BACHELOR THESIS

Autonomous quadcopter
for noninvasive wildlife surveillance
and analysis

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Abstract

Gathering environmental data presents a difficult challenge for conservation ecologists. The impracticality of placing or retrieving sensors, camera traps, and various other electronic devices in the field, sometimes renders projects hard to tackle.

An unmanned aerial vehicle equipped with appropriate sensing devices for acquiring environmental data could help solve this problem.

This thesis describes such a drone, from concept to implementation, and is accompanied by a practical project consisting of a functional prototype.

Keywords: drone, quadcopter, data acquisition, surveillance, ecology
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Chapter 1

Introduction

1.1 Motivation and objective

There are many long-standing problems looming over ecosystems all over the world. From land degradation, to resource depletion, to poaching and pollution, it is clear that human impact on the environment is a significant and urgent issue to tackle. Since human intervention is responsible for the creation of virtually all these threats, it is therefore due for human intervention to undo the damages and prevent any further hazards. In the relatively recent past, several decades ago, we lacked the support of high-tech developments to aid in these endeavours. But with today’s advances it is a safe bet to say that, given technology’s prevalence in virtually every field of activity, it is bound to continue emerging and to make a difference in ecology and conservation as well.

Thus, the motivation behind this project is to present a new, better solution to an existing set of ecological problems – specifically in the context of data acquisition. This can be achieved by bringing the invaluable help of cutting-edge sensing devices and recent drone development into the efforts of conservation, with the goal of eventually solving the predicament that the environment is currently in.

This thesis will focus on the practical aspects of implementing an unmanned aerial vehicle, in the form of a quadroto helicopter, or quadcopter. The first
Chapter introduces the issue that the project endeavours to tackle, the set of problems that it would solve, and also presents a brief overview of drone development. Chapter two examines any similar pursuits, both in the sense of drone usage in the field of ecology, and in light of current cutting-edge technology employed by aerial robotics. The third chapter describes the design specifications of the quadcopter proposed by this thesis, essentially what the end product should be able to accomplish. Chapter four details each module that makes up the drone, and the way in which all modules interact to shape the final device. In the fifth chapter, the actual step-by-step process of implementation is presented, elaborating the stages of development through which the practical project went through until completion. Chapter six evaluates the quadcopter in order to verify whether all the design goals were correctly met, and chapter seven examines any possible improvements and future work on the project. Finally, the last chapter draws conclusions that follow from the thesis, focusing on the author’s own innovations and contributions to the topic.

The objective of the practical project is to design and construct a quadcopter, that serves as a hardware base for acquiring environmental data through innovative and minimally intrusive methods. Its functionalities make it suitable for remote sensing and surveillance, specifically developed to focus on tasks within an ecological context. The finished drone allows biology and ecology specialists to gather more environmental and wildlife data than they are currently able to. A wide range of on-board sensors facilitates measuring relevant parameters such as temperature, humidity, sunlight, air quality, and noise. Additionally, the presence of a camera opens up the possibilities of image analysis to track down wildlife or to examine certain terrain or vegetation characteristics. Thus, the drone facilitates access to data that was previously unavailable due to either fixed or ground-based sensing devices. Interpreting this data could lead to meaningful conclusions and solutions to existing ecological problems, which is, in the long run, the motivation behind this project.

1.2 Practical considerations

To acquire data, the quadcopter will be equipped with a variety of sensors, depending on the purpose of each particular application. For example, a camera enables simple visual surveillance or image processing, chemical sensors
help detect concentrations of elements in the air, a thermometer and a photosensitive cell observe current weather conditions, a small microphone detects any potential noise pollution. As far as area coverage goes, the drone will be able to travel considerable distances from its transmitter, up to 750 meters. There is little concern regarding interference with other nearby devices, since the target operation area is expected to be remote and uninhabited.

In the future, the quadcopter will also be capable of locating itself globally via GPS, and locally, relative to its surroundings, via distance sensing technology. It will be able to relay its data wirelessly to a server, in order to lower on-board memory requirements and to reduce the risk of corrupting or losing acquired data in the event of an unsuccessful flight, malfunction or accident.

An observation that could lead to further improvements once the drone is constructed, is the following: some sensors don’t necessarily need to attach to the flying platform itself. An interesting way to enhance the rate and quality of data acquisition – especially in this particular case, environmental and wildlife analysis – would be to augment the quadcopter with a wireless device. This could serve as a central hub for an entire set of wireless sensing devices placed in relevant locations (such as small trackable chips or collars worn by animals, or temperature/humidity sensors scattered across a key area).

Overall, this thesis aims to lead toward future developments in using aerial drones in the fields of ecology and conservation. UAVs have the potential to unlock research possibilities previously unavailable due to various impediments – a quadcopter can perform tasks which to humans would be, for various reasons, impractical: tackling rough terrain, non-stop availability, avoiding or being impervious to danger.

Some very basic examples of drone missions include surveying wildlife population movement of one or more species (see figure 1.1 and figure 1.2, respectively), investigating landscape changes, preventing poaching of endangered species, and essentially any situations that benefit from the existence of an extra "eye in the sky". Due to the nature of the sensing technologies used, successful operation is entirely irrespective of potentially limiting factors like lighting conditions, time of day or night, ambient temperature, or ground-level danger. Thus, employing a UAV for such tasks is clearly superior to placing human workers in risky situations unnecessarily.
Depending on the types of data chosen to be acquired, there are quite a few different practical applications to explore:

- Simple monitoring of species population fluctuation over time
- Monitoring population over time, but while also keeping track of other factors, such as weather and other environment characteristics; determining the connection between external factors and population fluctuation
- Keeping track of wildlife via fur pattern recognition – this topic would require considerable efforts of image processing
- Tracking movement of herds or individuals, according to patterns such as migration or mating seasons; noticing changes in these patterns and investigating the cause
- Individually tagging each member of a group of animals, and observing behavioural patterns and social relations between individuals
- Mathematically modelling the evolution of a population, and comparing the model to the actual population being currently monitored
- Investigating and proposing solutions to existing environmental issues – for example: regions such as Busteni and Brasov are currently experiencing a severe problem regarding the local bear population, that
has grown unafraid of humans and ventures further and further into inhabited areas in search of food. Perhaps a closer inspection of their movement and eating habits using this project will yield peaceful solutions to the issue.

While this is a list of possible ecological topics to be approached, their actual algorithmic implementation is beyond the scope of this thesis. As previously stated, the thesis will tackle the practical approaches of physically constructing a functional quadcopter that would be fit for acquiring the environmental data necessary for the aforementioned tasks.

