الجمـــهوريـــة الجـــزائريـــة الديـمقراطيـــــــة الشـــعبيــــــة
THE PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA

وزارة التعـلـيـم العـالــي و الـبحـث الـعلـمي
THE MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH
جـامـعـة عمّـــار ثـلـيـــجـــي بالأغـــواط
AMAR TELIDJI UNIVERSITY OF LAGHOUAT

كـلـيـــة الـتكنولوجيا
FACULTY OF TECHNOLOGY

DEPARTMENT OF ELECTROTECHNIC

Master's dissertation

Field : Science and Technology
Course : Automatic
Option : Automatic and systems

By :

Djouadi Abderrahmen
Benzian Aissa

THEME

Design, Implementation and Analysis of missions for Autonomous Quadcopters

Publicly supported ahead of a jury composed of:

Mr.	*M.C.A*	*President*
Mr.	*M.C.A*	*Examinateur*
Mr. Benmouiza Khalil	*M.C.A*	*Supervisor*
Mr. OUBBATI Youcef	*M.C.B*	*Co-supervisor*

Academic year 2021/2022

Abstract

Quadcopters are inexpensive and agile aerial robotic platforms. Several applications are possible with these robots such as mine exploration or reconnaissance and rescue operations. These missions require navigating cluttered and unpredictable environments. The vehicle used must be able to quickly avoid obstacles while traveling at high speed. The quadcopter being under-powered is limited in its aggressiveness since it must tilt before accelerating. In addition, the conventional controllers used do not predict the behavior that the vehicle will have during the trajectory using its dynamics, which prevents it from diligently planning complex maneuvers. In this context, the main objective of this dissertation is to overcome these two limitations by developing a quadcopter capable of tilting its motors to accelerate faster and using a PID controller to complete its mission. The mathematical modeling as well as step by step realisation is viewed. In addition, a mission control and analysis using the PIXHAWK controller is also achieved.

key-words : quadcopter , Pixhawk , mission , control.

الملخص

المروحية الرباعية (كوادكوبتر) هي منصات روبوتية جوية غير مكلفة وعملية. لذلك فانها تمكن من استخدام العديد من التطبيقات مع هذه الروبوتات مثل استكشاف الألغام أو عمليات الاستطلاع والإنقاذ مع العلم ان هذه المهام تتطلب التنقل في بيئات مزدحمة ومباغتة .لذلك فيجب أن تكون السيارة المستخدمة قادرة على تجنب العقبات بسرعة أثناء السير بسرعة عالية.كما ان المروحية الرباعية المحدودة في قوتها يجب أن تميل قبل أن تتسارع. بالإضافة إلى ذلك ، لا تتنبأ أدوات التحكم التقليدية بالسلوك الذي ستحدثه السيارة أثناء المسار باستخدام ديناميكياتها مما يمنعها من التخطيط الجاد للمناورات التي تكون معقدة. وفي هذا السياق ، يتمثل الهدف الرئيسي لهذه العمل البحثي في التغلب على هذين المحددين من خلال تطوير مروحية رباعية قادرة على إمالة محركاتها لتسريع وتيرة استخدام وحدة تحكم لإكمال مهمتها. يتم عرض النموذج الرياضي وذاك خطوة بخطوة. بالإضافة إلى ذلك ، يتم أيضًا تحقيق التحكم في المهمة والتحليل باستخدام وحدة التحك (PIXHAWK) .

الكلمات المفتاحية: مروحية رباعية ، بيكسوك ، مهمة ، تحكم.

Résumé

Les quadrirotors sont des plateformes robotiques aériennes peu coûteuses et agiles. Plusieurs applications sont envisageables avec ces robots tels que l'exploration des mines ou les opérations de reconnaissance et sauvetage. Ces missions nécessitent de naviguer dans des environnements encombrés et imprédictibles. Le véhicule utilisé doit pouvoir éviter rapidement des obstacles tout en circulant à haute vitesse. Le quadrirotor étant sous-actionné est limité dans son agressivité puisqu'il doit s'incliner avant d'accélérer. De plus, les contrôleurs conventionnels utilisés ne prédisent pas le comportement qu'aura le véhicule durant la trajectoire en utilisant sa dynamique ce qui l'empêche de planifier assidûment les manœuvres complexes. Dans ce contexte, l'objectif principal de ce mémoire est de s'affranchir de ces deux limitations en développant un quadrirotor capable d'incliner ses moteurs pour accélérer plus rapidement et d'utiliser un contrôleur PID pour pour mener à bien sa mission. La modélisation mathématique ainsi que la réalisation pas à pas sont visualisées. De plus, un contrôle de mission et une analyse à l'aide du contrôleur PIXHAWK sont également réalisés.

mots-clés : quadcopter , Pixhawk , mission , contrôle.

Aknowledgement

First and foremost, I am very grateful to the almighty ALLAH S.W.T for giving me the key and opportunity to accomplish my master dissertation.

I wish to express my deepest appreciation to my supervisor, Dr. BENMOUIZA Khalil, for encouragement, guidance, suggestions, critics and friendship throughout finishing this project. I am proud and grateful for having had the possibility to work and learn from him. I wish to thank my co-supervisor, Dr. OUBBATI Youcef, for his constant support , availability and constructive suggestions , which were determinant for the accomplish of the work presented in this dissertation.

