and EMS don't usually get in time to help the victim. With the introduction of drones, a doctor could be watching what's happening through a camera and decide on what should be done. Since the drones can flight in a straight line, without the need to follow reads, or get stopped on a traffic jam, they are much faster traveling around the city than a land vehicle.

Alex Momont, creator of one of the first ambulance drone, says the surviving percentage could go up to 80% if the cities incorporated an EMS drone service. That means 576,000 more lifes could be saved a year in Europe with the introduction of drones for fast interventions in heart arrests.

[5] According to Delft University of Technology

Of course, the ambulance can't be eliminated, but having a doctor who can see what's happening through the drone sensors, and a drone full of elementary equipment such an AED (Automatized Electronic Defibrillator), disinfectant, and some basic medical pills and syringes would be a great improvement. Although this kind of drones are still in development, and many problems[6] need to be solved before we can see them flying around our cities, they will definitely be very useful in the near future, and researchers such as Momont continue exploring new ways to make these devices cheaper and better.

FIGURE 4. . Momont's First-aid drone prototype

SOURCE: CNN WEBSITE

[6] Such as laws and regulations, as at the moment most countries don't allow drones to fly around cities

5.4.2 Natural Disasters and Firefighting

Firefighting drones have been in use for a while now, and although they are not used to physically turn off the fire, they do help Fire Departments in many other ways, such as search and rescue, post fire or disaster assessment and scene monitoring. Within the last eight years, 20% of all drones sold to public agencies in the USA, were purchased by Fire Departments. This big percentage shows us how popular the drone is in the firefighting sector, and how useful these devices are to Fire Departments.

INTERVIEW BOX - Interview to Steve Rhode, from Wake Forest Fire Department (USA)

Steve Rhode is the President at Myvesta Foundation and also the Chief pilot at Wake Forest FD, in North Carolina, USA. Steve uses a DJI Matrice 210 to carry out missions for WFFD. As the chief pilot, he is in charge of duties such as UAS, UAV, and Drone ops for emergency response for water rescues, structure and open land fires, search and rescue, and natural disaster damage assessment. Steve has been flying drones since 2014, but he has been a pilot for a much longer period of time. "I started flying airplanes in 1988" as he told me, so he has a lot of experience in aircraft piloting.

How have drones benefited this field?

Drones have been a huge help to WFFD, as they have allowed the firefighter to gather information that wasn't previously available to them. In a recent article Steve wrote, he said drones greatly contribute when it comes to determining certain information about the wildfires. As Steve told me, drones are also really beneficial when it comes to search and rescue, as

thanks to their real time data gathering sensors, they can easily find lost people much quicker than other types of aircrafts, such as helicopters, and they are also much cheaper to operate. Although luckily Steve hasn't had the chance to try out the drone for a real Search and rescue situation, after doing many drills, he assured me the drone is one of the best tools WFFD has to easily locate missing people.

5.4.2.1 Search and rescue

The use of drones in search-and-rescue operations has largely increased in the past years, as these kinds of vehicles allow the responders to quickly have a bird's-eye view on the field. The fact that UAVs are an easy to use cheap technology means that many Fire Departments (FD) can have access to one of these devices. That is not only useful for fire rescue missions, but also in other kind of natural disasters, like floods, avalanches or snow slides, tornados, sea rescue, etc.

While a decade ago only major city FD had access to tools such as helicopters to search with a bird's-eye view, with the implementation of drones, which are much cheaper not only to buy but also to maintain and use, most of the Fire Departments can afford a UAV. This is a tool that allows the responders to quickly research a large area using heat sensors and infrared cameras to detect anybody who's been lost. The time of getting the drone in the air to recognize the terrain is much quicker than having hundreds of volunteers working on the ground.

Drones are also really useful when it comes to identifying survivors that are not visible form the ground. This new tech does not only help with catastrophic events such as tornados or huge fire or explosions, but it also provides aid with much smaller problems such as people in hazardous

situations in a smaller scale. This is the case of the Little Ripper, an Australian drone that saved two teenagers, who were stuck in a rip current, from drowning at the beginning of this year (2018). The drone provided the kids with inflatable lifejackets within 70 seconds after the UAV took off. This kind of recue would have taken a lifeguard an estimated time of six minutes. The Little Ripper can not only drop flotation pods but is also capable of detecting hazardous wildlife (such as sharks) on Australia's coasts, and also warning citizens about dangerous situations by using a powerful loudspeaker.

5.4.2.2 Scene monitoring

It is important to have as much information as possible when handling a situation like a fire. Before sending men to potentially dangerous places, it is important to know if they are going to be safe. Thanks to a variety of cameras and sensors the drone can gather information and analyze it. With FLIR (Forward-Looking InfraRed) cameras the drone can detect where the fire is hotter and thus stronger, or cooler even through smoke and walls. This provides the firefighters with information that can help when developing a strategy on how to turn off the fire. Although all this technology was already in use before drones, implementing it on a UAV allows to have a better and more peripherical view from the air.

5.4.2.3 Wildfires

Another of the major problems that small Fire Departments face are wildfires, as they don't usually have the tools to stop them, mainly because it's really hard to know what part of the area is on fire or burned out

without an air view. Thanks to drones, this small FD can easily detect where the fire is and where is going to, and with this information the firefighters can decide more accurately on what is the best thing to do. As in all previous cases, the drone technology is not really creating any new tech, but it's instead getting all the devices that we have on the ground and bringing them to the air, from where we can get a clearer view of an area. And the best part of it: it's doing all this for a much cheaper price, allowing town and villages FD to have access to this tech without the need of an expensive tool such a helicopter.

5.4.2.4 Post disaster assessment

Finally, UAVs can capture high-quality imagery and footage throughout and post-disaster. Drones can analyze the damage and use the recorded footage for future training or re-evaluation.

5.5 Research and environmental solutions

One of the most innovative and newest ways drones are staring to be used for is for research purposes. Drones allow researcher to have a sky view, which allows them to gather lots of data for their research.

These applications are especially useful for all the jobs nature related, and many researchers focused on the environment are using drones for their research.

This is the case of Liah McPherson, a marine biologist who has been using drones to research about dolphins (more info about her in the Interview box).

INTERVIEW BOX - Interview to Liah McPherson, Wild Dolphin Project

Liah McPherson is a marine biologist and photographer working for Wild Dolphin Project, a non-profit scientific research organization that studies wild Atlantic spotted dolphins. She has been using a DJI Maverick to spot and gather information about dolphins in the Bahamas.

How have drones benefited this field?

With the help of her DJI Mavic Air 2 pro, Liah was able to spot and follow groups of dolphins over long periods of time. This allowed her to record footage to study the dolphins' behavior with detail.

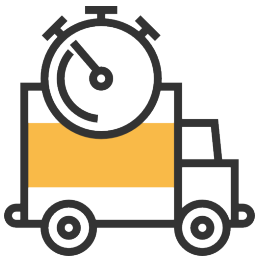
With the help of the drone she was able to find and follow dolphins much faster than by using more conventional tools. She was also able to take aerial footage of the dolphins, something that allowed her to determine how the dolphins were forming and how their behavior changed depending on the formations the dolphins had while swimming in groups.
As Liah told me during our interview "drones can improve a lot wildlife research and have a big impact on our field work".

On the other hand, the information collected by the drones can lead to concrete actions. While these projects are still under development, companies such as Microsoft have joined efforts with the University of California and Carnegie Mellon to, together with the Lindberg Foundation, fight against furtive hunting. The drones carry out surveillance at night and in an automatic way they are capable of detecting furtive hunters (thanks to artificial intelligence programs) and alert the foresters about the presence of hunters.

Another clear example closely linked to the planted alternatives that we have mentioned in the section about agriculture, would be the reforestation of hard-to-access areas in a much simpler, faster and more efficient way. According to the World Economic Forum "we are chopping down about 15 billion trees a year and planting about 9 billion. So there's a net loss of 6 billion trees a year. " A UK company has developed a drone capable of planting 100,000 trees in a single day[7].

[7] Check this video to see how it works: https://www.facebook.com/worldeconomicforum/videos/10154789863741479/

5.6 Delivery Drones



In a society where, online demand is greatly increasing from day to day, companies are continuously looking for a way to makes transportation prices drop. Drones could be the solution to this problem, as they are an easy, cheap and reliable way to move packages around. Companies such as Amazon are staring to ship some of their products with the help of autonomous drones. Amazon's drone can lift 2,3kg, and can deliver the package within half an hour. Of course, this technology is still not available everywhere, but it's starting to get popular around the globe. As we can see on the graph, it is estimated that drone delivery services will massively increase in the forthcoming years.

You can also find more information about environmental drone uses in this article: https://eos.org/features/drones-in-geoscience-research-the-sky-is-the-only-limit

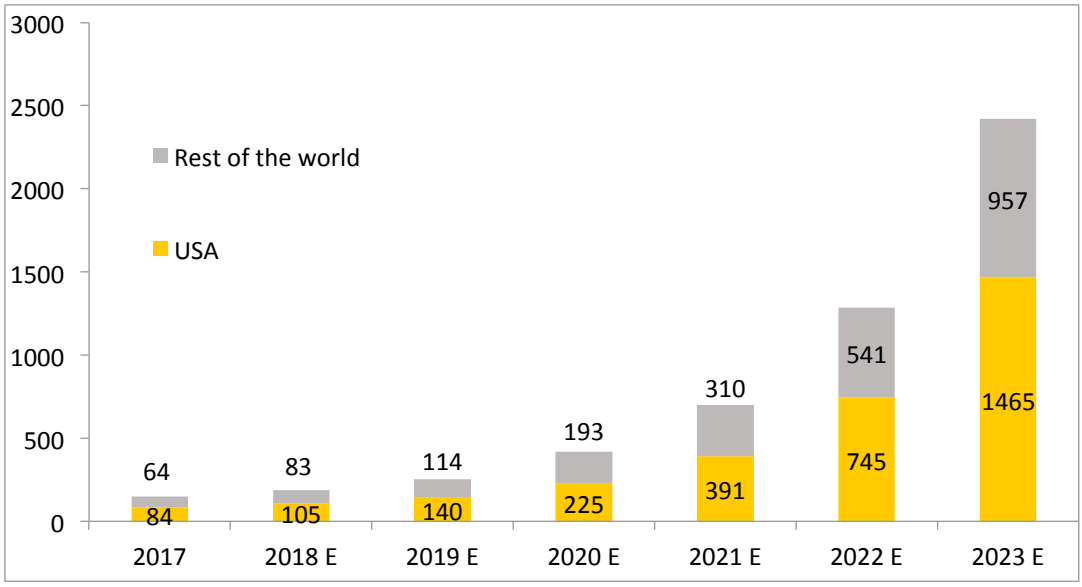


FIGURE 1. . Global Enterprise Drone Shipments (thousands).

Source: Business Insider Estimation

5.6.1 What is slowing down the introduction of delivery drones?

The main setback of this technology has to do with laws and regulation. Many governments don't allow drones to fly around cities, which means it would be illegal for companies to deliver packages in cities.

There's also another problem, which nobody has solved yet and it's deciding who owns the space above a piece of land. Before planes existed, owning a land usually meant owning also what was below and over it. According to the English law the proprietary of a piece of land owned it "up to Heaven and down to Hell", which is a clear example of that.

With the introduction of planes, countries decided that an owner only had right to 150m of air above his terrain, and everything above that would be considered public airspace. Nowadays, with drones gaining popularity, we

have a new problem: At what altitude can a drone fly over someone's private property?

According to Pew Research Center, more than 1 of 4 Americans would feel nervous, angry or scared if they saw a drone flying over their property. This clearly shows how important it is to handle the issue carefully, in order to for people to feel safe and avoiding any incidents while at the same time creating laws that allow companies to improve their delivery systems.