Figure 1.2: Surveying the movement of multiple species – wilderbeast and zebras, Maasai Mara, by Wildlife Photography Africa

1.3 Unmanned Aerial Vehicles

Unmanned Aerial Vehicles, also known by the name of drones, have long been used for military purposes (see figure 1.3), initially introduced to deal with situations too risky for a pilot to undertake. However, there has recently been a noticeable rise in the number of such drones, self-piloting as well as remote-controlled. Extending some of their functionalities from the military
field, UAVs have found a place in the ranks of civil emergency services, such as police and firefighting departments. They’ve also become more and more popular as commercial (non-military) mobile surveillance units. Hobbyists have been reinventing and customising their designs and functionalities to their own personal needs. Drones have even begun to take a rather artistic turn, since their use in film-making and aerial photography. Truly, there is a remarkable number of possible practical applications for what is, essentially, an airborne computer. From carefully targeted search-and-rescue, to exploration of uncharted areas – and from armed military attacks to conservation efforts – UAVs are increasingly prevalent, and their involvement in more and more fields is to be expected.

Figure 1.3: Example of a military UAV – MQ-9 Reaper in flight, USAF Photographic Archives

The first recorded historical reference to unmanned flight belonged to Nikola Tesla. In 1915, he described the concept in his dissertation, imagining a fleet of armed aircraft that operated without a pilot, created with the purpose of defending the United States in the event of an attack [1].

Taking matters one step further, engineer Archibald Low developed the "Aerial Target" project for the English military in 1916. The aim was to control an aircraft remotely, in order to pave the way to guided missile development. However successful, the project was cancelled at the end of World
War I, thought to no longer be necessary.

As is the case with many technological advancements, the military continued to be the only forefront of UAV research for a while. This is due partly to the obvious practical applications of such a device during wartime, such as espionage, remote attacks, and guided missiles, as well as to the onset of World War II which demanded that scientists and engineers work mainly on military projects. Both sides of the war are known to have used early versions of UAVs, and it is worth noting the US Army’s interest in the Ryan Aeronautical Company – this firm has successfully produced the first jet-propelled target drone series, called "Ryan Firebee".

Further armed confrontations throughout the following few decades, such as the Vietnam, Lebanon, or Gulf war, have seen additional developments aimed at drone autonomy, mainly to spare the lives of fighter pilots. Israel’s military was the first to perfect UAV real-time surveillance technology – this trend soon caught on, since surveillance is not necessarily an act of war, and proves particularly useful in defence and prevention of conflicts. This less aggressive direction of drone usage has continued to gain ground – the US developed, among other models, the Predator UAVs in order to aid them in confronting terrorism, and they have met with considerable success.

All these advancements leading up to the present day have seen more and more of the world adopting drone technology. As of February 2013, more than 50 countries employ UAVs for various purposes [2].

While there is no universally accepted classification of drones, there are a number of arguably useful ways to categorise them. Of these, it is worth noting the following: flight type – in the sense of lift and navigation; degree of autonomy – or level of intelligence; purpose – for those with specific usage; and US air force classification – in a system of tiers.

By flight type, drones can be split into:

- Fixed-wing aircraft – Lift is dependent upon the wing shape, and is generated by the vehicle’s forward speed. All aeroplane-like drones fall into this category, and they present a number of different types of propulsion, such as propellers, jet engines, or electric motors.
- Rotorcraft – Generates lift using rotor blades revolving around a mast. Depending on the number and placement of the rotors, these drones can
be one of two major varieties. Helicopters have one or two main rotors along with smaller stabilising rotors, and multicopters have several – they can be tri-, quad-, hexa- or octocopters, and the most prevalent are the quadcopters, visible in figure 1.4.

![Existing quadcopter models – IC01, TBS Discovery, DJI Phantom](image)

By degree of autonomy, two main categories arise:

- Remote-controlled – Such types of drones are under the direct and permanent control of a human operator. The remote command station establishes a constant data link with the UAV, sending orders and receiving feedback.

- Autonomous – These UAVs can act independently, according to the way they were pre-programmed, and require no further human intervention over the duration of their mission. In the field of robotics, autonomous drones qualify as intelligent agents. The principle of operation revolves around the interaction between the agent and its environment, interaction called "the perception-action cycle". The drone perceives the state of its surroundings with the help of sensors, takes decisions according to the control policy, and carries them out using its actuators. An example illustrating this cycle: the GPS reading pinpoints the drone’s current position; the control program detects that a checkpoint has been reached, and decides to head back to base; the device uses its motors to steer in the direction of the base.

According to their specific purpose, drones fall into one or more of the following categories:
• Sensing – Meant to gather raw data, this type of drones are equipped with a broad array of sensors according to their specific application: anywhere from biological, chemical, electromagnetic (mostly visual and infrared spectrum), and gamma ray sensors.

• Surveillance – Equipped with cameras to capture images and video footage, these UAVs serve to monitor large areas where it would be impractical to install many fixed ground-level cameras – in areas such as forests, roads, or farmland.

• Exploration – Due to eliminating the risk of placing human life in danger, drones are very useful in exploring unsafe or inhospitable territories – such as catastrophe sites, combat zones, deep sea or outer space.

• Transport – UAVs can generate sufficient lift in order to carry not only their own weight, but also certain payloads attached to their frame. While this has a visible impact on power consumption, it is still a practical way of quickly dispatching supplies to otherwise inaccessible locations.

• Combat – Since drones were initially thought-out as guided missiles, and soon after, as replacements for piloted fighter jets, it is no surprise that the military continues to develop and use them for these purposes.

• Search-and-rescue – This practice is characteristic to disaster zones, where access is limited and time is of the essence. Drones equipped with, for example, heat sensing cameras, could help detect trapped earthquake victims much quicker than the emergency services would normally take – thus increasing the number of survivors.

• Conservation – This is a relatively new field of UAV usage, a field which this thesis will focus on. Efforts are being made especially in protected areas and endangered species’ habitats, in order to prevent poaching. Drones are also useful in monitoring wildlife for research purposes, to be able to develop better conservation tactics.

The US Air Force has come up with its own classification of UAVs, by dividing them up into a system of tiers. A simplified version of this specification would be the following:

• Micro – The smallest in size, and most portable type of drone
• Low-altitude – Larger, and exhibit longer endurance

• High-altitude – Mostly the same as the previous category, but designed for operation at high altitudes

• High-altitude, low observable design – Stealth versions of the high-altitude drones
Chapter 2

State of the art

2.1 Drones in wildlife conservation – overview

Only recently, in the past year, projects involving UAVs in environmental activities have begun to appear. The following paragraphs present three such occurrences, all of them employing model aeroplane-like drones.

There are scarcely any instances of quadcopters used in conservation efforts, most likely due to the ease with which aeroplanes are constructed and used. However, it is arguable that their introduction would benefit both existing and future projects in this field. The complexity involved in building and piloting quadcopters is offset by the advantages that make them more suitable than existing drones – especially for tasks such as surveillance of endangered areas and wildlife, gathering measurements of different types of environmental parameters, and having a higher degree of aerial stability and maneuverability.