I would like to thank… , professor in the University of Laghouat for his acceptance to be the president of the eminent jury. Also, I would like to thank, …professor in the University of Laghouat , … in The university of Laghouat for their acceptance to examine this dissertation.

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 master dissertation.

Dedication

To my life, my mother

To my guide, my father

To my sisters and brothers

To all my family and friends

Thank you for believing in me

Benzian *Aissa*
&
Djouadi *Abderrahmen*

Contents

List of Figures

List of Tables

List of abbriviations

CW	:	Clock Wise
CCW	:	Counter ClockWise
ESC	:	Electronic Speed Controller
GPS	:	Global Positioning System
LiPo	:	Lithium Polymer
MP	:	Mission Planner
PID	:	Proportional,Integrative and Derivative control
PWM	:	Pulse Width Modulation
RC	:	Radio Control
RTL	:	Return to Launch
UAV	:	Unmanned Areal Vehicle

List of Acronymes

ε	:	Absolute linear position of the quadcopter is de ned in the inertial frame
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)
η	:	Angular position, is de ned in the inertial frame
q	:	Linear and angular position vectors
VB	:	Linear velocities in the body frame
υ	:	Angular velocity in the body frame
R	:	Rotation matrix from the body frame to the inertial frame
Wn	:	Transformation matrix for angular velocities from the inertial frame to the body frame
G	:	Vector of the gravity
g	:	Gravity
T	:	Thrust motor on the quadcopter (in the body frame)
TB	:	Total thrust on the quadcopter (in the body frame)
τ	:	Motor torque
I	:	Input current
$I0$	:	No load current
kt	:	Torque constant
P	:	Consumed power
V	:	Voltage drop across the motor
Rm	:	Motor resistance
ω	:	Motors angular velocity in the inertial frame
kv	:	Constant of RMF generated per RPM
υh	:	Air velocity
ρ	:	Density of the surrounding air
FD	:	Frictional force
kd	:	Frictional constant
A	:	Reference area (propeller cross-section, not area swept out by the propeller)
CD	:	Dimensionless constant
R	:	Radius of the propeller
b	:	Appropriately dimensioned constant
τD	:	Torque due to drag
τz	:	Complete torque about the z axis for the ith motor
$\tau\theta$	:	Pitch

General Introduction

The quadrotor is a flying robot. It belongs to the Multirotors family. The quadrotor has several characteristics (mechanical structure of reduced size, reduced weight, agility, vertical takeoff and landing), which gives several advantages over other types of flying robots [1-2]. However, despite all the advantages, the quadrotor has a dynamic model that is strongly nonlinear and fully coupled, In addition, manual flaying of the quadcopter is completely hard to achieve and non useful. Thus, the search and investigation for automatic control is needed [3-4].

In this dissertation, we aim to build a quadrotor, piloted via a radio control (RC), thus an embodiment of an inertial unit, which can be used later in the autonomous flight mode. Then develop a dynamic model of this quadrotor that will serve as a basis for a control PID approach to regulate the position of equilibrium (hovering) and the stability of the quadcopter.

The main objective was to build an automated takeoff and landing system for quadcopters. This will make unmanned aerial vehicles (UAVs) less dependent on human supervision which could improve for example swarms of quadcopters where humans cannot control everything in detail.

Quadcopters are used due to their mobility and ability to hover over a specific location, useful for surveillance and search missions. The system is self-contained and real time processing is done on board. To make the project possible, software for an onboard computer had to be developed and put on the quadcopter. The onboard computer is controlled from a ground station which can give high level commands such as takeoff, land and change altitude.

Experiments were conducted in a laboratory environment to measure the effectiveness of the takeoff, hovering, and landing commands. Then they are tested in real time with a flight mission in the university campus of the University of Laghouat, Algeria.

This dissertation is structured as follows:

Chapter 1 will give the state of the art of UAVs. A description of the different configurations of helicopter drones is given. Moreover, a description of the operating principle of the quadrotor drone is presented with a detailed description of its possible movements as well as ight modes, together with the pitch, roll and yaw angles, which designates the signals of input and their corresponding output responses. A set of benchmarks must be given before attempting to model the dynamics or kinematics of the quadrotor, this is explained in this chapter. Based on the laws of kinematics (Euler / Lagrange), this chapter presents a dynamic modeling of the quadrotor drone. Knowing the relationships between the thrusts of different engines and angular accelerations, a more useful model can be established and tested for stabilization purposes.

In Chapter 2, a step by step DJI 450 realisation is studied. A full description of each used material as well as electronics components is given. The selection of these components is illustrated. A detailed review of the heart of the quadcopter which is called Pixhawk was shown. In addition, the mission planner software that was used for control and configure the quadcopter is presented.

In Chapter 3, we will focus on the outdoor real time mission testing for the constructed DJI-450 quadcopter. Different flight modes are tested and the real results are discussed. In addition the tuning PID parameters are also given to ensure the quadcopter stability and to get the best smooth mission achievement.

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 1

Mathematical modeling of the quadcopter

1.1 Introduction

UAV stands for Unmanned Aerial Vehicles but can also be referred to as drones. They can be hardware or software controlled and can fly wirelessly with the help of a controller to accomplish various tasks. They are used where the use of airplanes or helicopters would be too expensive or risky. The capabilities and roles of Unmanned Aerial Vehicles (UAVs) are evolving and so are their applications. Drone itself is divided into two parts which is the basic platform and the equipment attached to it which is the payload. The drone, which is the flying platform can be made suitable for different goals. These goals can be achieved in combination with specific payload suitable for that load. In this chapter we will give a full overview of the drones as well as their principal working.