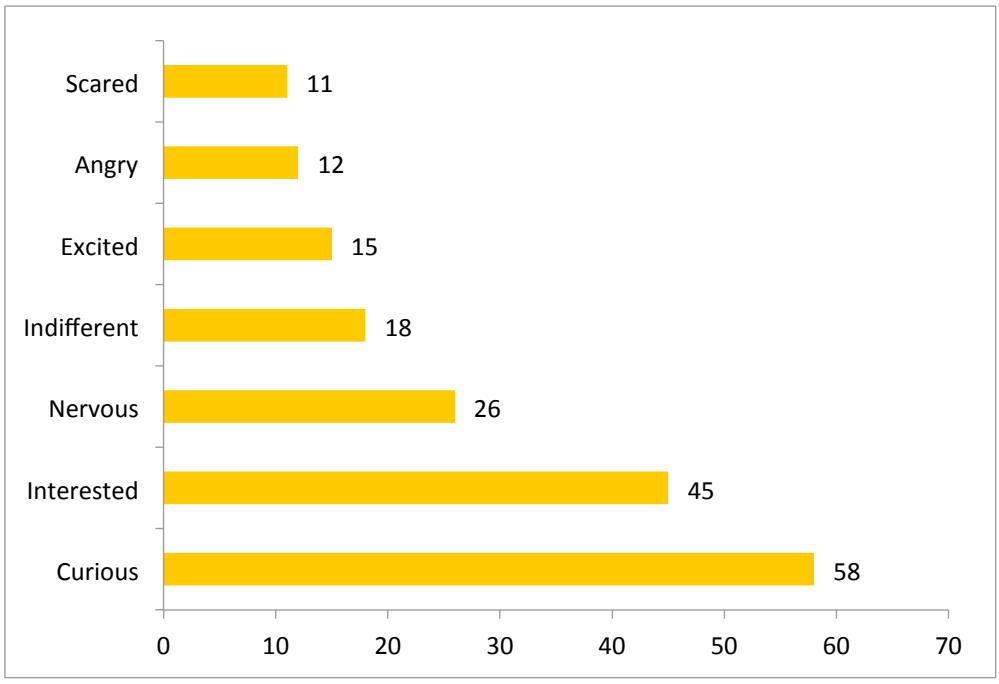


FIGURE 5. Percentage of adults who say they would feel _____ if they saw a drone flying close to where they live.

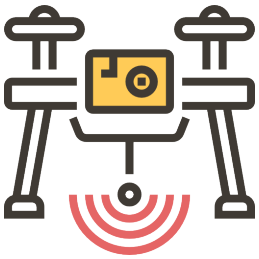
Source: Done by the Author with data from Pew Research Center[8]

Countries have been trying to get an answer to this question, but there is no agreement on a specific altitude. In these past years, there has been

[8] Respondents could choose more tan one option. Survey conducted May 2017. More data about this research on how americans feel about drones on theResearch Center website: http://www.pewresearch.org/fact-tank/2017/12/19/8-of-americans-say-they-own-a-drone-while-more-than-half-have-seen-one-in-operation/

several cases of drones being shot down while they were flying over someone's property. This is a huge problem, as this legal gap creates uncertainty and makes companies afraid of innovating in this field (as they want to avoid getting in trouble). The positive part is that as soon as these legal problems are solved, companies will invest copious numbers of money to improve drone technology, and that will benefit the whole industry (and at the end, everyone).

5.7 Ludic



Ludic drones have taken over the market for the past years. A decade ago, this was an expansive technology only affordable for some, but nowadays it has become so cheap that you can get a drone for less than what you pay for a book[9]. There are drones for all applications, prices and ages. The most popular brand is DJI, a Chinese company which almost has the monopoly on commercial drones. There are many things a user can do with a drone to have fun, so we will go over the main uses that UAVs have in modern society.

[9] Drones can be bought today for less than 15 euros. Many examples of that can be checked on Amazon, Ali Express or other online market places.

5.7.1 Different ludic activities

5.7.1.1 Racing

Drone races have been taking place since late 2013 and early 2014 when several amateur pilots met to participate in semi-organized races in Brisbane and Melbourne, Australia. From there, the sport became really popular, now reaching spectators all over the world, and races having millions of USD in prices. In these races, the pilots use FPV (first person view) goggles, in order to see what the quadcopter is seeing.

There are many different race classes, depending on the drone size. Frames can vary form 210mm up to 450mm[10]. In these races, drones must follow a trail and pass through small hoops and tight spaces to get to the end of the circuit. During the race, the drones get to speeds up to 130 kilometers per hour, so a crashing is the end of the race, as no drone can survive a crash at those high speeds.

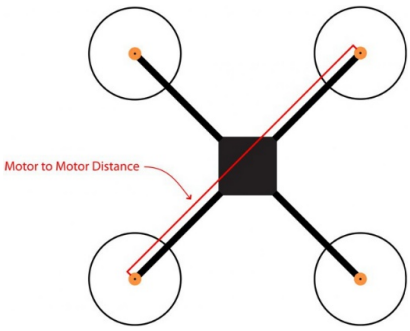


FIGURE 6. How to measure the size of a drone.

SOURCE: TJK ELECTRONICS

[10] Size is measured diagonally from motor to motor

IN DETAIL BOX - DRL

Drone Racing League is the major organizer of drone races. It was founded on 2015, and since then it has organized many events, and three seasons (2016 season, 2017 season and the 2018 season, which ended this September). These events are watched all over the world (the 2018 season has been shown in more than 75 countries).

DRL also produces drones which are on the top best racing drones. This past year (2017) they released the Racer 3, a drone that can from 0 to 130 kilometers per hour in less than a second and has a top speed of 150 kilometers hour. The Racer 3 can also fly up to 8 kilometers, a really long distance when compared to other racing drones in the market. DRL also has the remote-controlled quadcopter speed record, with the RacerX, a drone that got to a speed of 290 kilometers per hour[11]

This year (late 2018) DRL has announced that with the 2019 season, they are introducing a new type of race. This new event is called AIRR (Artificial Intelligence Robot Racing), and it's going to be a race where all the drones are autonomously controlled by computers onboard of the aircraft. By the end of the 2019 season, the best AI will challenge the DRL Allianz World Champion for the grand finale. Will the machine beat the best drone racing pilot in the world?

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[11] This was a really hard record to beat, and DRL pilots broke many drones to try to beat it. Many RacerX drones burst into flames because of the huge amount of power they were using when trying to get to those high speeds.

INTERVIEW BOX - Interview to the World's Best DRL Pilots

NurkFPV

This professional drone pilot, who is this year's (2018) world champion in the DRL first got into the world of drones on 2014 when he received a small Walmart drone for Christmas. From there he was instantly hooked. As he says, "The YouTube rabbit hole of learning everything that I possibly could about drone racing and FPV was all consuming, and I build and flew my first drone by March 2015". His first drone race was only a few months later, in June 2015, and his first national competition took place the following year (2016). That national tournament allowed him to get into worlds in 2016 where he placed second. Shortly after worlds, he was invited to participate in the Drone Racing League, and from there, "the opportunities have only skyrocketed".

NubbFPV

NubbFPV is a professional DRL pilot who was the second qualified in this year's DRL Allianz World Championship. He has been flying for a while, and he practices as much as he can to improve his piloting skills. He also owns and works on a hobby shop, where he sells drone components and other RC pieces, and advices and helps people who have problems with their drones.

How have drones benefited this field?

The improvements in drone technology have allowed for new type of sport to be created. Drone races are becoming more and more poplar around the world every day, and event organizers such as DRL draw in more spectators every year. Although it is not really common, and there's very few pilots who can do it, a good pilot can earn enough money to live just by racing drones. As the audience grows, the amount of money invested in this kind of events will increase, and there will be more racing drone users who professionally work as drone pilots.

5.7.1.2 Freestyle

This type of ludic activity consists on flying the drone around a place while performing different types of tricks and twirls, such as backflips, front flips, wall ridings, corkscrews, power loops, reach arounds, step rolls… These drones are pretty similar to racing drones, with the only difference being they use small size propellers with low pitch, so that the aircraft is more nimble (bigger blades are slower to speed up and slowdown, which means the drone can't change its speed as fast, making it less agile). This ludic activity is usually recorder to later create a short film or clip.

5.7.1.3 Photography and Video recording

Many people also use their drones to record what they do, usually adventure sports, as many of these drones can autonomously follow the user. These drones are also used to take high quality pictures with a bird's-eye view. They are the most expansive drones of this category, as they need huge amounts of power to be able to lift good cameras, and they also need a big battery, so that they can stay airborne for long periods of time. This kind of drones usually have around 25 minutes of flight times, while racing and freestyle drones have in between five and ten minutes.

5.7.1.4 Tiny whoop

This is a relatively new done category which has taken over the market in the past couple years. These drones are small, cheap quadcopters, which can be flown inside any building. They are like a smaller and much cheaper version of freestyle drones, and they are meant to be an easy and cheap way to learn how to fly a drone.

These drones are usually not really good, as they lack many parts that bigger drones have, and they do not have the same precision while flying as more expansive freestyle drones, but still tiny whoops are the perfect drone type to get into the world of drones, especially when you take into account that you can purchase one for less than 15€ (already including shipping costs to Spain). They are also great for kids to have fun without having to worry about getting hurt, as the motors in such small aircrafts don't hurt you even if you touch the blade when it's spinning at full speed[12].

[12] On the other hand, a more powerful motor, like the ones on racing and freestyle drones, could easily chop your finger when spinning at maximum speed.

6 UAV Types

6.1 Aerostat

This class includes all those aircrafts which use some time of buoyant gas to generate lift. They are usually called lighter than air aircrafts, and although they are not the most popular type of drone, they are starting to have an increasing demand on the photography sector of droning.

6.1.1 Airships and Blimps

FIGURE 7. Remote controlled Blimp.

SOURCE: RC-ZEPPELIN

This kind of lighter than air aircrafts get their lift force from buoyant gases, usually helium. The main difference between a blimp and an airship is the balloons structure. In an airship, the interior part of the inflatable has award structure that gives shape to the balloon. On the other hand, on a blimp,

there is no internal structure, so the balloon can be completely deflated and folded. Since these are extremely big aircrafts, the blimps seem to have much more popularity because they can be folded whenever needed, to make transportation much easier.

This type of drones has not been really popular over the past years, but nowadays many companies, especially the ones dedicated to aerial photography, are staring to produce them, since this kind of aircrafts have many advantages over traditional aerodynes.

First of all, a blimp can hover on a same spot, just like a multirotor, something that fixed wing planes can't do. But that's not all, a blimp is also much more stable than a multirotor due to its big size (strong winds are needed to be able to swing the aircraft, while multirotor drones, which are much smaller, have difficulties to hover even with weak winds), allowing it to take pictures much better and with a higher quality.

Last of all, and probably the most important point, is flight time. The biggest problem drones face nowadays is energy lack. Having to power an aircraft to maintain lift for long periods of time draws a lot of current form the batteries, but this problem is easily solved if introduce helium to the equation. With the lifting power of buoyant gases, this kind of aircrafts can use all their battery power to direct the aircraft, instead of having to worry about lift. This allows the aircraft to have much longer flight time. While a commercial photography multirotor drone has around 25 minutes of flight time, blimps have between 3 and 24 hours, depending on the size of the helium balloon. Despite having many advantages, blimps also have some drawbacks, such as movement speed. This kind of aircrafts can't usually get

over 20 kilometers per hour, while multirotor drones get to 75 kilometers per hour, and some even up to 100 kilometers per hour. This is a huge problem when dealing with fast moving targets (like cars or bikes) as the blimp won't be able to follow them.

6.1.2 Air Balloons

Air balloons work in similarly to airships. The main difference is air balloons can't move freely, as they have nothing to propel them forward. Instead they are moved with the wind currents. This makes them even better for long lasting flight sessions, as there is no need to have a battery or motors, but it also means the user won't be able to direct the balloon wherever he wants. Balloons are usually tied to the ground with a long light rope, so that they don't go too far from the pilot. These drones are the best at recording and taking pictures over a specific area, as they can be tied down on a spot, and they will record everything with a birds-eye view for a long period of time. On the other hand, this type of aircrafts is not of much use when it comes to recording a moving object.