2.2 Nepal

In June 2012, WWF (World Wildlife Fund) Nepal have successfully developed and deployed two model plane-like UAVs in Chitwan National Park (see figure 2.1). The main issue to be addressed by them was the protection of species in
critical danger of extinction – namely, rhinos and tigers. Initially introduced to assist the park’s rangers in tracking down and apprehending poachers, the drones have also been assigned for wildlife surveillance, and gathering various data considered useful for conservation. There are also plans to use the same drone model for similar purposes in Tanzania and Malaysia [3].

Figure 2.1: The Conservation Drone deployed in Chitwan National Park - photograph by WWF Nepal

However capable of following a pre-programmed flight path, the aeroplane-like structure of the drones limits their agility and movement capabilities, and wholly prevents them from coming to a halt or turning around – these maneuvers are certainly advantageous, for example in order to zoom in on a newly discovered problematic area. These are setbacks that a quadcopter-type drone could alleviate.

Another point to make note of is the Nepal drones’ cost: although marketed as "low-cost" at 2500$, this only holds true because there are scarcely any other UAV models designed for this purpose. A quadcopter such as the one described in this paper could accomplish all the required tasks for a tighter budget.

2.3 WWF’s Google Grant

In December 2012, Google’s Global Impact Award programme offered a 5-million dollar grant to WWF, to aid the organisation in its global fight against poaching. The grant is meant to be spent on technologies such as: autonomous aircraft that rangers can control by tablet PCs, radio tags meant
to be placed on animals to enable their tracking, and software tools to fa-
cilitate these tasks. One such tool is the Spatial Monitoring and Reporting
Tool — abbreviated as SMART. It is designed to detect the most vulnerable
species and areas, based on information extracted from images captured by
the drones. The drones have an aeroplane-like structure and are able to fly
straight either on a programmed path or according to commands via remote
control [4].

Apart from the previously mentioned limitations in maneuverability of aero-
plane type drones, there is another potential improvement that a quadcopter
could bring about. For an aeroplane that is flying comparatively fast in a
straight line, and is incapable of slowing down or turning, it would be inac-
curate to collect much information via sensors. As such, the WWF drones
are only capable of taking photographs, and the SMART software conducts
its analyses based on image data alone. It would be far more advantageous
to the tool to have more types of information available.

To illustrate the previous idea: weather data such as temperature and hu-
midity, could be useful in order to tell whether some areas are affected by
a shift in their climate. Chemical data — concentrations of different sub-
stances in air or water — would be an effective way to detect pollution. Even
sound data, like the number of decibels in ambiental noise, captured by an
attached microphone, could help analyse the environment. For example, it
could decide whether some areas of the reservation are too close to a source
of noise pollution such as a motorway or city. These sensing technologies are
far better suited for a more agile quadcopter, that can spend enough time
on a single waypoint in order to make all the correct measurements — rather
than a drone with an aeroplane-like structure and flight type.

2.4 India

In April 2013, authorities in Gauhati, India have deployed a set of remote-
controlled aeroplane-like drones for use in the Kaziranga National Park and
in the province of Assam (see figure 2.2). The aim of this project is video
surveillance by the park security guards, which is currently made difficult
by the extremely large area covered by the reserve — it encompasses nearly
500 square kilometres. The main goal is to cull the increase in poaching of
the one-horned rhinoceros. A secondary use that these drones will have is
analysis of the extent to which areas of the national park are affected by floods in the monsoon season. Once the initial tests obtain the approval of the Indian defence ministry, the UAVs will begin operating regularly [5].

Figure 2.2: RC drone used by Gauhati authorities – photograph by Anupam Nath

Regarding the aspect of surveillance, the points brought up in the previous paragraphs comparing aeroplane-type and quadcopter-type drones are still valid – ability to maneuver around to return or zoom in to problem sites, and possibility of gathering more types of data. The secondary use of the drones during monsoon season also raises some concerns. Considering once again the flight type and possible trajectories followed by an aeroplane and a quadcopter, respectively, it is notable that during the presence of perturbations such as gusts of wind or rainfall, the latter will be likely to perform much better – it is less susceptible to sudden variations in trajectory, and is capable of remaining airborne regardless of the direction of the wind, relative to the quadcopter. Conversely, the aeroplane-type drones currently in use could prove unfit for navigation in harsh weather – bursts of wind from certain sides of the aircraft could knock it off balance and make it impossible to re-stabilise.
Chapter 3

System design and architecture

3.1 Overview

The following sections will specify and explain the functionalities of all modules included in any standard quadcopter design. They will also present the particular choices for each of the modules’ components, intended to be used in constructing the quadcopter that comprises the object of this thesis.

3.2 Layout and mechanical structure

3.2.1 Frame

The frame of a quadcopter is a typically X-shaped structure that is meant to provide support for the motors at its extremities, and for the electronics in the middle. Sometimes it includes some form of shroud, which is a secondary assembly attached to the frame in order to protect the propellers from impact.

This project intends to use the frame of a DJI F450 drone in the final design, and a more easily replaceable custom-made simple wooden frame for testing. In the long run, it would also be desirable to fit the frame a light, wooden or carbon fiber custom-made shroud.
3.2.2 Propellers

A quadcopter has four propellers, the size of which influences the upward thrust and can vary anywhere between 5 and 10 inches. Two of them are meant to turn clockwise, and the other two counter-clockwise.

The quadcopter presented here has two complete sets of propellers, an 8-inch set and a 10-inch set. They can be used interchangeably, taking into account the fact that, given no change in the load of the aircraft, the shorter ones will cause the motors to draw more heavily and thus drain the battery slightly quicker than the longer propellers would.

3.2.3 Flight type

A quadcopter falls into the category of rotorcraft. To take off and to remain airborne, it uses the lift force generated by its propellers. Depending on what the application requires, there are two possible configurations in which the quadcopter could fly: "+" configuration, and "X" configuration, visible in figure 3.1. Both of them involve alternate placement of clockwise and counter-clockwise propellers. The key difference between them is the orientation of the drone’s front side, as perceived by its pilot.

In the case of this particular quadcopter, X configuration was chosen, due largely to its prevalence and ease of use.

Figure 3.1: The "+" and "X" quadcopter configurations – graphic representation by Thomas Jespersen
3.3 Electronic components and modules

3.3.1 Microcontroller

The microcontroller is the main processing unit of the quadcopter – it is mounted on the control board and interfaces with nearly all the external components that are attached to the board. For example, it connects directly with several digital or analog sensors such as temperature and humidity sensors, and also connects indirectly to the motors via the electronic speed controllers.

