Hochschule für Angewandte Wissenschaften Hamburg
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Bachelorarbeit

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Assembly, Design, and Control of Quadcopters for Healthcare Applications during a Global Pandemic

Fakultät Technik und Informatik
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Assembly, Design, and Control of Quadcopters for Healthcare Applications during a Global Pandemic

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Thema der Arbeit

Konstruktion, Design und Steuerung von Quadkoptern für Anwendungen im Gesundheitswesen während einer globalen Pandemie

Stichworte

Drohne, Quadcopter, Konstruktion, Design, Elektronik, Gesundheitswesen, Pandemie, UAV, FPV

Kurzzusammenfassung

Der Ausbruch der Pandemie im Jahr 2020 hat den Gesundheitssektor zum Erliegen gebracht und beispiellose medizinische Herausforderungen auf der ganzen Welt geschaffen. Der Zweck dieser Bachelorarbeit ist, den Leser eine Einführung in die Konstruktion und Konfiguration eines Quadcopters zu geben, um zu untersuchen, wie der Einsatz unbemannter Luftfahrzeuge (UAVs) zur Lösung einer Vielzahl von Problemen, umgesetzt werden kann, von der Desinfektion aus der Luft bis hin zu medizinischen Zustellungen. Die abschließende Beurteilung kombiniert konkrete Anwendungen mit einer persönlichen Einschätzung der gegenwärtigen und zukünftigen Möglichkeiten von Drohnen im Gesundheitswesen.

Gianluca Veschi

Title of the paper

Assembly, Design, and Control of Quadcopters for Healthcare Applications during a Global Pandemic

Keywords

Drone, Quadcopter, Construction, Design, Electronics, Healthcare, Pandemic, UAV, FPV

Abstract

The outbreak of the pandemic in 2020 has disrupted the healthcare sector and created unprecedented medical challenges all over the world. The purpose of this Bachelor Thesis is to introduce the reader to the assembly, construction and configuration of a quadcopter with the purpose of examining how the use of Unmanned Aerial Vehicles (UAVs) can be implemented to solve a broad variety of issues, ranging from aerial disinfection to medical deliveries. The final assessment combines real world applications with a personal evaluation of the current and future possibilities of drones in healthcare.

Contents

1 Introduction

Graduating in 2020 is a special opportunity for an engineering student. The world is currently facing a daunting unemployment rate and the transition from university to industry will not be as smooth as expected for most students but at the same time, the current global health crisis caused by the pandemic and the consequent inequalities that have been exposed in both high and low income countries have created a urgent need for long-term solutions to the problems that have arisen.

The new reality taking shape is made of uncertainty and in order to thrive and take advantage of new opportunities, industries need to change and become resilient. As the pandemic began, most countries tried to tackle the crisis with their own strategies, but over the course of time it has emerged that there are a set of similar problems which most industries, and at last governments, have to face with an engineering approach.

The purpose of this Bachelor Thesis is to explore how the use of drones and more generally Unmanned Aerial Vehicles (UAV) can be implemented to solve a broad variety of issues, ranging from aerial disinfection to medical deliveries and many others that will be analysed in details in the following pages.

In recent years there has been a steady decline in price for consumer electronics as many companies moved into the market and expanded on these innovations [43]. Being drones heavily dependent on electrical components, the price for their construction has also plummeted [9], allowing an increasing number of manufacturers and entrepreneurs to focus on this new innovative technology.

The combination of these factors has led to an increase in the number of start-ups creating innovation through new tailored applications, especially in developing countries, so it is useful to research the possible uses of quadcopters for healthcare purposes while at the same time providing the technical background to future start-up founders in the field of UAVs.

In this chapter a short personal motivation regarding myself and the reasons why I decided to invest my time on this project will be presented, followed by the objectives I want to achieve, the structure of the single chapters and finally a brief look at the history of unmanned aerial vehicles from their first usages until now. For the sake of familiarizing the reader with this very emerging field and its possible applications, the implications on current legislative and socioeconomic levels will also be taken into account when needed.

It is important to specify that I based my research on building a drone keeping a low budget by assembling a 280mm frame with the electronics of the **EaChine Tyro129**. In the following chapters I will focus on the state of the art of quadcopters combining my personal practical experience with the most recent articles, papers and researches that I was able to find online about the topic. It is also relevant to note that all external references will be appropriately mentioned in the bibliography and by no means I intend to say that I built a quadcopter which could be used in a real medical emergency scenario, but rather that I had a hands-on experience with a real flying device and that I have been exposed to most of the engineering trade-offs, problems and limitations that arise when working with both the electrical components and the software configuration of multirotors.

1.1 Motivation

Back in 2015, when I received my Diploma in European Foreign Languages and Literature from my High School in Pesaro, (Italy) I didn't really know much about Computer Science and Engineering in general. Not knowing anybody who had tried to pursue a scientific career after humanistic studies, I was a little afraid of jumping directly into an engineering degree, so it took me a few years of attempts before realizing that it didn't matter what kind of background I had, as long as I was motivated enough to pursue a career in the tech industry.

This project aims to combine most of the modules and concepts approached at the HAW Hamburg, ranging from electrical engineering to software development for embedded systems, while at the same time looking at how different technologies can be combined to solve real world problems related to the huge disruption caused by the current pandemic.

I see this final project as one of the most important opportunities that a student has to express the knowledge gathered over the years and this pushes me to create a valuable research for my personal growth as an engineer.

1.2 Objectives

- Research and analysis of the most appropriate components required for the construction of a drone considering a low-medium budget. (Less than 200€).
- Assembly of the mechanical and electrical components.
- Installation of the software for the microcontroller through a personal computer.
- Research of the possible applications of quadcopters in healthcare during an epidemic.

1.3 Structure of the Thesis

The focus of the first part of this thesis is a pure technical research about how to design and assemble a quadcopter through an in-depth analysis of its electrical components based on my personal experience.
Secondly I will research which healthcare problems are actually already addressed through drones and finally I will summarize the content and express my own opinion regarding which applications should employ such flying devices with respect to ground robots or other more classical approaches.

1.4 History

As often happens in history, the original use of drones was military. The first attempt to build and use an unmanned aircraft dates back to the Austrian incendiary balloon attack on Venice in 1849. [52]

During the First World War, some prototypes of unmanned aircraft appeared, such as the "Aerial Target", which was controlled by radio. Nonetheless the real race for drones started at the beginning of the '50s, when the technological development allowed to reach high quality at an affordable cost, bringing to the market technical solutions richer in features and cheaper in price.

The entry of drones in the civil field started with the reform of the FAA in 2012 by the

U.S.A., when the doors of the civil world were opened wide to drones, once confined in conflict zones. In fact, since the mid-2000's, as a result of rapid scientific progress, several companies had already begun to develop consumer products, similar to remote-controlled airplanes. One of the first to arrive was the Chinese **DJI**, which offers flying vehicles that are flexible to the needs of everyone, lightweight and durable.

Thanks to their ability to operate in various situations and environmental conditions, quadcopters have thus made their entry into countless areas, from surveillance to aerial filming and are also used to perform some complex activities which will be further discussed later.

The great challenge for the coming years will consist in facing the continuous updating of regulations and standards, necessary to keep up with the technological development of the sector.

2 Flight Dynamics Principles

Given the ease of use of today's drones, it is understandable to forget about how much physics is involved in the process of taking off, hovering, flipping and doing literally anything in the air when flying. Although it seems no more complex than playing a video game, there are actually a defined set of laws which have to be taken into account in order to let the magic happen. Luckily, most of the hard research work has already been done and it won't be difficult to shed some light on the wizardry behind the scenes.

Given four motors, every movement is accomplished by changing the spin rate of one or more motors, which in turn rotate the annexed propeller to generate the thrust needed to rise. This is achieved by adjusting the voltage supplied to each motor by the speed controller.

2.1 How do quadcopters fly

The **net upward force** F_{net} of the drone's four rotors in the vertical direction can be calculated by multiplying the mass m of the drone with its vertical acceleration a_y.

$$F_{net} = ma_y \tag{2.1}$$

The net force can also be decomposed into two distinct vertical forces, namely the **upward thrust force** F_T and the **downward gravitational force** mg , (which on earth is 9.8 N/kg). Note that gravity acts in the downward direction and therefore it has a negative sign.

This brings us to

$$F_{net} = F_T - mg \tag{2.2}$$

which can be rearranged into :

$$F_T = ma_y + mg \tag{2.3}$$

2.1.1 Throttle

The first keyword here is "**thrust**", which is the mechanical force used to overcome the weight of the vehicle. It is generated by the propellers and it can be compared to the propulsion system of a rocket, as they both system follow the application of Newton's third law of motion, which states that "for every action there is an equal and opposite re-action". Therefore, in order for the drone to rise from the ground, the total thrust generated by the motors has to be greater than the weight w_d .

Considering $\omega_0, \omega_1, \omega_2, \omega_3$ the four **rotation speeds** of the propellers, the condition for equilibrium in a quadcopter can be achieved by setting up two **adjacent** motors spin in the opposite direction and two **opposite** motors spin in the same direction.

$$(\omega_0 + \omega_2) - (\omega_1 + \omega_4) = 0 \tag{2.4}$$

More easily understandable in the figure below 2.1.

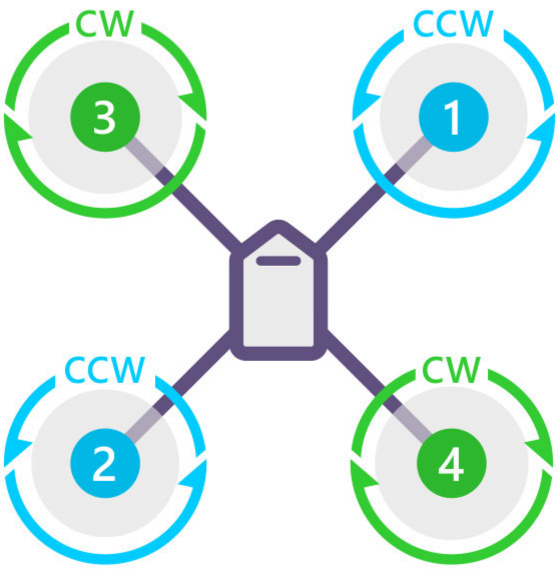

Figure 2.1: Motors rotation [7]

Considering F_0, F_1, F_2, F_3, the four forces generated by the propellers, there are basically three things a Drone can do in the vertical plane and they all depend on the amount of thrust supplied.

Hover: Thrust equals the weight of the system.

$$\sum_{i=0}^{3} F_i = -w_d \tag{2.5}$$

Climb: Thrust greater than the system's weight makes the quad rise upwards.

$$\sum_{i=0}^{3} F_i > -w_d \tag{2.6}$$

Descend: Thrust lower than the system's weight makes the quad descend.

$$\sum_{i=0}^{3} F_i < -w_d \tag{2.7}$$

Now that we are able to prove how the drone takes off and hovers, it is time to look at the possible movements that it can do in the air.

Taking the dimensions of earth as the **inertial** reference system X_E, Y_E, Z_E, and the quadcopter frame as the **drone** reference system X_D, Y_D, Z_D, it is possible to define the transformations between the two systems through three Euler angles, namely Pitch ϕ, Roll β and Yaw γ.

At the same time, the derivative of these three angles with respect to time indicate the angular rotation speed of the system, symbolised as Roll rate $\dot{\phi}$, Pitch rate $\dot{\beta}$, and Yaw rate $\dot{\gamma}$. Note that during equilibrium conditions these values are equal to zero.