6.2 Aerodyne

They are also called heavier than air aircrafts. This kind of airliners use aerodynamic lift, or powered lift to gain upward thrust. Aerodynamic lift is gained when there is forward

motion, that triggers Bernoulli's law[13]. On the other hand, powered lift airplanes use an engine to spin a rotatory wing (propeller), which pushes air down, making the aircraft go up.

Besides technical differences, the main variance that these types have in-field is that rotatory wing can stay still on one spot, while fixed wing (powered lift) aircraft need to be constantly moving in order to generate lift. This kind of aircrafts have what is called a stall speed, which is the minimum velocity the aircraft can have to provide lift. Below this speed, the plane wings don't generate enough lift, and the aircrafts starts to fall down. The second big drawback towards fixed wing planes is that they can't land or take off vertically, which means they need a landing track. On the other hand, fixed wing aircraft are better at long flight situations, as they are much more energy efficient.

6.2.1 Fixed Wing (Aerodynamic lift)

6.2.1.1 Planes

Planes are winged aircraft that get their lift with a forward force which creates a difference in the pressure below and above the wing. This difference in air pressure pushes the plane up, providing lift. This category of drones is one of the most used, as it is the most reliable when it comes to long distance flights. With the introduction of hand-launched fixed wing

[13] This law states that fast-moving air is at lower pressure than slow-moving air, so the pressure below the wing is higher than the one above it, thus creating an upward lift that is what allows the plane to takeoff.

drones they have become much more popular in the market, as this technological advancement allows users to dispose of the runway, which was probably the biggest drawback of this kind of drones.

6.2.1.2 Glider (Sailplane)

Gliders are a type of aircraft that doesn't use any type of power source to produce lift. Instead, this aircraft uses naturally stirring currents of rising air in the atmosphere to stay airborne. The main drawback of this drones is they need air currents to fly, and they are not as nimble and maneuverable as powered planes, but they are much more energy efficient, as they don't need to draw current from the battery to lift the aircraft.

6.2.2 Rotatory Wing (Powered lift)

6.2.2.1 Helicopters

This kind of aircraft uses a single motor to rotate a propeller that pushes air down. This downward force propels the helicopter up. These aircrafts don't have any type of motor to push them forward, so to move they tilt the whole aircraft towards the direction it need to go. For this same reason, this kind of aircraft have a much slower speed when compared to fixed wing planes, as moving forward means some of the force of the propeller that was providing lift is now being used to move the aircraft forward. These drones have what is called angle of attack, which is the maximum angle at which they can be tilted in order to maintain lift. The aircraft will go faster the more tilted it is, but if the angle of attack is overcome, the aircraft will start to fall down.

6.2.2.2 Multirotor

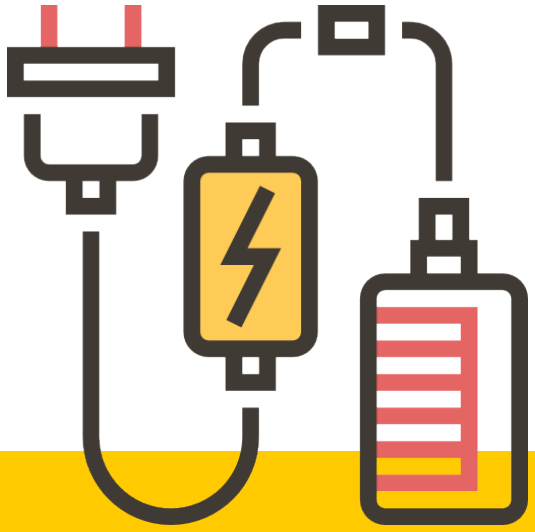
Multirotor are pretty similar to helicopters, with the only difference being that multirotor drones have more than one motor and thus more than one propeller providing lift. These types of drones change the speed of their various rotors in order to be able to throttle (up and down motion), yaw (turning clockwise or counterclockwise), roll (right and left motion) and pitch (forward and backward motion). Together with fixed wing planes they are the most common types of drones. Multirotor are the most popular class in the commercial sector, and although they started being sold as professional photography tools, nowadays there's models that are designed for child, and that are sold at a very modest price. There're many types of multirotor drones, depending on how many motors they have:

a. **Trirotor or tricopters** which have three motors, usually two on the front of the aircraft (one on each side) and one on the back.
b. **Quadcopters** have four motors, one on each corner of the drone. They are by far the most common type of multirotor. They are mainly used for tasks that need a fast and stable aircraft, such as racing, photography, freestyle, surveillance or data gathering.
c. **Hexacopters** have six motors, and they are the second most used type of multirotor. They are mainly used for weight lifting jobs, such as package delivering, or gathering data with heavy equipment. Some of these drones are designed to be capable of flying even without one of their 6 motors
d. **Octocopters** are not really used, having eight motors makes this kind of drone have a really low flight time (more motors mean

current is drawn quicker from the battery). They are usually used to transport really heavy stuff over a short distance or periods of time. One of the benefits that this drone has is that if for some reason a motor breaks, the aircraft can stay airborne, as the other motors will continue to provide enough lift force to push the drone upwards (even though the drone can fly without one of the motors, doing so will of course reduce the flight time and the maximum speed of the multirotor).

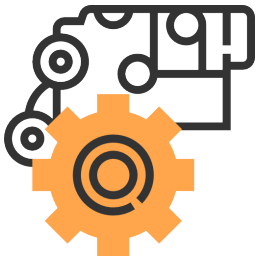
6.2.2.3 Autogyro

Autogyros use an unpowered rotor, that can spin freely, to generate upward thrust. With this thrust, the rotor gives lift to the aircraft, allowing it to sustain itself in the air. To generate this upward lift the aircraft needs to have forward speed, which is provided by an engine driven propeller. The autogyros look similar to a helicopter in appearance, but they work in a different way, as helicopters have an engine that spins the rotor to generate lift. This kind of vehicles are not used much in the drone world as there are other models which are much nimbler, energy efficient and easier to control.



7 UAV Parts and Components

7.1 Motors



Motors are one of the most important parts of drones, as this is the hardware part that provides the UAV with all the thrust needed to move. Motors can be classified in many different types, as there's many variables to consider when classifying them, such as motor size, KV, torque, number of poles and magnets in the motor, etc. Depending on all these variables, the motor will have different specifications, and will be used for different applications.

7.1.1 Motor KV

KV refers to the constant revolutions per minute of a motor. It is number of RPM that the motor will turn when one Volt (1V) is applied, and there is no load attached to the motor. This helps us understand how fast the motor will be able to spin.

7.1.2 Torque

This is the force at which the motors spin. It should not be confused with the motor KV, as they are different things. While the motor KV tells us how fast the motor spins (how many RPM the motor can achieve) the torque tells us with how much force it's spinning. Usually more spinning speed means less torque, and vice versa.

7.1.3 Number of poles (coils) and permanent magnets in the motor

The higher the number of poles and magnets, the motor will have more magnetic fields being created at the same time, and thus it will have more torque force. Having more poles and magnets also makes the motor heavier, and more importantly, it draws current from the battery much faster, as it needs to power more coils.

This makes motors vary a lot depending on what they will be used for. Racing drones' motors usually have in between 12 and 16 poles (number of poles needs to be an even number)

7.1.4 Motor size

The bigger the motor is, the bigger magnets and coils it will have. This means a bigger motor will be heavier and will draw a lot of current, but it will also create much bigger magnetic fields, therefore spinning faster. For drones, the size variates a lot depending on the drone function; a small toy quadcopter is going to have tiny[14] motors, while drones meant to lift heavy weights have much bigger motors.

FIGURE 8. Brushless Drone motor.

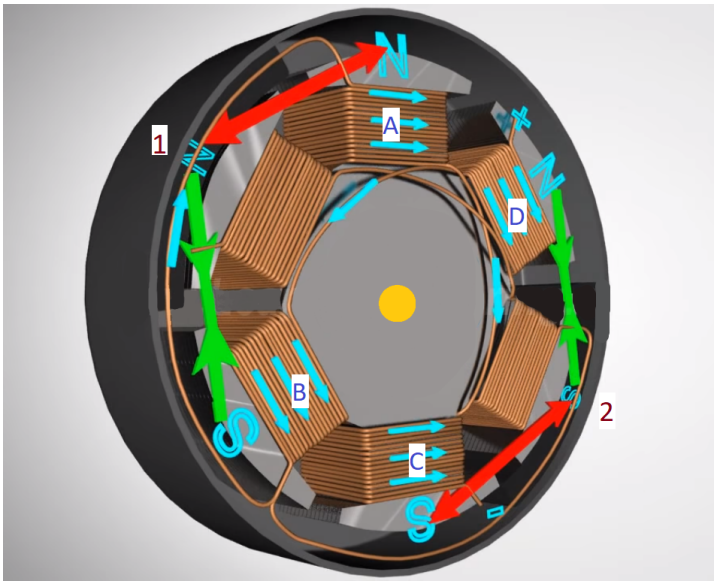
SOURCE: QUAD QUESTIONS

[14] The most common motors used in tiny whoops are 6mm in diameter, while racing drones are much bigger, in between 30 and 40mm in shaft diameter

IN DETAIL BOX: How does an electronic motor work?

An electronic motor generates rotation by creating magnetic fields. It is made of various permanent magnets (which are constantly creating a magnetic field) and several coils, which act as electromagnets (which only create magnetic fields when current flows through them). This magnetic fields attract certain parts of the motor and repel others this creating motion. Here's a picture, for easier understanding.

As we can see in the picture, motors permanent magnets attract and repel certain coils in order to make the motor spin. In this case, the coil B is negatively magnetized, and that is why it is pushed towards the positively charged magnet 1 (differently polarized poles attract, while poles with the same polarization repel each other). The same effect happens with coil D and the permanent magnet number 2 (green arrows). On the other hand, coil A is positively charged just like magnet number 1, which means they repel each other (red arrows). The same happens with coil C and magnet 2. As the exterior shell (black part) of the motor is tight down to a surface, and thus it can't move, all the force created with the magnetic fields makes the interior part of the motor spin. As the inner part of the motor spins, and the coils with it, the same process explained above is repeated over and over again. The shaft of the motor is in the center of the circle (the orange dot), and it also spins, together with all the inner motor components. This shaft is what is connected to whatever the motor is powering, in our case a propeller, but it could also be connected to many other things, such as a wheel.



7.2 Frame

The frame of a quadcopter is the main structure that contains all the components of the drone. The frame can be simply divided into two parts: the body and the arms. The body houses and protects all the electronic components such as the FC (Flight controller), the PDB (Power Distribution Board), FPV (First Person View) camera etc. The arms are where the motors, and usually the ESCs as well, are installed.

Frames can be classified in many different types, depending on size, material, etc.

7.2.1 Size

The size of a quad frame, also called wheelbase, is the diagonal distance from motor to motor, measured in millimeters.

The frame size determines various aspects of the drone such as the maximum propeller size, the motor size, the inertia of the aircraft and the weight of the drone. The size of the frame determines most of the components of the drone.

Frame Size	Prop Size	LiPo Battery
210mm	5 inches	1000-1300Ah – 3s/4s
250mm	6 inches	1300-1800Ah – 3s/4s
330-350mm	7-8 inches	2200-3200Ah – 3s/4s
450-500mm	9-10 inches	3300Ah – 4s

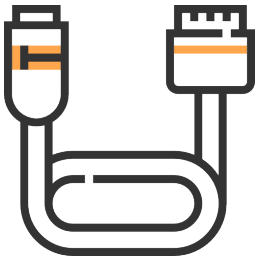
FIGURE 9. Frame sizes with their correspondent propeller size.