![Close-up of the ATmega328 microcontroller](image)

This project uses a microcontroller from the AVR family for the flight control board, and another for the sensor-reading board. The ATmega324 is used by the HK KK2.0 FC board, and the ATmega328 (visible in figure 3.2) is found on the Arduino Uno board. One of the more notable differences between them is the pin count, reflected of course in the cost – the former provides a total of 44 pins, while the latter only 32 [7] [6]. This is important to take into account when considering how flexible the quadcopter design is meant to be – how well it will accommodate future changes in functionality, by allowing more external sensing or actuating devices to be attached to it without any major change to the control board.
3.3.2 Sensors

The quadcopter’s sensors are any devices attached to it that are meant to measure a physical quantity (for example temperature, or altitude) and convert it to a form easily readable and processable by the microcontroller. There are many categories of sensors, according to their application, the type of measurement, or the technology used in measuring. Several kinds of sensors that are useful and sometimes mandatory for a quadcopter are: accelerometer and gyroscope, ultrasonic range finder, camera, compass, temperature and humidity sensor.

So far, this project has examined two sets of accelerometer-gyroscope sensors – one set included in the HK KK2.0 board, and another set where the two sensors are combined in a single module called an IMU (inertial measurement unit). The former benefits from more support in interfacing with the microcontroller, however the latter is far more customisable, albeit complex and more expensive. Only one of them is necessary in the final design of the quadcopter.

Other types of sensors are meant to be added after the IMU is in place and functioning correctly, as they are not vital to the drone being airborne in initial remote-controlled mode. The quadcopter prototype intends to use a broad array of sensors to enable the various functionalities described in previous sections. In short, these sensors measure: temperature, humidity, sunlight, gas, noise, and vibrations.

3.3.3 Motors

As the name suggests, a quadcopter uses four motors, placed at the extremities of the frame, alternating clockwise and counter-clockwise rotation (i.e. motor 1 rotates clockwise, and its adjacent neighbours, motor 2 and motor 4, rotate counter-clockwise, and so on – see figure 3.3). They are responsible for spinning the propellers in order to generate lift and allow the craft to take off and remain airborne. The motor characteristics are some of the most significant parameters to take into account when designing a quadcopter – they influence the weight that can be lifted, the current that must be supplied by the ESCs (Electronic Speed Controllers – see next paragraph), the draw on the battery, and as such, the flight time.
For this particular project, a set of four DJI 2112 motors have been chosen – they are quite powerful for their size, spinning at 920 rpm/V with a maximum draw of 30A, yet are not extremely hard on consumption as long as full throttle is not excessively used.

### 3.3.4 Electronic speed controllers

Electronic speed controllers, much like the name implies, are circuits that control the speed of the brushless motors of the quadcopter, and that connect them to the main processing unit. There is one corresponding to each of the four motors. Their principle of operation involves the notion of PWM – Pulse Width Modulation, a technique used to translate the digital commands issued by the microcontroller into a voltage applied to the motors. They are
connected to the aircraft in the manner illustrated in figure 3.4.

Choosing a type of ESC for this particular quadcopter was quite simple – since they need to be compatible with the motors, the key characteristic was the maximum allowed current, 30A.

### 3.3.5 Batteries and power consumption

Batteries aboard the aircraft need to supply power to all of its components, and they can potentially add a lot of weight to the frame. This risks becoming a vicious cycle: more weight to lift results in more power consumption, which results in a need for a larger battery. The problem, however, can be easily tackled – lithium-ion polymer batteries are almost always used in applications where weight is an issue, especially in aircraft. They have an excellent storage capacity to weight ratio, even though this advantage involves a trade-off: they are considerably more expensive than conventional batteries.

When choosing a LiPo battery for a quadcopter, it must necessarily have three or four cells in a series connection, and must be able to supply the maximum current that the motors could draw when in full throttle.

<table>
<thead>
<tr>
<th>Propeller</th>
<th>Battery</th>
<th>Throttle</th>
<th>Draw</th>
<th>Load</th>
<th>Flight time</th>
</tr>
</thead>
<tbody>
<tr>
<td>10x3.8</td>
<td>11.1V</td>
<td>50%</td>
<td>2.8A</td>
<td>310g</td>
<td>29.5min</td>
</tr>
<tr>
<td>10x3.8</td>
<td>11.1V</td>
<td>100%</td>
<td>10.7A</td>
<td>810g</td>
<td>7.71min</td>
</tr>
<tr>
<td>8x4.5</td>
<td>14.8V</td>
<td>50%</td>
<td>3.7A</td>
<td>380g</td>
<td>22.3min</td>
</tr>
<tr>
<td>8x4.5</td>
<td>14.8V</td>
<td>100%</td>
<td>13.2A</td>
<td>920g</td>
<td>6.25min</td>
</tr>
<tr>
<td>10x3.8</td>
<td>14.8V</td>
<td>50%</td>
<td>3.9A</td>
<td>470g</td>
<td>21.2min</td>
</tr>
</tbody>
</table>

This particular project called for a current of 120A, so a four-cell battery with a 5500mA capacity and a discharge rate of 25C provides a safe margin of up to 137.5A. The data contained in table 3.1 was gathered using both 3-cell and 4-cell battery packs, both with the same previously mentioned capacity. This capacity, weighed against the current draw of the motors, resulted in the estimated flight time in the last column. For a broader spectrum, the tests were conducted using both available sets of propellers – it is visible that the set with a slightly greater length resulted in more current draw (see rows 3 and 5 for comparison).
3.4 Degrees of autonomy

3.4.1 Piloting via remote control

The natural step to take before attempting any kind of autonomy is to enable the drone to be piloted via remote control. As a rule, in order to fly a quadcopter, the pilot’s transmitter – and, of course, the craft’s receiver – must operate on at least four or five different radio channels. Four are mandatory, as there is one controlling each motor, and a fifth is usually necessary in order to set the flight mode. If other components on the aircraft need to be controlled, for example a servomotor connected to a camera, separate remote control channels are required. In the case of this quadcopter, in order to maximise its potential for future extensions, a 6-channel remote was chosen.

3.4.2 Static path planning

Any drone that needs to be able to navigate without being directly controlled by a pilot, should have some means of locating itself. Solutions that don’t involve localisation are quite impractical for UAVs, since the large majority of their functionalities, and the missions they undertake, involve path planning in one way or another.

A very straightforward solution is GPS, which, in spite of its poor positioning accuracy of up to several meters, is perfectly viable for planning a path between two waypoints. Once in range of the waypoint, the quadcopter could navigate more precisely toward it – by using an infrared beacon, for example. Both GPS and beacons are planned to be tested and implemented in order to obtain an autonomous drone.

3.4.3 AI – versatile planning

As soon as a satisfactory degree of autonomous navigation is achieved via GPS and beacons, further complexity will be added to the drone in terms of software. This improved AI will make it capable of dynamically adapting its path to variations in the initial plan – an unexpected encounter of obstacles,
a mission revision commanding it to change course, some sensor readings that trigger an alarm state, and other similar situations.