2.1.2 Roll

Roll is indicated with the Greek letter ϕ and it refers to the movement on the longitudinal axis running from the front to the back of the aircraft, the angle of rotation along the axis $X_E||X_D$. Moving the ears towards the shoulders so that the head tilts to either side is a good analogy for it

Roll rotation equation :

$$\dot{\phi} = k_R((\omega_0 + \omega_3) - (\omega_1 + \omega_2)) \tag{2.8}$$

2.1.3 Pitch

Pitch is indicated with the Greek letter θ and it refers to the nose of the drone going up or down, the angle of rotation along the axis $Y_E \| Y_D$.
It's helpful to think of it as climbing or diving. It can be adjusted by applying more thrust to one set of rotors and less to the others.

Pitch rotation equation :

$$\dot{\theta} = k_P((\omega_0 + \omega_1) - (\omega_2 + \omega_4)) \tag{2.9}$$

2.1.4 Yaw

Yaw is indicated with the Greek letter ψ and it refers to the nose of the drone turning left or right, the angle of rotation along the axis $Z_E \| Z_D$.
It moves the quadcopter around in a clockwise/anticlockwise rotation as it stays level to the ground and one could think of this as turning. To adjust its yaw, or make it turn left or right, the quadcopter applies more thrust to one set of motors which have the same direction. For example a quadcopter may apply more thrust to the two motors that spin clockwise to turn right.

Yaw Rotation equation :

$$\dot{\psi} = k_Y((\omega_0 + \omega_2) - (\omega_1 + \omega_3)) \tag{2.10}$$

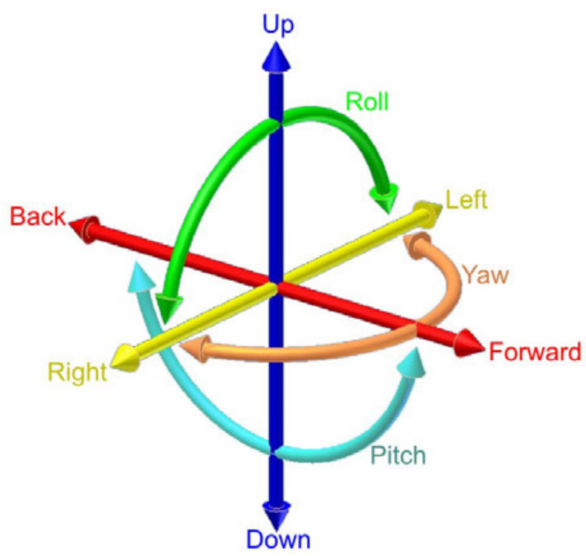

Figure 2.2: Principal axes

3 Hardware Assembly and Design

Drones have come a long way since they have been made available to the public. The hardware powering RC vehicles has followed the steady improvements that have taken place in electronics, making it possible for this technology to expand in different branches. For this reason, it is snot possible to define a single solution for all the possible existing applications that exist. Nonetheless the considerations on the architecture of quadcopters in the following chapters are structurally valid and provide a detailed picture of what is the current state of the art of commercial drones.

3.1 Flight Controller

The very first module worth mentioning is the Flight Controller FC : a small circuit board of varying complexity which stands at the heart of the hardware stack and serves multiple purposes. It controls the on-board electrical components with the assistance of a microprocessor and enables a correct communication of the many peripherals connected to it [21].

3.1.1 Processor

The brain of the Flight Controller is the Micro Controller Unit MCU, which stores the firmware code and handles logical operations. It can be compared to the CPU of a computer in smaller scale and commercially speaking all most common processors are based on different variants of the **STM32**, being **F4**, **F7** and **H7** the most advanced up to date. The parameters to look for when choosing a proper processor are : processing power, RAM and flash memory. At the time of writing this thesis the F7 is the most popular choice, because despite a lower clock speed than the H7, it is still compatible with most firmware and has DSP capabilities, which means it can be flashed with optimized flight control algorithms once they are available.

3.1.2 Firmware

Using a micro USB cable connected to a computer the FC can be flashed with **firmware** specific to the chosen FC configuration software. The most common firmware configurator

Figure 3.1: Eachine F4 FC Backside

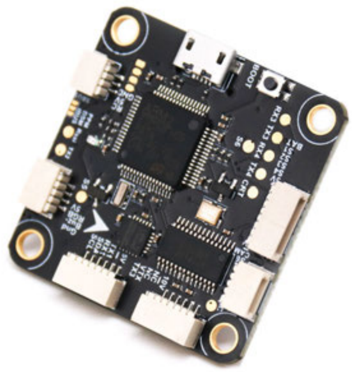

Figure 3.2: Eachine F4 FC Frontside

is **Betaflight** as it is backed by a solid open source community and allows a high freedom of tuning. The firmware configures the board with the program and does most of the hard-work required to manage and control the quadcopter but it's still possible to customize and change the boards settings such as PID's, receiver configuration, failsafe setup and flight modes. More details will be explained in the software overview 4.

3.1.3 Communication Protocol

FCs employ sensors to supplement their calculations, which can be connected with solder pads, pin header holes, plugs, or a combination of the three. These peripherals range from simple gyroscopes for orientation to barometers for automatically holding altitudes.

The microprocessor communicates with the peripherals using the **UART** protocol, which stands for Universal Asynchronous Receiver/Transmitter and it's a physical circuit in a microcontroller with the main purpose of sending and receiving serial data. Its main advantages are that it only needs two wires and that data is transmitted asynchronously, relying to start and stop bits in the data packet being transferred instead of a clock signal. Two of the main characteristics are the reading and response time, respectively known as the **gyro update frequency** and the **PID loop frequency**.

3.1.4 Internal Modules

Let's have a look at all the various components that could be found within a FC.

In the majority of cases a module called **Power Distribution Board** (PDB) is embedded into the FC, so that the power from the battery can be evenly distributed to the motors and all other components. For instance, humans wouldn't be capable of controlling the rotational speeds of more motors simultaneously with enough precision to balance a craft in the air and this is where the PDB comes into play. This solution is known as "All-in-One" and although it is more sensitive to circuit failures it is still widely adopted for its cheap and easy implementation.

A **Gyroscope** is a microchip, secondary to the main processor, which detects the angular velocity or the speed at which a quadcopter rotates in the roll, pitch and yaw axis. Using calculus mathematics and gyro inputs, the microprocessor can estimate the distance a quadcopter has rotated and whether its rotation is accelerating or decelerating.

In order to determine position and orientation of the drone while flying, an additional module called **Accelerometer** is used, which detects the amount of electrical current moving through the structure, indicating a change of position relative to gravity. As drones become more autonomous, these are essential to maintain adherence to flight rules and air traffic control. For applications where stability is paramount, from surveillance to delivery of fragile goods, **Tilt sensors**, combined with gyros and accelerometers, can also provide input to the flight-control system in order to maintain level flight.

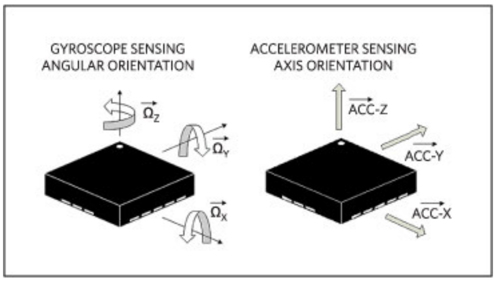

Figure 3.3: Gyroscope and Accelerator [13]

A great addition to the FC is the **On Screen Display** (OSD), a small PCB which communicates with the camera and the VTX to provide useful information such as flight time, battery voltage, current level, RSSI and GPS Coordinates to be displayed on the FPV Goggles or monitor to facilitate troubleshooting.

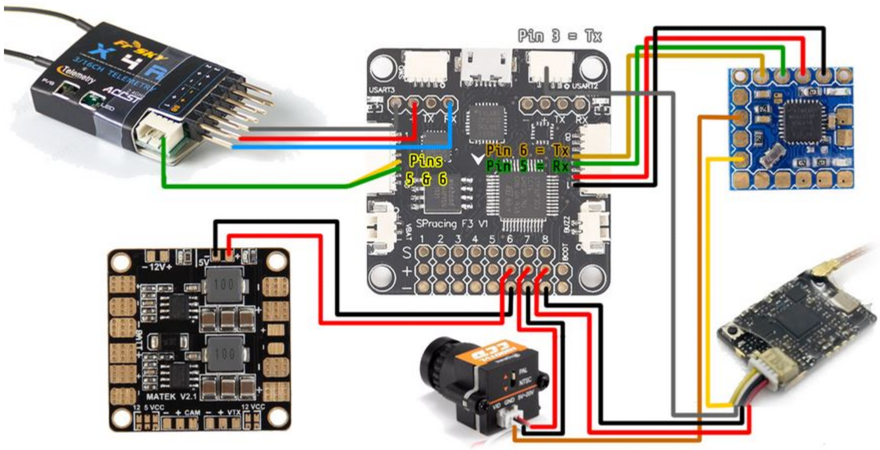

Figure 3.4: Flight Controller Wiring Plan [13]

3.2 Motors

The types of motors used in the drone industry can either be with or without brushes but the vast majority of manufacturers have opted for the BrushLess solution using Direct Current, also called **BLDC** . They are more powerful, more efficient, and also last way longer than their brushed counterparts, as there are no brushes to wear out or to limit the maximum speed of the motor. There are really no disadvantages against it beside the higher price for the manufacturing and the need of **Electronic Speed Controllers**. That's why brushes are still used for micro and toy drones.

3.2.1 Parts of a Brushless Electric Motor

The two main parts of a brushless motor are the **stator** and the **rotor**, which respectively stand for stationary and rotatory part. A motor size is defined by the width and height of a stator, so for instance a 2305 indicates a 23mm in width and 05mm in height.
Other smaller but also equally important parts are **coils** and **magnets**, which in a very intelligent way allow the motor to spin around the **shaft**.

3.2.2 How do BLDC Motors Spin

A motor uses magnets to create motion, it is common knowledge that magnets have two sides, one attracts and the other repels. The copper coils are fixed in place on the stator whereas the magnets are placed both on stator and rotor. When the magnets on the stator become

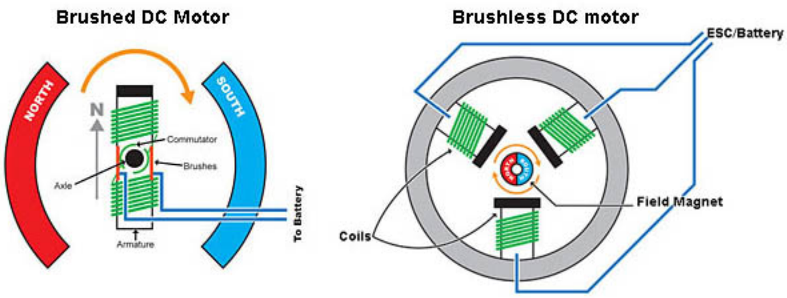

Figure 3.5: Motors Anatomy [32]

energized, a temporary magnetic field is created, which repels against the permanent magnets present inside the motor, causing the shaft to rotate.

As explained in the flight dynamics principles 2, the direction by which the motors rotate is important for the conditions of equilibrium, so motors can either spin clockwise (CW) or counterclockwise (CCW). This rotation direction can be reversed by swapping two of the three wires coming from the ESC.

3.2.3 Motors Performance Factors

As mentioned earlier, the minimum thrust produced by the motors should be 2:1 to lift off, or with other words, at least twice the total weight of the quadcopter. This factor is know as the **Thrust to Weight Ratio**, which for fast quadcopters can even reach 13:1. A very high ratio allows for greater agility and acceleration but it can quickly become too hard to control. The sweet spot recommended for most applications is around 6:1 as this also provides room for extra payload in cargo applications 5.4.