1.2 Drone definition

Drones, sometimes referred to as "Unmanned Aerial Vehicles" (UAVs) are meant to carry out tasks that range from the mundane to the ultra-dangerous. Originally developed for the military and aerospace industries, drones have found their way into the mainstream because of the enhanced levels of safety and efficiency they bring. These robotic UAVs operate without a pilot on board and with different levels of autonomy. A drone's autonomy level can range from remotely piloted (a human controls its movements) to advanced autonomy, which means that it relies on a system of sensors and LIDAR detectors to calculate its movement [5].

1.3 History of Drones

In what follows, we will give a brief history of the evolution of drones ;

- **1849 :** First battle drone

The bombing of venice although balloons today do not generally belong to the group of drones, their concept was convincing enough that after the invention of classic aircraft. The first records of the use of drones date from 1849, when the Austrians attacked Venice with unmanned balloons filled with explosives fired from a battleship presented in the Figure 1.1 [5].

FIGURE 1.1 : The Bombing of Venice

- **1917 :** First automatic gyro UAV (Curtiss N-9)

In 1917, Peter Cooper and Elmer A. Sperry invented the first automatic gyro stabilizer, which allowed the aircraft to keep the balance forward flight. This technological achievement successfully transformed the U.S. Navy Curtiss N-9 training aircraft into the first radio-controlled unmanned aerial vehicle (UAV) shown in Figure 1.2 [6].

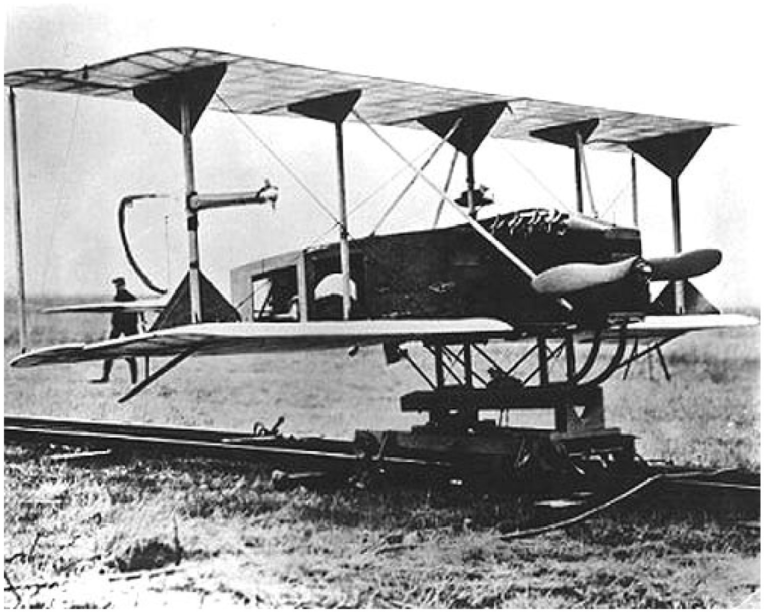


Figure 1.2 : First Automatic Gyro UAV

- **1935 :** Queen bee drone

Aircraft before 1935 could not fly back to the take-off point, so they could not be reused. The invention of the Queen Bee allowed the drone to return to the take-off point, making the technology more practical look at the Figure 1.3 [7].

Figure 1.3 : Queen Bee Drone

- **1950 :** Ryan firebee UAV

In the early 1950s, the Ryan aeronautical company produced 32 unmanned aerial vehicles powered by jet engines that were flying at subsonic speed known as Ryan "Firebee". Firebee's UAV (Unmanned Aircraft Vehicle) design dominated the world's history of drone development presented in the Figure 1.4 [].

FIGURE 1.4 : Ryan Firebee UAV

- **1956 :** Convertawings quadrotor

This unique quadrotor was the prototype for a larger civil quadrotor helicopters during the war. The first flights took place in March 1956 shown in Figure 1.5 [8].

FIGURE 1.5 : Convertawings Quadrotor

- **1986 :** RQ2 pioneer UAV

The pioneer series of UAVs, and it was put into practical use for the first time in December 1986. Pioneer is still in service, taking off with a rocket boost, taking off weight of 416 pounds, and a speed of 109 miles per hour. The plane can float on the water and be recovered by landing on the sea look at the Figure 1.6 [9].

FIGURE 1.6 : RQ2 Pioneer UAV

- **2006 :** DJI commercial use of drones

In 2006, the DJI UAV company that affected the world 's civilian drone pattern was established. DJI is the world's largest manufacturer of civilian drones, occupying more than 70% of the world's market share, whether in rich countries such as Europe and the United States, or less developed countries such as Asia, Africa, and Latin America presented in the Figure 1.7 [10].

FIGURE 1.7 : The DJI UAV

- **2014 :** Amazon drone delivery

Amazon makes a big bet on drones, believing that delivering goods by air is the fastest and most efficient way from point A to point B. In order to be able to work with drones as couriers shown in Figure 1.8 [11].

Figure 1.8 : Amazon Drone Delivery

- **2018 :** First passenger drones on the market

In 2018, Chinese drone manufacturer Ehang announced at CES in Las Vegas that it will build a fully autonomous passenger quadrocopter. Recently, the company showed a video dedicated to the first test flights of the device in China. A taxi drone that will never get stuck in traffic will take the passenger along look at the Figure 1.9 [12].