SOURCE: DONE BY THE AUTHOR WITH INFORMATION FROM PICTURE SALOON

7.2.2 Material

Although most quadcopters are built with carbon fiber (CF) frames, because it is a durable, resilient and light material, some are made with other substances, such as durable plastic. Carbon fiber is made of many sheets of braided carbon fibers, which are then set one on top of the other and compressed strongly. The best thing about CF is that even being ten times stronger than steel, it is 5 times lighter as well. The biggest drawback to CF is that is really hard to cut and drill, so really specific equipment is needed to do so. Also, although CF is really resistant, if at some point the sheets of fibers start to split up, the whole frame is going to break quickly, as ones the sheets start to separate, CF becomes much weaker, and it is impossible to repair or recompress the interweaved sheets of fibers.

7.3 ESCs



Electronic speed controllers are essential in any drone, as they are the component that receive throttle signal from the flight controller and drive the brushless motors at an optimum velocity by providing the proper level of electrical power. Most ESCs from major brands perform similarly and allow the drone to fly in a reliable and smooth way. ESCs allow the motors to change their speeds whenever needed. Without ESCs a quadcopter would only be able to go up with a constant speed, as it would not have anything to slow down the motors thus allowing the UAV to throttle, roll, pitch and yaw. ESCs also allow motors to spin on reverse.

7.3.1 Current rating

One of the most important things in an ESC is current rating, which is measured in Amperes (A). Motors need electrical current in order to spin, and this current goes through the ESCs. The current rating is the number that determines how much current the ESC can support before getting fried. If the motor draws more current than what the ESC is cable of supporting this last one will overheat and break, and in some cases, it could even burst in flames. Some of the things that make the motor draw more current are the motor KV, the motor size, o the propeller size (length and pitch). ESCs tend to have two different current ratings: continuous rating and burst rating. The

first one is the amperage the Esc can handle during long periods of time, while the second one is the is amperage that the ESC can support during a short amount of time (around 10sec). The burst amperage is usually the Amps that will flow through the ESC while at maximum throttle. The burst rating should not be used as a reference, as even when racing, the drone will not be flying at maximum speed for long periods of time. Due to the fact that an ESC with a current rating below what the motor is asking is going to breaks, it is also a good idea to have an ESC with a current rating a bit over the current that your motor needs to fly, as there is no downside to using ESC with a higher current rating.

7.3.2 Size and Weight

Although it is not always the case, usually the size and weight of an ESC is directly related to the Amp rating. Although small quads tend to have smaller ESCs, there is a limit to this as ESC can't get smaller without losing performance, mainly because of cooling problems. ESCs don't have a cooling system, and they get cooler because the surface of the ESC is in contact with air. For that reason, the smaller the ESC, the less surface it has and thus the cooling is much less effective.

7.3.3 Input Voltage

ESCs have a maximum voltage they support. Some get up to 6S, others are limited to 4S LiPo batteries. For this reason, it is always necessary to check the ESC is compatible with the battery voltage.

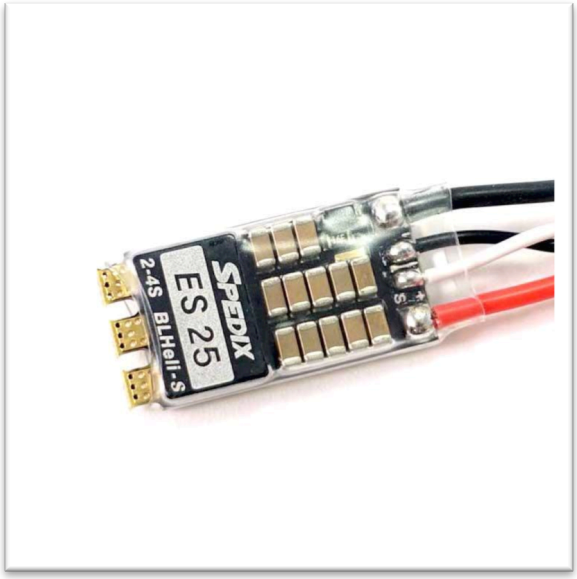


FIGURE 10. 25A BLHeli-S ESC.

SOURCE: QUADCOPTER.CO – DRONE RACING SPECIALISTS

7.3.4 ESC Firmware

The ESC firmware is the software that runs on all ESCs, and which determines the ESC's overall performance, which protocols the ESC supports, and what configuration can be used. The firmware that an ESCs can use depends on the hardware. ESCs can use many different firmware although the most commonly used nowadays is BLHeli.

7.3.4.1 BLHeli

Both BLHeli and Simonk were used on most of the ESC's until about 2015, but since then BLHeli has taken over the market because of its more comprehensive and user-friendly interface and due to the fact that this firmware is being updated consistently. BLHeli has launched two more generations of firmware since 2015: BLHeli_S and BLHeli_32. These updates improved the ESCs firmware, and it also made it more complex, as it included new features while keeping it easy to use at the same time.

7.3.4.2 SimonK

This ESC firmware was as popular as BLHeli until 2015, but after that year, it has almost been forgotten, and barely used, mainly because Simonk firmware has not been updates, which is a huge drawback when compared to BLHeli firmware.

7.3.4.3 Other manufacturers' own firmware

Some companies that produce ESCs have their own firmware for their hardware. This is the case, for example, of KISS (which stands for Keep It Super Simple), an ESC manufacturer that sells all their ESCs with KISS firmware.

7.3.5 ESC Protocols

ESC Protocol is the type of codes or language that the ESC uses to communicate with the Flight Controller, in order or that last one to give orders (such as how fast the motors should be spinning) to the ESC.

Different protocols have different signal width, which is the time that it takes for one data packet to be send form the flight controller to the ESC. Here's a graph on the main miniquad protocols, and their speeds.

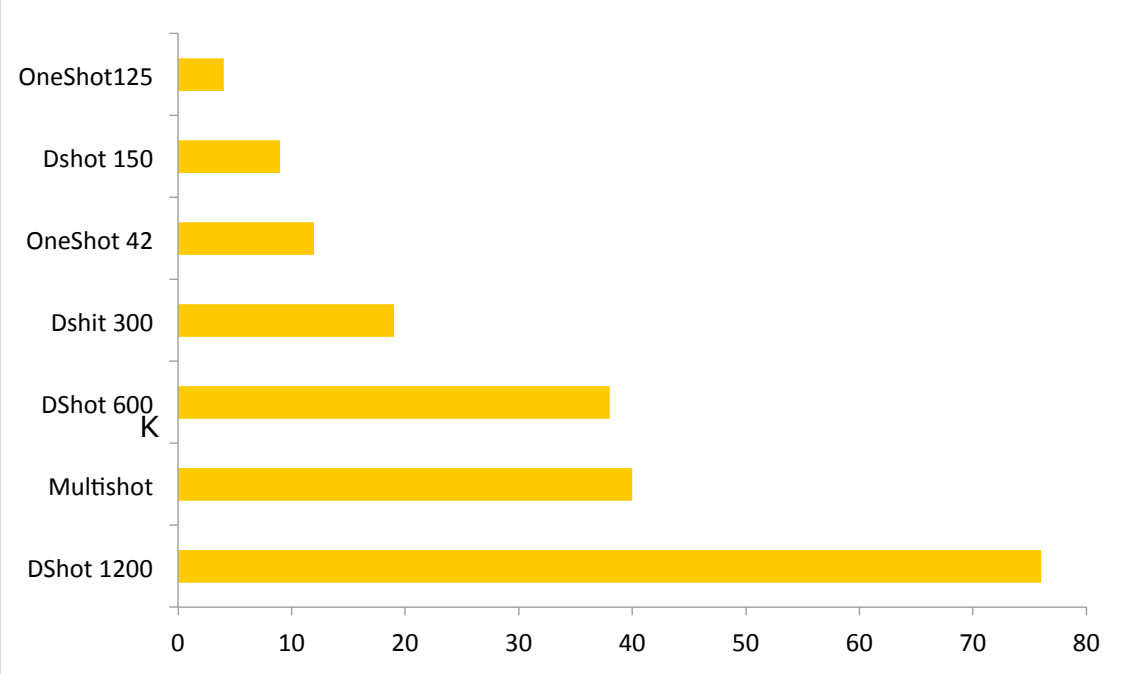


FIGURE 11. ESC PROTOCOL SPEED COMPARISON AT 100% THROTTLE.

SOURCE: OSCAR LIANG, HTTPS://OSCARLIANG.COM/DSHOT1200-ESC-PROTOCOL/

7.4 Flight controller

The flight controller is a CPU (the brain of the drone), as it's the component that receives the information from the receiver, interprets it, and sends the order to the correspondent drone part. The flight controller is usually connected to the PDB, although some flight controllers have an integrated PDB.

7.4.1 Firmware

The FC firmware is the software that runs on the FC. The most commonly used firmware is, with no doubt, Betalight but there are many other open sourced firmware such as Baseflight, Cleanflight, iNav or OpenPilot.

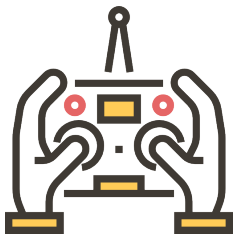
Despite this, there are some companies which have their own firmware and this last one is only compatible with their hardware. This is the case, for example, of Raceflight or KISS.

7.4.2 Sensors

Drones have many sensors, and although more advanced UAVs have sensors which do not form part of the FC (such as thermal cameras or light sensors) most FC have some basic sensors that allow the flight controller to know where and what position the aircraft has.

- **Accelerometer**, which measures the acceleration forces.
- **Gyroscope**, which measures the rotation forces, and can detect what position the drone is in one spot (the inclination it has)
- **Magnetometer** (compass)
- **Barometer**, which measures the air pressure, allowing the drone to determine its altitude.
- **GPS**, which detects where the drone is.

7.5 Tx & Rx – Radio System



The radio transmitter (Tx) and the receiver (Rx) are two components that are constantly sending and receiving radio signals that contain the commands that the drone must follow. The Rx is a component that is soldered to the FC, and forms part of the drone. On the other hand, the Tx is the controller that is used to pilot the aircraft (and it's obviously not attached to the drone). These components are the main factor when determining the range of the aircraft.

7.5.1 Transmitter (Tx)

The transmitter is the actual ground-based controller which allows the pilot to control the aircraft. This essential part of the drone can incorporate many different features to make it a more reliable tool, and to establish a better and longer-range signal in between the aircraft and he ground controller.

7.5.1.1 Frequency

The frequency in which the transmitter works needs to be compatible with the frequency the receiver can interpret. The frequency is also what determinates the maximum range the drone can fly. There are two different frequencies, 2.4Ghz and 5.8, being 2.4 the most common one. The most obvious advantage of 5.8Ghz over 2.4Ghz is the fact that 2.4Ghz is more susceptible to get interferences, due to the massive number of devices that use this frequency (computers, Wi-Fi routers, mobile phones, Bluetooth

devices…). For this reason, 5.8Ghz frequencies are much better while flying close o high populated areas, but there is really no difference in between both frequencies while flying in a place with a low number of electronic devices.

A drone can sometimes include both frequencies and use one frequency for the FPV and camera signal transmission, and the other one to give the orders and commands to the aircraft. That way you can make sure that both signals won't interfere with each other.

7.5.1.2 Channels

A channel is each of the different commands that the transmitter can send to the receiver. A drone transmitter has at least 4 channels, one for each different direction at which the drone can move (throttle, yaw, pitch and roll). From there, the more channels that are added to the transmitter this one will to be able to communicate more different types of commands. Some of the most important and common things that extra channels can be programmed for include:

- Arming and disarming the quad (starting and stopping the motors without having to unplug the battery).
- Beeper (makes the drone beep, so the pilot can easily find it when lost).
- Failsafe (stops the motors when the signal between the Tx and the Rx is lost, or in more complex UAVs, the drone returns to its takeoff spot when the signal is lost).
- Rotating the onboard camera.
- Making the drone flip backwards or frontwards.