Another important parameter to look at is the velocity constant known as **KV**, which theoretically represents the speed at which the motor rotates when voltage goes up, or better formulated, the theoretical increase of rotation per minute (RPM) for every volt applied to the motors. This value has to be considered for ideal scenarios without propellers or any type of load, so the actual KV rating will be different when flying given the weight of the build and the air resistance.

The rotatory force that spins the propeller is the **torque**, which is heavily affected by the quality of magnets and copper windings in the rotor. It determines how responsive the quad will perform to inputs and how tight it can turn , but generally speaking, this value is mostly important for racing drones.

Motors are without doubts the most resource hungry components and they have a high **current draw** rating. Knowing this number is useful to select a proper ESC accordingly, as this should be able to withstand at least 20% more than the current drawn at 100% by the motor.

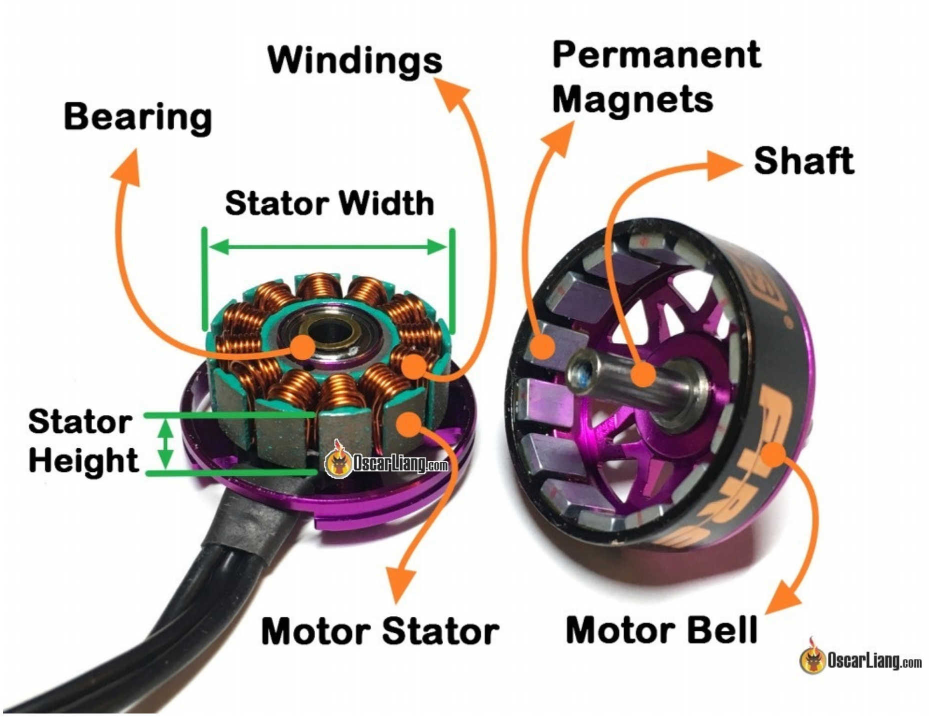

Figure 3.6: Brushed and Brushless motors schematics [32]

3.3 Electronic Speed Controllers

Each individual motor should receive the same amount of power from the battery and although a first distribution is done by the above mentioned PDB, the electronic module responsible for connecting the flight controller to each individual rotor is the **ESC**.

There are **two main set-ups** : Invidual ECSs attached on the arm of the drone between the FC and the motor and 4in1 combo units in which all 4 ESCs are combined into one circuit board and internally mounted in the main stack. Both setups are functionally equal and the modularity of having four separated units is often traded for the cleaner look of a single component.

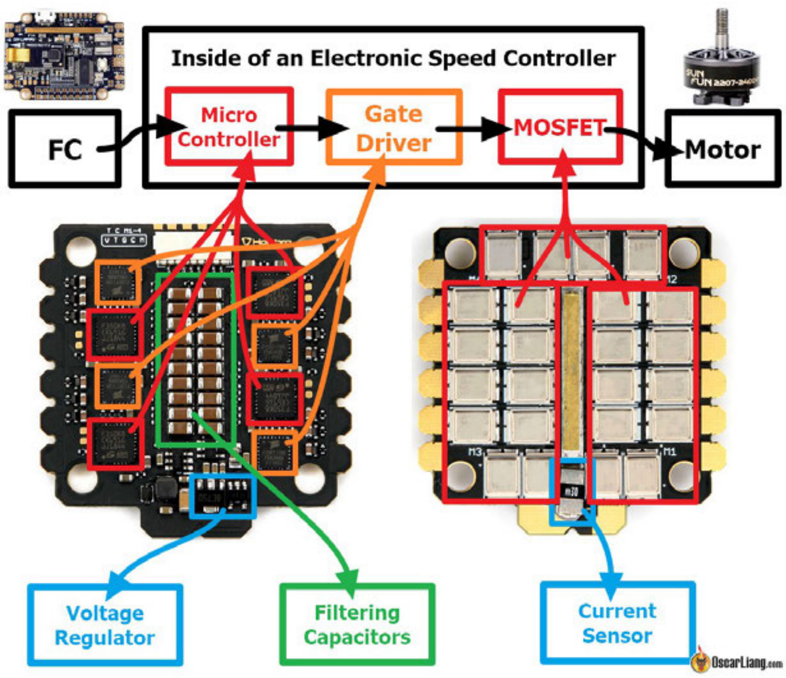

Figure 3.7: ESC Anatomy [22]

Most ESCs on the market are controlled by on-board 32-bit processors, running the **firmware** determining the performance and the supported protocols. The earliest option was **SimonK** but since 2015 it has been deprecated in favor of **BLHeli**, as it allows user-customization and can communicate with faster digital protocols, such as Oneshot, Multishot and DShot.

3.3.1 Communication Protocols

The “language” that the FC and ESC use to communicate is made of ones and zeros. The most fundamental task is telling the motor how fast it should be spinning. For many years this was the traditional pulse width-modulated signal (PWM) but since recently much faster digital signals have taken over,

DShot stands for Digital Shot and it’s a new transmission protocol developed by the German Hamburg-based company Flyduino [47]. In recent years the improved versions Dshot600 and Dshot1200 also came out, where the number stands for the bitrate (kilobits sent per second). Increasing numbers means faster transmission speeds, and ultimately lower latency.

The digital protocol was developed to solve the problems related to analog signals, which suffer voltage spikes and measurement inaccuracies due to the possibly different speed of the oscillators in ESC’s and FC.

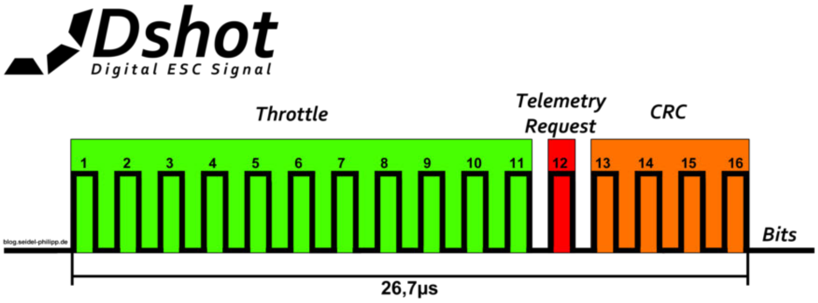

Figure 3.8: DShot Signal characteristics [47]

The new digital protocol sends a 16-bit-long data packet and it’s composed as follows:

- 11 Bit—Throttle value
- 1 Bit—Telemetry request
- 4 Bit—CRC checksum (checks the correctness of the signal)

Because of the nature of digital signals, which consist of ones and zeros, the resistance to electrical noise will be much more robust and the clock differences in delay between the ESC and the flight controller won’t affect flight.

3.3.2 ESC Performance Factors

The main characteristic to look for in a ESC is the **primary rating**, indicating the measure of how much current can be passed to the motors. ESCs should have a higher amperage than the motors to maintain a margin of safety. Larger motors tend to draw more current, and propellers with a greater pitch will also draw more current. 30A is enough for most 4-cell LiPo batteries applications and 50A is the best option although heavier and more costly. ESCs are also rated in their ability to handle voltage, ranging from 3S-4S to 6S.

The voltage spikes generated by the brushless motors are a very common issue and in recent years filtering electrolytic **capacitors** have been added to absorb the power that could overheat the wires in the electronic equipment.

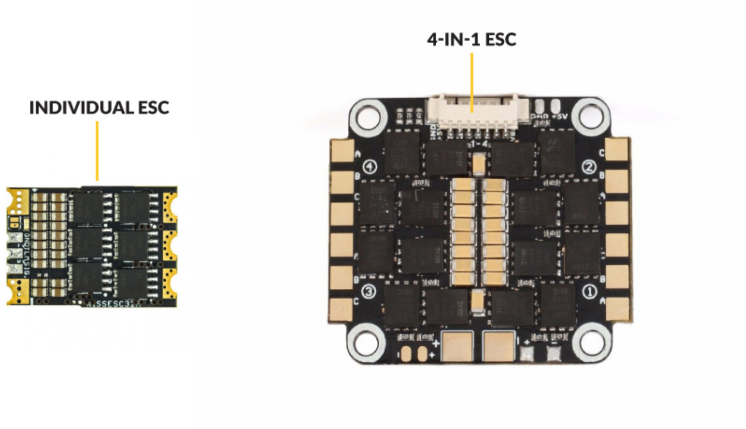

Figure 3.9: Electronic Speed Controller Setups [31]

3.4 Frame

The frame gives a drone its shape and holds all of the subsystems in place. Because of the mechanical function it serves, the most important material's properties that would be suitable for every application are **lightness** and **resilience** to crashes. Unfortunately these features often contradict each other, and the final product will always be a trade-off among weight and strength as the ideal frame is defined by its application.

Figure 3.10: Mixed Drone Frames [31]

Industrial applications require a high degree of safety and sometimes producers need to foresee the continually developing regulations in Europe and particularly in Germany [25] to adapt the products to the market. These standards are especially strict in case of surgical and medical applications and sometimes it's difficult to choose between a safe landing and a fast delivery.

3.4.1 Material

A strong frame is by definition going to be heavier and less agile in the air and so far **carbon fiber-reinforced composite** (CFRC), has been proven to be the best option compared to plastic and fibreglass. Its popularity is mainly attributed to its low density yet 'stronger than steel' tensile strength. Although it is quite expensive to produce, it is usually the ideal material.

Larger commercial drones will often use **aluminium tubing**, where carbon fibre would be an expensive alternative and plastics would lack the required rigidity.

3.4.2 Size

The size of a frame is referred to as the **wheelbase** and it indicates the distance between motors in millimeters. The name of the frame will normally include a number that corresponds to this data-point, which is especially important when choosing the propellers, as they need to be as big as possible to produce the highest amount of thrust without touching each other or any part of the electronics.

Smaller quads between 100 and 200mm offer more flexibility as they can fly in smaller spaces, but it's going to be harder to solder smaller components on them, and they obviously have less room to mount everything. On the other hand, large quadcopters are easier to work with as they allow for bigger propellers and also have the option to mount more sensors.

3.4.3 Weight

Currently in most countries light frames under 250g won't be restricted by possible regulations while bigger drones need to be registered with the government. While commercial drones can sacrifice some added weight in order to be more affordable, industrial drones prioritise performance. A material which is high in strength can be used in smaller quantities, making for an even lighter, higher-performance drone.

3.4.4 Layout

For such a mechanically simple component, the frame has a huge influence on the flight characteristics and aerodynamics of the drone, a mere inch added to the arms can wildly alter the total stability of the drone once up in the air. The more noticeable design characteristic are variations of the following three forms and each has different uses within the industry.