Figure 1.9 : First Passenger Drones

1.4 Type of drone

We will explore the different types of drones out there in the market – some of which are just concepts, while most others are already in action. "Drones" can be classified on a different basis – say based on 'usage' like Drones for Photography, Drones for aerial mapping, Drones for Surveillance etc. However, the best classification of 'Drones' can be made on the basis of aerial platforms. Based on the type of aerial platform used, there are 4 major types of drones [13].

1.4.1 Multi rotor drones

Multi rotor drones are the most common types of drones which are used by professionals and hobbyists alike. They are used for most common applications like aerial photography, aerial video surveillance etc. Different types of products are available in this segment in the market – say multi-rotor drones for professional uses like aerial photography (whose price may range from 500USD to 3K USD) and there are lots of variants for hobby purposes like amateur drone racing, or leisure flying (price range from 50USD to 400USD). Out of all the 4 drone types (based on aerial platform), multi-rotor drones are the easiest to manufacture and they are the cheapest option available as well presented in the Figure 1.10 [14].

FIGURE 1.10 : Multi Rotor Drones

1.4.2 Fixed wing drones

Fixed wing drones are entirely different in design and build to multi-rotor type drones. They use a 'wing' like the normal airplanes out there. Unlike multi-rotor drones, fixed wing type models never utilize energy to stay afloat on air (fixed wing types can't stand still on the air) fighting gravity. Instead, they move forward on their set course or as set by the guide control (possibly a remote unit operated by a human) as long as their energy source permits. Most fixed wing drones have an average flying time of a couple of hours. Gas engine powered drones can fly up to 16 hours or higher. Owing to their higher flying time and fuel efficiency, fixed wing drones are ideal for long distance operations (be it mapping or surveillance). But they can not be used for aerial photography where the drone needs to be kept still on the air for a period of time shown in Figure 1.11 [15].

Figure 1.11 : Fixed Wing Drones

1.4.3 Single rotor drones

Single rotor drones look very similar in design & structure to actual helicopters. Unlike a multi rotor drone, a single rotor model has just one big sized rotor plus a small sized one on the tail of the drone to control its heading. Single rotor drones are much efficient than multi rotor versions. They have higher flying times and can even be powered by gas engines. In aerodynamics, the lower the count of rotors the lesser will be the spin of the object. And that's the big reason why quadcopters are more stable than octocopters. In that sense, single rotor drones are much efficient than multi-rotor drones look at the Figure 1.12 [14].

FIGURE 1.12 : Single Rotor Drones

1.4.4 Hybrid vtol

These are hybrid versions combining the benefits of Fixed wing models (higher flying time) with that of rotor based models (hover). This concept has been tested from around 1960's without much success. However, with the advent of new generation sensors (gyros and accelerometers), this concept has got some new life and direction presented in the Figure 1.13 [16].

FIGURE 1.13 : Hybrid Vtol

1.5 Multi copters

A multicopter is a mechanically simple aerial vehicle whose motion is controlled by speeding or slowing multiple downward thrusting motor/propeller units. MultiCopters are aerodynamically unstable and absolutely require an on-board computer (aka autopilot) for stable flight. As a result, they are “Fly by Wire” systems and if the computer isn’t working, you aren’t flying. The autopilot combines data from small on-board MEMs gyroscopes, accelerometers (the same as those found in smart phones) to maintain an accurate estimate of its orientation and position [17].

The basic element of multicopters is the frame, which should be maximum light. The classification of frame construction is mainly based on the number of arms. Due to the number of arms and the motors used the drones can be divided into ;

1.5.1 Bicopter – 2-motor multicopter

The bicopter has two motors that can be moved by servos to desired tilt angles. Here is an example of the bicopter avatar gunship. Bicopter could be the cheapest multicopter config to build among all because it only uses two motors and two servos. But it’s also the most difficult platform to stabilize in flight. It has the least lifting power given the fact that it only has 2 motors shown in Figure 1.14 [17].

FIGURE 1.14 : Bicopter – 2-Motor Multicopter

1.5.2 Tricopter – 3-motor multicopter

The tricopter has 3 motors, and typically in a “Y” shape, where the arms are usually 120 degrees apart. Tricopters can sometimes be found in a “T” shape too. Two propellers on the front arms spins the opposite direction to counter each other out. The rear motor can be tilted left and right by a servo to enable the yaw mechanism. The tricopter uses a servo to achieve yaw so it loses less thrust when the same situation happens. It also has lower lifting power because of the smaller motor numbers look at the Figure 1.15 [17].

