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THEME

Design and Implementation of Mission Control System for Autonomous Quadcopter using Pixhawk

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Abstract

Unmanned Aerial Vehicles (UAVs) have brought about a paradigm shift in various industries by revolutionizing the way tasks are approached and information is gathered. These versatile aircraft operate autonomously, eliminating the need for a human pilot and offering a multitude of applications and advantages. Among the diverse range of UAVs available, quadcopters have gained immense popularity due to their exceptional capabilities and unique four-rotor design, offering inherent stability and maneuverability for optimal task efficiency.

This dissertation focuses on the design, implementation, and testing of an advanced quadcopter drone equipped with the Pixhawk flight controller and a comprehensive mission control system. The objective is to develop a sophisticated system for autonomous mission planning, execution, and monitoring. By leveraging the quadcopter's inherent stability and maneuverability, combined with the capabilities of the Pixhawk flight controller and mission control functionality, the proposed drone aims to enhance surveillance capabilities and enable autonomous operations.

Key-words: Unmanned Aerial Vehicles (UAVs), versatile aircraft, Quadcopter, Pixhawk, Mission control system, autonomous mission planning.

ملخص

أحدثت المركبات الجوية بدون طيار (UAVs) نقلة نوعية في مختلف الصناعات من خلال إحداث ثورة في طريقة التعامل مع المهام وجمع المعلومات. تعمل هذه الطائرات متعددة الاستخدامات بشكل مستقل، مما يلغي الحاجة إلى طيار بشري ويقدم العديد من التطبيقات والمزايا. من بين مجموعة متنوعة من الطائرات بدون طيار المتاحة ، اكتسبت المروحيات الرباعية شعبية هائلة بسبب قدراتها الاستثنائية وتصميمها الفريد رباعي الدوارات ، مما يوفر الاستقرار الكامن والقدرة على المناورة لتحقيق الكفاءة المثلى للمهام.

يركز هذا المشروع البحثي على تصميم وتنفيذ واختبار طائرة بدون طيار متقدمة رباعية الدفع مزودة بجهاز تحكم طيران Pixhawk ونظام شامل للتحكم في المهمة. الهدف هو تطوير نظام متطور لتخطيط المهام المستقلة وتنفيذها ومراقبتها. من خلال الاستفادة من الاستقرار والقدرة على المناورة المتأصلين للطائرة الرباعية ، جنبًا إلى جنب مع قدرات وحدة التحكم في الطيران Pixhawk ووظيفة التحكم في المهمة ، تهدف الطائرة بدون طيار المقترحة إلى تعزيز قدرات المراقبة وتمكين العمليات المستقلة.

الكلمات المفتاحية: المركبات الجوية غير المأهولة (UAVs) ، الطائرات متعددة الاستخدامات ، كوادكوبتر ، Piwhawk ، نظام التحكم في المهمة ، تخطيط المهام المستقلة .

Résumé

Les véhicules aériens sans pilote (UAV), ont provoqué un changement de paradigme dans diverses industries en révolutionnant la manière dont les tâches sont abordées et les informations sont collectées. Ces aéronefs polyvalents fonctionnent de manière autonome, éliminant ainsi le besoin d'un pilote humain et offrant une multitude d'applications et d'avantages. Parmi la gamme diverse de UAV disponibles, les quadricoptères ont connu une popularité immense grâce à leurs capacités exceptionnelles et leur design unique à quatre rotors, offrant une stabilité et une maniabilité inhérentes pour une efficacité optimale des tâches.

Ce mémoire se concentre sur la conception, la mise en œuvre et les tests d'un drone quadricoptère avancé équipé du contrôleur de vol Pixhawk et d'un système de contrôle de mission complet. L'objectif est de développer un système sophistiqué pour la planification, l'exécution et la surveillance autonomes des missions. En exploitant la stabilité et la maniabilité inhérentes du quadricoptère, combinées aux capacités du contrôleur de vol Pixhawk et à la fonctionnalité de contrôle de mission, le drone proposé vise à améliorer les capacités de surveillance et à permettre des opérations autonomes.

Mots-clés : Véhicules aériens sans pilote (UAV), aéronefs polyvalents, quadricoptère, Pixhawk, système de contrôle de mission, planification autonome des missions.

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Finally, I wish to think all my professors, staff and technicians in the university of Laghouat for their cooperation, indirect or directly contribution in finishing my license dissertation.

This thesis is dedicated to my loving family, whose unwavering support and belief in my abilities have been the driving force behind my academic journey. I am grateful for their constant encouragement and understanding, which have propelled me forward in pursuit of my goals.

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To my dear friends, thank you for your unwavering friendship and for being a source of inspiration and laughter during this demanding journey. I am indebted to the participants who generously shared their time and knowledge, as their contributions have enriched this study.

Finally, I extend my sincere gratitude to all the participants who generously contributed their time, insights, and expertise to this study. Without their valuable contributions.

BOUFATAH Amani.

Dedication

With deep gratitude and sincere words that I dedicate this modest thesis to my dear parents, who sacrificed their lives for our success, they have been and they will always be an example for me by their human qualities, perseverance and perfectionism. I hope that one day, I can give them back a little of what they have done for me, may God grant them happiness and long life.

I also dedicate this work to my brothers and sisters and nephews, May God preserve them and I hope their life will be all about success, determination, and happiness and their future years will bring more opportunities that will help them get closer to achieving all of their dreams.

Finally, my deep gratitude to all my friends and all my teachers who have taught me and to all those who are dear to me.

***KHENCHA Abderrahim*.**

Table of contents

List of figures

List of Tables

List of abbreviations

UAV : Unmanned Aerial Vehicle

VTOL : Vertical Take Off and Landing

RC : Radio Control

RTF : Ready To Fly

HALE : High Altitude Long Endurance

MALE : Medium Altitude Long Endurance

TUAV : Tactical Unmanned Aerial Vehicle

ESC : Electronic Speed Controller

GPS : Global Positioning System

PID : Proportional, Integrative and Derivative control

LiPo : Lithium Polymer

MP : Mission Planner

RF : Radio Frequency

PWM : Pulse Width Modulation

RTL : Return to Launch

APM : ArduPilot Mega

FBWA: Fly By Wire A (Fixed Wing)

FBWB: Fly By Wire B (Fixed Wing)

List of acronyms

F : Force generated by propellers (F_1, F_2, F_3, F_4)

E : Earth fixed frame (E_x, E_y, E_z)

B : Body fixed frame (B_x, B_y, B_z)

θ : Pitch angle (the rotation of the quadcopter around the y = axis)

φ : Roll angle (the rotation of the quadcopter around the x = axis)

Ψ : Yaw angle (the rotation of the quadcopter around the z = axis)

General Introduction

Robotics is a multidisciplinary field that encompasses mechanics, computers, and electronics, and it has seen a growing number of applications since its inception [1]. This growth stems from the need to automate repetitive and challenging tasks in all areas of daily life, replacing human labor. Mobile robots, such as drones and mobile wheeled robots, are the most well-known and popular in the field of robotics.

In particular, The twenty-first century has seen a rapid spread of Unmanned Aerial Vehicles (UAVs) that are telemetry monitored and controlled by pilots on the ground, who can either be nearby or far away (depending on the application). Initially, developments were limited to large military drones, however, advances in motors technology, drive electronics, microcontrollers and access to GPS navigation, encouraged manufacturers to develop smaller and cheaper drones [2].

UAVs can be classified as either fixed-wing or rotary-wing aircraft, with the latter being globally of interest due to their elegant dynamics, simplicity of construction, and the ability to perform vertical take-off and landing (VTOL). Rotary-wing drones are found in various applications, including media, fire services, power production, agricultural industry, express delivery services, search and rescue tasks, inspection, and surveillance.

Operating a drone requires a sophisticated control system that can generate the necessary control signals for safe and stable flight, especially for rotary-wing drones. To achieve this, researchers worldwide are working on improving drone control systems, which employ advanced algorithms. One such system is the Mission Planner, a popular open-source software used for ground control of UAVs. The Mission Planner allows users to plan and execute autonomous missions, monitor live data, and update firmware. It also offers a variety of features such as real-time telemetry, mission planning, and camera control

Among rotary-wing robots, the quadcopter has gained popularity due to its graceful dynamics and simplicity of construction compared to other designs. It offers several advantages, including the capability of vertical takeoff and landing (VTOL), which enables launching and landing in minimal space. The quadcopter also possesses hover capability, high maneuverability for both longitudinal and lateral flight, and agility. In comparison to a standard helicopter with a single rotor, the quadcopter's configuration of four symmetry- equivalent rotors provides it with additional advantages, such as small size, efficiency, and safety [3]. These characteristics make the quadcopter an ideal subject for our study.

Project objective

To achieve the set objective, we will follow a work plan that consists of three chapters structured in the following manner:

Chapter 1: In the first chapter, we will provide a comprehensive description of drones, exploring their history and classifying them based on various criteria. We will offer insights into the different categories and types of drones available, with a particular emphasis on quadcopters and their four-rotor configuration. We will explain the fundamental components and operational principles of quadcopters, including their movements and maneuverability.

Chapter 2: This chapter will present a detailed description of the design and realization steps involved in creating our quadcopter prototype. It will provide an overview of the various components used in the prototype and delve into the design considerations. Additionally, we will conduct an in-depth analysis of the Pixhawk flight controller, examining its key features and discussing the software that will be utilized for its operation. Step-by-step guidance will be offered to facilitate the understanding and replication of the prototype.

Chapter 3: This chapter focuses on real-time outdoor mission testing of the DJI-450 quadcopter the primary objective of this chapter is to enable the quadcopter to perform tasks accurately and efficiently. The chapter covers various aspects, including testing different modes, discussing real results, and providing PID tuning parameters to ensure stability and smooth task completion. By leveraging the capabilities of the mission planner, the goal is to improve the quadcopter's autonomy, performance, and mission execution capabilities.

The implementation work will be showcased through a series of photos, and a recorded video of the quadcopter in flight will be included.

At the end this work, a general conclusion is then given as well as some recommendations for the present work and the future development.

Chapter I
Generalities of Quadcopters

I.1 Introduction

UAVs (Unmanned Aerial Vehicle) a remotely controlled airplane without a on board pilot. Mostly known as a "drone", Although UAVs have their origins in military contexts, they have also become valuable for scientific and commercial applications, particularly over the previous decade. Most popular UAV is Quadcopter and is preferred due to small size and high stability.

In this chapter, we will define drones and explore their history, configurations, and specifically focus on quadcopters. We will explain the fundamental components, operational principles, movements, and maneuverability of quadcopters.

I.2 Drone

A drone is an unmanned aerial vehicle (UAV) that is typically controlled remotely or autonomously. It can range in size from small handheld models to large, sophisticated aircraft with advanced capabilities. Drones are used for a variety of purposes, including military operations, surveillance, and commercial applications. They are equipped with cameras, sensors, and other technology that allows them to gather data and perform tasks without the need for human intervention [4].

I.2.1 History of drones

In this section, we delve into the captivating history of drones. Unmanned aerial vehicles or UAVs at the consumer level are a more recent phenomenon. All technological advances had to start somewhere, though. Almost every famous invention we know about had humble beginnings. Many great ideas fall by the wayside without us hearing about them, but not hobby drones [4].