7.5.2 Receiver (Rx)

The receiver depends on the transmitter, as in order to detect and interpret the radio signal they both need to be compatible. This is one of the reasons why it is a good idea to have a Rx and Tx from the same company, that way you can now they will be compatible for sure.

7.5.2.1 Telemetry

This is one of the features some receivers have. Telemetry is a way to send real time data from the aircraft to the transmitter. Telemetry provides the pilot with important information such as the battery voltage and amperage, the speed at which motors are spinning, the flight controller load etc. All this information is showed in an OSD (On Screen Displayer), which is usually attached to the transmitter (some Tx have integrated OSDs)

7.6 PDB

The PDB (Power distribution board), is an electronic board where the battery is connected, and from there, the current is appropriately distributed to all the rest of the parts of the drone. The PDB is completely necessary, as it is responsible to provide each part with the right voltage and amperage. Even a small error with the PDB, or with the soldering tin, could cause some parts of the drone to melt due to the electrical energy. For instance, a motor needs to draw much more electrical power from the battery than the camera, and the PDB is the part that responsible for

delivering the right amount of energy to each part. If the camera received the same quantity of current, it would instantly get fried.

The PDB is directly connected to the flight controller, which is the part that receives and interprets and transmits the orders to control the drone. The PDB is the part responsible of delivering the electrical power to all the other drone components according to the orders given by the flight controller.

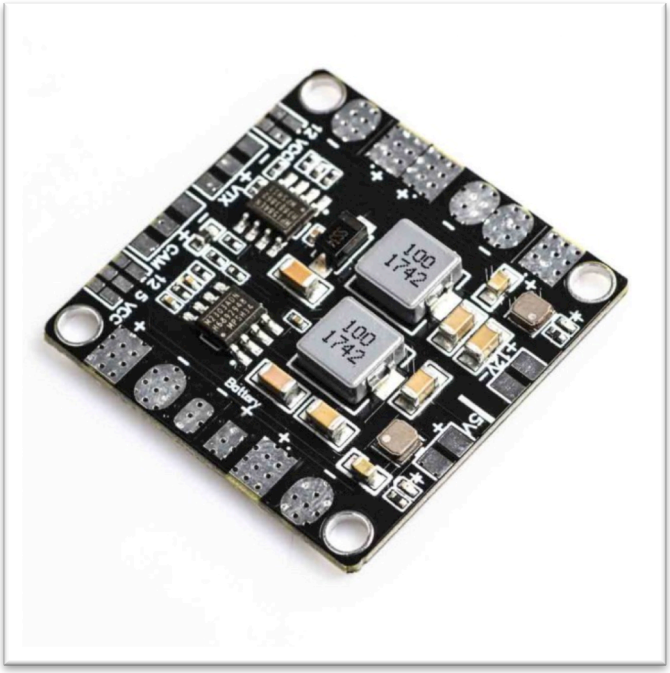
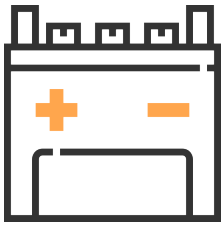


FIGURE 12. PDB

SOURCE: AKK WEBSITE

7.7 Battery



Every multirotor needs a source of power to be able to fly. The most commonly used batteries are LiPo batteries. Lithium polymer batteries, also known as LiPo batteries, have high energy density, a light weight and high discharge rate, which make them a perfect candidate for radio control applications. LiPo batteries are relatively safe, although (like most batteries we use) they are likely to catch on fire when they overheat. An overcharged or physically damaged battery can catch on fire easily.

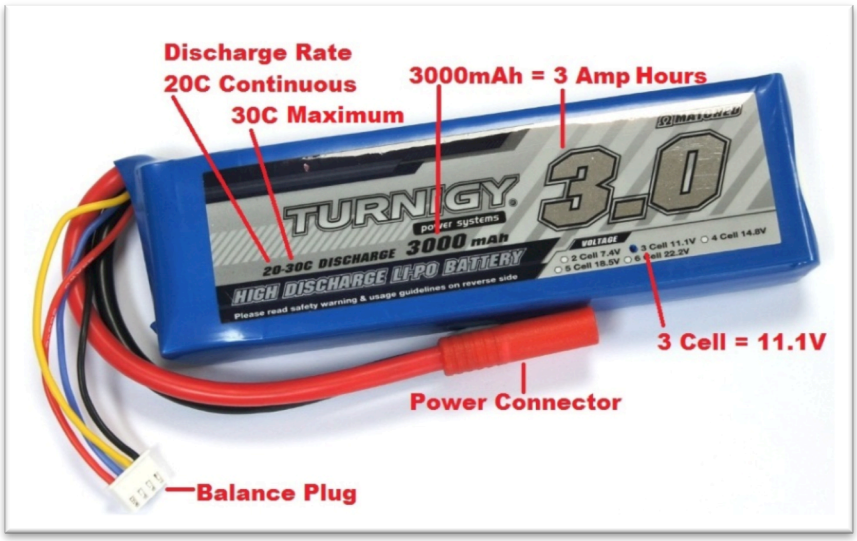


FIGURE 13. Batteries for UAV.

SOURCE: DRONES ARE FUN

Batteries can be classified in many different types, depending on voltage, capacity, discharge rate, etc.

7.7.1 Voltage

LiPo batteries are made up of various cells, each with a nominal voltage of 3.7 volts, connected in series. The voltage is the quantity of energy per unit charge. This means that the more voltage the battery has, the more energy is delivered to the motors (or whatever is connected to the battery). Therefore, a motor connected to a 2-cell battery (2S) will spin slower than the same motor connected to a 4 cell (4S) battery, as more energy is drawn from the battery. The nominal voltage of a battery is the average voltage of that battery. In a LiPo battery the voltage can get down to 3.2 volts before breaking, and up to 4.2 volts before overcharging, making 3.7V the nominal voltage, the middle point between those two values.

7.7.2 Capacity

The capacity of most batteries is measured in milliamps hour (mAh). This is a unit used to measure electric power over time. It is an indication of how much current you can draw from the battery in an hour until it is it's empty. A battery with more capacity will allow you to have a longer flight time, but it also means the battery will be heavier and larger in physical size (making the drone less agile and slower).

7.7.2.1 Discharge Rate (C Rating)

The C rating is a measure of the rate at which the LiPo battery is discharged relatively to the maximum capacity of the battery. In layman's terms this value tells us how fast we can discharge the battery. It is really important when choosing a battery to take into account which motors, we are going to

use. If the battery has a low C Rating, the motors will try to draw more current form the battery discharging it at a faster rate than the battery is prepared to, causing the battery to get damaged. A high C Rating will not cause any problems, as the motors will discharge it at a rate way lower than what the battery can get up to. In conclusion it is better to get a C Rating a bit over of what the motors require, but not too much, as a battery with more C Rating is also heavier (meaning the drone will have to lift extra weight, that we could avoid lifting by using a lower C Rating battery)

7.8 Propellers

Propellers generate thrust by revolving and therefore pushing air. The faster the prop is spun the more air it can move, and thus the more thrust it generates. Every quadcopter has two motors that spin clockwise (CW) and two counterclockwise (CCW), therefore matching CCW and CW propellers are required to generate thrust, but also to have opposite yaw motion to cancel each other out while flying. Propellers are only used subsonic airspeeds, around 800 km/h as above this speeds the tip of the props causes high drag and can even bend or break. Propellers have different size, pitch and shape and number of blades. The type of propeller the aircraft needs depend on both the size of the aircraft and the power of the motors.

Propellers can be classified in many different types, depending on size/length, shape, pitch, etc.

7.8.1 Size/Length

The size of the propeller is the distance from one tip to the other tip, ot the diameter of the circle the prop makes when spinning.

Propellers with a bigger size are harder to spin and halt, which makes the aircraft lose a lot of maneuverability, but they also push much more air, which makes them great to lift weight. Bigger blades also provide more stability to the drone.

On the other hand, small sized props allow the quad to be more agile and much more responsive to the commands. Usually big propellers are used in photography drones, that way the propellers give stability to the quad, and also allow the drone to carry a bigger and better camera that takes nice pictures.

Middle to small sized blades are used in racing drones, because they provide a decent amount of thrust while also giving the quad more maneuverability. Last of all small props are used in freestyle drones, as for this type of drone we need a lot of responsivity and not so much thrust.

7.8.2 Shape

There are different shapes a propeller can have, and each one different pros and cons. The more surface area, the more air the propeller can move and thus generate more thrust, but also consuming more energy from the battery. There are three main types of propellers shapes: pointy nose, bull nose (BN) and hybrid bull nose (HBN). Pointy tip blades are the most

effective of the three, however they also pull the least thrust. The outline of the tip also modifies how the prop interacts with airflow when rotating.

7.8.3 Pitch

The pitch of a propeller is the angle of attack, or angle of inclination that the blade of the prop has. A blade with a higher (steeper) pitch will have more thrust, thus providing the quad with more speed, but it will also draw more electricity from the battery.

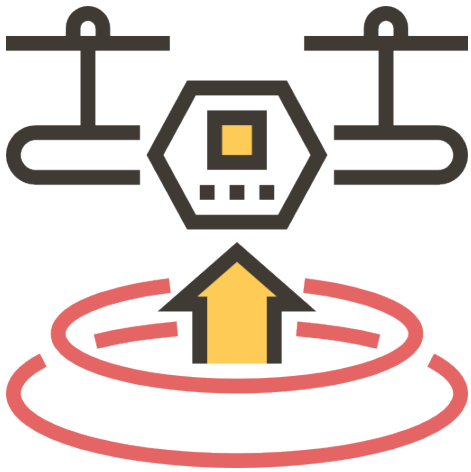
The pitch of the propeller is also directly connected to the power of the motor: a higher pitch will require a more powerful motor, otherwise the motor won't be able to move the prop fast enough for the quad to fly. On the other hand, a propeller with a really low pitch can also damage the motor. The motors are prepared to be used with some resistance and using them without any props on will make the motor break. The same happens if we do use props, but we use ones with a low pitch. The motor will spin faster than it should due to the low resistance the prop creates.

Number of blades

Each propeller can have a different number of blades, varying from one blade up to 8 blades. Although there can be many blades in a propeller, the ones that are mostly used are the 2-blade, the 3-blade (or triblades) and sometimes the 4-blade propellers. The more blades a propeller has the more thrust it generates but in the expense of more current draw.

For small quads (210mm, 250mm and even 330mm) 2-blade and 3-blade props are the most commonly used. Although sometimes the 4-blade props are used as well, as they are the best at cornering.

Bigger drones need more power to get on the air, so they usually use 4 or even 6 bladed props. Although bigger quads do need more thrust this can also be obtained by having a higher pitch blade or a longer blade, so it is not necessary for all big quads to use 4 or 6 bladed propellers.



8 Things to consider when purchasing a UAV: Building a racing drone

One of the key factors when buying a drone is determining if you are going to buy and RTF, an ARF or a drone piece by piece. RTF or Ready to Fly drones are fully build when they are purchased, and the only thing needs to be purchased is a Tx. ARF or Almost Ready to Fly are packs with the most basic parts of a drone. ARF drones don't usually include all the components, and the consumer needs to purchase them independently. This kind of drone has more option and variability than RTF, but not as much as drones that have been bough piece by piece.

This last category is the best one in terms of price and it is also the best one when it comes to changeability, as the user can choose the pieces he prefers and make the drone more suitable for the purpose he wants. On the other hand, ARF and RTF are fixed drone parts which come with the same package, so they cannot be modified as much as a drone which has been built piece by piece.

Another important factor when building your own drone is determining what is the main purpose of the drone. Typically, only racing drones are built by pilots depending on the pilot needs (more speed, more maneuverability, more agility…), and other types of drones (such as photography drones) are built and sold by companies such as DJI because this type of aircraft is more or less the same for everybody.

FIGURE 14. Main pieces of my drone.