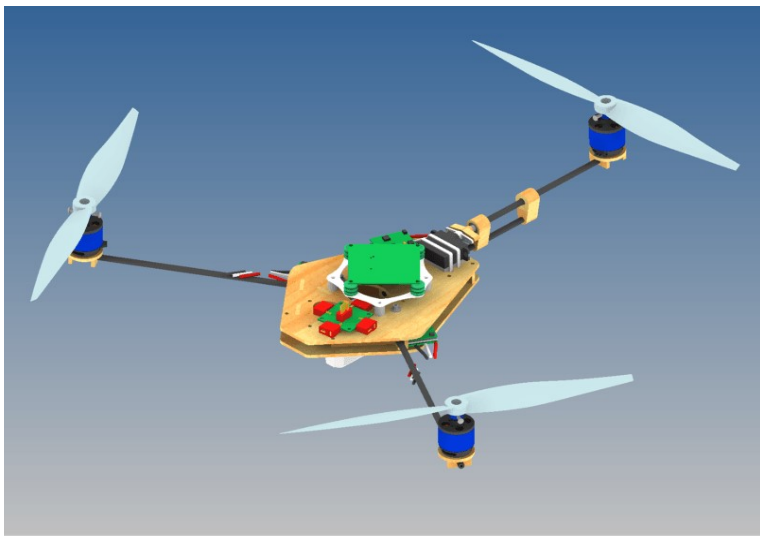


FIGURE 1.15 : Tricopter – 3-Motor Multicopter

1.5.3 QuadCopter – 4-motor multicopter

It has 4 motors mounted on a symmetric frame, each arm is typically 90 degree apart for the X4 config. Two motors rotate CW (clockwise), and the other two rotate CCW (counter clockwise) to create opposite force to stay balance. Quadcopter is the most popular multirotor configuration, with the simplest mechanical structure. It’s widely used for drone racing in the form of “mini quad”presented in the Figure 1.16 [17].

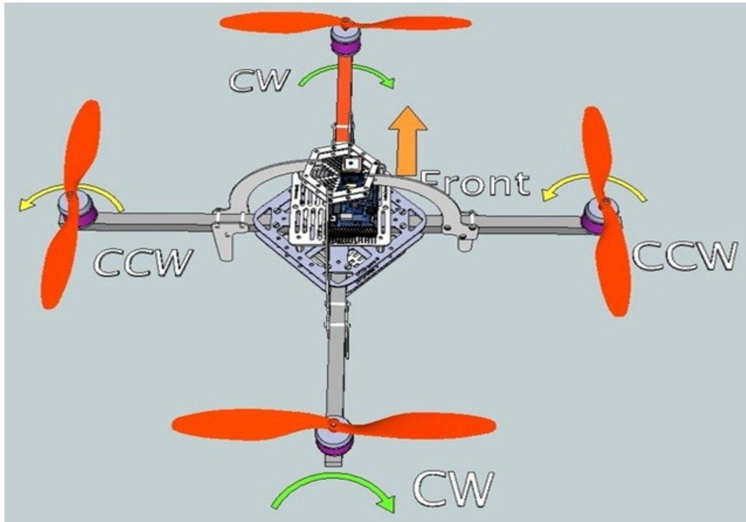


Figure 1.16 : QuadCopter – 4-Motor Multicopter

1.5.4 Hexacopter – 6-motor multirotor

The hexacopter has 6 motors mounted typically 60 degrees apart on a symmetric frame, with three sets of CW and CCW motors/propellers shown in Figure 1.17 [17].

Figure 1.17 : Hexacopter – 6-Motor Multirotor

1.5.5 Octocopter – 8 motors multirotor

A typical octocopter has 8 motors on the same level with four sets of CW and CCW propellers. However the large number of motors means they draw more current, and you will probably need to carry multiple battery packs. Also it's going to be expensive look at the Figure 1.18 [17].

Figure 1.18 : Octocopter – 8 Motors

1.6 Mathematical modeling of quadcopter

The knowing of the mathematical modeling of the quadcopter is an essential part to control and stabilize its movement. The modeling consists of defining the structure of the quadcopter, modeling its kinematics, motors, forces, torques and its equations of movements.

1.6.1 Frames

The quadcopter structure is presented in Figure 1.19 including the corresponding angular velocities, torques and forces created by the four rotors (numbered from 1 to 4).

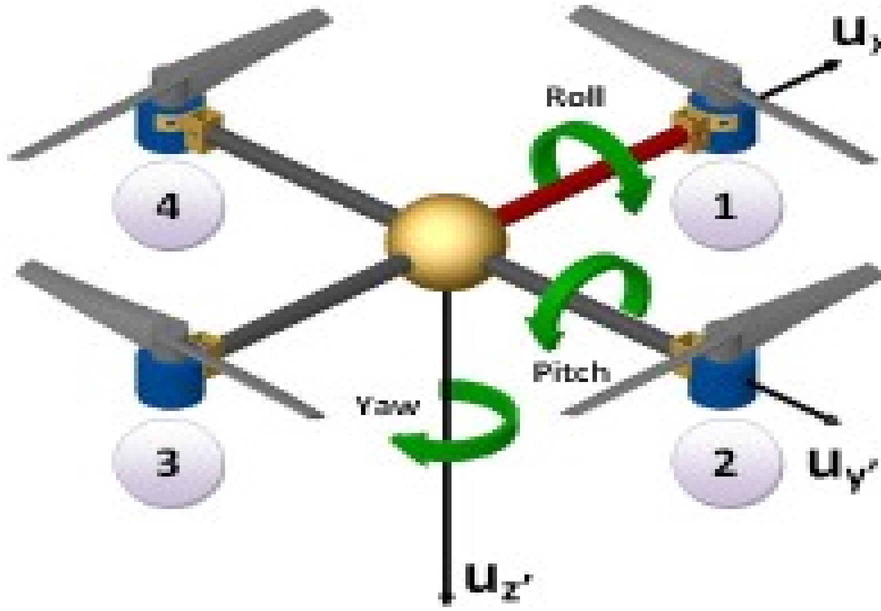


Figure 1.19: The Inertial and Body Frames of a Quadcopter.