Yet another improvement would be to discard the initial step of path planning before the start of the mission, and to have the drone come up with its own plan according to its current location, sensor readings, and mission priorities. It could, for example, track down animals’ radio collars and document their location if there are any nearby, while at the same time using the camera to detect any suspicious activity. If the image processing software decides anything is abnormal, the initial mission of tracking radio collars is paused, and the drone directs its path to zoom in on the potential danger captured on camera.
Chapter 4

Implementation

4.1 Mechanical setup

4.1.1 Frame and flight configuration

The process of choosing a quadcopter frame consisted in comparing and contrasting various commercially available frames and custom made solutions. One element to weigh in, literally, was the material from with the frame was constructed.

Some frames are made out of wood, which is considerably lightweight assuming the correct type of wood is chosen. However, in the event of a crash, wooden beams are rather easy to break, and no matter how cheap it is to replace them, it’s highly impractical to constantly repair a broken frame.

Another option, one step up the price scale but still affordable, is a frame made out of hollow aluminium rails. Aluminium is one of the lightest metals available, results in a rigid construction, and does not break or damage on impact as easily as wood does. It is still not the ideal choice, though, as the vibrations coming from the motors will likely be very well conducted through the aluminium rails to the center plate where the sensors are placed, possibly affecting readings.

A more expensive but worthwhile option is carbon fiber. Extremely rigid,
difficult to bend or break, and able to absorb vibrations, it is often the top recommendation for RC aviation due to its light weight. The only downside apart from the high price, is the fact that the dust produced when cutting a piece of carbon fiber can be toxic, making home-made frames less prevalent than store-bought ones.

Yet another possible option – the one chosen for this project – is a class of injection-molded materials based on nylon and glass fiber. Evidently, this type of material is practically impossible to mold or process manually, and therefore must be purchased readily molded. A particularly strong frame that was found commercially available at a good price, was the DJI F450 PA66+30GF quadcopter frame. It has proved to be a good choice not only because of the strength and lightness of the material, but also because of the layout and component rigging solution it provided for the center plate, as detailed in the following section.

Regarding the flight configuration, this was chosen to be of the X type, already discussed in the previous chapter. It was chosen on the basis of flexibility in terms of attaching additional modules to the center plate, and ease of use when flying in RC mode.

### 4.1.2 Central mount and power distribution

The frame that was chosen for the project includes a particularly useful center plate system, as seen in figure 4.1. Apart from securely connecting the four arms of the frame together, it is used to attach components such as the flight controller and the sensors, to provide adequate power distribution without a cumbersome power harness, and to accommodate either 3-cell or 4-cell lithium polymer batteries.

A number of holes drilled into the center plate serves a dual purpose: to lessen the total weight of the frame by using a smaller quantity of material, and to ease the fastening of all the necessary electronic equipment. It can easily accommodate anything from screw-holes and zip-ties to velcro and double-sided adhesive tape without any modification of the original design. Thus, it facilitates projects that require a lot of prototyping and trial-and-error, such as this one.

On the topic of power distribution, it is generally thought that a pair of cables
from each of the four arms must be soldered together and then soldered to the two battery leads. However, simply soldering end of cables together in such a manner can have a number of disadvantages, such as bulkiness in the resulting cable harness, or badly soldered joints due to high-gauge cables. The latter could result in an insufficient amperage delivery to one or more motors, which could spell failure for the end project. This particular center plate, however, provides a solution: the power distribution is embedded in the plate, in the form of a thick layer copper, with small exposed areas dedicated to cable soldering. This eliminates the need to create an entire power harness, and therefore the problems associated with it.

Another advantage of this particular center plate is the dedicated battery space it provides. It takes into account all possible battery sizes for this type of aircraft, providing a good fit for all varieties of 3-cell and 4-cell lythium polymer batteries. There has, however, been a small issue in constructing the frame for this project. The batteries used were a pair of 2-cell LiPos connected in series, essentially forming a 4-cell LiPo. In terms of power, this was perfectly adequate for the aircraft. Mechanically, however, two 2-cell batteries on top of each other are slightly more voluminous than a single 4-cell battery. This resulted in a need to make a slight modification to the center plate, by using a different set of screws to fasten the bottom of the plate in order to create some more space to fit the batteries in.
4.1.3 Anti-impact shroud

Considering the safety of the pilot, bystanders, environment, and aircraft itself, is quite an important issue, especially with the ecological concerns of this project. Thus, an additional frame called a shroud has been taken into consideration.

A shroud is meant to enclose the propellers of the quadcopter such that they cannot be hit by obstacles when approached from the side. Some commercial projects come with their own shrouds, but in this case a home-made one was adequate for the prototype. The material had to be as light-weight as possible, and reasonably strong – not necessarily as strong as the frame itself, as the risk of a high-speed sideways crash is lower than that of a direct vertical crash.

After some testing, a combination of PVC and styrofoam was used. Long pieces of PVC have been attached to the arms such that they extend the frame sideways, further than the propellers’ reach. Styrofoam has been added to the underside of the frame, at the extremity of each arm, in order to act as a bumper for landings. The setup has proven to be successful, albeit not as sleek as store-bought versions. It has served its purpose, by preventing the quadcopter from bumping sideways into various obstacles several times during early flight tests when stability was still a problem, and it potentially saved quite a few propellers from breaking.

4.1.4 Motor and ESC setup

The next step in the mechanical setup of the quadcopter was to choose a set of motors and attach them to the four arms. Judging by the estimated total weight of the aircraft, a fairly common type of brushless motor was chosen, a DJI 2212 running at 920 rpm/V. Used with a 14.8V battery, they yield nearly 14,000 rpm in no-load conditions. Tests indicate that, for an aircraft weight of just under a kilogram, full-throttle consumption is about 13A.

Whenever brushless motors come up, it is impossible to mention them without their controlling counterparts, the ESCs, or Electronic Speed Controllers. It was critical to choose a type of ESC compatible with the motor, since an improper choice could easily lead to the ESC burning out, or the motor be-
coming damaged. The main characteristic to look for is current: since the motors were rated at 15-25A standard draw, and 30A peak, the ESCs chosen are also meant to accommodate the 30A maximum.

To test the motors and ESCs together, without intervention from the flight control board, the signal cable of each ESC was, in turn, plugged into channel 3 THR (throttle) of the RC receiver. The main battery was connected, then the throttle stick on the RC transmitter was moved to check whether the motor span accordingly. This functioned correctly for all of the four motor-ESC pairs.

An issue that arose at a later point, when interfacing the ESCs with the flight controller, was ESC calibration. The FC expected a certain type of data exchange with the ESCs, indicating the minimum and maximum throttle limits and adjusting the ESC control interval accordingly. However, the firmware on the particular ESCs used in this project was unable to perform this calibrating operation, resulting in a slight offset in motor start – all four motors failed to start simultaneously.

This problem was addressed, as described in a later section, using the minimum throttle setting on the FC. A more thorough approach planned for the future, is to reprogram the ESC firmware altogether, in order to eliminate the impossibility of calibration, and to potentially improve overall flight quality by calibrating the ESC properly. As this is a complicated and potentially risky procedure, in terms of ESC firmware becoming irreparably damaged, it was not included in this prototype.