Here's a quick breakdown on the history of drones:

- **1907:** The first quadcopter (4 rotor drone) took to the skies called Gyroplane No.1 was invented by Two French brothers, Jacques and Louis Bréguet, As shown in the following picture:

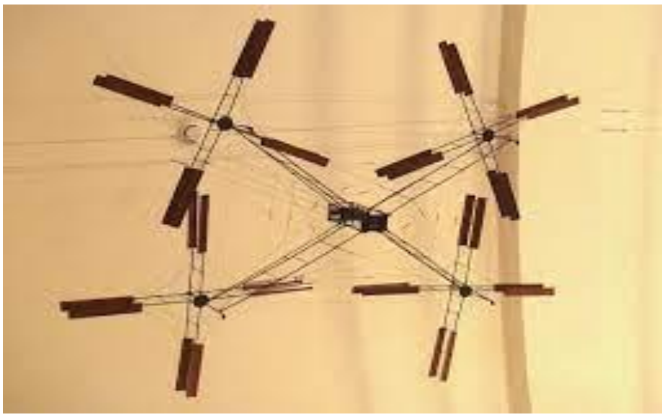


Fig.I.1The first quadcopter [5]

- **1917:** Nikola Tesla created the first military pilotless RC aircraft the idea was to use the Aerial Target as a flying bomb, deliverable by RC, As illustrated in the subsequent image:

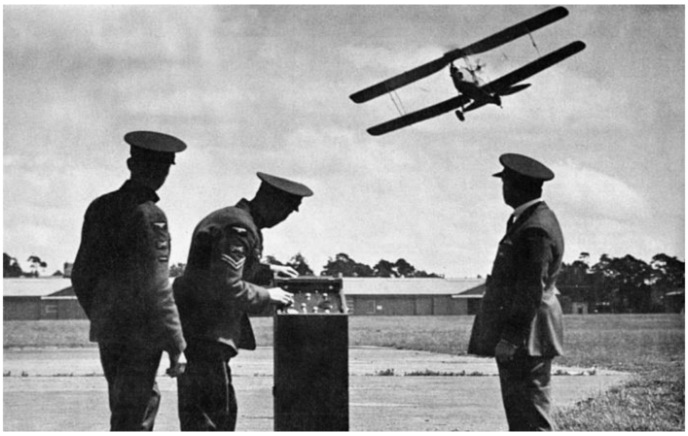


Fig.I.2 The first military pilotless RC aircraft [6]

- **1943:** Saw the FX-1400 (nickname Fritz X) radio-controlled bomb presented in the subsequent image:

Fig.I.3 Fritz X at RAF Museum Cosford [7]

- **1960s:** First unmanned RC aircraft became available to consumers.

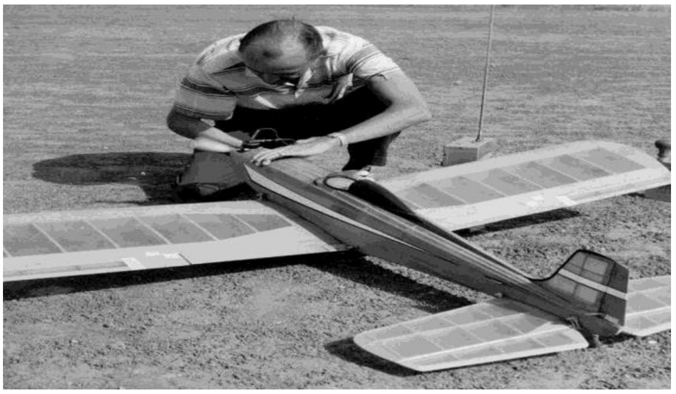


Fig.I.4 Radio controlled model airplane, Crusader, 1960[8]

- **2006:** The first use of non-military drones 'commercial drone' started in 2006 by FAA.

Fig.I.5 Personal drones started to take off literally [9]

- **2010:** Parrot introduced the first ready-to-fly (RTF) Wi-Fi drone, As illustrated in the subsequent image:

Fig.I.6 Parrot's AR Drone prototype in flight [10]

- **2013:** Amazon introduces the concept of drone deliveries, was announced by Jeff Bezos, As indicated by the image below:

Fig.I.7 Jeff Bezos's drone delivery [11]

- **2015:** A year know for the Lily Flying Camera disaster.

Fig.I.8 Lily drone [12]

- **2016:** DJI's Phantom 4 set new standards for camera quads.

Fig.I.9 DJI Phantom 3 Standard quadcopter Drone [13]

- **March 2021** Zipline started delivering COVID-19 vaccines to healthcare providers in Ghana as part of the United Nation's COVAX initiative.

Fig.I.10 Drones deliver COVID-19 vaccines to remote communities [14]

- **August 2021** Alphabet's Project Wing announced that it would pass the 100,000 drone delivery mark, which is another step toward proving that drone delivery at scale is possible, As demonstrated in the provided picture:

Fig.I.11Alphabet's drone delivery [15]

I.2.2 Classification of drones

UAVs can be classified based on various factors such as size, purpose, and capabilities. Here are a few common ways in which UAVs are classified:

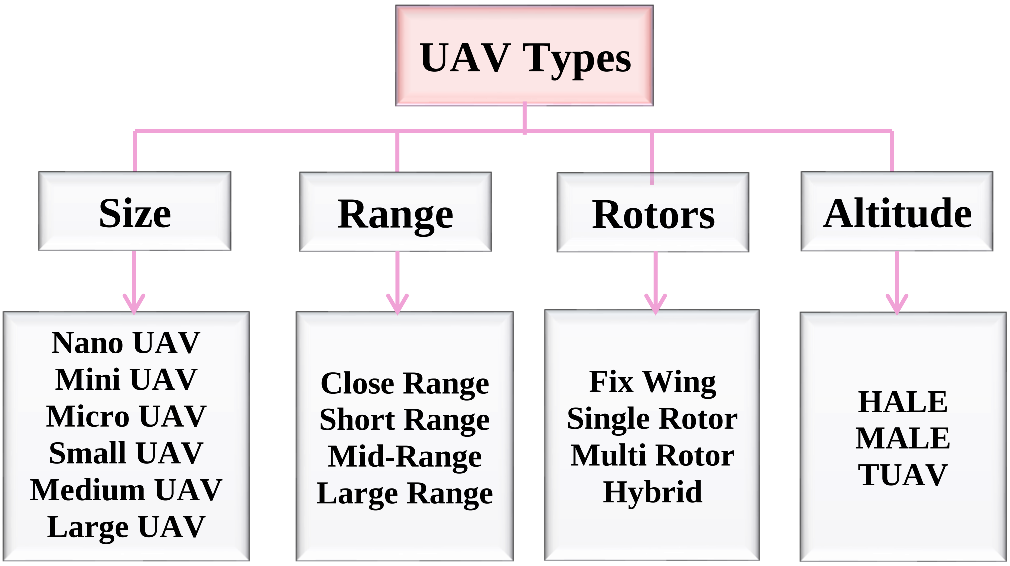


Fig.I.12 UAV types

a) According to size

Drones can be classified by their size into several categories, ranging from very small micro-drones to larger, more complex drones from (Fig.I.13) to (Fig.I.18):

Nano drones These are the smallest drones available, usually measuring less than 50mm in diameter and weighing a few grams. They are often used for indoor flight and may not require registration with aviation authorities.

Fig.I.13 Nano drone [16]

Mini drones These are slightly larger than micro drones, measuring less than 250mm in diameter and weighing up to 2 kg. They are often used for aerial photography and videography, and some models can be flown indoors or outdoors.

Fig.I.14 Mini drone [17]

Micro drones Slightly larger than nano drones, micro drones typically measure less than 100mm in diameter and weigh less than 100 grams. They are often used for recreational purposes, such as flying in parks or backyards.

Fig.I.15 Micro drone [18]

Small drones small drones can range in size from 250mm to 500mm in diameter and can weigh up to 5 kg. They are often used for commercial and industrial purposes, such as inspecting infrastructure, surveying land, or monitoring crops.

Fig.I.16 Drone with small sizes [19]

Medium drones These drones typically measure between 500mm and 1 meter in diameter and can weigh up to 20 kg. They are often used for more complex tasks, such as aerial mapping, search and rescue operations, or wildlife monitoring.

Fig.I.17 Drones with medium sizes [20]

Large drones These are the largest drones available, measuring over 1 meter in diameter and weighing up to several hundred kilograms. They are often used for military purposes, such as surveillance, reconnaissance, and targeted strikes.

Fig.I.18 Large drone [21]

b) According to range

Another useful classification method for UAVs is to categorize them by range.

- **Close range UAVs** This class includes UAVs that have a range of 50 km and endurance time of 1 to 6 hours. They are usually used for reconnaissance and surveillance tasks [22].
- **Short-range UAVs** Short-range drones are drones that can fly up to 150 km away from the controller. With very powerful batteries, they can stay in the air for 8-12 hours and are usually used for combat as well as surveillance purposes [23].
- **Mid-range UAVs** the mid-range class includes UAVs that have super high speed and a working radius of 650 km. They are also used for reconnaissance and surveillance purposes, in addition to gathering meteorological data [22].
- **Endurance UAVs** also known as large-range these drones can cover vast distances of over 400 miles (644 km), with some models able to cover even hundreds of thousands of square miles, without experiencing any signal loss. They are also used for reconnaissance and surveillance purposes.

c) According to the propulsion mode

Drones can be classified based on various criteria, including their frame type. The frame is the structure that holds the various components of the drone together and provides stability during flight. Here are some common classifications of drone frames, as illustrated in the subsequent image:

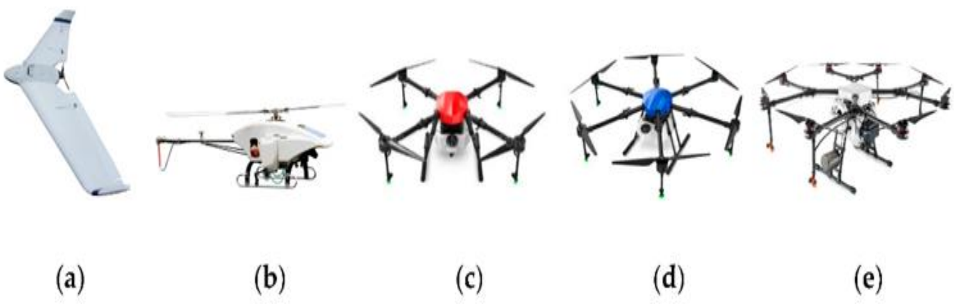


Fig.I.19 Classification of quadcopters according to the propulsion mode [24]

1. **Fixed Wing:** Fixed-wing drones have a traditional airplane-like structure with a rigid wing that generates lift. They are typically used for long-range surveillance and mapping missions, and require a runway for take-off and landing [25].

Fig.I.20 Fixed-wing drone

2. **Single Rotor:** Single rotor drones have a large rotor that generates lift and a smaller rotor at the tail for stability and control. They are commonly used for heavy lifting and transportation, such as in agriculture or construction industries [25].

Fig.I.21 Single rotor drones

3. **Multi-Rotor:** Multi-rotor drones have multiple rotors that generate lift and control the motion of the drone. Such drones have common uses for photography and video surveillance [26]. They can be further classified based on the number of rotors, here are some common types:

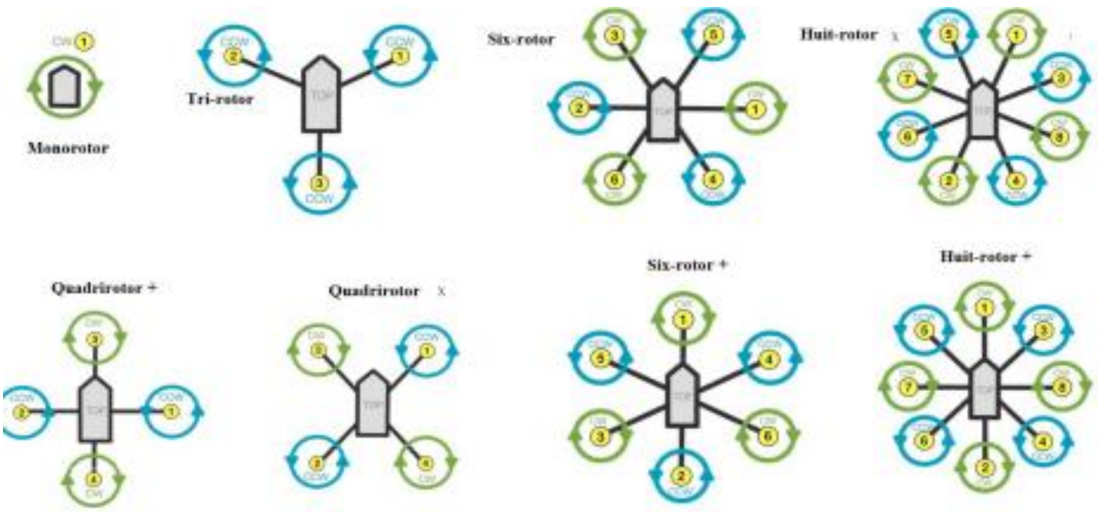


Fig.I.22 Some basic configurations of multicopters [27]

- **Quadcopter:** Quadcopters have four rotors and are the most common type of drone. They are easy to maneuver and stable in flight, making them popular for aerial photography and videography.

Fig.I.23 Quadcopter

- **Hexacopter:** Hexacopters have six rotors and can carry heavier payloads than quadcopters. They are commonly used for industrial applications such as inspection of infrastructure and aerial surveying.