The absolute linear position of the quadcopter is defined in the inertial framex, y, z-axes with. The attitude, i.e. the angular position, is defined in the inertial frame with three Euler anglesη. Pitch angle θ determines the rotation of the quadcopter around the $y - axis$. Roll angle φ determines the rotation around the $x - axis$ and yaw angle ψ around the $z - axis$. Vector $q$contains the linear and angular position vectors[18-19].

$$\varepsilon = \begin{bmatrix} x \\ y \\ z \end{bmatrix}, \eta = \begin{bmatrix} \phi \\ \theta \\ \psi \end{bmatrix}, q = \begin{bmatrix} \varepsilon \\ \eta \end{bmatrix} \tag{1.1}$$

1.6.1.1 Yaw, pitch and roll angles for quadcopters

a) Yaw angle

Starting with the Yaw it's a rotation of the head of the quadcopter whether right or left and it could be realized without moving a quadcopter from his hovering position, this kind of movements is frequently seen on Arial photography where the quadcopter stay stationary and turning left and right to capture whether it's a sport event or the any action.

b) Pitch angle

The pitch is the movement when a quadcopter moves backward and forward. For transition mad with a speed changes on the front and rear motor, to pitch forward the rear motor accelerate and those on the front deaccelerate in this case the quadcopter will move formard, thns the opposite to go backward.

c) Roll angle

The roll is a movement just like the pitch but in this case when a Roll movement is needed the quadcopter will dodge left or right. This movement is whether dodging or sliding without any angels changes,

1.6.2 Kinematics

Before entering the physics of quadcopter motion we have to formalize the kinematics upon the body and inertial frame. In the body frame, the linear velocities are determined by V_B and the angular velocities by ν.

$$V_B = \begin{bmatrix} V_x, B \\ V_y, B \\ V_z, B \end{bmatrix} \tag{1.2}$$

The angular velocities equal to $\dot{\theta} = \left(\dot{\phi}, \dot{\theta}, \dot{\Psi}\right)^T$. However, note that the angular velocity vector $\upsilon \neq \dot{\theta}$. The angular velocity $\upsilon = (p, q, r)^T$ is a vector pointing along the axis of rotation, while is just the time derivative of yaw, pitch and roll.
The rotation matrix from the body frame to the inertial frame is,

$$R = \begin{bmatrix} C_\psi C_\theta & C_\psi S_\theta S_\phi - S_\psi C_\phi & C_\psi S_\theta C_\phi - S_\psi S_\phi \\ S_\psi C_\theta & S_\psi S_\theta S_\phi + C_\psi C_\phi & S_\psi S_\theta C_\phi + C_\psi S \\ -S_\theta & C_\theta S_\phi & C_\theta C_\phi \end{bmatrix} \tag{1.3}$$

In which $Sx = sin(x)$ and $Cx = cos(x)$. The rotation matrix R is orthogonal thus $R^{-1} = R^T$ which is the rotation matrix from the inertial frame to the body frame.
The transformation matrix for angular velocities from the inertial frame to the body frame is $W\eta$, and from the body frame to the inertial frame is w_n^{-1} , as shown in [14],

$$\dot{\eta} = w_n^{-1}\nu \tag{1.4}$$

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\Psi} \end{bmatrix} = \begin{bmatrix} 1 & S_\phi T_\theta & C_\phi T_\theta \\ 0 & C_\phi & -S_\phi \\ 0 & S_\phi / C_\theta & C_\phi / C_\theta \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \tag{1.5}$$

$$\upsilon = w_n \dot{\eta} \tag{1.6}$$

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & 0 & -S_\phi \\ 0 & C_\phi & C_\phi S_\theta \\ 0 & -S_\phi & C_\theta C_\phi \end{bmatrix} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\Psi} \end{bmatrix} \tag{1.7}$$

In which $Tx = tan(x)$. The matrix $W\eta$ is invertible if $\theta \neq (2k-1)\phi/2, (k \in Z)$.

1.6.3 Acceleration

In order to calculate the acceleration of the quadcopter, the Newton-Euler formalization is used.

1.6.3.1 Newton-Euler equations

The quadcopter is assumed to be rigid body and thus Newton-Euler equations can be used to describe its dynamics. In the body frame, the force required for the acceleration of mass and the centrifugal force are equal to the gravity and the total thrust of the rotors.

$$m\dot{V}_B + v \times (mV) = R^{\mathrm{T}} G + T_B \tag{1.8}$$

In the inertial frame, the centrifugal force is nullified. Thus, only the gravitational force and the magnitude and direction of the thrust are contributing in the acceleration of the quadcopter

$$m\ddot{\varepsilon} = G + RT_B \tag{1.9}$$

$$\begin{bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix} = -g \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} + \frac{T}{m} \begin{bmatrix} C_\Psi S_\theta C_\phi + S_\Psi S_\phi \\ S_\Psi S_\theta C_\phi - C_\Psi S_\phi \\ C_\theta C_\phi \end{bmatrix} \tag{1.10}$$

In the body frame, the angular acceleration of the inertia, the centripetal forces $\upsilon \times (I\nu)$ and the gyroscopic forces are equal to the external torqueτ. The quadcopter is assumed to have symmetric structure with the four arms aligned with the body $x-$ and $y-axes$. Thus, the inertia matrix is diagonal matrix I.