4.2 Electronics

4.2.1 Flight controller

Choosing a main flight control board meant choosing the core of the quadcopter. It is responsible for keeping the aircraft level while hovering, and for properly transforming RC transmitter commands into movement. It achieves this by using the input from an inertial measurement unit, or IMU, consisting of a gyroscope and an accelerometer. This input is interpreted so that the board can read the quadcopter’s current angles relative to the six axes, each
corresponding to a degree of freedom. According to these readings, the FC then transmits the appropriate signals to the ESCs, with which it connects directly, in order to command which motors to speed up and which to slow down. Additionally, it interfaces with the RC receiver, which in turn is controlled by the RC transmitter. It can, therefore, interpret the pilot’s stick movements and determine the quadcopter to reflect them correctly.

There are several different ways in which to put together a proper FC as described above, and several different FCs available for direct purchase. Weighing the costs and benefits carefully, this project was settled to use a readily available FC, specifically the KK2.0 board, visible in figure 4.2. It meets all the previously mentioned requirements, has a very low cost compared to the vast majority of FCs available on the market, and has been successfully used by a large number of RC pilots [7].

An alternative is to use an Arduino board as a FC, as long as an external IMU is available to connect to it, and appropriate firmware is uploaded. The possibility will be explored in future work on the prototype, and the other functionalities of the Arduino on the quadcopter platform will be described in the following section.
4.2.2 Arduino

The Arduino board used in this project is responsible for all sensor data acquisition, storage, processing, and display – with the exception of image data. It is an easy-to-use, open-source platform dedicated to prototyping, and especially user-friendly when it comes to sensor readings. It can interface with digital sensors through the pins on its digital ports, which can be read to check whether they display a low or a high voltage level. It can also interpret data from analog sensors, because it includes a functionality called ADC – Analog-to-Digital Converter, that maps a voltage reading between 0V and 5V to a binary value between 0 and 1023.

Apart from its primary purpose of reading sensor data, the Arduino can and will be used for digital and analog output. Its applications within this project include lighting up LEDs or LED strips in certain patterns, activating a buzzer such that it plays certain notes as alarms or warnings, and displaying data on an LCD.

The Arduino board was chosen for this project due to its flexibility when it comes to prototyping. Any data acquisition and processing that is currently done by it, will be upgraded in the future to run on a custom-made board containing the same microcontroller as the Arduino. The new board will be designed in a more application-specific manner, containing no more than the circuitry required for the project to function, and no more. This design will result in a solution much cheaper than the Arduino board, since it omits all the components that are unnecessary, redundant, or that remain unused by the current instance of the project. Additions may be further prototyped using the Arduino board again.

4.2.3 Sensors

The following section briefly describes each sensor used by the project, in turn. All sensors are connected to the Arduino, in a manner detailed below. Testing the accuracy of the readings was initially done by connecting the board to a PC and using the serial monitor.

Temperature is measured using a DHT22 integrated circuit, also known by the name of RHT22, RHT03, or AM2302. The cost was reasonably low,
taking into consideration the fact that the circuit also includes a humidity sensor, described in the following paragraph. The temperature range is -40 to +80 degrees Celsius, with an accuracy of 0.5 degrees Celsius. The readings are transmitted to the Arduino through a single-wire interface on a digital pin. Connecting the DHT22 required no additional components, or any calibration, making it very easy to use when prototyping.

The level of humidity is also measured with the DHT22 integrated circuit. It is capable of producing a reading anywhere between 0% and 100% RH (relative humidity), with an accuracy of 2% RH [8]. The data is relayed to the Arduino board through the same one-wire interface as described above. It proved highly convenient to use a single integrated circuit for two different sensing operations, thus saving valuable space and weight on the quadcopter frame.

The ambiental noise is measured using a small microphone, which in this case functions just like any other analog sensor: the measurement is transmitted to the Arduino through one of the analog pins [10]. It is worth noting that the noise made by the motors and propellers will be continuously perceived by the microphone, however it is possible to process the audio data in such a way as to permit filtering of the motor noise. Thus, it is entirely possible to measure the level of noise in the target area, regardless of the sounds produced by the aircraft itself.

Sunlight is measured using a small circuit containing a photoresistance. The circuit can sense any type of light, although most future missions of the quadcopter will very likely take place in an open, outdoors area, so the target measurement will be sunlight. The photoresistance in the circuit is sensitive to variations in light, and changes its resistance value accordingly. Thus, the voltage drop across it also becomes modified, and the Arduino can read this voltage on one of its analog pins.

The air quality is measured in terms of smoke and combustible gas presence. The gas sensor also connects to one of the analog pins of the Arduino board, however it requires a small amount of additional circuitry in order to function correctly. The sensor has a lower level of conductivity when the air around it is clean, and a higher conductivity when combustible gasses exist – the conductivity keeps rising higher as the concentration of the gas rises. It is highly sensitive to LPG (liquefied petroleum gas), propane and hydrogen [9].

An additional sensor, however less oriented towards environment data like
the previously described ones, is the piezo vibration sensor. It makes for a good addition because of its versatility: the piezo can be used as both an analog input, capturing the level of vibrations present on the quadcopter’s center plate, and as an analog output, functioning as an audible buzzer [11]. For this reason, the project uses two of them. The first one, functioning as a vibration sensor, could lead to potential improvements in the quadcopter’s frame, by monitoring the level of vibration in different areas of the frame and under different flight conditions. The second, used as a rudimentary speaker, serves to communicate warnings or all-clear messages to the pilot via beeps or buzzes of different pitches and frequencies.

4.2.4 RC system

The RC system consists of a Turnigy 6XS FHSS transmitter and an XR700 receiver. The pair works in the 2.4GHz frequency range and employs a spread spectrum technique in order to increase resistance to interference. They can communicate with each other while up to 750 meters apart, given clear weather conditions and a lack of obstruction. There are six channels that the transmitter can send signals on, four of which are plugged into the flight control board – aileron, elevator, throttle, and rudder. Although the channel names correspond to a model plane setup, the transmitter can also be used to control a quadcopter, the four becoming roll, pitch, yaw and throttle, after being processed by the flight controller.

![Figure 4.3: Stick movement in PPM-Audio](image)

The signals sent by the transmitter come in PPM (pulse-position modulation) form, and they were checked for accuracy by connecting the transmitter to a PC. A minor modification to the transmitter’s training port permitted the connection of a standard audio cable between the port and the Line In of any PC. Appropriate software was installed to sample the input waveforms: PPM-Audio and Winscope. Both visual representations of the transmitter
Figure 4.4: PPM signal in Winscope

signal, figure 4.3 illustrates the effect that transmitter stick movement induces in RCAudio, and figure 4.4 shows a screenshot of Winscope displaying a clear PPM signal.