Fig.I.24 Hexacopter

- **Octocopter:** Octocopters have eight rotors and can lift even heavier payloads. They are used for tasks that require high stability and precision, such as cinematography and 3D mapping.

Fig.I.25 Octocopter

4. **Hybrid:** Hybrid drones combine the features of fixed-wing and multi-rotor drones, allowing them to take off and land vertically like a multi-rotor and fly long distances like a fixed-wing drone. They are commonly used for surveying and mapping large areas[28].

Fig.I.26 Hybrid drone [28]

d) Classification according to altitude

Weibel (2014) classified the UAVs as HALE, Male, mini and micro.

- **HALE UAV** (High Altitude Long Endurance) flies at altitude above 15000 m with more than 24 hours endurance and can carry out extremely long-range (trans-global) reconnaissance.
- **MALE UAV** (Medium Altitude Long Endurance) flies at an altitude of 5000–15000 m and has about 24 hours of endurance. Their roles are similar to the HALE systems but generally operate at somewhat shorter ranges, but still in excess of 500 km and from fixed bases.
- **TUAV** (Tactical Unmanned Aerial Vehicle) has ranges up to 300 km with 10 to 12 hours of endurance flying at altitudes beyond 3000 m [29].

I.3 Quadcopters

A quadcopter, also known as a quadrotor, is a type of unmanned aerial vehicle (UAV) that is powered by four rotors, typically arranged in a square or X-shaped configuration. Each rotor is attached to a motor and a propeller, which allows the quadcopter to lift off the ground and maneuver in the air. Quadcopters can be controlled remotely or programmed to fly autonomously, and can be equipped with a variety of sensors and cameras for applications such as aerial photography, surveillance, and research. The quadcopter shown in fig.I.27

Fig.I.27 A simple quadcopter [30]

I.3.1 Basic components of quadcopters

A quadcopter consists of the following essential parts:

- Frame.
- Propeller x4 (2 clockwise and 2 counter-clockwise).
- Motor x4.
- Electronic Speed Control (ESC) x4.
- Flight Control Board.
- Radio transmitter and receiver.
- Battery and Charger.
- Other sensors.

I.3.2 Mathematical modeling of quadcopter

The mathematical modeling of the quadcopter is an essential part before any flight testing. The equation issued from these modeling compasses the frame kinematic acceleration, motor physics, and force-torque relationship. To this end, we have used the modeling presented in Ref. [31].

I.3.3 Summary of the quadrotor operation

Possible movements of a quadrotor are shown in Fig.I.29 and Fig.I.30. A quadrotor is a type of rotorcraft that uses four rotors to generate lift and control its motion. Each rotor is responsible for producing thrust, torque, and drag forces. The quadrotor's propellers are divided into two pairs: two pusher blades and two puller blades. These blades work in contra-rotation, meaning they rotate in opposite directions, to produce null net torque when all propellers turn with the same angular velocity. This allows the quadrotor to remain still around its center of gravity.

In order to define an aircraft's orientation (or attitude) around its center of mass, aerospace engineers usually define three dynamic parameters, the angles of yaw ψ (rotation around z-axis), pitch θ (rotation around y-axis) and roll φ (rotation around x-axis) [32]. This orientation is crucial because the forces used to control the aircraft act around its center of mass, causing it to pitch, roll, or yaw (see Fig.I.28). Changes in these parameters are induced by varying speeds in the propellers, enabling the quadrotor to maneuver in any direction [33]. To control the motion of a quadrotor, a combination of control inputs is utilized, including motor speed, pitch, roll, and yaw angles. These inputs can be generated either by an on-board computer or by a human pilot using a remote control, as can be observed in the following picture:

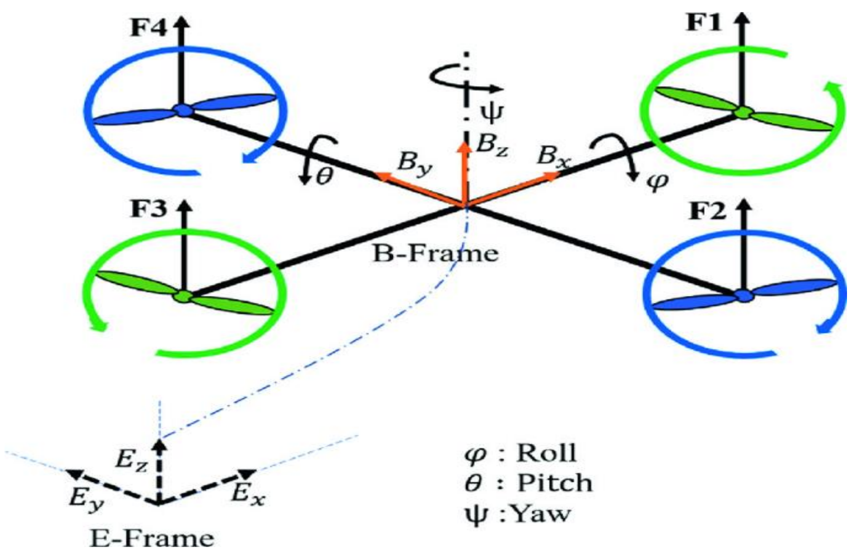


Fig.I.28 Yaw, pitch and roll rotations of a common quadrotor [34]

I.3.4 The movement of a quadrotor

The motion of a quadcopter can be described using six degrees of freedom: three for translational movement (surge, sway, heave) and three for rotational movement (roll, pitch, yaw). These degrees of freedom correspond to specific directions of movement or rotation.

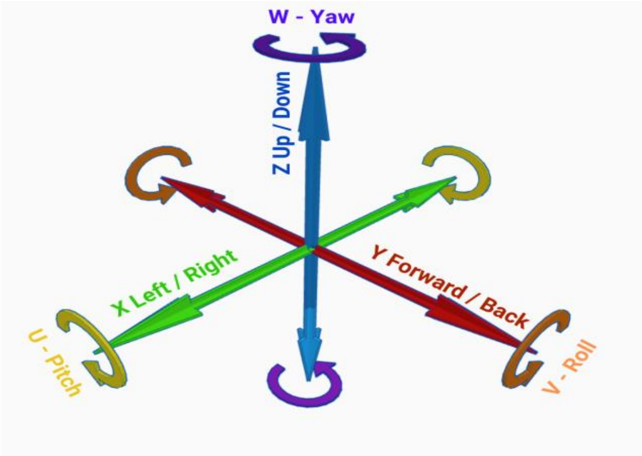


Fig.I.29 Illustration of the various movements of a quadrotor [35]

The quadcopter's basic movements are carried out by varying the speed of each rotor to adjust the thrust. These movements are interdependent, which means that it is impossible to create a translation without inducing rolling or pitching.

The quadcopter has five main movements: vertical movement, rolling movement, pitch movement, yaw movement, and translational motion as can be observed in the following picture:

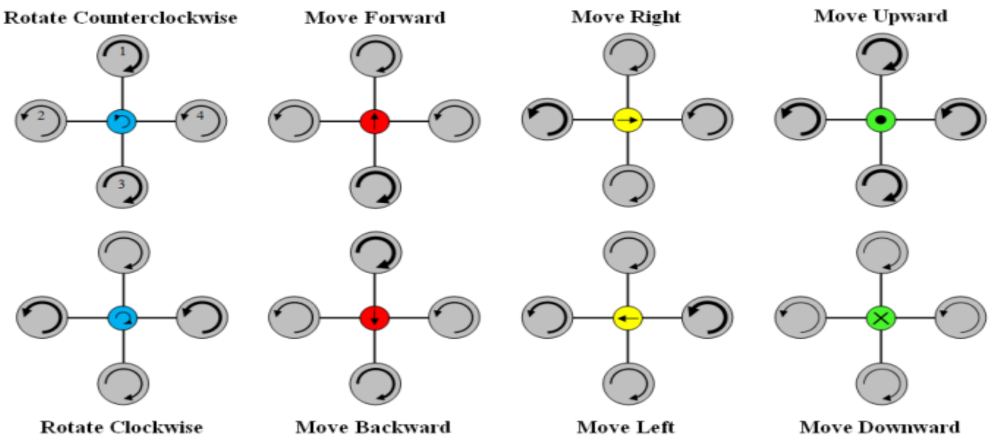


Fig.I.30 Motion characteristics defined by propeller rotation intensity [36]

1. **Altitude:** Altitude is the vertical movement of the drone, either up or down. This movement is controlled by adjusting the speed of all four rotors simultaneously, with an increase in speed causing the drone to rise and a decrease in speed causing it to descend.

2. **Roll:** A roll is a lateral movement where the drone tilts to one side and moves in that direction. This movement is controlled by adjusting the speed of the rotors on one side of the drone, causing it to tilt.

3. **Pitch:** A pitch is a forward or backward movement where the drone tilts forward or backward and moves in that direction. This movement is controlled by adjusting the speed of the front or rear rotors, causing the drone to tilt.

4. **Yaw:** A yaw is a rotational movement where the drone turns left or right around its vertical axis. This movement is controlled by adjusting the speed of the rotors on one side of the drone while decreasing the speed on the other side.

5. **Forward/Backward Movement:** The quadcopter can move forward or backward horizontally by adjusting the speed of the rotors in the front or the back of the aircraft.
6. **Lateral Movement:** The quadcopter can move left or right horizontally by adjusting the speed of the rotors on one side of the aircraft and decreasing the speed of the rotors on the other side.

I.4 Conclusion

In this chapter, a strong foundation has been established for comprehending the background, classification, and operational principles of drones, with a specific focus on quadcopters.

The next chapter will delve into the practical realization of our work, where we will introduce the tools and development environment utilized specifically the mission planner and Pixhawk system. These tools will provide a practical framework for implementing and evaluating quadrotor manipulation systems, allowing us to assess their capabilities and explore potential applications in greater detail.

Chapter II

Design and Implementation of Quadcopter

II.1 Introduction

Practical realization is now the heart of our work, and so this chapter is the way to evaluate the functioning of our realization .In this chapter we begin at first with the general design of the quadrotor which explains the overall concept of operation of the quadrotor, then we move on to describe the components constituting quadrotor and their characteristics, and test each one how to function. Secondly, we focus on the two main circuits, command flight and flight control, who are responsible for issuing and receiving the commands and stabilization of the quadrotor. At the end we illustrate different photos of our realized quadrotor with flight tests.

II.2 The overall idea of our project

The project's overall idea involves building a quadrotor using the Pixhawk flight control system and Mission Planner software. Our approach focuses on leveraging the advanced capabilities of the Pixhawk to enable autonomous mission planning and execution. We have divided the project into two main circuits to achieve this goal.

The first circuit incorporates the Pixhawk flight controller as the central component for quadrotor control. Through a radio frequency receiver, the Pixhawk receives commands from a ground station, allowing precise and responsive control of the quadrotor's movements. This eliminates the need for traditional RC control and provides a more sophisticated and capable control system.

The second circuit, known as the flight controller, is located at the center of the quadrotor. It receives command data from the flight control circuit, which includes information from the radio frequency receiver. Additionally, the flight controller utilizes data from the gyroscope sensor, which provides roll, pitch, and yaw angles. With the help of a well-established algorithm, the flight controller generates four signals in PWM (Pulse Width Modulation) form. These signals are crucial for managing the pre-actuators ESC (Electronic Speed Controllers) that control the brushless motors' rotation speed. This arrangement ensures a stable and controllable quadrotor. Fig.II.1 shows the main components used in the installation.