- **H Frame**: The very first quads used to be designed with the arms directly connected to the two sides of the body, creating a "H" shape.
- **X Frame**: The perpendicular distance between the center of each motor is the same, so the quad has the same level of stability on all axes. Due to the reduction of the material used, it is lighter than other frames and it's currently the most popular design.

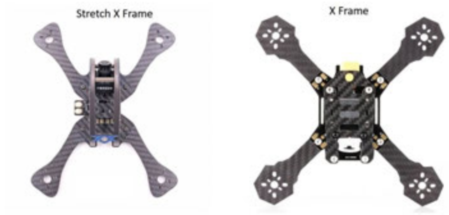

Figure 3.11: X / Stretch X Frame

Figure 3.12: H / H-X Frame

- **Stretch**: Stretching out the arms can be both applied to X and H-Frames and It favours stability at the cost of a heavier build.

3.5 Propellers

The spinning blades that create the airflow needed to lift the quad into the air are considered as wings to the craft. Propellers have a direct impact on how drones fly. They use the voltage supplied to the motors to transform rotary motion into linear thrust, which provides the aircraft with the necessary lift to take off. All the movements and flight modes mentioned in flight dynamics principles 2 are a direct consequence of how the rotating speed of the propellers varies.

There are different designs and characteristics but generally speaking their size must be matched to the rest of the quadcopter. When choosing a propeller the three main measurements specified by the manufacturers are quoted in the form A x B x C, indicating the length of the propeller from tip to tip, the pitch and the number of blades respectively. Note that these numbers are usually specified in inches.

Figure 3.13: Quadcopter Propellers Size [15]

3.5.1 Size

As previously mentioned in the frame chapter 3.4, the size of the propellers is directly dependent to the size of the frame, though there are still adjustments that can be made for a particular flying characteristic.

The size of the propellers affects how much air is swept through the air and as a rule of thumb, the more air is moved, the faster the drone will be able to fly. This characteristic is particularly noticeable in **large** propellers but of course it also causes more energy to be drawn from the battery, which will result in a slower response to inputs.

On the other hand, **short** propellers provide more agility at the price of less thrust. A fast input response can be helpful if the particular application requires a drone to go through small and cluttered areas.

3.5.2 Pitch

The Pitch refers to the angle of each of the blades on the propeller and also indicates how far forward the propeller will move. This concept is applied to propellers for any kind of application, varying from boating to airplanes. It is important that propellers stay within a specific range of angles to keep pushing air downwards and maintain flight.

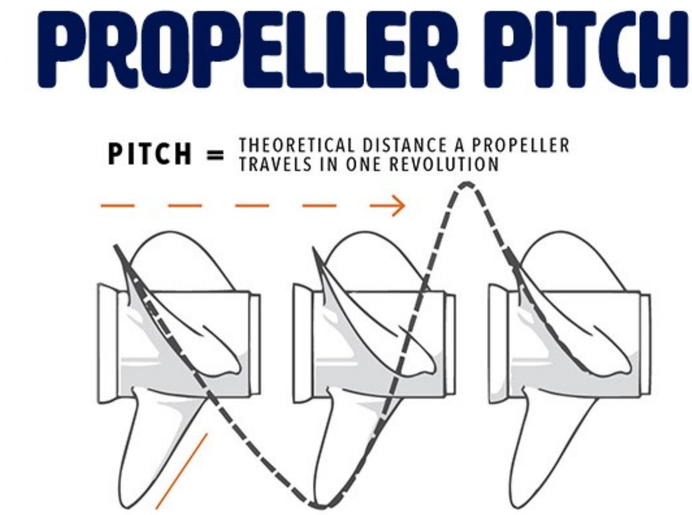

Figure 3.14: Propeller's Pitch [49]

3.5.3 Blade configuration

The number of blades on the propeller can vary from two to five and affects the amount of thrust and grip in the air. The aerodynamics behind the different blade configurations is quite complex and it's not possible to simply state that increasing the number of blades is as efficient as increasing size, but as a rule of thumb **less blades** are preferable where faster motor response is needed, while **more blades** give more control for fast flowing turns.

3.5.4 Material

The two main characteristics to look for in the materials used for props are stiffness and durability. It is desirable to maintain stability when flying regardless of how fast the motors spin, but this rigidity comes at the price of a faster shattering after crashes. Nonetheless it is important to keep in mind that propellers are the first thing that gets damaged and they should be easily replaceable. Nowadays they are being made using **polycarbonate**, as it's very flexible and able to bend rather than break if it hits something hard.

3.6 Batteries

There are currently two types of batteries used in the RC world : **NiMH** and **LiPo**. The difference lies in the chemical properties they are built on, respectively **nickel** and **lithium-ion** technology. Most batteries used for drones are based on Lithium Polymers. They have gained a lot of popularity among radio controlled airplanes, helicopters and multicopters because of their **weight/power ratio**. They can in fact offer more energy relative to their capacity than NiMH batteries, and can achieve longer drive time and a better overall performance.

There are three main factors that make them the perfect choice for radio-controlled devices compared to traditional rechargeable batteries such as NiCd or NiMH:

- Lighter weight.
- Larger capacity, meaning they can store a lot of power in a small area.
- Greater power output (Voltage drop across the load of the circuit).

3.6.1 How do LiPo Batteries work

LiPo batteries use a polymer electrolyte **separator** sheet that resembles a thin plastic film. This separator is inserted between the anode and cathode of the battery to allow the exchange of lithium ions, from which it is named. This method allows the realization of very thin batteries and numerous cell shapes and sizes.

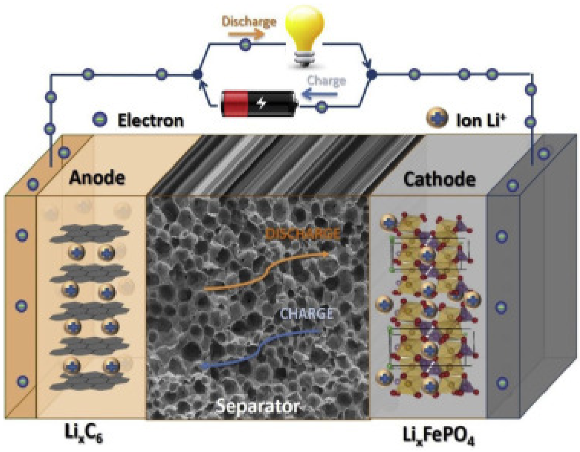

Figure 3.15: Battery Anatomy [12]

3.6.2 Batteries Performance Factors

The main parameters to take into account when choosing a LiPo battery are the following:

- **Cell Count** : It indicates the number of voltage cells in a row and it's indicated with an "**S**". It states how much voltage is going to be provided to the load and it's directly related to the **speed** of the vehicle. When putting two or more voltage cells in series their value gets added so given a 4S battery and the nominal voltage of 3.7V of each cell we would have a total voltage of 14.8V.

- **Capacity** : It refers to the amount of power the battery can hold and its unite of measure is [**mAh**]. It is directly related to the **time** the battery will last before it needs to be recharged and given the high amount of available types it is also important to look at its size related to the drone. Bigger capacities are heavier, require more space and also need more time to cool down in order to avoid burning up the motors.

- **C-Rating** : It's measure of the rate at which a battery is discharged relative to it's maximum capacity. The maximum current that can be draw from the LiPo safely without damaging the battery can be calculated by multiplying the C-Rating with the Capacity. This parameter indicates the "continuous" rating but there is also a "burst" C-rating, which is only applicable in periods of time within 10 seconds.

3.6.3 Safety Concerns

The **problem** with LiPos is that the exchange of lithium ions through the polymer electrolyte is slow and therefore greatly reduces discharge and charging rates. This problem can be overcome by heating the battery to allow rapid lithium ion exchange through the polymer between the anode and cathode, but is not practical for most applications.

If this problem were solved, the **safety risk** of lithium batteries would be greatly reduced. With the big push towards electric cars and energy conservation, there is no doubt that further developments and studies will create ultra safe LiPo in the coming years. Theoretically, this type of battery could be made in a flexible form, almost like a fabric; and would bring enormous changes to the industry [50].

Ultimately it's important to know that this is the most delicate component in a drone, if not handled properly it could be dangerous and eventually cause fire. It should be stored half charged at 3.8-3.85V as this is the most stable-state and for no reason it should be stored at high-temperatures.

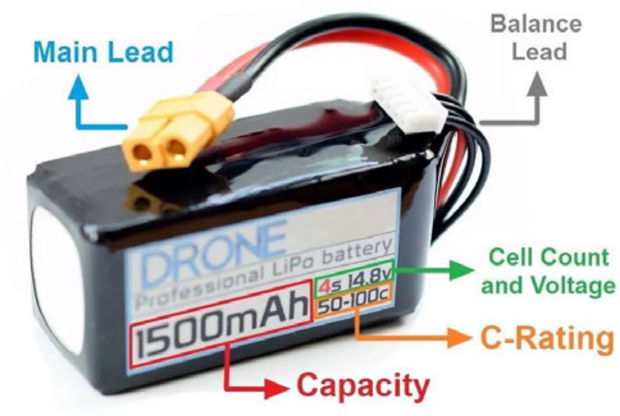

Figure 3.16: LiPo Battery Specifications Explained [36]

3.7 Radio Transmitter and Receivers

Drones can be remotely piloted through a **transmitter**, which in a very simplified way reads the gimbals inputs from the pilot and sends them wirelessly over the **receiver** using **radio signals**. Once this information is available it is then passed to the flight controller, which will translate the commands into movements of the quadcopter.

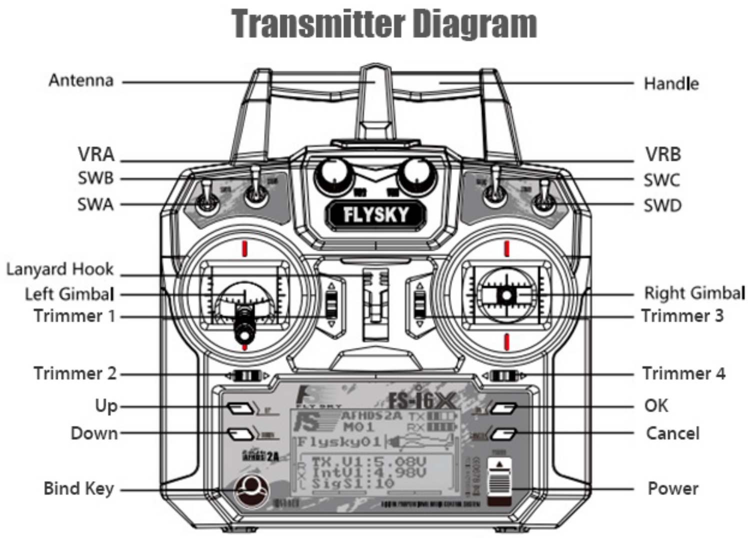

Figure 3.17: Radio Transmitter Diagram [23]

3.7.1 Frequency

There are four popular frequencies used for Drone flight but the most used one is 2.4GHz. [33] One of its main advantages is that it is suitable for **frequency hopping**, which is a technique used to switch to unused frequencies to maximise the available bandwidth. The frequency range also impacts the size of used antennas, which commonly tends to be smaller for higher frequencies. [20]

3.7.2 Channels

On a transmitter there are channels used to transmit commands to the aircraft and each individual channel can be considered as one specific action. The four main channels reflect the possible movements illustrated in the Flight Dynamics Principles 2, Throttle, Yaw, Pitch and

Roll while other knobs and switches can also be configured as channels to set up other actions such as arming the drone or changing the flight mode.