SOURCE: ISAAC BASSAS

8.1 USA Practice

During my stay in the US, I joined a robotics team, the Livonia Warriors, which is sponsored by many companies such as Roush Industries, Ford Motor Company, Denso International or AISIN TCA. In this team I had the chance to help with a drone project. Within the project, I helped assemble a racing drone course, for the team members to compete between them to improve their driving and piloting skills. I also taught many team members the basics on how to fly a drone, and I gave tips to more experienced team members on how to improve their skills (inside the team, the robot drivers were better at drone piloting that the ones that had never driven any type of RC vehicle).

Last of all, I also oversaw the maintenance of the drones, which were regularly getting broken due to the crashes that unexperienced pilots had. During this year, I also improved a lot my drone piloting skills, as I had the chance to fly the drone in a racing course almost every day, and I had access to different types of drones that I had never flown before, which forced me to adapt to the new drone (all drones perform similarly, but they all have some differences, and the more different drones you fly, the more you learn how to adapt to these small differences).

The whole point of doing this was not only to lean and improve my piloting skills, but also to try many different types of drones and components to understand how they work and how each one performs. Trying this many different components allowed me to determine what were the components that would be better for my drone. This in-field practice made me have a lot of practical experience, which was really useful at the moment of deciding which components best suited my drone and my flying style. Thanks to my previous experience I was able to easily determine what I needed with a more precise way, as although many reviews can be read on the internet, there is nothing like trying each component by yourself.

8.2 Building my drone

8.2.1 Online Stores

One of the biggest problems I faced when looking for drone parts was the lack of physical stores in Catalonia. There are several RC stores, but most of them haven't started selling drone components yet. The closest RC store, that has a decent number of drone-related things is in Badalona. The store is called RCInnovations, and although they sell some drone racing parts and ARF drones, the majority of what they sell are drones for kids or high-performance photography drones. This clearly shows that the drone racing world has still not arrived at Catalonia. For this reason, all the components and drone parts I bought were purchased online. Most of what I bought is available in Spain, but there are some parts that I acquired while I was living in the US, and that are not currently being shipped to Spain. Some of the major online stores where I bought all the pieces for the drone are:

8.2.1.1 Amazon

This would probably my first-choice online store, not only because of their great variety of products available, but also because of the incredible short delivery time (especially with Amazon Prime, which you can get for free for a month).

8.2.1.2 Banggood and AliExpress

Both these Chinese companies have a much smaller assortment available, and the delivery time is in between one and one and a half months,

something which is quite a long period of time. The main benefit to purchasing parts in this website is the lower prices they have. Overall, I found that drone parts were, on average, 56% cheaper on these stores in comparison to Amazon[15].

8.2.1.3 GetFPV and RotorRiot

GetFPV and RotorRiot are worldwide suppliers of drone and FPV gear. The main advantage of both online stores is the huge amount of stock they have available. While previous stores did not have a vast amount of assortment, these companies sell almost everything that's on the market, as they are stores that are specialized on drone products, and don't sell anything else. The shipping times are also good, getting close to Amazon or even surpassing it. The main problem with these stores is the price tag, which is well above Amazon's on some products, and slightly above on most of them.

8.2.2 Drone parts and components

8.2.2.1 Frame

The frame should be the first thing to choose when purchasing a drone. Deciding what size of frame, you want, is really up to you. Depending on where you intend to fly or what speeds you want to get to you should choose one frame or another. Smaller frames are lighter and therefor can

[15] Data gathered after comparing the price of 10 different things that are sold on both stores.

fly around cities, but they are also affected much more by weather conditions such as wind. On the other hand, bigger frame sizes (210-250mm) are faster but they have more legal restrictions.

FIGURE 15. The frame of my drone.

SOURCE: Isaac Bassas

I personally chose a 250mm frame because I found a cheap CF frame on Amazon. Also, I am looking forward to compete in drone races soon, and 250mm frames are the most commonly used, which means it's easier to find races for my drone class.

No matter what frame size you choose, an important fact before purchasing is you make sure it's a carbon fiber frame. CF is a light but strong material, so especially for unexperienced drone pilots, a CF frame is a much better than a plastic frame, as this last one will easily break when the drone crashes.

FIGURE 16. FPV of my drone.

SOURCE: ISAAC Bassas

In addition, the frame I bought included a simple camera stabilizer, which is something I also wanted to include in my drone. The FPV camera is useful to see what the drone is seeing, but when it comes to taking pictures, having a sports camera onboard makes the quality improve a lot. A camera stabilizer allows the sports camera to take neater pictures.

8.2.2.2 Propellers

When it comes to propellers the decision was simple: only 5- and 6-inch propellers fit un my frame, so there was not much to choose. Although, based on my experience, I already knew I would prefer 5030 props before buying them, I still purchased many types of propellers. Props are a really cheap part, which easily brakes, especially when you are an unexperienced pilot. For this reason, I bought a 40 biblade 5030 propeller pack, which was the propellers I would usually use, but I also bought four triblade 5030 propellers and 4 biblade 6030 propellers. With all these different types of propellers I can have different flight experiences, as with big propellers the drone would be faster, and with smaller propellers, it will be nimbler. Also,

buying different propellers will not be a problem economically speaking, as propellers are the cheapest part of the drone.

8.2.2.3 Motor

Motors are needed in all UAVs, as it's the part that transforms the electrical energy into rotatory motion. For that reason, choosing the motor model is a key decision when building a quadcopter. The motors are one of the components that mainly determine the flight speed, the drone performance and the flight time. The motors are also one of the most expansive parts, mainly because four of them are needed, which means, in the end, the price is going to be quadrupled.

- For this reason, one of the biggest factors when purchasing the motors is going to be the price.
- Another of the most important decision when buying the motors is the motor KV. The KV determines the maximum RPM at which the motor is capable of spinning with no loads. Both these magnitudes are related to the frame size we have chosen. A bigger drone frame will weigh more and therefore need more lift power in order to fly, while a smaller frame won't need as much power. With my frame (250mm frame), the appropriate motor KV for a racing and freestyle drone is in between 2000 and 2600. This number depends on how fast you want your drone to be, but also on the battery the drone will have, as a higher voltage battery will make the motor spin faster than a lower voltage battery (no matter what their KV is).
- Another important thing is the stator size, which has to do with the propeller size we have chosen. The longer and more pitch the props

have, the bigger the stator will need to be. With the propeller size that I have chosen (5030), the stator size should be 2204 or 2205.

Prop Size	Stator Size
3 inches	1306
4 inches	1806
5 inches	2204
6 inches	2206
7 inches	2208
8 inches	2210
9 inches	2216

FIGURE 17. Propeller sizes depending on the size of the motor stator

SOURCE: DONE BY THE AUTHOR WITH INFORMATION FROM QUAD QUESTIONS

I personally compared over 70 different motors (average price 20€), and from there I eliminated any of them that were above 25€, as the price would have skyrocketed if I had bought 30€ motors. During this same selection I also eliminated any motor that didn't meet the necessary requirements for my frame size and prop size, as with a low KV and smaller stator size the motors would not have been capable of lifting the quad. Also, a too high stator size and KV means the motors would draw much more current from the battery, so the drone would have a much shorter flight time. With all these criteria I had only 6 motors left, something that dropped down to 4 when I checked which motors were available in Spain. I was indecisive and didn't know which motor to buy, so in the end, the factor that determined the final decision was price. The motor I finally bought was

the LHI MT2204□ 2300KV. I found a great deal on Amazon for them, as the company was selling them in packs of 4 (2CW and 2CCW) for only 31€, which is less than 8€ for each motor, something that is well below the average motor price. The motors are something that could be easily broken at any crash, so with that in mind I decided to go for the cheapest of all 4 motor models I had left. My idea was that with these motors I would be able to fly the drone without having to worry much about breaking the them, as if something happened it would be cheap to replace one of them. On the other hand, if I had bought the most expansive ones I would be scared when flying, as I would fear breaking one of those expansive motors.

FIGURE 18. LHI MT2204□ 2300KV

SOURCE: ISAAC Bassas

8.2.2.4 ESC

ESCs are a crucial part of every UAV, and that's the reason why they need to be carefully chosen depending on the purpose the drone is designed for.

- One of the first things we need to consider when choosing our ESC is the current rating. It is important we decide what motor model and brand we are going to buy, so we can then check online specifications and therefore know how much current it is going to draw, in order to

decide how much current rating our ESC needs. Remember that it is always better to go over the current rating, as there is no downside to it. In fact, having a higher current rating ESC has some benefits, such as lower chance of overheating the ESC, and more energy efficiency. It is not good though to go well above, as higher current rating ESC are usually heavier, and more importantly, more expansive.

- Another of the most important things to look at is the firmware that the ESC has. Although most of them have BLHeli firmware, it is always a good idea to make sure you are not buying a rare and unknown firmware, as that may cause problems in the future.
- Last but not least it is also important to look at the price of the ESC, as although they might seem cheap, we need to take into account that we need four of them, so the price is going to be quadrupled.

After comparing more than 45 different racing ESCs I personally chose Gemfan Maverick 30A ESCs for many reasons, the most important one being current rating, and then price. First thing I did was checking online how much current the motors I bought would draw, and from there I formed a list with all the ESCs that had a current rating of 20A or more (as my motors draw a bit over 12A at a normal speed, and a bit over that at full throttle, so 12A ESCs would not be safe enough to run with my motor configuration). From all the I compared and calculated the average price of all these ESC, which was 12,4€ and from there I also eliminated all the ESCs above that price, and all the ESCs that were not sold in major online

stores that ship to Spain and the US (Amazon, Banggood, AliExpress, GetFPV, RotorRiot and Drone World). With all the remaining ESC models I compared one by one and decided that the two best ones were the Racerstar RS30A and the Gemfan Maverick 30A. As we can see, both ESCs have a 30A current rating, while I only needed a bit over 12A for my motor configuration. The reason for this is because the price difference between the 30A version and the 20A version was only 1,1€ something that I considered was a small price difference, so I decided that buying the 30A ESCs would give me more security, and more energy efficiency for a tiny amount of money.

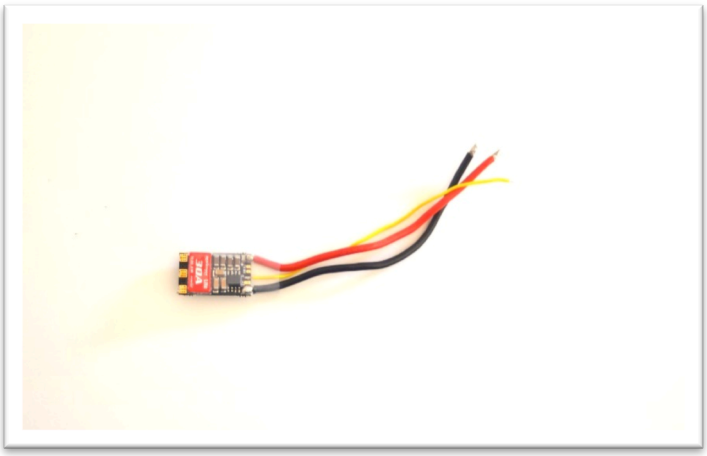


FIGURE 19. GEMFAN MAVERICK 30A

SOURCE: ISAAC BASSAS

8.2.2.5 Flight controller

One of the main reasons why I choose the Matek Systems F405-CTR was because it has a built-in PDB, which would make my drone cleaner as it would avoid having to add an extra component to the frame (the PDB). Another big reason is the fact that this flight controller supports Betalight, a firmware that I had used many times before, and that I know how to use,

so I decided it would be better to buy a FC with this same firmware so I didn't have to learn how to program a different firmware. Also, Betalight is the most commonly used firmware, so if for any reason I had a problem it would be easy to look up for solution on the internet.