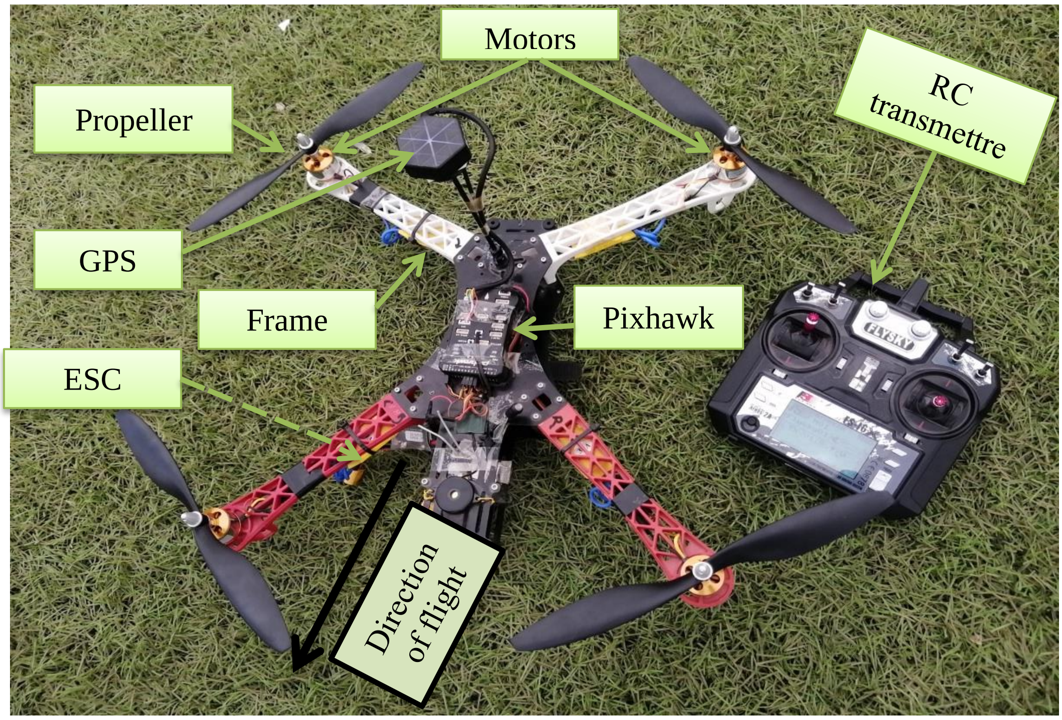


Fig.II.1 The quadcopter DJI F450 used in the experiment

II.3 General description of the components used

There are various designs of quadcopters, each tailored to their specific use and mission. For instance, a quadcopter used in military applications will differ from one used for personal use, such as for delivery services. However, there is a common design that includes the main components necessary for constructing a quadcopter. For the common design, we will need:

II.3.1 The Main DJI F450 Frame

The DJI F450 is a popular quadcopter frame known for its lightweight, modular design, and durability. It is made of glass fiber and consists of a center plate and four arms that can be easily assembled and disassembled. The frame can support a range of payloads and is compatible with different motors and propellers [37]. It also comes with a landing gear system that provides stability and protection during landings. The DJI F450 Frame shown in figure bellow:

Fig.II.2 DJI F450 Frame

II.3.2 Motors

Brushless motors are the most commonly used motors in quadcopters. They are more efficient than brushed motors because they have no physical contact between the rotor and stator, which reduces friction and wear. Turnigy D3542/6 1100 KV brushless motors were chosen for our quadcopter due to its power, efficiency, and reliability, additionally, the motor's unique design allows for easy installation and maintenance, making it a popular choice among hobbyists and professionals alike [37], as demonstrated in the provided image:

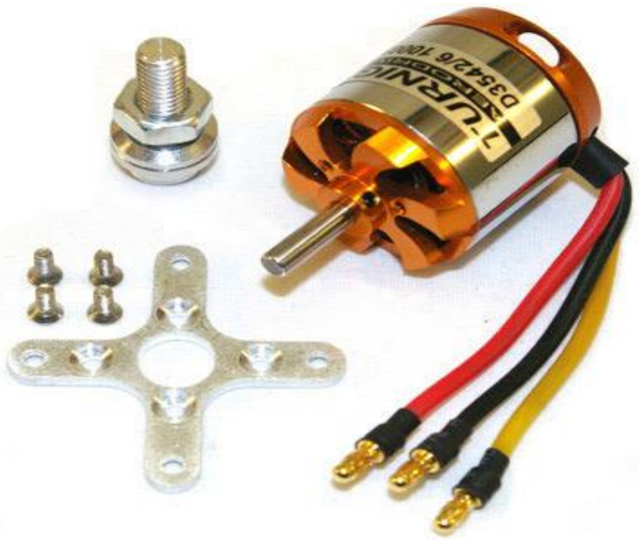


Fig.II.3 D3542/6 BLDC Motor

II.3.3 Propellers

The quadcopter is equipped with two-blade propellers as opposed to three-blade ones, as the former offers superior pitch compared to the latter. The specific propellers used for this purpose are the GWS 10 x 4.7 model. Propellers are typically identified by two numbers: the first number denotes the propeller's diameter in inches, while the second number refers to its pitch value, which represents the distance traveled upward per one revolution of the propeller [37]. Propellers are available in two rotational shapes, clockwise and counterclockwise, which produce varying pitch directions despite having the same motor rotation direction.

Fig.II.4 GWS 10 x 4.7 Propellers

II.3.4 ESC Electronic Speed Controller

An Electronic Speed Controller (ESC) is a device that regulates the speed of brushless motors in RC vehicles by adjusting the voltage and current supplied to the motor. It plays a crucial role in the performance and safety of the vehicle. The SimonK Afro 30A is a reliable and high-performance Electronic Speed Controller (ESC), with a maximum current capacity of 30A and a built-in BEC to power the flight controller and other electronics. Its use of SimonK firmware allows for precise throttle control and fast response time [37].

Fig.II.5 Afro 30A ESC

II.3.5 Battery and Charger

Quadcopters typically use a LiPo battery for power. The specific battery configuration will depend on the size and specifications of the quadcopter, but a current purpose.is a 3-cell LiPo battery with a voltage of 11.1V and a capacity of 2200mAh (milliamp-hours). This type of battery provides enough power to fly most mid-sized quadcopters for several minutes on a single charge, it's important to use a charger that is compatible with the battery type and capacity [37]. A charger that is too powerful can damage the battery or cause a fire, while a charger that is not powerful enough will take longer to charge the battery, it can be shown in the following picture:

Fig.II.6 LiPo Battery

II.3.6 RC Transmitter and Receiver

The radio transmitter and receiver are critical components of a quadcopter's remote control system, with the FS-i6 2.4 being a popular option for controlling the quadcopter. The transmitter sends control signals to the receiver, which communicates with the electronic speed controllers and other components on the quadcopter to control its movements. The FS-i6 2.4 is a 6-channel radio transmitter that operates on the 2.4GHz frequency band and features programmable features and an LCD display [37]. When paired together, the transmitter and receiver enable precise and accurate control of the quadcopter.

Fig.II.7 Fly Sky fs-i6

II.3.7 Ublox Neo-M8N GPS with Compass

The Ublox Neo-M8N GPS with HMC5883L Compass is a powerful and reliable navigation solution for quadcopters and other unmanned aerial vehicles. When combined with the Pixhawk flight controller, it provides an advanced and flexible system for autonomous flight and control. With its high level of accuracy and compatibility with multiple global navigation satellite systems, the module is capable of delivering precise location and heading information, essential for navigating and orienting the quadcopter [37], so it can be shown in this picture:

Fig.II.8 Ublox Neo-M8N GPS with Compass [38]

II.4 Flight Controller

A flight controller is the brain of the quadcopter that controls the motors and adjusts the aircraft's orientation and motion. It uses sensors such as accelerometers, gyroscopes, magnetometers, barometers, and GPS modules to determine the aircraft's position and make adjustments accordingly [37]. In our case, we used a Pixhawk flight controller. This board is explained in detail below

II.4.1 Pixhawk flight controller

Pixhawk is an advanced autopilot system of 3DR. It features transparent for hardware and convenient for re-development. Pixhawk integrates with two advanced processor, STM32F103 backup failsafe 32-bit co-processor provides for manual recovery and has its own power supply if one processor breaks down, delivering incredible performance, flexibility, and reliability for controlling any autonomous vehicle. Users can also adjust the configurations of Pixhawk according to different use and hobbies for different vehicles. In recent years, as one of the cores of autopilot system, Pixhawk has gained a profound popularity among developers and hobbyists for being practical, easy to handle, economical [39], As illustrated in the subsequent image:

Fig.II.9 Wiring diagram [40].

II.4.2 Features

•Advanced 32-bit ARM Cortex® M4 Processor running NuttX RTOS (68 MHz / 252 MIPS Cortex-M4F) real-time operating system.

•14 PWM/servo outputs (8 with failsafe and manual override, 6 auxiliaries, high-power compatible).

•Abundant connectivity options for additional peripherals (UART, I2C, CAN).

•Integrated backup system for inflight recovery and manual override with dedicated processor and stand-alone power supply.

•Backup system integrates mixing, providing consistent autopilot and manual override mixing modes.

•Redundant power supply inputs and automatic failover.

•External safety button for easy motor activation.

•Multicolor LED indicator.

•High-power, multi-tone piezo audio indicator.

•micro-SD card for long-time high-rate logging.

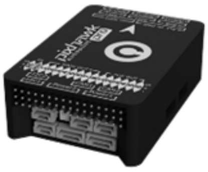
II.4.3 Generations of Pixhawk

Pixhawk 4: Manufactured by Holybro, and based on FMUv5, the Pixhawk 4 is the latest update to the successful family of Pixhawk flight controllers

Pixhawk 4 Mini: Manufactured by Holybro, and based on FMUv5, the Pixhawk 4 mini is a compact autopilot with abundant performance features.

MindRacer: Manufactured by Airmind, and based on FMUv4, the MindRacer is incredibly lightweight and is stackable with an optional power distribution board and isolated IMU rack.

MindPx: Manufactured by Airmind, and based on FMUv4, the MindPx has built-in isolated IMU redundancy and 16 PWM output channels



Pixhawk 3 Pro:

Manufactured by Drotek, and based on FMUv4, the Pixhawk 3 Pro is intended for space constrained applications with sufficient I/O for most applications without expansion and can function as a modular multi-board flight controller.

mRo PixRacer R14: Manufactured by mRobotics, and based on FMUv4, the mRo PixRacer R14 is sized for FPV racing but has all the inputs necessary for a fully

featured autopilot system and has built in Wi-Fi for convenience

Pixhawk V3: Manufactured by CUAV, and based on FMUv3, the Pixhawk V3 has a vibration dampened IMU with redundant sensors and is intended for commercial systems.

mRobotics-X2.1: Manufactured by mRobotics, and based on FMUv3, the mRobotics-X2.1 has nearly identical connectivity to the Pixhawk 1 and features a smaller footprint with updated sensors.

mRo Pixhawk: Manufactured by mRobotics, and based on FMUv3, the mRo Pixhawk is a hardware compatible replacement for the Pixhawk 1.

Pixhawk: 2 (The Cube): Manufactured by Pro CNC, and based on FMUv3, the Pixhawk 2 includes connections for a companion computer and has built-in IMU vibration isolation