3.7.3 Gimbals

The two sticks used to control the quad are called gimbals and they are commonly configured to control the four main communication channels that translate pilot's input into data to be transmitted to the radio receiver.

Gimbals can be either based on analog or digital technology, namely using **potentiometers** or **hall sensors**. The second solution is the most prominent one as similarly to motors, they avoid using brushes that could wear out in favour of sensors with magnets to capture the stick position value.

3.7.4 Radio Receivers

The radio signals emitted by the transmitter are picked up by the radio receiver, which is able to decode the data and pass it to the flight controller, so that it can be converted into specific actions. All of this in a matter of few milliseconds.

Receivers not only passively get input commands, but can also send important pieces of information such as battery voltage and signal strength back to the transmitter in small data packages called **telemetry**. This data can then be displayed on a screen or read aloud by the transmitter, so that important warnings are not missed and pilots are able to stop flying and avoid crashes.

These devices come in different sizes and shapes and the main difference is that small ones need to be soldered while big ones can simply be plugged in and be reused. Most receivers have two **antennas** made from a coax cable to guarantee the best reception.

3.7.5 Communication Protocols

In order to communicate with each other the transmitter and the teceiver devices need to be **binded** with each other and use the same **Tx protocol**, which is mostly different between brands.

On the other hand data transmission between the receiver and the flight controller takes place through **RX protocols**, which are universal across different manufacturers of RF equipment. The most common ones are PWM, PPM, SBUS and IBUS.

Only one transmitter is allowed to communicate with one receiver at a time, but sometimes two receivers can be connected to the the same transmitter, so that if one loses connection, the second one can take over.

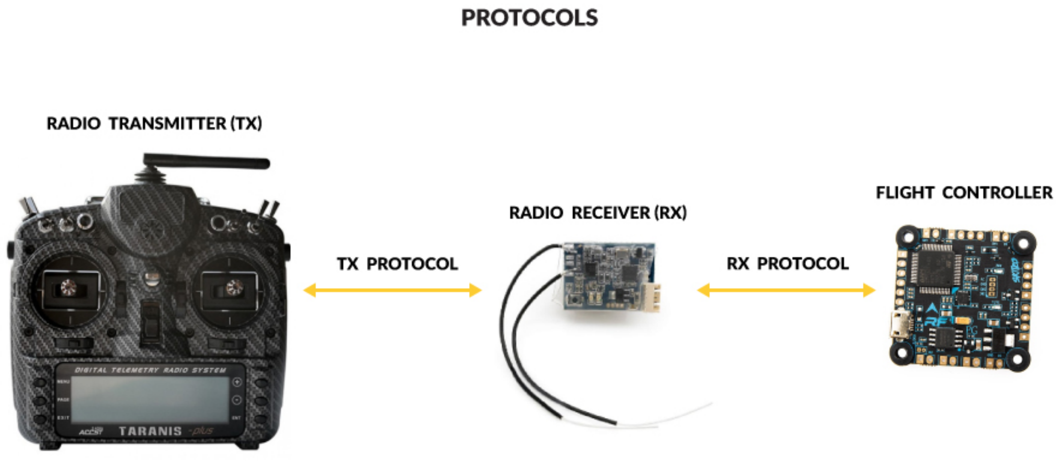

Figure 3.18: Data transmission between Transmitter, Receiver and Flight Controller [19]

3.8 First Person View System

One of the most revolutionary technology in the field of UAVs is the ability to see what the drone sees in real time. Piloting the multirotor **Line Of Sight** (LOS) by visually observing it in the sky and controlling it from the ground has many limitations and confines the amount of applications to a very low range, but thanks to the recent improvements in **video transmission technology**, it is now not only possible to have a video feed on a screen but also directly in a pair of goggles, which gives the pilot a much more immersive experience and opens a brand new world of possibilities to medical and rescue scenarios. This perspective is known as First Person View (FPV).

A camera mounted on the front of the vehicle can be connected to a video transmitter (**VTX**) that sends the real time footage to a video receiver (VRX), which is usually directly integrated into a pair of goggles featuring a monitor.

Although all of this sounds like magic, the technology behind it is still relatively immature and progresses are still being made. These systems are developing very quickly and many improvements will emerge in the near future thanks to the next generation of cellular and WiFi technology named 5G [16].

3.8.1 Comparison of Analog and Digital Communication Systems

The video feed signal sent through the air follows by nature the analog format. In order to have a digital representation of an analogue radio frequency there needs to be a digital modulation, which brings huge advantages to the final image quality at the expense of having a much more complex system and a higher latency, without mentioning the greater cost.

Although great developments have been made in recent years, the FPV communication until now has been following the analog path as it is still way more reliable. In spite of that, most of the considerations and concepts for the hardware involved are valid for both technologies, but one must always keep in mind the different trade-offs between the two and choose the most appropriate solution to the specific application.

3.8.2 FPV Camera

Cameras used for FPV purposes are specifically designed to be compact and fit in a very tiny space. Their main purpose is to have an extremely low transmission latency and provide a

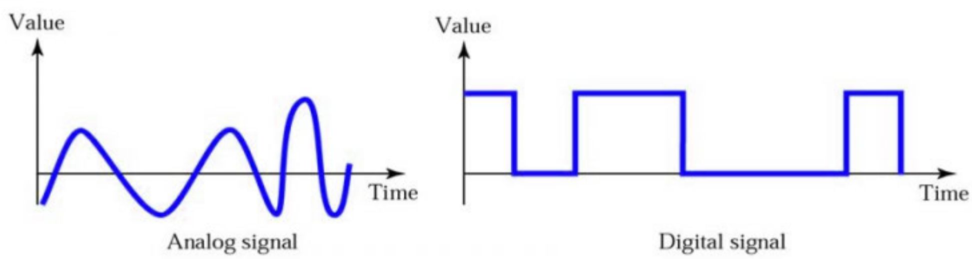

Figure 3.19: Comparison of Analog and Digital signals [11]

good Wide Dynamic Range (WDR), which implies that both bright and dark conditions can be handled correctly regardless from the lighting conditions.

3.8.3 Video Transmitter and Receiver

The electronics used for data transmission together with the **antenna** are responsible for the quality of the video signal and the range that can be covered.

The video caught by the camera is passed to the VTX, which is responsible for the actual transmission through the air. The accurateness with which the VTX transmits the data at the intended frequency is very important as it can prevent the pilot from crashes but this quality is also strongly affected by interference from other sources.

The VRX must listen to the same frequency in which the communication is taking place, in order to be able to capture the oscillation radio waves and convert them into data which can be fed to a screen, according to the PAL or NTSC formats. For this purpose the most popular frequency in video transmission is 5.8GHz [33] as it allows for small antennas.

3.8.4 Antennas

The range and signal strength of FPV systems is strongly defined by the Antenna mounted on the drone. Its main purpose is to convert electrical power into electromagnetic waves and the standard for FPV drones are Circular Polarized Antennas (CP), although Linearly Polarized Antennas (LP) can also be found.

The reason for this choice is the lower sensitivity to "multipathing interference" caused by the noise in the video feed and the higher flexibility in mounting the antenna to the drone as CPs don't need to be perfectly aligned as LPs. The latter design is nevertheless still preferred in some scenarios as they can be made smaller and lighter despite the worse RF performance.

Figure 3.20: Flying FPV with goggles [24]

3.8.5 FPV Goggles

Through a pair of FPV Googles it is possible to observe the live video feed transmitted from the video transmitter connected to the camera on the quadcopter. There are different designs but the low profile format is the most common one as it doesn't simply consist of a regular single screen but instead it features two small LCD screens for each eye, along with a special magnification lens to focus and enlarge the picture.

The measure of how big the FPV screen appears is defined as Field of View (FOV) and it is measured as the angle from the centre of the eyes to the diagonal edges of the screen. It ranges between 25 to 80 degrees, but the sweet spot is around 40° as it offers the biggest screen resolution without the need of moving the eyes to see the edges. The two different **aspect ratios** that are used are either 4:3 or 16:9, and it should fit the same aspect ratio of the camera in order to avoid a squashed or stretched image.

4 Software Overview

The code running on the main microprocessor of the flight controller is designed to tell the drone where to go and what to do according to the pilot's input, but actually, the software stack is much more complex, as the vast amount of data coming from the sensors can be analyzed and processed it in a useful way by a more powerful computational device, either on board or on a server.

In this chapter we will just scratch the surface of the complexity of UAVs software components and get a general idea of how the architecture of such systems is structured, taking two famous open-source suites as reference, namely ArduPilot [1] and PX4 [3].

There are different layers in the software operating in the drones, which are connected in a defined hierarchy so that each part has it's own role, namely the Flight stack and the Middleware.

4.1 Middleware

The component that sits between the physical device and the flight stack is called middleware and it is responsible for sending commands to the motors and handling the most low-level drivers, which communicate with sensors and external peripherals.

Furthermore it functions as an abstraction wrapper for the communication of the most critical data, like gps coordinates, while also providing a "task manager" that keeps track of running processes and a data storage to log essential information.

4.2 Flight Stack

The collection of control algorithms for **autonomous** drones is known as the flight stack. Not all UAVs are meant to be able to fly on their own but it is common to implement useful features such as the **Active Track Mode** to make the quadcopter follow the pilot or the **Return to Home** function which enables the capability to automatically return to a designated point.

In the diagram in figure 4.1 it is possible to see an overview of the building blocks of the flight

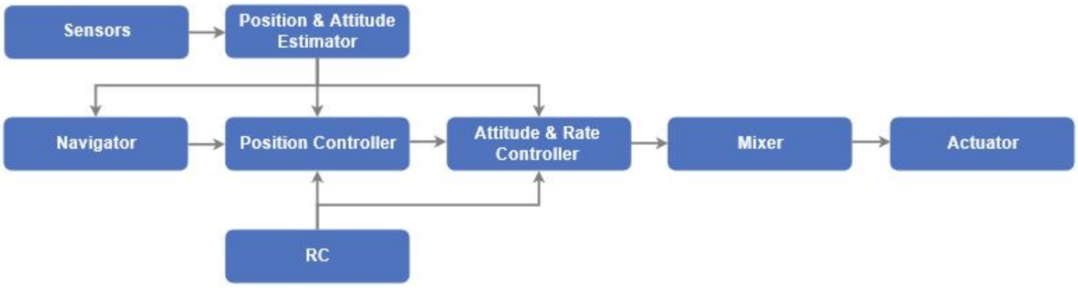

Figure 4.1: Overview of the building blocks of the PX4 flight stack [45]

stack and how they interact with each other. The measured raw data coming from the sensors is taken as an input from the **Estimator**, which is able to combine the data and compute a "Vehicle State", as for instance the altitude of the quad. This package of data is then passed to the **Controller**, who's main goal is to adjust the measured state to a predefined setpoint and calculate what is the correct adaptation to reach the desired condition. The adjustment is finally translated into an action from the **Mixer**, which directly communicates with the actuators, generally the motors.

4.3 Firmware Configuration

In order to flash the flight controller's MCU with the correct firmware it's necessary to download and use a dedicated configurator. There are many players in the game but as previously mentioned, **Betaflight** [2] is the most popular open-source flight controller software used to fly multi-rotor craft and we are going to take it as an example to understand what it can do and how it works.

Nearly all flight controllers on the market run on a STM32 processor and major RC manufacturers are supported by Betaflight, so basically each electrical component mentioned in this paper has some degree of settings that can be customized and personalized, although the most powerful characteristic of a firmware is that most of the generic configurations are implemented out of the box. Furthermore Betaflight implements several safety features to prevent dangerous misuses such as preventing arming when the drone isn't leveled and switching off the vehicle in case of wrong orientation.