Figure 4.5: FMS software, simulating control of a model aeroplane

After the transmitter signals were verified as described above, the transmitter and receiver were bound together. This is normally a process that involves
powering them up in a certain order, and resetting them at just the right moment, however in this particular case the binding was done automatically as soon as both transmitter and receiver were powered up. A green LED on the receiver indicated that a correct binding has occurred. To test this, a servo motor can be connected to any receiver channel, and the corresponding stick on the transmitter should cause it to move.

Another test that the RC system had to undergo was to fly a model plane in a software simulator. The software, called FMS (flying model simulator), can be seen in use in figure 4.5. The transmitter behaved very well during the tests and was deemed suitable for use.

4.2.5 Power supplies

The main power system consists of a pair of 2-cell lithium polymer batteries, both with a capacity of 5500mAh and a discharge rate of 25C. They are connected together in series to form what is essentially a 4-cell LiPo battery pack, needed in order to properly power the quadcopter – as this type of aircraft require either 3-cell or 4-cell packs to function correctly. This main power rig supplies all the four ESCs, whose job it is to supply the motors accordingly to FC commands.

![Diagram of LM7805 connection](image)

Figure 4.6: The LM7805 connection diagram, according to the datasheet

The maximum amperage of a single motor, as described in a previous section, is 30A, thus resulting in a total maximum current draw of 120A at full throttle and under load. The battery pack can supply up to 137.5A (value calculated by multiplying the capacity and the discharge rate), thus leaving plenty of
headroom in extreme situations. The characteristics of the battery were chosen specifically for this purpose, bearing in mind the overall maximum draw of the craft.

The power is distributed to each of the four ESCs via the central plate, that acts as an electronic PCB (printed circuit board) copper-plated on both sides – one for the positive battery lead, and one for the negative lead.

The secondary power system supplies a constant voltage of 5V to the logic levels of the on-board electronics. In order to avoid potential noise and power loss issues, the choice was made to separate the secondary power system from the main one entirely. This is accomplished via a small circuit (see figure 4.6 based on a LM7805 voltage stabiliser, that takes its input from a 9V alkaline battery.

4.3 Firmware and tuning

4.3.1 KK2.0 board firmware and settings

The flight control board is equipped with version 1.2 of the KK2.0 firmware. This enables the user to interact with it via the on-board LCD and a row of four buttons. The firmware allows pilots to navigate through a number of settings in order to properly tune the device for their particular aircraft.

The "PI editor" is meant for PI gain adjustments for each of the craft’s axes – roll, pitch, and yaw. The "Receiver test" menu facilitates the interaction of the receiver and flight controller, ensuring that all four channels are correctly interpreted. "Mode settings" contains features like self-levelling, arming, and simultaneous roll/pitch tuning. Under "Stick scaling" it is possible to modify the factor with which all the transmitter inputs are scaled. The "Miscellaneous settings" menu contains a throttle threshold and a contrast setting. "Self-level settings" allows modification of the gain and limit while in self-levelling mode. In the "Sensor test" screen, all the six inertial sensor readings are displayed – the X, Y, and Z axes of the accelerometer, and the same axes of the gyroscope.

The "Sensor calibration" command requires the aircraft to be placed on a
level surface in order to determine the sensor readings that correspond to
the horizontal position. Under "ESC calibration" it is possible to perform
a sequence of operations in order to correctly set the full-throttle to idle-
throttle interval interpreted by the ESCs. The "Mixer editor" permits a
more advanced customisation of the flight mode, and of the way in which
transmitter commands are interpreted and translated into motor commands.
The two "Motor layout" menus allow choosing and visualising a detailed view
of the aircraft’s motor layout.

For this particular aircraft, the motor layout was set to "Quadcopter X",
since it is meant to fly in X configuration. This displayed a figure showing
the correct rotation of each of the four motors.

The settings in the "PI editor" were modified to reflect what the author of
the firmware suggests as a pre-tuning configuration: roll/pitch P-gain 30, P-
limit 100, I-gain 0, I-limit 20 and yaw P-gain 50, P-limit 20, I-gain 0, I-limit
10.

The readings given by the "Receiver test" menu were used to correctly switch
channels 1 and 2 on the receiver, and to reverse the input on channels 1 and
4.

"Sensor calibration" was run once with the quadcopter placed on a level
surface, and subsequent readings in the "Sensor test" menu modified correctly
according to orientation.

Other settings were edited at a later time, as needed.

It was determined that a firmware update would be beneficial in terms of
quadcopter performance. The latest firmware is version 1.6, available as
a precompiled .hex file online, freely provided by the author. An initial
attempt to update the firmware used the KKmulticopter flash tool along
with a USBasp programmer. This was, however, unsuccessful, because of a
faulty programmer. The next logical step was to replace the programmer,
but as there was no identical device readily available, a different solution was
researched.

Since an Arduino board was already on hand as part of the project, the
decision was made to temporarily convert it to an AVRISP programmer by
uploading a specific ArduinoISP sketch available among the Arduino IDE
eamples. The upload functioned as intended, and was tested by using the
Arduino to program a .hex file and then a bootloader to another AVR chip (not the FC).

This was achieved by connecting the proper pins, as displayed in figure 4.7. Afterwards, the same connections were replicated between the Arduino used as programmer and the FC board, and the .hex file corresponding to the updated firmware was prepared. The following line was entered into the command prompt:

```
c:>avrdude -P COM7 -b 19200 -c avrISP -p m324pa -v -F
```

The command did not function as expected, and after some inspection the error was found to originate inside the avrdude configuration files. The description of the particular type of AVR chip used by the FC was missing. After finding the missing description within a newer version of the avrdude binaries, it was pasted into the configuration file and the command was run.
again. This time, the prompt indicated success, and permitted flashing the updated .hex file to the FC chip using the following command:

```c:\>avrdude -P COM7 -b 19200 -c avrisp -p m324pa -v -e -U
flash:w:kk2.hex:i
```

The flashing process concluded successfully and the FC was disconnected from the Arduino and powered on. The updated firmware version was now in effect.

### 4.3.2 Ground-level tests

Initial tests were conducted with the quadcopter settled on solid and level ground, and with all the propellers removed, for safety reasons.

First, the transmitter was turned on, the main and secondary power system were connected, and the FC was led through the arming procedure (which means there is a signal going through to the ESCs). Then, the throttle stick was slowly turned up in order to check whether all the motors were spinning correctly – motor 1 clockwise, motor 2 counter-clockwise, motor 3 clockwise, and motor 4 counter-clockwise. Noting motors 2 and 4 spinning opposite, the throttle was lowered to idle and the main power was disconnected. A pair of wires leading from the second and fourth ESCs to their respective motors were interchanged (any two of the three motor wires) and the above steps were repeated in order to confirm the change.

Next, with a low amount of throttle, the response to the other sticks was verified. Roll forward should spin the two back motors faster, and roll backward should spin the two front motors faster. Pitch left should spin the two right motors faster, and vice-versa. And yaw left should spin the two counter-clockwise motors faster, and again vice-versa.