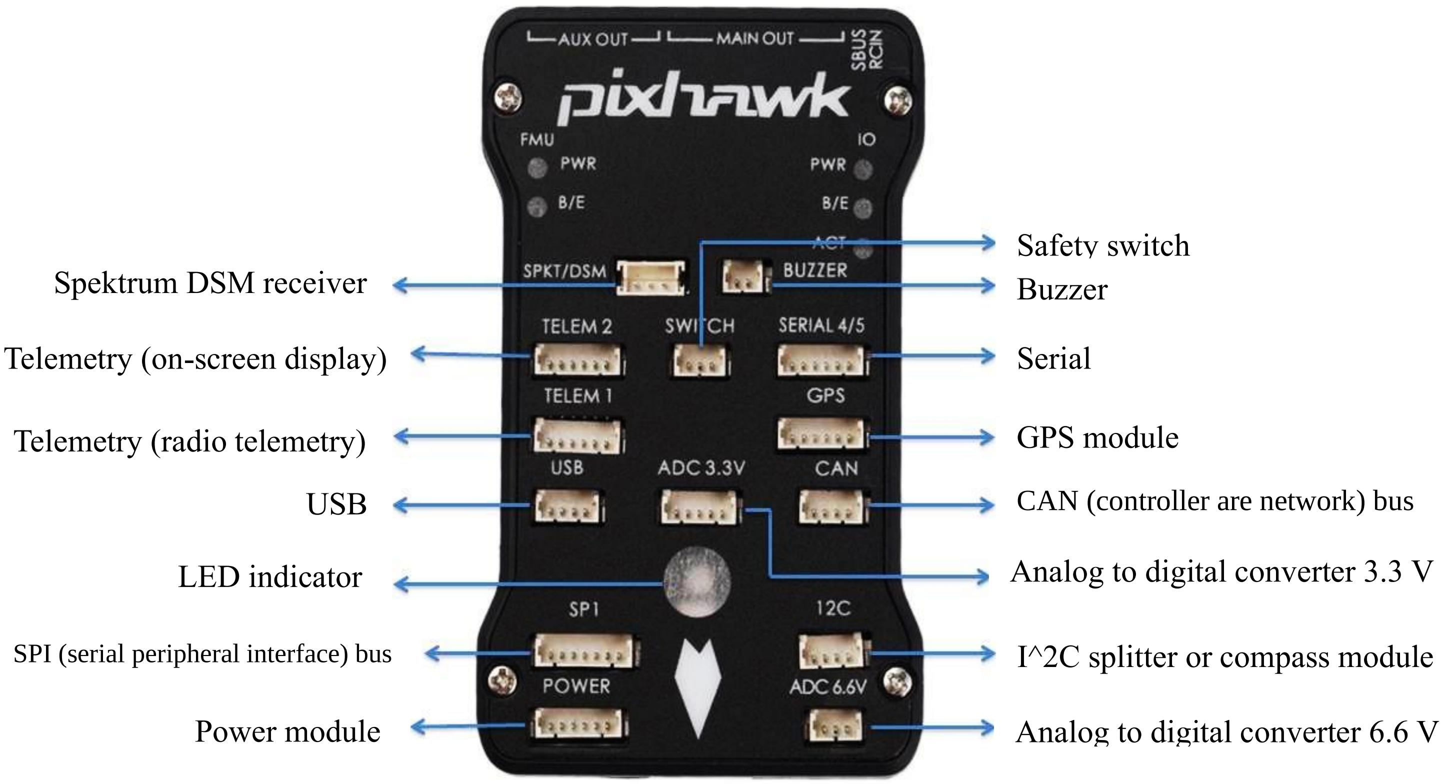
DroPix: Manufactured by Drotek, and based on FMUv2, the DroPix includes integrated Linux-like programming environment and an integrated backup system for inflight recovery.

Pixfalcon : Manufactured by Holybro, and based on FMUv2, the Pixfalcon is derived from the Pixhawk 1 and is optimized for space-constrained applications

HKPilot32: Manufactured by Hobby king, and based on FMUv2, the HKPilot32 is software compatible with the Pixhawk 1 and physically similar but is not connector compatible

II.4.4 Pixhawk connector assignments

They can be evidenced by the pictures below:



1→ Flight management unit (FMU) power

2→ FMU bootloader mode (flashing) or error (solid)

3→ Input/output unit power

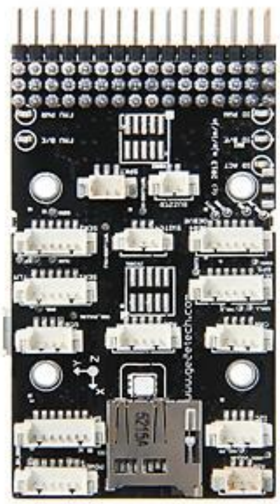
4→ 1/0 bootloader mode (flashing) or error (solid)

5 →Activity (flashing indicates all units responsive

1→Radio control receiver input
2→S.Bus output
3→Main outputs
4→Auxiliary outputs

II.4.5 Interior design


BACK


FRONT

II.4.6 LED Indication

Blue and red flashing: Initializing

Yellow flashing twice: Error, Arming rejected

Blue flashing: System locked and GPS is searching signals. Please note that no matter which mode (Auto/Loiter/RTL) is, GPS needs to be locked.

Green flashing: System and GPS locked and ready to be armed. Please note that there would be two fast d sounds to notify from locked to unlocked status.

Green always on + a long D sound: Armed and ready to take off

Yellow flashing: Transmitter failsafe activated

Yellow flashing + repeated fast D sounds: Battery failsafe activated

Yellow/Blue flashing +High/High/Low sounds: GPS data error or GPS fail safe activated

II.4.7 Safety button indicator

Continuous flashing quickly: System auto checking

Flashing intervalley: System is ready. Press the button to activate the system

Always on: Ready to be armed.

II.4.8 Other components

II.4.8.1 Buzzer

The buzzer is a small, simple component that produces an audible sound. It is typically used as a warning or alert system, such as to signal low battery or to help locate a lost drone [41].

Fig.II.10 Buzzer [41]

II.4.8.2 Common Power Module

The AttoPilot 180A is a power module specifically designed for use in high-power applications. It is a current sensor and power module in one compact package, and it provides real-time current, voltage, and power measurements to help ensure safe and efficient operation of the system [42].

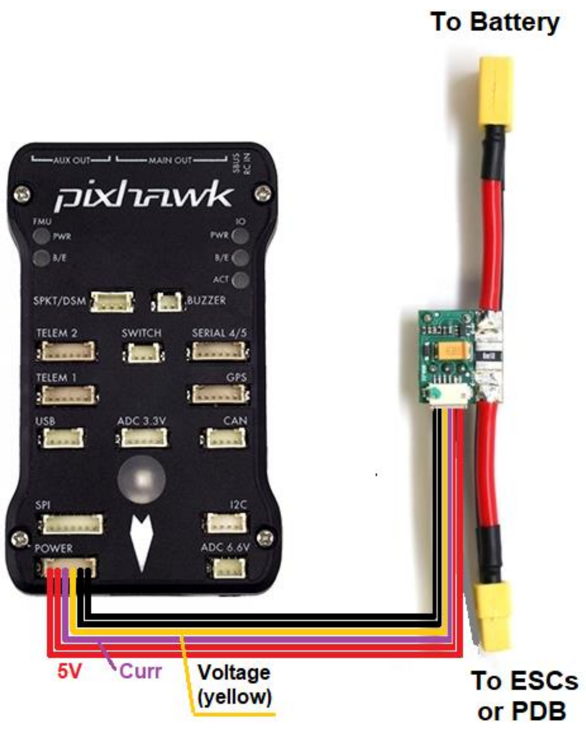


Fig.II.11 Common Power Module [42]

II.4.8.3 SiK Telemetry Radio

The SiK Telemetry Radio is a wireless communication system to transmit telemetry data and commands between the ground station and the aircraft. It operates on either the 433 MHz or 915 MHz frequency band, has a range of several kilometers, uses UART communication, and provides 128-bit AES encryption for secure communication as depicted in the subsequent image [42]

Fig.II.12 SiK Telemetry Radio

II.4.8.4 PPM Encoder

A PPM Encoder is an electronic device used to convert multiple individual channel signals from a receiver into a single PPM (Pulse Position Modulation) signal. This single signal can then be sent to the flight controller to control the aircraft's movements as depicted in the subsequent image [43].

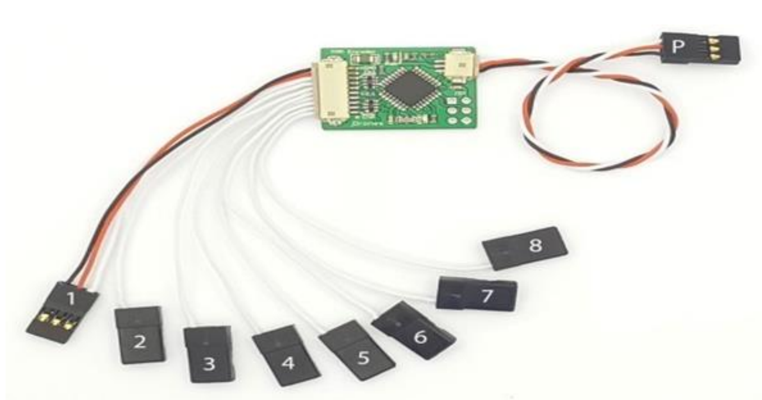


Fig.II.13 PPM Encoder [43]

II.4.8.5 Safety Switch

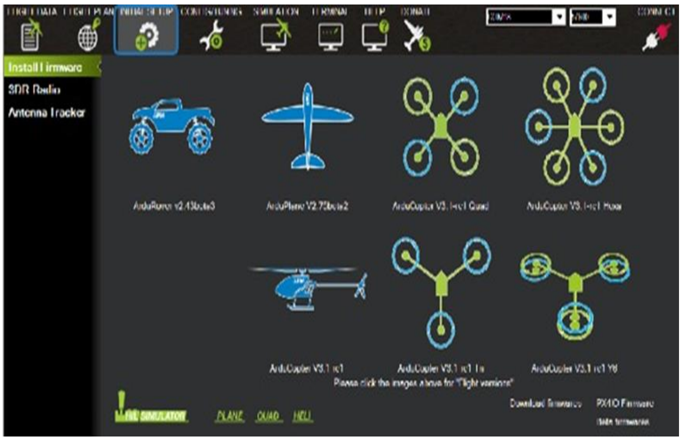
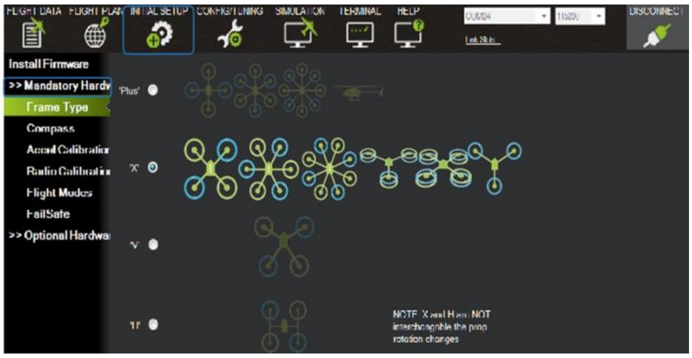
A safety switch can be used to enable/disable the outputs to motors and servos. The switch controls the “Safety” state of the vehicle [44].

Fig.II.14 Safety Switch [44]

II.5 Software Resources

Software resources are essential for operating a quadcopter, as they control its movement, plan its flights, and analyze its data. One of the most commonly used software tools for unmanned aerial vehicles is Mission Planner. This free and open-source software allows users to plan, execute, and analyze autonomous drone flights with real-time telemetry data and camera control. Mission Planner offers users the ability to configure the parameters of their Pixhawk flight controller, including motor outputs, sensor calibration, and GPS settings [45]. With its user-friendly interface and extensive capabilities, Mission Planner is an ideal choice for managing and controlling quadcopters.

Here are some steps to configure a mission planner for our quadcopter:

Step 1: Installation Begin by opening the setup wizard file and installing all suggested drivers. Connect Pixhawk to your computer using the micro-USB cable, but do not select Connect at this time. Install APM firmware, which is essential for the autopilot operation, by installing a mission planner application on your ground station computer. Select Initial Setup, Install Firmware, and select your vehicle. Load the firmware onto Pixhawk by following the directions and power cycle the board.	
Step 2: Frame type Select the appropriate frame type for your drone, as this will determine the physical characteristics and capabilities of your device.	
Step 3: Connection With Pixhawk connected to your computer, select the communication option from the drop-down menu for PX4 FMU, set the rate to 115200, and select the Connect icon. Select Initial Setup and Mandatory Hardware to access the calibration wizards. are this correct	

Step 4: Compass calibration

Enable the compass, allow automatic declination calculation, and specify Pixhawk in the software. Launch the Live Calibration wizard and follow the prompts to calibrate the compass

Step 5: Accelerometer calibration

Select Accel Calibration, check the box for AC 3.0+, select Calibrate, and follow the prompts to calibrate Pixhawk's accelerometer. Wait a couple of seconds before and after changing the positions of the vehicle.

Step 6: RC Calibration

Teach Pixhawk to work with your RC transmitter by selecting Radio Calibration. Turn on your transmitter, select Calibrate Radio, and move all sticks and switches to their extreme positions. Select Click when Done once the red bars are set for all available channels.