$$I = \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \tag{1.11}$$

$$I\dot{\nu} + \nu \times (I\nu) + T = \tau \tag{1.12}$$

$$\dot{\upsilon} = I^{-1}\left(- \begin{bmatrix} p \\ q \\ r \end{bmatrix} \times \begin{bmatrix} I_{xx}p \\ I_{yy}q \\ I_{zz}r \end{bmatrix} - I_r \begin{bmatrix} p \\ q \\ r \end{bmatrix} \times \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \omega_T + \tau \right) \tag{1.13}$$

$$\begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} (I_{yy} - I_{zz})qr/I_{xx} \\ (I_{zz} - I_{xx})pr/I_{yy} \\ (I_{xx} - I_{yy})pq/I_{zz} \end{bmatrix} - I_r \begin{bmatrix} q/I_{xx} \\ -p/I_{yy} \\ 0 \end{bmatrix} \omega_T + \begin{bmatrix} \tau_\phi/I_{xx} \\ \tau_\theta/I_{yy} \\ \tau_\Psi/I_{zz} \end{bmatrix} \tag{1.14}$$

Where , $\omega_T = \omega_1 - \omega_2 + \omega_3 - \omega_4$. The angular accelerations in the inertial frame are then attracted from the body frame accelerations with the transformation matrix $W\eta^{-1}$ and its time derivative,

$$\ddot{\eta} = \frac{d}{dt}(W_n^{-1}\nu) = \frac{d}{dt}(W_n^{-1}\nu) + W_n^{-1}\dot{\nu} \tag{1.15}$$

$$\ddot{\eta} = \begin{bmatrix} 0 & \dot{\phi}C_\phi T_\theta + \dot{\theta}S_\phi/C_\theta^2 & -\dot{\phi}S_\phi C_\theta + \theta \dot{C_\phi}/C_\theta^2 \\ 0 & -\dot{\phi}S_\phi & -\dot{\phi}C_\phi \\ 0 & \dot{\phi}C_\phi/C_\theta + \dot{\phi}S_\phi T_\theta/C_\theta & -\dot{\phi}S_\phi/C_\theta + \dot{\theta}C_\phi T_\theta/C_\theta \end{bmatrix} \upsilon + W_n^{-1}\dot{\upsilon} \tag{1.16}$$

1.6.4 Physics

In order to properly model the dynamics of the quadcopter system, firstly we should understand its physical properties. At first stage, a quick description of the used motors on the quadcopter, as well as its power is introduced. We suppose that the four motors are identical, which mean that we can analyze only one motor then apply it on the other three motors. The propeller are mounted on opposite sides, where two are clockwise and other two are counter clockwise on the Quad X configuration as shown in Figure 1.19[18,20].

1.6.4.1 Motors

In a brushless motor, the commutation of the windings is done not mechanically as before but electronically by a system complex called "ESC or electronic speed controller". This transforms the direct current into a three-phase current at a variable frequency and will power successively the motor coils to create the rotating field and therefore the rotation that interests us. The function of the produced torque is produced as follows;

$$\tau = k_t (I - I_0) \tag{1.17}$$

Where:

- τ: Motor torque ;
- I: Input current;
- I_0: No load current;
- k_t: Torque constant.

The voltage across the motor is given as follows ,

$$V = IR_m + k_\nu \omega \tag{1.18}$$

Where :

- V: Voltage drop across the motor ;
- R_m: Motor resistance ;
- ω: Angular velocity ;
- k_v: Constant of RMF generated per RPM .

In order to calculate the consumed power, we use the following equation,

$$P = IV = \frac{(\tau + k_t I_0)(k_t I_0 R_m + \tau R_m + k_t k_\nu \omega)}{k_t^2} \tag{1.19}$$

To simplify the equation of power, we will assume that the motor resistance is negligible.

$$P \approx \frac{(\tau + k_t I_0) k_\nu \omega}{k_t} \tag{1.20}$$

To simplify this equation, we assume that $KtIo \ll \tau$.

$$P \approx \frac{k_\nu}{k_t}\tau\omega \tag{1.21}$$

1.6.4.2 Forces and torques

In the quadcopter, we have to modelized the forces and torques of both the motor and the quadcopter frame. Hence, we will give in what follows the full modeling equations.

a) Motors

The use of power in the quadcopter is to help it stay aloft, basing on the conservation of energy, then the power is generated like so ;

$$P = T\nu_h \tag{1.22}$$

When the vehicle is assumed low, so ν_h is the air velocity when hovering, and the free stream velocity, v_∞ is zero, the momentum equation for hover velocity as a function of thrust.

$$\nu_h = \sqrt{\frac{T}{2\rho A}} \tag{1.23}$$

Where :

- ρ: is the density of the surrounding air
- A: swept area by the rotor

Using the previous simplified equation for power, we obtain :

$$P = \frac{k_\nu}{k_t}\tau\omega = \frac{k_\nu k_\tau}{k_t}\mathrm{T}\omega = \frac{\mathrm{T}^{\frac{3}{2}}}{\sqrt{2\rho A}} \tag{1.24}$$

Generally ,$\tau = \vec{r} \times \vec{F}$. Hence, the torque is proportional to the thrust T by some constant ratio k_τ determinated by the blade configuration and parameters. The Thrust is given using the following equation;

$$T = \left(\frac{k_\nu k_t\sqrt{2\rho A}}{k_t}\omega\right)^2 = k\omega^2 \tag{1.25}$$