Here is a short list of each tab and what can be configured through it:

- **Ports** : Configure peripherals and external devices connected to the flight controller via UART.
- **Configuration** : Adjust many basic settings related to the flight performance such as ESC Protocol, Accelerometer, Barometer and Telemetry.
- **Power and Battery** : Display battery status.
- **Modes** : Set a feature for a specific trigger in the transmitter such as arming the drone or enabling a customized flying mode.
- **Receiver** : Confirm the correct binding of the different channels set in the radio rransmitter. Moving the sticks will result in a change in the corresponding channel.
- **Motors** : Confirm the correct spinning direction of the motors and reverse spin direction if needed.
- **OSD**: Decide which telemetry information will be displayed on the FPV Monitor through the On Screen Display Chip.

4.4 Stabilization and Control Algorithms

One very important feature for a drone is the ability of hovering and maintaining a correct position automatically. This feature is highly affected by the specific characteristic of the vehicle and often neglected in toy drones but it is extremely important for industrial applications, as it sets the difference between a safe flying device and a dangerous one.
Luckily, dedicated firmware such as Betaflight allows **PID control** , which stands for **Proportional–Integral–Derivative** and determines the stability and ease of use of quadcopters.

Commanding a system effectively is the study of **Control Theory**, which is a vary broad subject and for the sake of simplicity, only a basic overview of the involved objectives will be taken into consideration. Practically the Drone is the system that we want to control and what we aim to do is to find the correct input signal, that will produce the desired behaviour.

PID control is a part of the controller software that evaluates the sensor data and drives

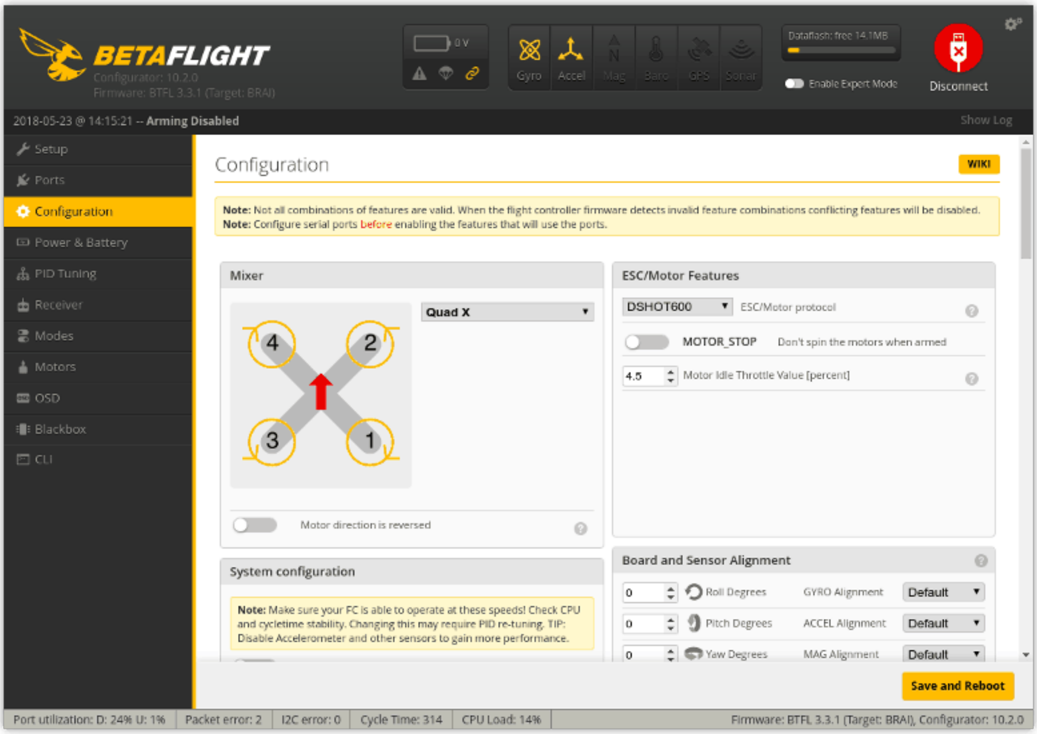

Figure 4.2: Screenshot of Betaflight Configurator after FC connection

the motors accordingly in order to retain the desired speed. It's goal is to minimize the difference between the position measured by the gyro and the desired rotation speed, simply known as the "error".

Proportional gain coefficient

The **P-Gain** stands for **Proportional** and it's the most important regulator. It's a measure of how quickly the FC will react to the pilot inputs, it can in fact be said that it's related to the sensitivity of the transmitter. If this value is too low, a stable attitude cannot be maintained because the controller won't intervene swiftly enough and increase the thrust too slowly, whereas if it's too high, the copter will try to adjust itself too aggressively and switch continuously between standstill and maximum speed, resulting in an undefined behaviour.

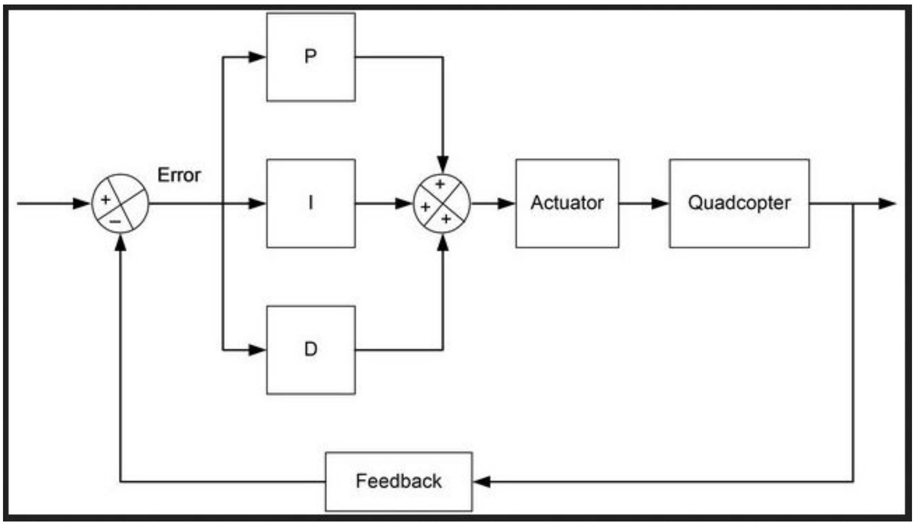

Figure 4.3: PID Control Block Diagram

Integral gain coefficient

The **I-Gain**: stands for **Integral** and indicates the summing of the signals coming from the sensors over time. It's a measure of how hard the FC will work to hold the drone's attitude against external forces such as wind.

Derivative gain coefficient

The **D-Gain**: stands for **derivative** and it's not always present in flight controllers as it's considered a final touch to the tune. It works to counteract the over-oscillations of excessive P gain and is generally used to compensate the "prop wash oscillation", which is the turbulent air created on the backside of a spinning propeller

The error is optimized recursively in every **loop**, which is the lapse of time between reading sensor data and calculating the adjusted output. The amount of "loops" per second is known as "**Looptime**" and can reach up to 32KHz, although a faster value is not always synonym of a better performance.

Taking everything into account, the tuning of a rotor vehicle is not an easy task because of its complex nature, and given the many techniques that can be used to tune the perfect PID for a specific configuration, there is no solution that works for all drones as it is highly subjective. Only trial and error over time brings the optimal result.

4.5 Flight Simulators

Investing some time in learning how to fly a quadcopter exactly like aeronautical and military pilots do is extremely important and worth of mention. Simulators are software programs meant to recreate the experience of flying a drone in a specific flying scenario and are a requisite for applications which require a high degree of safety. Prior experience with a simulator is also a requirement for drones heavier than 250g by the German Federal Ministry of Transport and Digital Infrastructure [41] among other countries.

Attempting to flying a drone without prior experience in a simulator can often result in

Figure 4.4: DJI Simulation Software [14]

a quick crash followed by a high repair cost, which could be avoided by a few dollars investment in a simulator, which allows for unlimited virtual repairs and the basic instruments required to become a expert pilot. Software such as **LiftOff** or **Velocidrone** can help get confidence with tricky maneuvers in tight spots, which would result in a higher precision and confidence when flying in real life so the effectiveness is definitely undoubted.

Advanced Flight simulators feature accurate physics and multiple Flight Modes as well as different Point Of Views. Another feature that can be found on a simulator is the "comprehensive physics engine" to replicate the feeling of real flight and realistic flight experience featuring wind effects and simulated crashes.

5 Drone Applications in the Corona Virus Crisis

Digitization and automation have been buzzwords in a lot of industries in the recent years, but the healthcare sector is more conservative and tends to take more time in adapting to new technologies given the high safety concerns involved. Nonetheless there are quite a lot of processes that could be improved by technology, and drones have demonstrated to be appropriate candidates for addressing some of the common health issues.

Quadcopters have been used in all kinds of ways to tackle the current pandemic. Some of the main applications were already active way before any virus was spreading around the world but generally speaking the industry received a boost, with more and more people trying to bring to the table a solution which could save lives and become profitable. The purpose of this chapter is to research the best use of this technology in four main areas : **Aerial Disinfection**, **Temperature Scanning**, **Surveillance** and **Medical Delivery**.

Emergencies create space for innovation and people start being proactive to feel a sense of purpose by applying technologies to a good use. The opportunity of being able to fly a device to transport objects, transmit information or even "spray disinfectant" without ever leaving home can be quite attractive when millions of people can't do anything but stay at home.

This goodwill though can have little to no impact if not applied properly and at worse, it can cause more harm than good. It is therefore important to look at both good and bad scenarios.

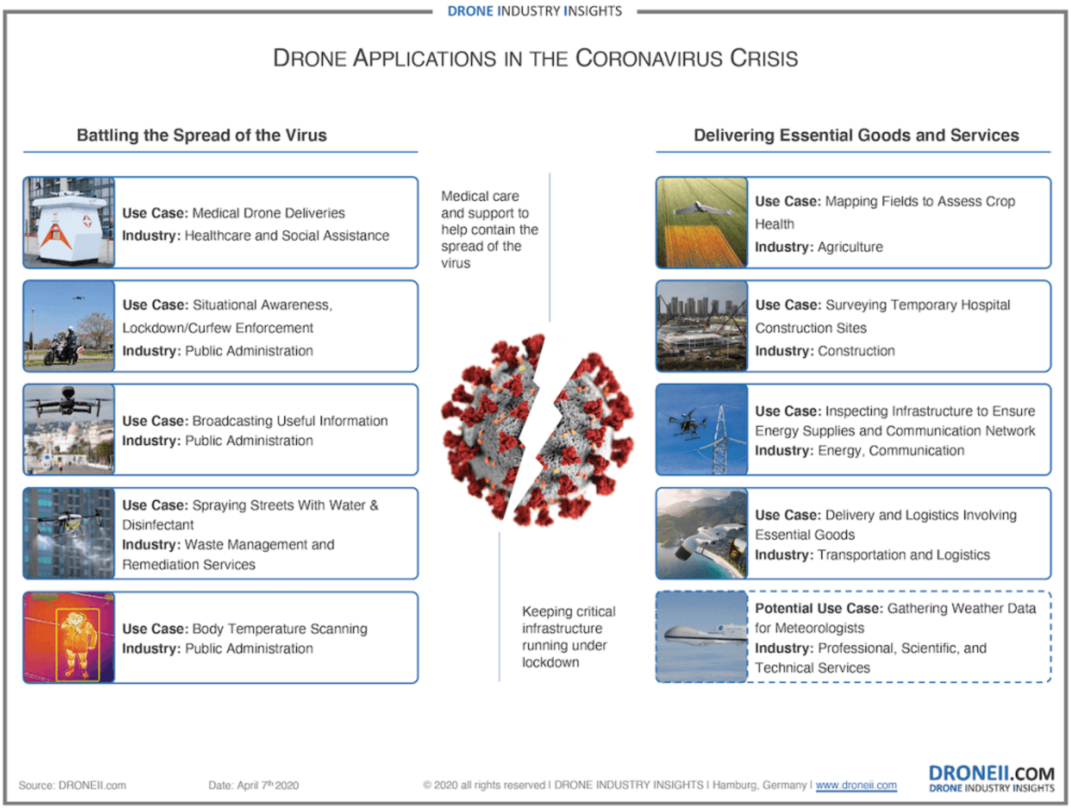

Figure 5.1: Drone Applications in the Corona Virus Crisis [28]

5.1 Aerial Disinfection and Spraying

One of the safety measures that has been put into place since the beginning of the pandemic is the **disinfection of public and shared spaces**. It has been proven that disinfecting commonly touched surfaces in hospitals, schools or elsewhere can help kill germs [48] but there is still a big debate regarding the use of spraying sanitizing solutions into the air against Covid-19, which has led many experts to doubt its effectiveness [30].