Step 7: Flight modes

Finally, select the appropriate flight modes using the mission planner software, move each switch on the transmitter to its available positions, and assign a mode for each switch position by selecting Save Modes. By completing these steps, you can ensure a successful configuration process for your drone

II.5.1 Pixhawk flight mode

Each flight mode has its own set of characteristics that determine how the drone will behave and how the pilot can control it. Here are some key characteristics of each flight mode:

a. Stabilize mode

Keeps the drone level and does not require GPS lock. Wind can still push the drone around, and throttle is managed as a factor of model tilt.

b. Altitude Hold mode

Uses the barometer to maintain height, and the drone manages throttle to stay at a constant height. Throttle between 40% and 60% keeps the model at height.

c. Loiter mode

Maintains the current position, heading, and height. The pilot controls the position while altitude is controlled the same way as in Altitude Hold mode.

d. Return To Launch (RTL) mode

Returns the drone to the GPS location stored at arming. Climbs to 100ft (default), flies back, maintains heading, hovers over home for set time (default 5 seconds), and then automatically lands. Requires GPS lock.

e. Auto mode

Flies a programmed mission and uses controls from Altitude Hold and Loiter mode. During mission roll, pitch, and throttle are ignored. Ensure that LAND or RTL are the last command in a mission.

f. Acro mode

Maintains attitude, and throttle is completely manual. Requires constant control input, and inputs are related to the body of the model. V3.1 and above include ACRO Trainer mode. Considered the most difficult to master.

g. Sport mode

Also known as rate controlled stabilize plus Altitude Hold. Designed for FPV and filming, the model retains attitude and will not lean more than 45 degrees (default). Height is managed automatically.

h. Drift mode

Allows for plane-like control with automatic turns. Yaw is managed by the controller, and the mode allows for slight drift with one stick. Throttle is manual.

i. Guided mode

Allows for control of the drone by clicking on a map. Needs a wireless Mission Planner Connection and active MAVlink. The model flies to the specified location and then hovers, same principle as Follow Me mode.

j. Circle mode

The model circles a set position with the nose pointing inwards. Useful for video where you have a point of interest. The diameter of the circle is configurable, and throttle only controls height.

k. Position mode

Identical to Loiter but with manual throttle control.

l. Land mode

Lands the drone, descends to 10m at the rate set by LAND_SPEED (default 50cm/s), and automatically shuts down motors and disarms when done.

m. Follow Me mode

Works similarly to Guided mode, links to a ground station, and uses GPS position of the ground station to set position. Can use a Bluetooth or normal MAVLink connection. Safety of this mode is not guaranteed.

Mode	Roll	Pitch	Throttle	Gps	Summary
MANUAL	-	-	-		Manual control surface movement, pass-through control
FBWA	s	s	-		Roll and pitch follow stick input, up to set Limits
FBWB	s	A	A	Y	Like FBWB, but with automatic height end speed control
CRUISE	A	A	A	Y	Like FBWB, but with ground course tracking and terrain following
STABILIZE	+	+	-		Wing-leveling on stick release

AUTOTUNE	s	s	-		Like FBWA, but learns attitude tuning while flying
TRAINING	+	+	-		Manual control up roll and pitch limits
ACRO	+	+	-		Rate controlled mode with no attitude Limits
AUTO	A	A	A	Y	Follows mission
LOITER	A	A	A	Y	Circles point where mode switched
CIRCLE	A	A	A		Gently turns aircraft
GUIDED	A	A	A	Y	Circles user defended point from GCS
Return To Launch (RTL)	A	A	A	Y	Returns to and circles home or rally point

Symbol	**Definition**
-	Full manual control of flight surfaces
+	Manual control with stabilized limits or assistance
s	stabilized control with limits
A	Automatic control

Table II.1 Summary of all flight modes [46]

II.6 Conclusion

In conclusion, this chapter has provided a comprehensive overview of the practical aspects of our quadrotor project. We have covered the overall idea, hardware requirements, and software resources necessary for its implementation. The significance of the Pixhawk flight controller as a crucial controlling electronics system has been emphasized, highlighting its role in the operation of the quadrotor.

The integration of the Pixhawk flight controller and the mission planner offers a practical framework for controlling and monitoring the quadrotor during flight, ensuring precise navigation and stability. Building upon this foundation, the upcoming chapter will focus on the actual flying of the quadrotor, exploring its capabilities and performance in various scenarios.

Chapter III

Mission analysis and results discussion

III.1 Introduction

After configuring the Pixhawk with the Mission Planner software, this chapter delves into the utilization of the mission planner's capabilities to enhance the quadcopter's autonomous mission planning and execution. The primary objective is to enable the quadcopter to carry out missions with utmost precision and efficiency. To achieve this, the chapter focuses on key tasks such as waypoint identification, mission execution, and result simulation. By effectively leveraging the mission planner, the quadcopter can navigate along precise flight paths, accomplish designated objectives, and optimize its performance.

III.2 Mission Results

The selection of an appropriate mission location is crucial for conducting quadcopter testing and evaluating its performance. In this section, we focus on the mission location in Laghouat, Algeria, and discuss the key aspects that make it an ideal setting for our quadcopter operations.

III.3 Quadcopter Mission Location

Laghouat is situated in the heart of Algeria, approximately 400 kilometers south of the capital city, Algiers. It covers a vast area of 25,000 square kilometers, offering diverse landscapes and terrains for our quadcopter missions. The region is known for its unique geographical features, combining the Saharan Atlas zone and the high plateaus and Saharan plateaus zone.

The Saharan Atlas zone is characterized by altitudes ranging from 1000 to 1700 meters and consists of ancient forested massifs. This terrain provides an interesting challenge for our quadcopter, requiring precise maneuvering and navigation capabilities. On the other hand, the high plateaus and Saharan plateaus zone features altitudes ranging from 700 to 1000 meters, offering a different set of flight conditions and testing scenarios [47].

III.3.1 Laghouat Map

To provide a visual representation of Laghouat's location, Fig.III.1 depicts the geographic positioning of Laghouat within Algeria.

Fig.III.1 Laghouat Location on The Map

III.3.2 Climate in Laghouat

Laghouat experiences one of the warmest climates in Algeria. The average daily high temperature in Laghouat is 26 degrees Celsius. The region maintains consistently warm to hot temperatures for several months of the year, with temperatures often exceeding 25 degrees Celsius and occasionally reaching up to 40 degrees Celsius. The average wind speed in Laghouat is also a noteworthy factor to consider for quadcopter operations, in pictures bellow represent the average temperature (Fig.III.2) and wind speed in laghouat (Fig.III.3):

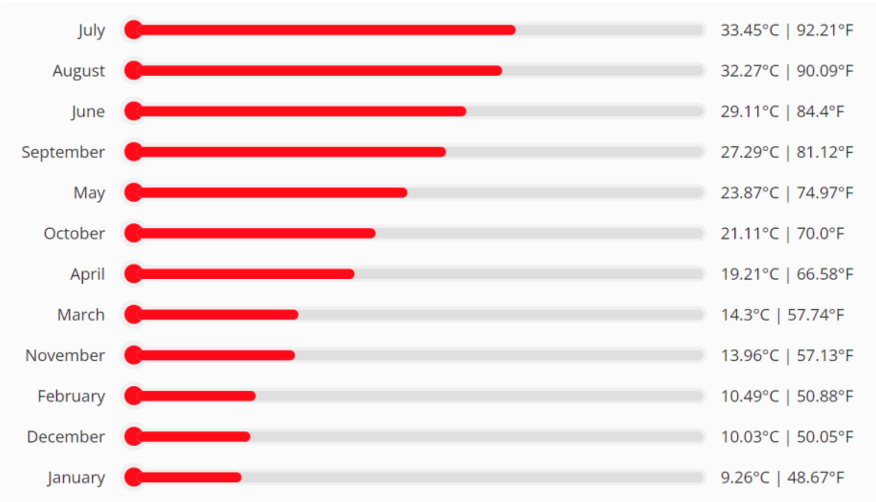


Fig.III.2 Average Temperature in Laghouat [48]

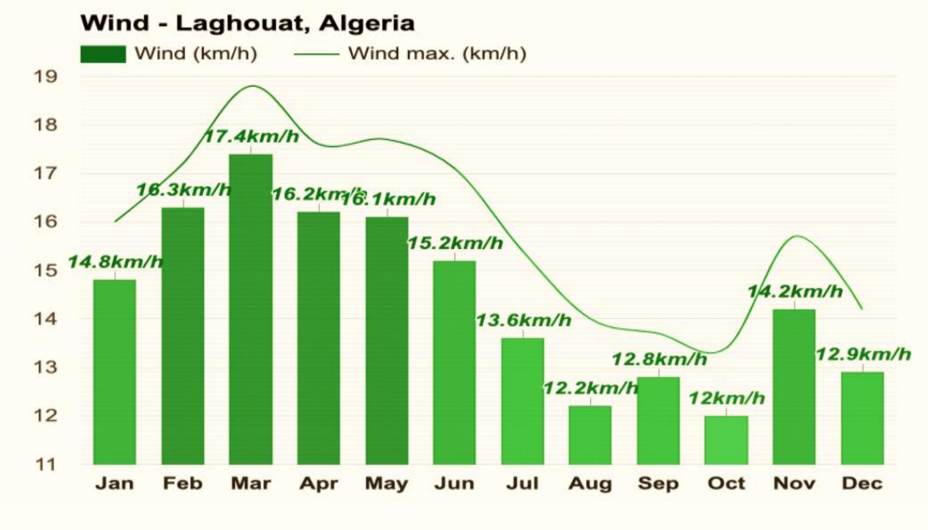


Fig.III.3 Average Wind Speed in Laghouat [49]

Note: All climate data presented in the graphs is collected from the official meteorological station in Laghouat, located at an altitude of 763 meters above sea level. This information was obtained on May 18th,2023.

III.4 Quadcopter mission location

Our quadcopter mission was carried out at The New Campus of Amar Telidji University in Laghouat.

The New Campus of Amar Telidji University is located in Laghouat, Algeria, situated approximately 400 kilometers south of the capital city, Algiers. The campus provides a diverse range of facilities and open spaces, which facilitated our mission planning and execution. Its geographical location within Laghouat offered various terrains and scenarios for testing the quadcopter's maneuverability and navigation capabilities, Quadcopter mission location shown in the picture bellow:

Fig.III.4 The New Campus (Amar Telidj University), Laghouat

Fig.III.5 Amar Telidji University Stadium

III.5 Case Study: Implementation of Mission Control System

In our research work, we divided our activities into two sections: manual control and autonomous control of the quadcopter. Each section focused on specific aspects of the mission control system implementation.

III.5.1 Manual Control of Quadcopter

In this section, we conducted a thorough evaluation of the quadcopter's performance using the Mission Planner software. The primary objective was to validate the accuracy of the Pixhawk flight controller and ensure precise and intended flight behavior.

During the test flights, we carefully piloted the quadcopter using a radio transmitter, adjusting throttle, roll, and yaw inputs. We closely monitored the drone's stability, maneuverability, and responsiveness to our manual control inputs. We have done the manual control evaluation as shown in the figure bellow (Fig.III.6):

Fig.III.6 Manual Control Evaluation: Validating Quadcopter Performance with Mission Planner Software

During the test flights, we closely observed and analyzed the quadcopter's performance under manual control. We noted that the quadcopter maintained its intended flight path and exhibited satisfactory maneuverability, showcasing the suitability of the selected materials and the effectiveness of our manual control techniques.

III.5.2 Autonomous Control of Quadcopter

In the autonomous control section, we focused on assessing the quadcopter's performance in various flight modes and conducting a multi-waypoint autonomous flight mission.

III.5.2.1 Flight modes

After successfully controlling the quadcopter manually, we calibrated the flight mode settings based on our specific requirements. We had the flexibility to choose between different flight modes to ensure optimal performance.

The flight modes we selected were as follows:

- Flight mode 1: Land
- Flight mode 2: Stabilize
- Flight mode 3: Auto
- Flight mode 4: RTL (Return to Launch)
- Flight mode 5: Loiter

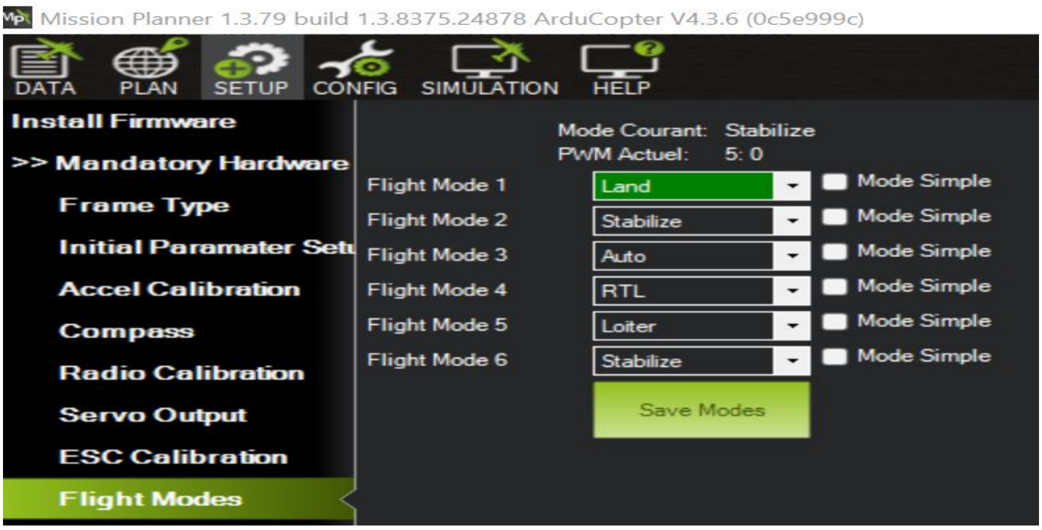


Fig.III.7 Flight Modes Setup

III.5.2.2 Multi-Waypoint Autonomous Flight Mission

In this experiment, we created quadcopter flight routes using the mission planner software. Fig.III.8 and Fig.III.9 illustrates our mission planning and events setting in this experiment, we selected five waypoints with additional 1-second delays between WP1 to WP4. The flight altitude was set at 2 meters throughout the mission.