8.2.2.6 Battery Parts

One of the most important things when deciding what battery to buy is the cells the battery has. It is important to look for a battery that has a cell count (voltage) that the ESC can support. In my case, since I didn't buy a PBD, because it was integrated in the FC, I also had to make sure the battery voltage was not over the FC maximum voltage. Despite that at the beginning I was looking at 3S batteries, in the end I decided to go for a 4S battery, so that my drone would have more power, and thus would be faster, but also because it's the most widely supported battery voltage, which means most drone components are prepared to support this voltage. Another important thing to look at when deciding the battery is the mAh this one has. This determines the capacity of the battery. The higher the mAh the longer the battery will last, but it is also important to look at the weight, as higher mAh batteries tend to be heavier. In my case, I purchased a 1550mAh battery that weights 194 grams when fully charged (battery weight can slightly change depending on the voltage the battery has). Last of all, it is also important to look at the C rating, or discharge rate. This value indicates how fast the battery can discharge. In other words, it tells us how much current the motors will be able to draw from the battery. The higher the C rating, the more power the motors will receive, and thus the faster they will spin.

FIGURE 20. PARTS OF THE BATTERY

SOURCE: ISAAC BASSAS

Battery related drone parts, which include the UAV battery itself (in the middle), a Velcro Zip Tie, used to attach the battery to the drone frame, and the battery charger and with its wires (on the left). The battery charger is essential, as LiPo batteries are volatile, fragile and can be easily overheated. Connecting them directly to a wall plug could easily cause an accident, but with a LiPo charger this is prevented, and the charger stops sending current to the battery once this last one is fully charged.

8.2.2.7 RX & TX

RX and TX are one of the easies things to choose, as there are not as many choices as other parts have. Another big issue is the fact that the TX and the RX need to be compatible in order to get bind. Without any doubt the

top one choice for the RX is are both the Taranis QX7 and the Taranis X9D. To avoid having problems with the connection in between the Tx and the Rx, I decided to buy both components to the same company, and since the best Tx are both from FrSky, I also bought the Rx from this company. The Rx wasn't hard to choose, as I bought the newest receiver that FrSky had put in the market. I decided to do this because this receiver is, by far, the most commonly used, and the idea was that if I had any problem, I could easily look on the internet for a solution. About the Tx I finally went for the Taranis QX7, mainly for an economical reason, as the Taranis X9D was almost twice the price the Taranis QX7 (160€ vs 90€).

FIGURE 21. TARANIS QX7

SOURCE: ISAAC BASSAS

8.2.2.8 Tools used

FIGURE 22. TOOLS USED

SOURCE: ISAAC BASSAS

To build and put together all the drone pieces I used some tools that can be easily found in any hardware store. These includes small sized screw drivers and Allen wrenches, a monkey wrench and a pair of scissors. Last of all, I also used a tin soldering iron, probably the least common tool on the list. This tool was necessary to solder the wires of many electrical components together.

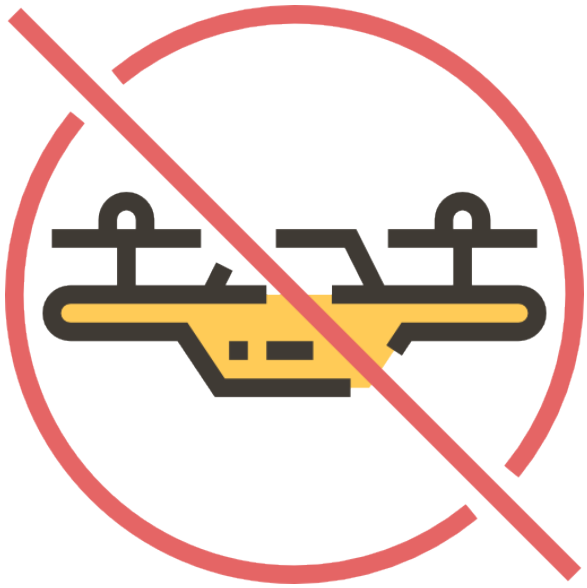
Apart from these tools I also used some Loctite to glue some parts together, and as a thread locker, and many Zip ties to make sure the parts were strongly tightened and would not get loose and fall in mid-flight.

8.2.2.9 Drone specifications

Drone Specs	
Drone Dimensions	250mm
Power	1500g[16]
Motor RPM (4s battery)	38,640 rpm
Motor RPM (3s battery)	28,98 rpm
Range	1.5km
Drone speed	100kmh[17]
Weight (without camera)	671g
Weight (with camera)	542g

[16] [17] All measurements were taken with domestic tools. Values could change slightly if measured with professional equipment.

Drone Part	Cost (€)
Frame	16,99
FC	31,96
ESCs	40
Motors	32,99
Propellers	16,34
Battery	34,64
RX	24,87
TX	95,28
FPV System	47,28
Battery charger	34,65
Total cost	375



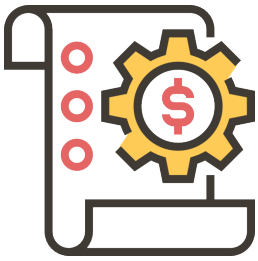
9 Laws and Regulations (Spain 2018)

Drones have been around for a long time in tech-developed countries, such as the US, but in Spain it's a relatively new thing. The fact that drones have not been as popular in Spain is actually something good. As drones are not as common in Spain, the law is not as strict as in other countries[18]. Most of the articles published in the BOE don't really restrict the use of drones, instead they just say the pilot has the full responsibility of the aircraft. Also, Regional Authorities can have their own drone regulation, so it's a good idea to do local research before flying. For the moment we will focus on the laws that apply to Catalonia.

First of all, the Spanish law makes a clear difference between commercial and recreative drones, and each of those groups has some slightly different laws they must follow (although the general/main rules apply to both categories).

[18] Drones still lack a unified regulation worldwide, similar to the ones we have for vehicles, like planes, cars or ships. So, for now, we will focus only on the Spanish regulations and laws that need to be fulfilled in order to fly a drone.
EU is working on a common regulation for their member countries. European Aviation Safety Agency (EASA) has proposed a regulation framework, which is now being discussed at the EU Commission, and expected to be approved by the end of 2018. Update of this process can be found at EASA website:
https://www.easa.europa.eu/easa-and-you/civil-drones-rpas
In the US each state has its own laws. A good review of USA laws can be checked online at the National Conference of States Legislatures:
http://www.ncsl.org/research/transportation/current-unmanned-aircraft-state-law-landscape.aspx

9.1 Commercial drones



This group includes all drones that are used for a professional use, which includes any type of paid job. When operating a drone in this circumstance it is compulsory to have two things:

- General paperwork, which everybody has to do and includes things such as a valid permit (which you get after taking drone classes), a medic certificate, a damage insurance and finally to be registered in the AESA (*Agencia Estatal de Seguridad Aérea*) database
- Specific part, which is a test on a specific drone type/model.

9.1.1 Common part

For the common part, the most complicated thing is getting a drone permit, as before receiving the permit you need to attend 80 hours of class and then take a test (120 questions). This is not an easy test, as there are many tricky questions, and almost no mistakes can be done in order to pass the exam. Once you have the permit, all the other things are much easier. Getting registered on AESAs database can be easily done from anyplace with an internet connection, and the medical certificate is just a quick test to check your eyesight and reflexes (just like the medical certificate required to get a regular driving license).

9.1.2 Specific part

Once the general part is completed, it is still necessary to take one last exam to get the final license. This test consists on a quick quiz (60 questions) about a specific drone model. After the theorical test, there is a practical part, in which an examiner tests your piloting skills for that drone model. Once you approve both exams, and have all the paperwork for the common part, you will receive a drone license, which will allow you to legally fly the drone you took the specific part about. If for some reason, you want to start working with a different drone model (such as DJI Mavick, DJI Mavick, DJI Phantom etc.), you would have to do the specific part for that new drone model you want to fly. There is no limit on how many times you can take the specific part, as you will have to do it once for every different drone model you want to. Apart from all this paperwork, these drones are also subjected to the general drone laws (certain laws that every UAV needs to fulfill), explained below.

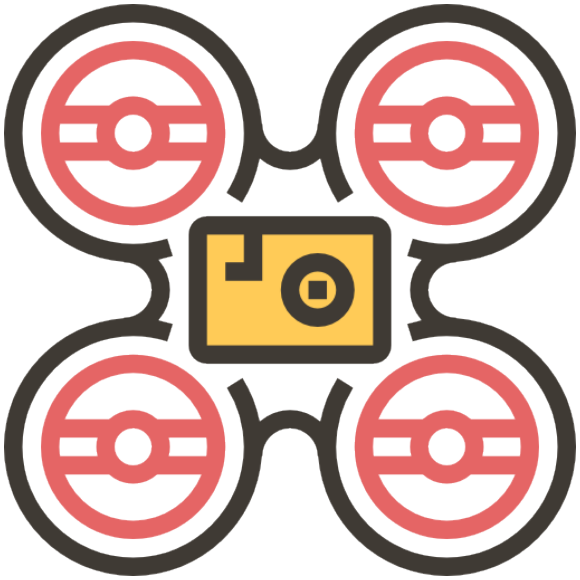
9.2 Recreational drones

For this kind of drones, it is not required any type of license or permit except when flying in controlled airspace (within 8 km form any airport). These rules depend on three things, the weight of the aircraft, the

area where it's being flown, and the type of communication/visibility there is between the aircraft and the pilot. Here's a list with all the regulations:

- UAVs can be flown up to an altitude of 120 meters above the ground, or above the highest object in a 150 m radius.
- Drones may only be flown during daytime. For UAVs weighting less than 2 kilograms at take-off, flights can also be carried out at night, as long as the drone stays within the 50 m altitude (from the ground or from the highest object in a 150m radius).
- Drones must always be flown within the VLOS (visual line of sight). During FPV (First Person View) flights a second visual observer must monitor the drone with the eye and be in direct contact with the pilot. Permission is needed in order to fly BVLOS (Beyond Visual Line of Sight), and even with the proper authorization most of the times an observer in direct contact with the pilots is needed to keep an eye on the drone at all times.
- Drone pilots must keep a distance of at least 8 kilometers to airports and airfields in uncontrolled airspace, or 15 kilometers on permitted BVLOS flights (Beyond Visual Line of Sight flights).
- Drones that weight over 500 grams must maintain a 50-meter range or more from people not involved in the flight and from tall buildings. Drones between 250 and 500 grams can fly in city parks, but not above buildings or city streets, and must also maintain a 50-meter range from crowds. UAVs lighter than 250g can fly in the cities and over crowds as long as they don't fly higher than 20m.

- To fly in national parks, you need authorization from the AESA. The use of UAVs in no-fly areas must be legitimated by the Spanish Ministry of Defense.



10 Conclusions

After all the research I've done, I have learned many new things, some of them I would have never guessed. Thanks to this project I have not only learnt more about drones, their uses and how they work, but I have also gained a lot of knowledge on how to research about a topic, and how to write a large-sized project such as this one.

NOT JUST LIKE, NOW I'M IN LOVE WITH IT

After many months of research about drones, leaning new things every day, my passion for drones has only become stronger. With all the knowledge I have gained about this subject the more throughout the past months, I clearly see it's a technology with a lot of potential. Despite its evidently a field which is still on development, and we still have much to learn and improve, sooner than most of us expect, drones will be all around us. In the next few years, UAVs are going to become part of our daily lifes, and we will depend on them as much as we depend on many other thigs such as cars or mobile phones.

MY FUTURE STUDIES IN COLLEGE

Building a drone does not only teach you about electronical components, but also how to program some general code lines that are needed in order to fly the drone. This knowledge is going to be really useful in a nearby future, as its closely related to what I want to study. In a society where smartphones and computers form part of our daily lifes, having some basic

knowledge on programming is a necessity. The truth is we fully depend on this technology to do many of the things we do every day. Despite that, most of us have no idea about programming. Building a drone yourself can easily introduce you to the world of programming. Most FC firmware such as Betaflight are incredibly easy to use, and yet they provide the user with some basic knowledge on how to program.