Independently from medical purposes, drones have been strongly employed in recent years to spray fields, so that it would be relatively easy to switch from herbicide to sanitizing spray. Agricultural drones are almost fully autonomous thanks to the steady improvements in automated driving and they can be easily adapted to meet the urgent need for rapid and thorough disinfection. Compared to manual spraying, these smart devices can protect operators from unnecessary exposure to viruses and disinfectants but it is yet to understand how effective can drones be in sanitizing outdoor areas.

They can definitely cover large regions safely, as well as targeting a specific area where

Figure 5.2: DJI Agras Spraying [53]

a precise spot spraying and deep cleaning have to be undertaken, but then due to battery limitations, they are unlikely to fly for more than 20 minutes without recharging. Nonetheless using a small fleet of drones it is possible to disinfect thousands of square meters in one day, a task that would normally require a vast work-force to complete. Moreover, with the ability to precisely control the sprayed output, they would consume much less disinfectant than the traditional approach of manual spraying.

For instance, in February the Chinese agricultural tech company **XAG** set up a 5-million-yuan special fund on Coronavirus response [37] , calling for drone disinfection operations in China, and in March the Harper Adams University in the UK started cooperating with them for researching disinfection operations to fight the spread of the disease. [44].

According to the XAG, high concentrated disinfectants are more effective through drone spraying [54]. When ejected from the drone nozzles, the disinfectant is diluted with moisture in the air until it falls onto a surface to create a virus-free environment. In addition to their improved spraying performance, drones can follow police and medical personnel on duty to disinfect vehicles such as ambulances, moving between affected and unaffected areas.

The main obstacle to aerial spraying disinfection in Europe is that it is banned by most countries within the EU, although there is an exception to be made with Spain, which has been the first European country in attempting this approach [39], where the Military Emergency Unit has deployed agricultural drones to spray disinfectant around large outdoor areas as well as inside large vehicles using both DJI's AGRAS MG-1 and the DRONEHEXA XL by Spanish drone maker DroneTools.

Another similar attempt has been advertised by the American company **BE Aerospace**, which claims to have developed a drone that can fly into tight spaces and use ultraviolet wavelengths to kill germs that routine cleaning can't. [8]. It is an accepted truth that UV light kills germs but it is still up for debate if Covid-19 can be affected by it and if yes, how long should the exposure to the light be.

In consonance with the mentioned examples, it is still too early to state that spraying drones can be adequate at aggressively impacting the transmission of the disease in large areas as more testing is needed. Nonetheless this approach can be quite useful in specific environments, such as large hospitals and health service institutions, where the amount of infected people is unequivocally higher and a profound disinfection is needed on a regular basis.

5.2 Temperature Scanning

In order to understand if temperature scanning through drones can really be effective, it is useful to have an Idea of how thermal energy is detected. In contrast to the human eye and regular digital cameras, which use a detector to receive the visible **light energy** and turn into an image, thermal scanners make pictures from infrared or **thermal energy**, commonly known as "Heat". Both types of energies belong to the electromagnetic spectrum but the detectors used to capture them aren't the same as they sense energy with different wavelengths, which are much larger in the case of thermal energy, up to around 14,000 nm.

Thermal cameras make use of a **thermal imaging detector** to look for small differences in thermal radiation and the measure used to define when a detector has reached its limit to resolve a thermal signal is the **Noise Equivalent Temperature Difference** (NETD), which is equivalent to the smallest measurable temperature difference not affected by noise. Tipically expressed in milli-Kelvin. In order to read temperature values from an Infrared Image it is first necessary to transform into a radiometric one through IR thermography, and use an artificial color mapping such as shades of grey or different color palettes.

With this knowledge in mind it is now interesting to understand what is the **range** at

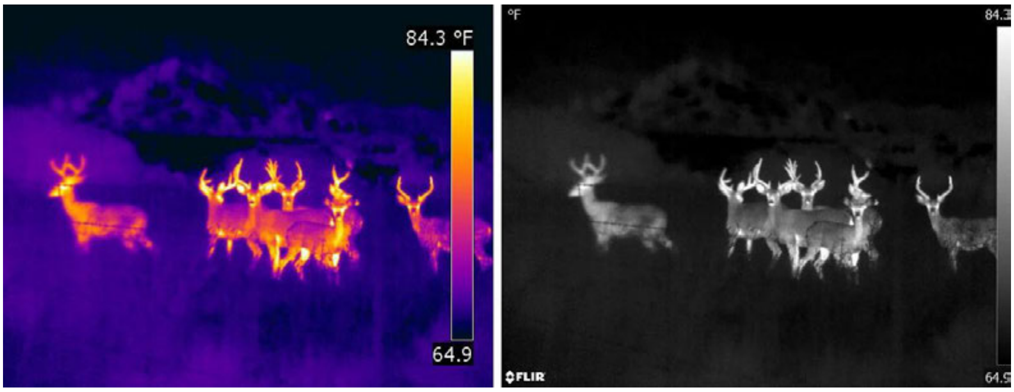

Figure 5.3: Heat differences displayed in different color palettes [18]

which a thermal camera can effectively distinguish between two slightly different body temperatures. According to the Drone Potential Use-Cases for COVID-19 published by DJI, a reliable reading can only be measured at **less than 2 meters** away from an individual, which would make this solution useful only in the context of a line of people queuing, where the Drone can actually fly over everybody at a close proximity. On the other hand the industry-leading manufacturer **Draganfly** claims to have developed a thermal scanning technology that can accurately detect infectious conditions from a distance of 58 meters [27].

One important consideration to be made is that independently from the actual range of action of the thermal scanner, which still has to be confirmed, a high forehead temperature wouldn't necessarily imply the presence of Covid-19 in an individual, as other effects such as coughing or sneezing have to be taken into account. For this reason Draganfly has partnered with **Vital Intelligence Inc.** and the **University of South Australia**[27], to combine their sensors with a computer vision system that makes use of deep learning algorithms in combination with healthcare data to detect people sneezing and coughing in crowds as well as displaying respiratory rates.

One such experiment with Thermal-scanners mounted on a drone to check the temperature of people took place in Treviso, Italy by the local police who decided to use a DJI Mavic aircraft to screen the health of citizens in public areas. [4]The drone, from a height of 20 metres, should supposedly be able to detect the temperature of all the people in the same area, so that any person with fever could be stopped by the agents for further diagnostic testing. The commander of the police finally specified that they are still in a testing phase waiting for the necessary authorizations but this didn't stop the public opinion to ignite a debate about privacy implications. Other such experiments have been reported in New Delhi [40] and China [38] , where local authorities have begun to test fever-detecting drones for mass Covid-19 screening.

Unfortunately, despite a lot of hype, there's almost **no evidence** that these fever-detecting drones actually help in getting information about the spread of Covid-19. The studies published by Draganfly have all taken place in controlled settings and they haven't released any reports to independently assess if this technology can really capture the population's health data, so that this might be just another example of companies releasing untested technologies after a disaster under the claim of not having enough time.

The development of drones equipped with thermal cameras might not be extremely helpful for the current epidemic, but it's a good timing to start researching this technology as it's already widely used in fields such as building Inspection and firefighting.

5.3 Surveillance and Lockdown enforcement

When the Chinese government imposed the first lockdown on earth on the 23rd January 2020 in an effort to quarantine the center of the outbreak, the rest of the world reacted with fear and partly condemned the adopted strict measures. It was only a matter of time before many other countries realized the need of such restrictions and followed suit, gradually leading billions of people to stay at home in order to avoid contact with others.

Social distancing was among the first measures adopted and it's also the most effective, as Covid-19 mainly spreads among people who are in close contact for a prolonged period of time, nonetheless it hasn't been an easy task for politicians to convince civilians to actually respect the imposed measures and law enforcers started to get creative. In this context, drones have emerged as one effective way of **tracking gatherings** and intimidating people to disperse, but the huge privacy implications combined with the unwillingness of people to undertake restrictions have resulted in the necessity of rethinking social laws.

In order to surveil large crowds and be able to distinguish among a group of widely spaced

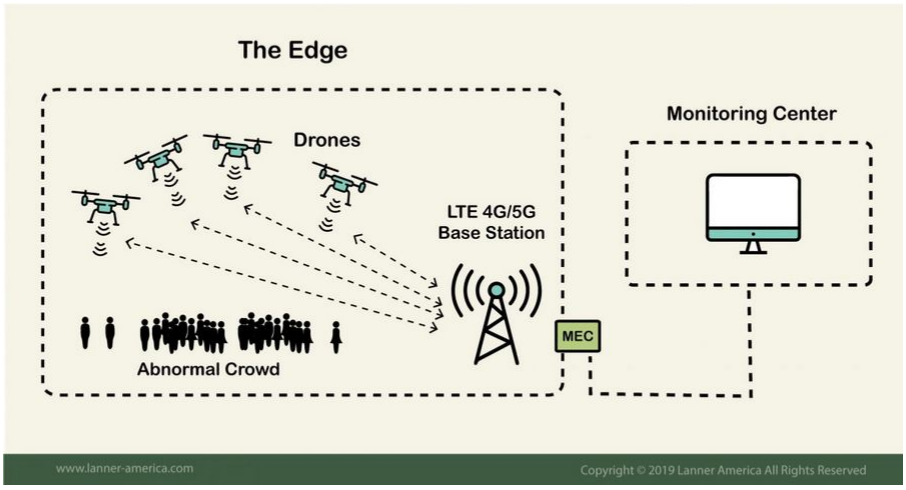

Figure 5.4: Drone for Crowd Analysis [6]

people and a packed place, drones have to be equipped with **high-resolution cameras** implementing computer vision technology for "**Real time crowd analysis**", which can analyze the camera video feed and the data captured by the sensors to extract useful information about the unique number of people and their behaviour in a confined area.

Image processing has received immense attention due to large scale applications in safety monitoring and although many sophisticated algorithms have emerged in the last few years, crowd management in real time conditions is still a challenging problem. In a nutshell **Crowd analysis** attempts to interpret the behaviour of human groups and their movement patterns looking for things such as crowd density, unique people count, gender distribution and emotion recognition through the use of AI-based algorithms.

Supposing that drones can be equipped with such image-detecting technologies, they also have to be able to convey the message to the public, which means they need a loud-speaker capable of playing custom voice recordings or even a real-time audio feed. Although this approach could be helpful for reaching certain areas where access by patrol cars is more difficult or maybe refugee camps, where people might not even be aware of the most recent developments, this technology might end up having the opposite effect : drawing crowds of curious people to gather, or worse, create a dystopic scenario which wouldn't reassure citizens.