The waypoint navigation speed settings were as follows:

- Linear speed : 750 cm/s
- Radius speed : 200 cm/s
- Speed up rate: 250 cm/s
- Speed down rate: 150 cm/s
- Loiter speed : 1000 cm/s

The mission waypoints were as follows:

- Waypoint 1: Take off
- Waypoint 2: Waypoint
- Waypoint 3: Waypoint
- Waypoint 4: Waypoint
- Waypoint 5: Land

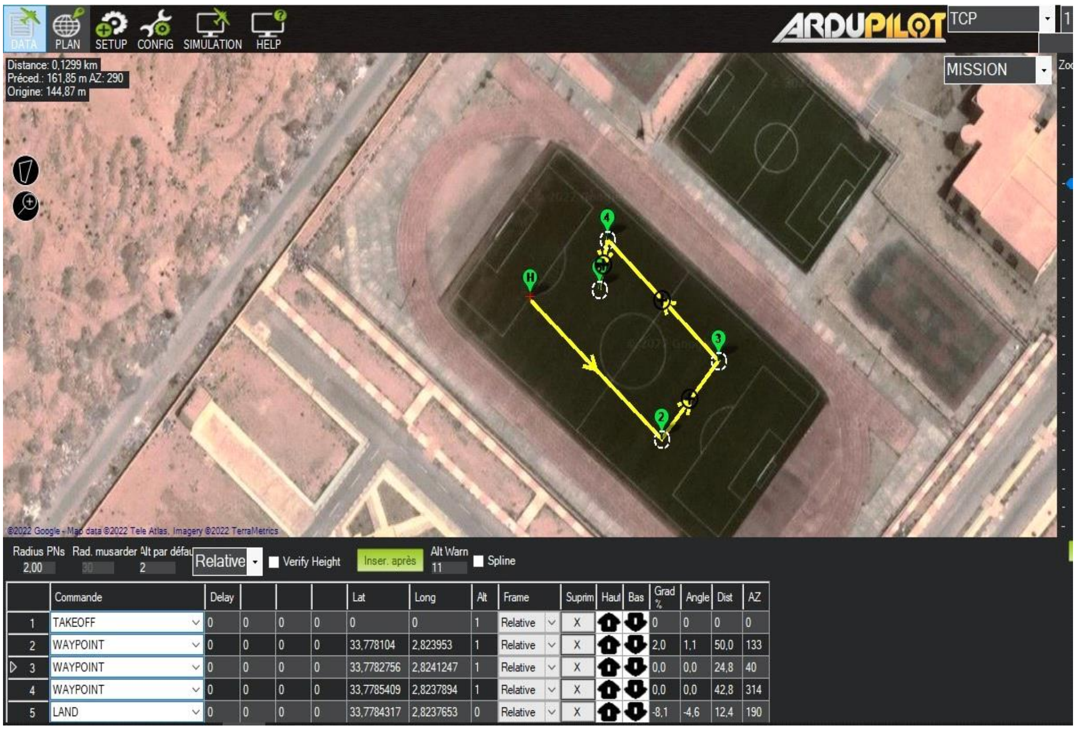


Fig.III.8 Flight Plan. Waypoints. 1 second delay was added for each Waypoint

Fig.III.9 Quadcopter Mission Trajectory

III.5.3 Mission Results and Analysis

To ensure smooth flight and precise mission execution, meticulous PID tuning parameters were applied. The desired output, representing the desired pitch, roll, and yaw angles, was carefully compared with the quadcopter's actual output obtained from the Pixhawk system. By fine-tuning the proportional, integral, and derivative gains of the pitch, roll, and yaw controllers, the quadcopter's behavior was adjusted to closely match the desired angles.

The pitch, roll, and yaw controllers are of utmost importance as they guarantee that the quadcopter accurately maintains the demanded pitch, roll, and yaw angles throughout the mission. Achieving the expected behavior relies on selecting the appropriate PID gains, which directly influence the response characteristics of the quadcopter. The gains were meticulously adjusted to optimize the quadcopter's performance, ensuring precise maneuvering and adherence to the mission objectives.

During the initial stages, the quadcopter's behavior was fine-tuned through a process of trial and error in the assisted mode. This involved carefully evaluating the quadcopter's handling qualities and making iterative adjustments to the PID gains. The objective was to strike a balance between responsiveness and stability, allowing the quadcopter to effectively navigate its flight path while maintaining acceptable handling characteristics.

The assisted mode served as a valuable testing ground for assessing the quadcopter's response to various inputs and flight conditions. By closely monitoring its behavior and making incremental adjustments, the quadcopter's handling qualities were refined to meet the desired standards. This iterative process allowed for the identification of optimal PID gains, ensuring that the quadcopter exhibited improved stability, accuracy, and maneuverability throughout the mission. The optimal gains are presented in Table III.1:

	Roll	Pitch	Yaw	Velocity	Throttle accel
P	0.135	0.135	0.180	2	0.5
I	0.135	0.135	0.018	1	1
D	0.0036	0.0036	0	0.5	0

Table III.1 The optimal PID gains for the quadcopter

III.5.3.1 Experimental and results

- **Altitude**

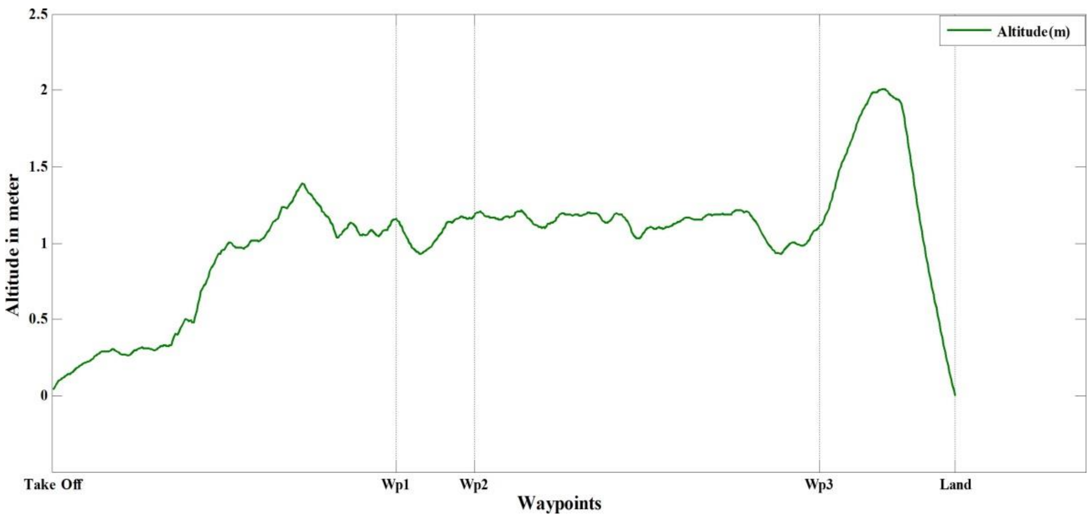


Fig.III.10 The Desired Altitude for The Proposed Mission

The curve at the top represents the changes in the desired altitude to perform the mission in meter, Depending on time in relation to the waypoints.

We can see here some Delay in reaching the desired altitude and it's normal and should be expected, this is likely due to the influence of many factors such as the force of gravity and weather conditions on the time to achieve the given altitude.

➢ **Pitch, roll and yaw**

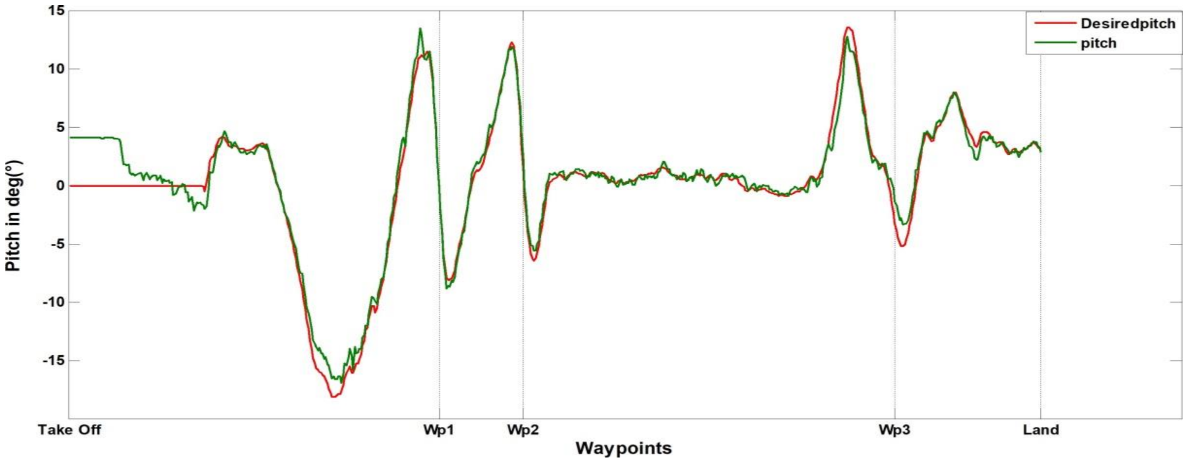


Fig.III.11 The Desired and Output Pich Results

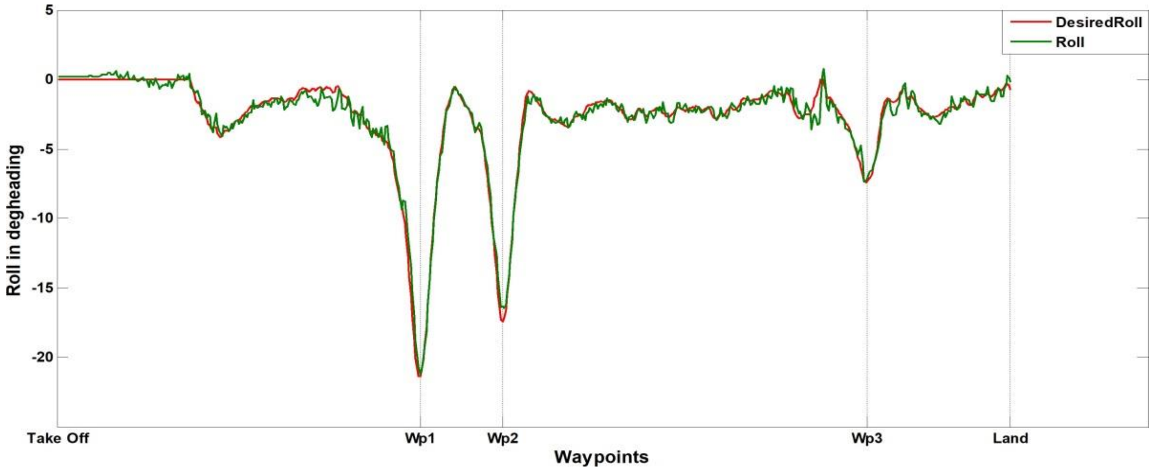


Fig.III.12 The Desired and Output Roll Results.