DEVELOPMENT OF OTHER ABILITIES WITH THE USE OF DRONES

Another great skill that can be acquired with a drone is piloting. Driving a drone at fast speeds is something that takes a lot of practice and reflexes. Learning how to pilot a drone is just like learning how to drive: despite at first it may seem hard and complicated, after some practice and experience it becomes something much easier to do. Also, a great skill you acquire just by piloting a drone is space vision. This is a skill that we use every day without even knowing. Every time we see a ball quickly moving to some direction, or when we have to decide if our car can squeeze in a parking lot, it is our space vision that determines where the ball is heading or whether our car will fit or not in the parking.

WHAT ARE DRONES USED FOR PROFESSIONALY?

Last but not least, building a drone is an easy way to get into the world of electronics. Learning how to work with electronic boards, and how to use some basic tools such as a tin solder it’s becoming a really important skill in

tech companies and building your own drone forces you to learn these skills.

After talking to many professionals in the sector, I've realized drones are now on their initial steps to becoming a new job and field of expertise. Most of the people I was able to contact during my project professionally work as drone pilots and experts, something which clearly shows there is a new drone related profession which is being created. These new occupations go from drone maintenance and racing to drone piloting instructors. Thanks to drones many of these experts in the field have been able to improve their company's performance in many different ways. Although it is still in development, and for this reason numerous companies around the world are still afraid to use them, drones have a countless number of applications for several sectors.

On the other hand, drones which are used for ludic purposes also generate new workplaces. First of all, we have the professional racing pilots, which although there's still very few of them who can live just by racing, it is something that can be done right now. In a recent future, as the hobby expands and becomes more popular more and more pilots will be able to work as racing pilots. But that is not the only job ludic drones provides society with. Another job that drones have created is hobby stores. This is the case of NubbFPV, a professional drone pilot who works both as a racing pilot and selling drone components. With the popularity of drones increasing every day, more and more hobbyists will start their own businesses by opening up new RC shops.

WHAT CAN WE EXPECT IN THE NEAR FUTURE?

Drones have a huge market, which is increasing day to day, and according to Goldman Sachs, they will be a 100 billion market by 2020. This clearly shows drones are still on their early stage of development, and many improvements and upgrades are yet to come, but sooner than we expect they will be everywhere. There are still many uses and applications that we can't even imagine now, but UAVs will for sure form part of our future lifes. After all my research I discovered there are actually more projects that involve drones than one would expect. Although it is accurate to say that all this are small scale projects, and that companies are not prompting to invest in bigger scale drone projects because they are too afraid of losing money with this recently created technology which is still in development this will soon change. There are some major companies such as Amazon or Goggle which have invested huge numbers of money to improve drone technology. All the people I contacted agreed that this is a technology which is still on its early development, and there are still some problems due to legal vacuums, but as soon as laws are updated, and the technology is improved and became more reliable, companies will invest crazy amounts of money to have the most advanced technology.

LEARNING HOW DRONES ARE USED

Throughout this project I also got to the conclusion that drones are being used for many things most people do not know, such as agriculture or

topography. With all my research I was able to determine drones are used for many things, although most of them are still in an early development. One of the fields where drone technology has spread around rapidly is in agriculture, especially in the US. Although there are still many things to improve, many farmers have seen that this technology can provide many benefits, and that's why many of them are starting to use it.

On every field drone technology can provide different aids over conventional technology, but there are still some drawbacks that drones need to overcome in order to take control over may fields. The two main problems drones have are the flight endurance, as most drones are electrically powered and to this day we still don't have the technology to make better batteries, and payload weight, which is a consequence of the first disadvantage (as not having enough electrical energy means a drone carrying a heavy payload won't be able to stay airborne for too much). Due to the lack of more powerful and higher capacity batteries, drones are still not good enough to be introduced to certain fields, such as long-distance package delivery. Thanks to this project I was able to contact with many people who professionally work on the field, so I had the chance to talk to people who have firsthand experience with the benefits and drawbacks of drone technology. This was something that helped me understand all these problems drones are facing, and all the advantages they are providing to some work fields.

WHAT ARE DRONES BEING USED FOR IN CATALONIA?

During my research I was able to get in touch with Seidor, a Catalan tech company which is based in Barcelona, Catalonia. With their help I found out that the technological sector in Catalonia is advancing quickly, with many big companies that work on an international level. Also, the Generalitat is working on many projects to keep enhancing the sector, such as the MWC or the Catalonia Smart Drones, an association which has nearly 90 members. With all this help, the sector will keep being improved, allowing Catalan industry and the Catalan companies become better than other companies on a worldwide level.

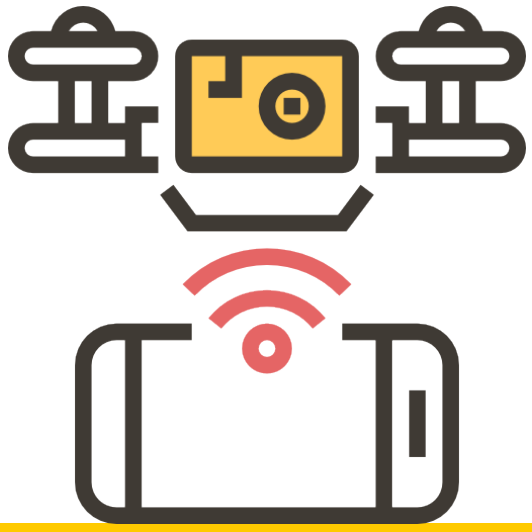
LEARNING HOW A DRONE WORKS

After all the research I now have learned not only what a drone is and what it is used for, but also how all its components work and interact between each other in order to make the aircraft fly. I have not only learned how all the drone parts work, but also what the interactions between them are. I also discovered building a drone piece by piece is a bit cheaper than buying a RTF drone, and it also gives the user much more variability, as this last one can decide what pieces to buy, while on a RTF drone the user receives a fixed type of pieces, and in case he wants a different brand component, this needs to be bought apart.

With my initial research I saw when it comes to building a racing drone there are different models of components manufactured by several, but if what you want is to build a photography drone, there are not as many options on the market. This is because racing pilots want to personalize

their drones to fit their flying style, while photography drones are more or less the same for everyone, as there is no need to have such a level of drone personalization as in racing drones.

After finishing my practical part, I had spent a bit aver 400€ in all drone components and pieces. Although this might seem really expansive, a decent racing drone can be built for as little as 150€. On the other hand, after contacting with two of the world's best racing pilots (NurkFPV who is this year's 2018 world champion and NubbFPV who got the second place in this year's DRL Allianz World Championship), they both agreed that in order to participate in major events, and be able to have a chance to win, around 1,500 € need to be spent in the drone.



11 Glossary

- **AED**. Automatized Electronic Defibrillator.
- **Aerodyne** heavier than air aircrafts.
- **Angle of attack** is the maximum angle at which an aircraft can be tilted in order to maintain lift.
- **ASM** Air-to-surface missile.
- **Autogyros** This kind of aircraft uses an unpowered rotor, that can spin freely, to generate upward thrust. With this thrust, the rotor gives lift to the aircraft, allowing it to sustain itself in the air.
- **Bernoulli's principle** states that when a fluid increases its speed, it also decreases its pressure.
- **BLHeli**. Firmware most commonly used in drones.
- **BVLOS**. Beyond Visual Line of Sight.
- **C rating** is a measure of the rate at which the LiPo battery is discharged relatively to the maximum capacity of the battery.
- **CF**. Carbon Fiber.
- **DRL**. Drone Racing League
- **Dynamic Braking** is the use of an electric motor as a generator when decelerating a vehicle
- **EMS**. Emergency Medical Services
- **Energy Density**. How much energy can provide a kg of a certain material, or, in some case how much energy can provide a fully charged 1kg battery.

- **ESC firmware** is the software that runs on all ESCs, and which determines the ESC's overall performance, which protocols the ESC supports, and what configurations can be used.
- **ESCs**. Electronic speed controllers are essential in any drone, as they allow the motors in the quad to change their speeds whenever needed.
- **FD**. Fire Departments.
- **Flight time** is the period of time the aircraft can stay airborne
- **FLIR**. Forward-Looking InfraRed cameras
- **FPV**. First Person View.
- **Frame of a quadcopter** is the main structure that contains all the com ponents of the drone.
- **Gliders** are a type of aircraft that doesn't use any type of power source to produce lift.
- **Hexacopters** are a type of drone that has six motors, and they are the second most used type of multirotor. They are mainly used for weight lifting jobs, such as package delivering, or gathering data with heavy equipment.
- **ISR drones**. Intelligence, Surveillance and Reconnaissance drones.
- **KISS**. Electronic components company. Stands for "Keep It Super Simple".
- **KV** refers to the constant revolutions per minute of a motor. It is number of RPM that the motor will turn when one Volt (1V) is applied, and there is no load attached to the motor.

- **LiPo battery**. Lithium polymer batteries, also known as LiPo batteries, have high energy density, a light weight and high discharge rate, which make them a perfect candidate for radio control applications. They are the most commonly used batteries.
- **mAh**. The capacity of most batteries is measured in milliamps hour (mAh). This is a unit used to measure electric power over time. It is an indication of how much current you can draw from the battery in an hour until it is it's empty.
- **Maximum range**. Maximum distance the drone can go before losing the signal with the remote controller.
- **MUAVs**. Micro Unmanned Aerial Vehicles.
- **NDVI**. Normalized Difference Vegetation Index is an index (equation) capable of detecting how healthy a plant is by analyzing the light spectrum that is reflected on its leave.
- **NIR cameras**. Near InfraRed cameras.
- **Octocopters** are a kind of drones that have eight motors and are usually used to transport. They are not as commonly used as other types of multirotor drones.
- **PDB**. Power Distribution Board is an electronic board where the battery is connected, and from there, the current is appropriately distributed to all the rest of the parts of the drone.
- **PG AGM**. Precision-Guided Air-to-ground missiles.
- **Pitch** (drone) Forward and backward motion of the drone.

- **Pitch** (of a propeller). Is the angle of attack, or angle of inclination of the blade of the prop. A blade with a higher (steeper) pitch will have more thrust, thus providing the quad with more speed, but it will also draw more electricity from the battery.
- **Propeller**. Propellers generate thrust by revolving and therefore pushing air. The faster the prop is spun the more air it can move, and thus the more lift it generates.
- **Quadcopters** have four motors, one on each corner of the drone. They are by far the most common type of multirotor. They are mainly used for tasks that need a fast and stable aircraft, such as racing, photography, freestyle, surveillance or data gathering.
- **RGB cameras**. Cameras that only gather the three main colors in the light spectrum: Red, Green and Blue. All the other light frequencies (each frequency is equivalent to a color) we can see in a picture are just a mix of those three elemental colors.
- **Roll**. Right and left motion.
- **Rotatory wing** all aircraft that use a rotatory wing, also called propeller, to generate lift
- **SEAD**. Suppression of Enemy Air Defenses.
- **Size** (of the propeller). Is the distance from one tip to the other tip, or the diameter of the circle that the prop makes when it is spinning.
- **Size or wheelbase**, is the diagonal distance from motor to motor, measured in millimeters.
- **Stingers**. Air-to-air missiles.

- **Throttle**. upward and downward motion of the drone.
- **Torque**. The force the motors have when spinning.
- **Trirotor or tricopters** drones that have three motors, usually two on the front of the aircraft (one on each side) and one on the back.
- **UAS** (Unmanned Aerial Systems) which include the drone, a remote controller on the ground, and a communication system between the two of them
- **UAV** (Unmanned Aerial Vehicle), commonly known as drone, is an aircraft that is piloted by a remote control, or with onboard computers
- **UCAVs**. Unmanned Combat Aerial Vehicles.
- **VLOS**. Visual Line of Sight.
- **Voltage**. The voltage is the quantity of energy per unit charge. This means that the more voltage the battery has, the more energy is delivered to the motors (or whatever is connected to the battery).
- **Yaw**. Looking at the drone from above, is the turning motion this one has (clockwise or counterclockwise).

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NOTE:

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CREDITS

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