Such experiments first took place in China [34] where UAVs were used to patrol a 10 square kilometre urban area in an hour, saving the work of more than 100 police officers in dozens of patrol cars in the city of Shenzhen. The same approach has been documented in various US states, where quadcopters have become part of the local response to the pandemic to reinforce social distancing.

To summarize, there are heavy concerns that surveillance drones could really be effective for the current scope and the public is afraid that such invasive technologies could persist even beyond the end of the pandemic. It would be understandable for the authorities to use aerial surveillance measures only in specific contexts where other alternatives such as ground patrolling wouldn't be feasible.

5.4 Medical and cargo deliveries

Frequent supply challenges caused by poor transport networks, extreme weather conditions, natural disasters or traffic congestion in urban areas could be solved through delivery by drones, which can potentially overcome the logistic issues of ground transportation as they are not subjected to traffic delays, and most importantly, they are able to reach regions that lack adequate roads.

Using cargo drones to deliver essential medicines and collecting patient samples for Covid-19 testing is being widely promoted around the world. Countless startups are working to push innovation and the use of drone delivery technology to make a positive impact globally, but the speed of its adoption is slowed down by the lack of regulations around drone flight. There is not a worldwide agreement for cargo delivery and in certain countries it is even considered illegal under all circumstances beside military purposes [17].

Delivering pizzas using UAVs doesn't really sound revolutionary but setting up effective flying medical deliveries would be a game-changer that opens a broad variety of possibilities. Although the technology is already there [26], it's still taking a significant amount of time for drones to take off given the safety implications and the high quality standards [46]. The delivery of fragile medications or blood would be practical only if the quality of transported products is not adversely affected. Thus, drones as a method for medicine transportation, must be tested to determine their impact on medicine quality.

The pandemic is not a typical emergency and may serve as an added push, in September 2020 Walmart has been granted permission by the FAA to start testing drone deliveries for household goods and groceries [51] and it's just matter of time before other companies reach the safety standards and get the same approval.

Items such as blood for transfusion, organs for transplant and clinical samples for testing and pathology are among the most needed ones and as many hospitals have been decentralised and facilities have expanded into different areas, the logistical requirements for this materials is an ever-growing challenge. The vast majority of these items need to be stored at a specific temperature and factors such as vibration during flight, changes in pressure or humidity also add up to the equation.

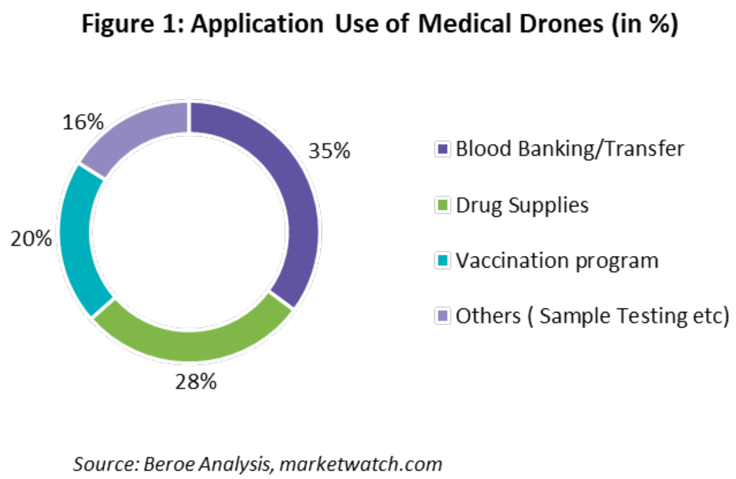

Figure 5.5: Application use of Medical Drones [26]

A recent research tested the impact of drone transportation of medicines and found no evidence of adverse impact on Insulin [35]. The study took the effects of temperature and vibration into consideration and proved that this method of transportation is feasible. Insulin is an important medicine and also a good test case, but at the time of writing this thesis there are no pharmaceutical products that have been shown to be safe and effective for the treatment of Covid-19 [42], so a higher number of medicines should be tested to jump-start the delivery once a cure or a vaccine is ready.

The study also proposes a set of other medicines that make good candidates for delivery by drone, such as adrenaline and vaccines for local outbreaks of disease but again, a wider data set is needed to accurately measure the safety of drugs delivery.
Furthermore a set of five parameters that should be tested when trying the same experiment on another medicine is proposed:

- Safe flight time and range
- Quality of the medicine post flight
- On board conditions experienced by the medicine
- Security of the drone supply chain

- Effect of drone failure on both the medicine and the environment.

Taking a look at concrete examples it has emerged that the market of drone services for medical deliveries is still small and the biggest provider is the American **Zipline**, which has made more than 66,081 [55] deliveries up to date and has partnered with United Parcel Service to build a drone network to allow 50–150 daily deliveries of blood and vaccines to 20 clinics in remote areas of Rwanda. Two other big players are the American **Matternet** and the German **Wingcopter**, which have respectively provided direct aid to the population of Haiti following the earthquake in 2015 [10] and delivered blood samples in Tanzania [29].

Medical delivery is definitely the most mature application undertaken by quadcopters as it has been researched for years. During the pandemic even more benefits have emerged, such as delivering patients sample to testing labs for faster screening and treatments, but there are still high barriers imposed by flight regulations, which slow down the adoption in healthcare.

Ultimately, there is one more important problem that has to be addressed, and that's how to

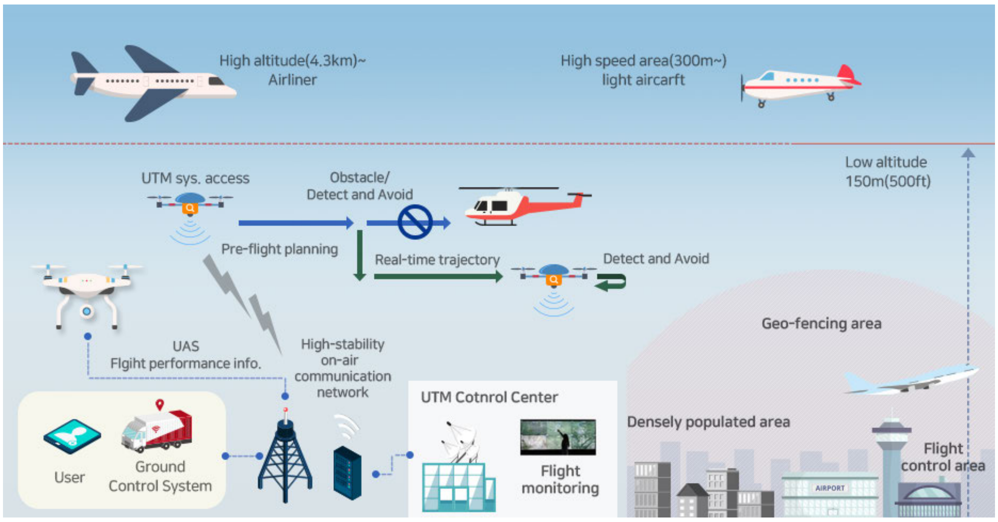

Figure 5.6: Drone management system. [5]

properly handle the aerial traffic caused by multiple drones flying in the same area. Exactly as it happens for commercial aircrafts, an unmanned traffic management platform has to be developed to allow UAVs to navigate around each other, avoid obstacles such as power lines and possibly sidestep areas trafficked by civilians. All these complications pose a challenge to a swift success of medical delivery services, but on the other hand they also open further opportunities.

6 Conclusion

The fundamental objective of this project has been to provide a guide for building a quadcopter from scratch, looking at each single unit in detail and researching how drones have been used for addressing healthcare issues related to the global epidemic caused by the SARS-CoV-2 Coronavirus.

First of all the document presents a short theoretical explanation of the basic flight dynamics principles of quadcopters coupled with the actions that can be carried out by a drone. The mathematics involved in aerodynamics can get quite complex and for this reason only notional concepts have been illustrated as they would have exceeded the pragmatical scope of this study.

After a generic introduction, the focus of the research has zoomed into the electrical and mechanical parts within the assembled system, in pursuance of understanding the behaviour and functioning of each single component on its own and how multiple modules can talk with each other through specific communication protocols.

During the development of the various chapters, it has emerged that every component has specific characteristics, which can be tweaked and adjusted to fit a targeted application, as there is not a solution that fits all scenarios. Given the high number of electrical components containing a cascade of embedded "subsystems" and the complexity of the topic, some generalizations had to be made for the sake of simplicity, although when possible, the historical technical development of UAVs technologies has been exposed to provide a more conscious understanding of the current state of the art.

After focusing on the hardware with so many details, it has been essential to take a look at what kind of software allows the drone to take off, be piloted, and even fly on its own. In the interest of brevity, the research conducted on the architectural structure of the code running on the main MCU of the flight controller could only barely scratch the surface of the intricacy of such systems.

The main takeaways are that, the program running on the embedded system is the backbone of the athletic power of the quadcopter, but what actually sets the difference among different UAVs is the processing of the data coming from the sensors, which has a huge potential for improvement given the countless number of features that could be added.

With a solid technical knowledge of the main characteristics and limitations of quadcopters, it has been possible to dive into the vast number of applications in healthcare, taking real world examples as evidence of a transformation that is already taking place, and has only been accelerated by the current emergency. The research could in no way analyze all the possible employments of unmanned flying vehicles in the world, so it has been attempted to provide a countermeasure to the most pressing tasks, such as how to slow down the spread of the virus among individuals and how to deliver essential goods, amid the largest lockdown that the world has ever seen.

Providing an answer to such critical dilemmas is not trivial, but it can be inferred that drones and robotics in general, will play a crucial role in holding down the escalation of diseases around the world, by replacing humans in dangerous tasks that have proven to be harmful. As if often happens for technological advancements, there will be unpredicatble disruptions in the way people work, but on the long run robots and machines in general have to be designed to free people from hazardous burdens and let us focus more on human to human relations.

In multiple cases it has also been shown that improper uses of UAVs can do more harm than good, and that there are only specific scenarios where they should be used under certain safety measures.

Last but not least, it could be seen that there huge privacy implications which must be taken into account before undertaking surveillance inspections. People in general do not like to feel watched by flying devices and the public opinion wants to make sure that this technology is well regulated and not used on a continuous basis, but only for emergencies and unambiguous necessities.

Taking into account all the retrieved information and putting in balance the advantages of using quadcopters for improving the healthcare sector and the challenges posed by such a newborn technology is both intimidating and exciting, but in my opinion, the shift to automation has already started to pervade most of people daily lives and it is extremely important to continue researching this scientific achievement using a technical approach coupled with an ethical framework for the benefit of society at large.

7 Acknowledgments

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I wish all my Italian friends from Montecchio and Pesaro were here to celebrate this milestone with me.

Gianluca Veschi

List of Figures

Glossary

CP Circular Polarized Antennas. 31

FAA Federal Aviation Administration. 47

FC Flight Controller. 9

FOV Field Of View. 32

FPV First Person View. 30

LOS Line Of Sight. 30

LP Linear Polarized Antennas. 31

MCU Microcontroller Unit. 9

PDB Power Distribution Board. 11

PID Proportional, Integral, Derivative. 35

RC Radio Controlled. 9

UAV Unmanned Aerial Vehicle. 1

VRX Video Receiver. 30

VTX Video Transmitter. 30

WDR Wide Dynamic Range. 31

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I hereby assure that I have written this work without any help from others and that I have only used the given tools.

[redacted]

Hamburg, November 23, 2020 Gianluca Veschi