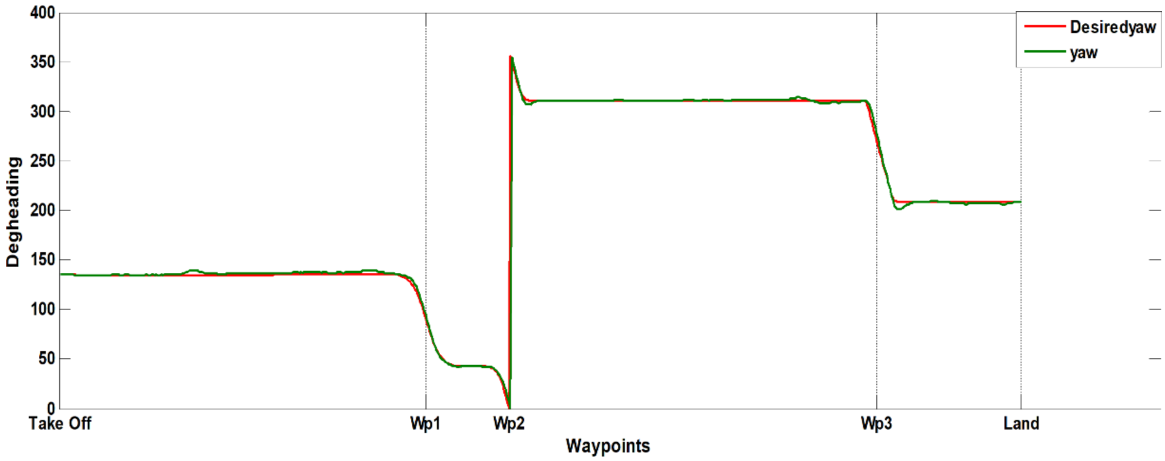


Fig.III.13 The Desired and Output Yaw Results.

The figure "Fig.III.11 and Fig.III.12 and Fig.III.13 ", present the output results of the changes in pitch, roll and yaw angles in order, shown in green and their comparison with the desired results during the mission represented in red.

The mission trajectory closely resembles a rectangular pattern, causing the quadcopter to exhibit a constant tendency to turn in one direction. This can be attributed to the planned waypoints and expected trajectory of the mission. However, it is important to note that external factors such as wind can affect the flight dynamics of a quadcopter. Therefore, slight vibrations may occur during the test due to the interaction between the wind and the controls of the quadcopter. These vibrations are normal and expected as the drone adapts to changing wind conditions.

- **Speed**

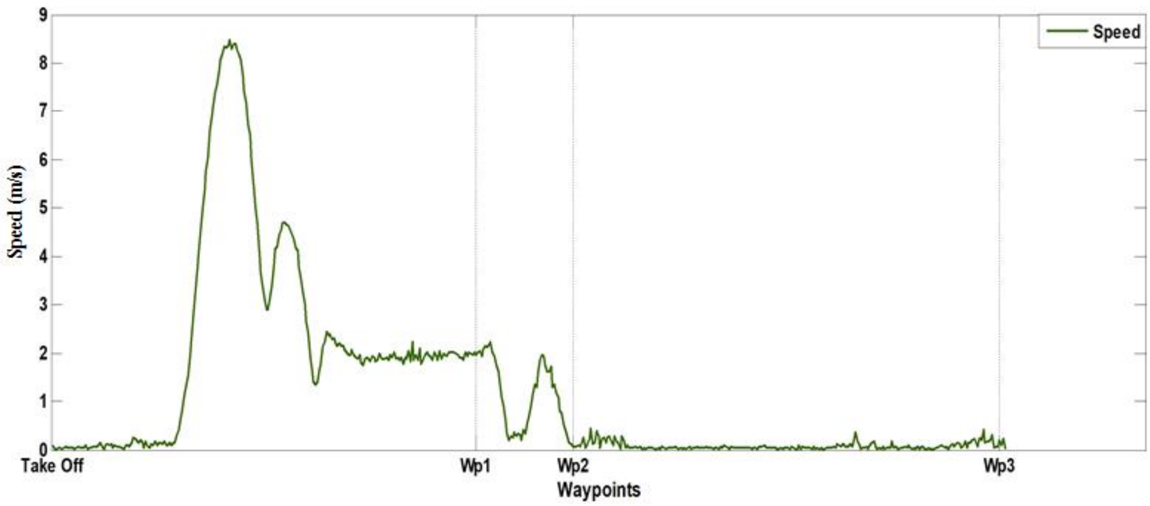


Fig.III.14 Quadcopter Speed

With the curve shown in the above figure, representing the changes of the speed of the quadcopter, depending on time between the waypoints, we can say that the drone's speed during the mission shows some variation in speed between waypoints. At the start, there is an increase in speed from the starting point "take off point" to the first waypoint (Wp1), which indicates a rapid acceleration phase to reach speed 8.5 m/s. Later, there is a drop in speed between the first and second waypoints, and then it ended with a 0 m/s speed when it finished the mission at land point. This change may be explained by the speed and direction of the wind during the mission.

➢ **Pressure and temperature**

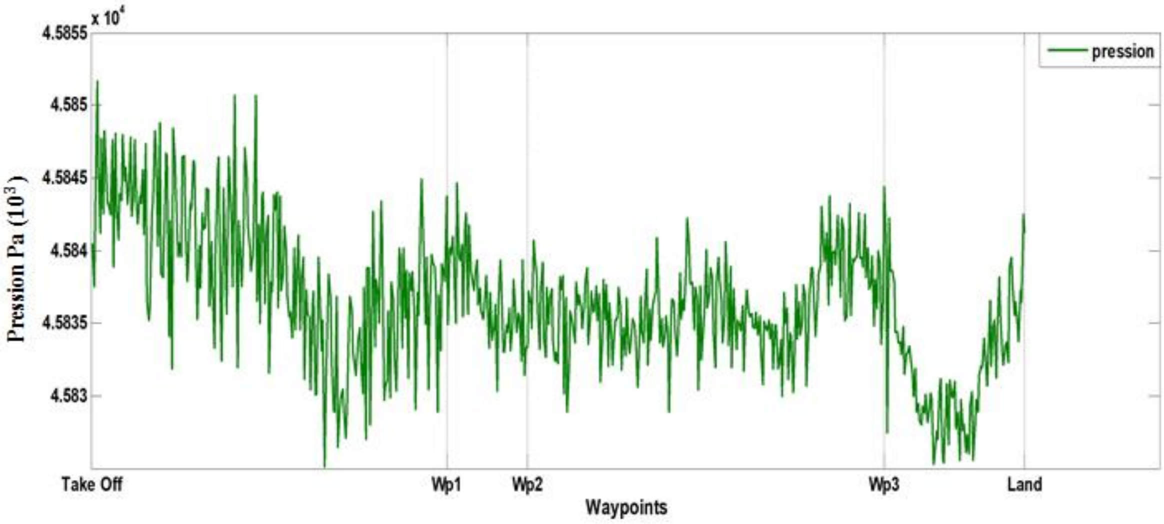


Fig.III.15 The Output Pression of The Quadcopter.

The figure “Fig.III.15”, Represents in green the curve of pressure changes on the drone in Pascal (Pa) between the waypoints during the mission.

The changes observed in the pressure changes curve gave the drone valuable insights into flight dynamics such that this change could be explained by changes in altitude, That is, the higher the altitude, the higher the atmospheric pressure, and vice versa, or the effect of atmospheric conditions on the pressure, as we can see that slight changes and maintaining almost the same pressure values in general mean that the mission is going excellent and almost complete stability in flight and we can see how healthy the quadcopter is during the mission.

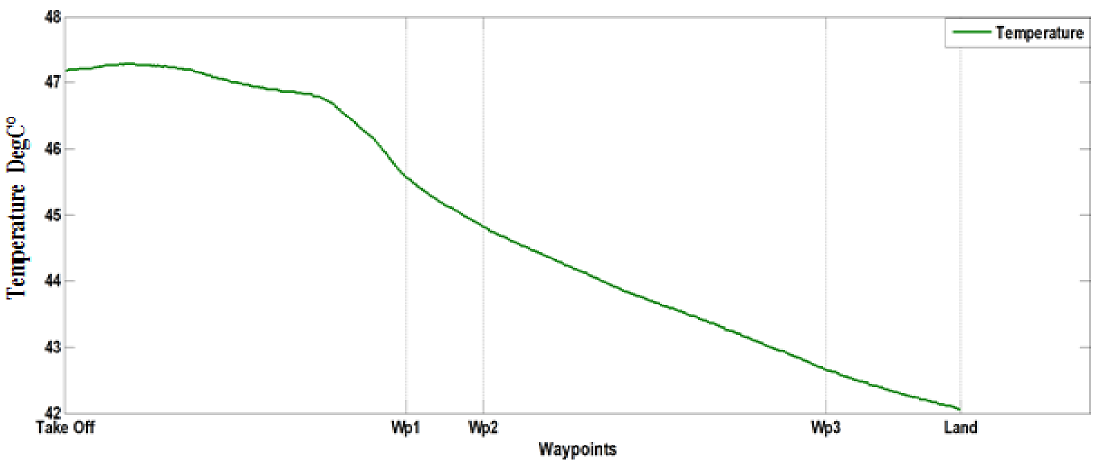


Fig.III.16 The Output Temperature of The Quadcopter

The figure below represents a temperature change curve while performing the mission in degrees Celsius (°C). We notice a decrease in the temperature since the drone was launched from the starting point, as the temperature was 47 °C and continued to drop to 42 °C.

We can explain this decrease by the effect of cold winds during the flight, so that when cold air flows over the outer parts of the drone, it may be cooled, and thus the temperature decreases.

We can also explain this decrease to the effect of altitude, The higher the altitude, the colder the weather, and this is what the Weather was like on the day of the experiment.

At the end of this chapter, we can see here some real footage for the tests of the mission outside shown in Fig.III.17. Note here that we have elaborated several tests under different conditions which are sometimes too hard especially in the presence of rain or wind.

Fig.III.17 Real Footage for The Tests of The Mission Outside

III.6 conclusion

In this chapter, a quadcopter mission analysis was performed to assess its performance and response. The mission included a predetermined set of waypoints. The purpose of this mission is to evaluate how accurately the quadcopter can reach each waypoint and successfully complete the mission with minimal errors.

During the mission, the quadcopter shown a commendable ability to follow the desired and set angles 'pitch, yaw, roll' of all points of the trajectory. The quadcopter's control system proven to be well-tuned and effectively translates desired angles into the actual movements of the quadcopter, maintaining stability and precision throughout the mission. The results obtained from the analysis show that the quadcopter performs satisfactorily in terms of angles and altitude tracking, which indicates its reliability and effectiveness in completing the mission.

General Conclusion

The main focus of this work was the design, implementation and performance evaluation of a four-rotor unmanned aircraft (quadrotor) system based on Pixhawk flight control. Our goal was to study the stability of the quadcopter's performance during a real-time mission, and to develop an autonomous take-off and landing system without human intervention, and to advance understanding of its autonomous capabilities. Hence, based on this some conclusion can be extracted from this dissertation:

- We have successfully built and tested automatic quadcopter flight with No human supervision, which means the system can be active on a constant basis and also reduces the risk of human mistakes. It’s also essential for swarm robotics where it is not possible to control every unit in detail.
- Implementing an autonomous system in quadcopters, has the potential to revolutionize various industries by reducing reliance on human supervision. This is a first step to develop a fully autonomous system that could be used for e.g., surveillance or search and rescue missions.
- Pixhawk controller is an independent open hardware project that aims to provides users with advanced mission planning opensource software such as mission planner. It made the work easy and fast especially for the large opportunity of changing several parameters as well as flight modes.
- The mission planner is a user-friendly ground control software that enables to plan, monitor, and execute autonomous mission for quadcopter. It allows users to define waypoints specifying actions at each point and set flight parameters like altitudes, speed…
- Several factors must be taken into consideration, such as the quality of electronic components and batterie, brushless motors, as well as the frame whose play a crucial role in the performance and reliability of a drone, because they will provide better control, longer flight times, improved stability in order to get the best and optimal experience.

Future works

Future work can focus on enhancing the quadcopter system to create a robust and autonomous platform suitable for a wide range of applications. This includes improving navigation capabilities by integrating advanced positioning systems, developing algorithms and sensors for real-time obstacle detection and avoidance, integrating additional sensors to enhance perception capabilities, and advancing intelligent decision-making algorithms. Continuous improvement through research, field testing, and collaboration with experts will contribute to the reliability and versatility of the quadcopter system. The ultimate goal is to enable safer and more efficient operations in complex environments.

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