Noting the correct reactions, ground testing was concluded with a check of FC responsiveness, as follows. The quadcopter was lifted up in the air and purposefully tilted sideways – the correct reaction from the FC was to speed up the motor or motors that were lower. This was not immediately visible, given the barely noticeable difference in motor rotation when the aircraft was
tilted gently, but more rough sideways movements made it obvious that the FC was compensating with the proper motor commands.

### 4.3.3 First flight

The first attempt at hovering the quadcopter was done immediately after the ground-level testing described in the previous subsection. The initial tendency was to oscillate quite violently instead of maintaining a constant angle close to horizontal, so the P-gains were lowered substantially. Thanks to the shroud, none of the propellers took any damage. After this modification, the oscillations were gone, but a new problem arose. The aircraft did not level itself, but instead flipped over upside-down as soon as the throttle was sufficient to lift it.

After some debugging and research, the FC board was repositioned on the quadcopter’s center plate, so as to face upward, lie completely level with the frame, have the LCD pointing forwards, and the buttons pointing backwards. The accelerometer and gyroscope calibration procedure was repeated, and the quadcopter was powered up again. The tendency to flip over was gone, and the craft could now hover above the ground reasonably level, however under heavy influence from the surrounding wind, which caused significant drift. This problem remained to be solved via tuning the PI parameters, as described in the section below.

### 4.3.4 PI tuning

The PI tuning enabled by the firmware permits the modification of P and I gains and limit values separately for roll, pitch and yaw axes. There are separate P and I gains for the self-leveling mode of the FC, however these are not important as this feature was not mandatory for achieving stable hovering of the quadcopter.

The actual tuning process is started by setting all I gains to zero and working on the P gains first. For an aircraft of this size, it is recommended that the initial P gain on the roll and pitch axes is set to 30, and the one on the yaw axis to 50. The limits should be 100, and 20, respectively.
To search for an optimum value for roll/pitch P gain, the initial gain value should be increased in steps of 5 to 10 units, and a flight test should be done after each step. As the gains increase, the quadcopter reacts quicker to RC commands, and may start oscillating. When it does start to oscillate, the gain should be decreased by fractions of a step until the oscillations are gone. To add an I component to roll/pitch, a similar procedure should be followed, increasing the I gain until any drift is gone and the craft is able to maintain attitude.

Finding a good yaw P gain requires the same step-by-step increase in value, checking whether the response is quick and the yawing overshoot is acceptably small. Higher gain means more overshoot, and also the possibility that the aircraft cannot maintain a constant height. Adding an I value should either reduce overshoot drastically or eliminate it altogether.
Chapter 5

Evaluation and testing

The implementation was a success, and resulted in a working prototype of the quadcopter. The on-board sensors are all functional, and they are perfectly capable of acquiring data of the following types: temperature, humidity, light intensity, flammable gas concentration, ambiental noise, and frame vibrations. The camera is also well rigged to the craft, and able to function as intended.

The tests to which it was subjected were meant to evaluate:

- Overall flight quality and prompt responsiveness to commands
- Correct in-flight operation of sensors; adequacy and accuracy of sensor data
- Central plate stability, in relation to the drone's ability to capture interpretable images
- Quality and quantity of image and video data obtained by the on-board camera
Chapter 6

Improvements and future work

This project has considerable potential for adding extra modules - either to increase its number of functionalities, or to improve its current performance. Although it is, at present, a finished prototype, there is plenty of room to enhance it in several ways, described below.

Full autonomy is a highly desirable trait for any aerial drone. However, to achieve this, a localisation system must be in place. A simplistic approach is GPS (global positioning system) - although it is rather expensive and lacks the accuracy required for indoor flight, it is acceptably well suited for a craft such as the prototype quadcopter. Outdoors, in the context of gathering environment data from a certain area, a positioning error of about 3 meters is largely negligible. As accuracy requirements become more stringent, some augmentation of the GPS is needed. One possibility is to place beacons along the quadcopter’s path. They would each transmit a signal to the FC – for example ultrasonic, or infrared – enabling it to calculate the craft’s distance from the beacon. This improved localisation system would enable more complex path planning to take place. It could, for example, allow the quadcopter to recalculate its path based on what new information each beacon provides. Beacons could also be identified via image recognition - a solution that is highly practical for landing the drone in a desired spot, with high accuracy.

Another possible improvement would be the addition of a wireless sensor network, with nodes found at fixed ground locations in the area targeted for analysis. It would be practical in terms of power consumption to have all
the nodes transmit their readings periodically to a central hub located on
the quadcopter, instead of keeping the nodes’ communication channels open
and interacting with the rest of the network at all times. Additionally, these
nodes could be designed in such a manner as to capture data that the drone
is unable to – soil humidity, or wind intensity, for example.

One more area that could stand enhancements is the power supply. This is
a valid point not only for the quadcopter discussed here, but for the entire
class of both manned and unmanned robotic devices, as most of them run
on batteries — LiPos, especially. For the previously mentionned wireless
sensor nodes, and for the logic circuitry of the drone, minimisation is key,
and there have been some recent developments regarding micro-batteries
created using 3D printing technology [12]. As far as the high-draw batteries
that supply the motors are concerned, it remains to be seen whether this
type of breakthroughs will also result in improving the ratio of capacity to
weight.

Finally, the idea of replicating the quadcopter and creating a swarm of drones
that have the capacity to communicate and cooperate is highly appealing.
Working as a team could mean better path planning: knowing in advance
where peers are about to navigate allows a drone not to duplicate that area’s
data and fly in an uninvestigated territory. It could also mean the drones
have an improved response to problematic situations: suppose a suspected
poacher is spotted by a craft, but is fleeing out of its range – the craft
would then signal any nearby swarm members, and video surveillance of the
suspicious activity would be resumed by another craft.
Chapter 7

Conclusions

The development of this project brought to light impediments as well as opportunities in the process of environmental data acquisition.

All the encountered setbacks contributed to an increased pool of knowledge regarding the construction and operation of unmanned aerial vehicles. For example, the unexpected oscillatory behaviour led to a better grasp of PI controller parameters. The improper initial placement of the FC board highlighted details about the manner in which an IMU functions. Solving these problems as they appeared was vital to the successful completion of the project.

Having passed all the tests devised for it, and displaying all the required functionalities, the project proved itself a success, and will be further developed in the future according to the points raised in the previous chapter.

The author’s principal contribution to the field consists in the idea of using a quadcopter to acquire environmental data – this has never been done before, and it has been proven possible and effective by a prototype. The drone is functional and capable of measuring temperature, humidity, level of sunlight, concentration of flammable gases, ambiental noise and vibrations, as well as capturing aerial images of the surrounding area. As previously argued in chapters 1 and 2, using a quadcopter drone instead of a model aeroplane drone is far more advantageous, mainly in terms of sensing capabilities, and maneuverability.
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