Where, k is some appropriately dimensioned constant. Summing over all the motors, we find that the total thrust on the quadcopter (in the body frame) is given by ,

$$T_B = \sum_{i=1}^{4} T_i = k \begin{bmatrix} 0 \\ 0 \\ \sum \omega_i^2 \end{bmatrix} \tag{1.26}$$

In addition to the thrust force, we will model friction as a force proportional to the linear velocity in each direction. This is a highly simplified view of fluid friction, but will be sufficient for our modeling and simulation. Our global drag forces will be modeled by an additional force term .

$$F_D = \begin{bmatrix} -kd_x\dot{x} \\ -kd_y\dot{y} \\ -kd_z\dot{z} \end{bmatrix} \tag{1.27}$$

If additional precision is desired, the constant k_d can be separated into three separate friction constants, one for each direction of motion. If we were to do this, we would want to model friction in the body frame rather than the inertial frame.

a.1) Torques

Now that we have computed the forces on the quadcopter, we would also like to compute the torques. Each rotor contributes some torque about the body z axis. This torque is the torque required to keep the propeller spinning and providing thrust, it creates the instantaneous angular acceleration and overcomes the frictional drag forces. The drag equation from fluid dynamics gives us the frictional force:

$$F_D = \frac{1}{2} R\rho C_D A v^2 \tag{1.28}$$

Where, ρ is the surrounding fluid density, A is the reference area (propeller cross-section, not area swept out by the propeller), and C_D is a dimensionless constant. This, while only accurate in some in some cases, is good enough for our purposes. This implies that the torque due to drag is given by

$$\tau_D = \frac{1}{2} R\rho C_D A v^2 = \frac{1}{2} R\rho C_D A (\omega R)^2 = b\omega^2 \tag{1.29}$$

Where, ω is the angular velocity of the propeller,R is the radius of the propeller, and b is some appropriately dimensioned constant. Note that we've assumed that all the force is applied at the tip of the propeller, which is certainly inaccurate, however, the only result that matters for our purposes is that the drag torque is proportional to the square of the angular velocity. We can then write the complete torque about the z axis for the i^{th} motor:

$$\tau_z = b\omega^2 + I_M\dot{\omega} \tag{1.30}$$

Where,I_M is the moment of inertia about the motor z axis, is the angular acceleration of the propeller, and b is our drag coefficient. Note that in steady state flight (i.e. not takeoff or landing), since most of the time the propellers will be maintaining a constant (or almost constant) thrust and won't be accelerating. Thus, we ignore this term, simplifying the entire expression to

$$\tau_z = (-1)^{i+1} b\omega_i^2 \tag{1.31}$$

Where the$(-1)^{i+1}$ term is positive for the i^{th} propeller if the propeller is spinning clockwise and negative if it is spinning counterclockwise. The total torque about the z axis is given by the sum of all the torques from each propeller:

$$\tau_\psi = b\left(\omega_1^2 - \omega_2^2 + \omega_3^2 - \omega_4^2\right) \tag{1.32}$$

The roll and pitch torques are derived from standard mechanics. We can arbitrarily choose the $i = 1$ and $i = 3$ motors to be on the roll axis, so

$$\tau_\phi = \sum r \times T = L\left(k\omega_1^2 - k\omega_3^2\right) = Lk\left(\omega_1^2 - \omega_3^2\right) \tag{1.33}$$

Correspondingly, the pitch torque is given by a similar expression,

$$\tau_\theta = Lk\left(\omega_2^2 - \omega_4^2\right) \tag{1.34}$$

Where, L is the distance from the center of the quadcopter to any of the propellers. All together, we find that the torques in the body frame are:

$$\tau_B = \begin{bmatrix} Lk\left(\omega_1^2 - \omega_3^2\right) \\ Lk\left(\omega_2^2 - \omega_4^2\right) \\ b\left(\omega_1^2 - \omega_2^2 + \omega_3^2 - \omega_4^2\right) \end{bmatrix} \tag{1.35}$$

The model we've derived so far is highly simplified. We ignore a multitude of advanced effects that contribute to the highly nonlinear dynamics of a quadcopter. We ignore rotational drag forces (our rotational velocities are relatively low), blade flapping (deformation of propeller blades due to high velocities and flexible materials), surrounding fluid velocities (wind), etc. With that said, we now have all the parts necessary to write out the dynamics of our quad-copter.

b) Quadcopter

To determine the forces and torques of the hall quadcopter, we will use the Euler-Lagrange equations[18,21].

Euler-Lagrange equations

The Lagrangian $L$is the sum of the translational E_{trans} and rotational E_{rot} energies minus potential energy E_{pot}[22].

$$L(q,\dot{q}) = E_{trans} + E_{rot} - E_{pot} \tag{1.36}$$

$$L(q,\dot{q}) = (m/2)\dot{\varepsilon}^T\dot{\varepsilon} + (1/2)\,\nu^T I\nu - mgz \tag{1.37}$$

As shown in [10] the Euler-Lagrange equations with external forces and torques are:

$$\begin{bmatrix} f \\ \tau \end{bmatrix} = \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}}\right) - \frac{\partial L}{\partial \dot{q}} \tag{1.38}$$

The linear and angular components do not depend on each other thus they can be studied separately. The linear external force is the total thrust of the rotors. The linear Euler-Lagrange equations are

$$f = RT_B = m\ddot{\varepsilon} + mg\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \tag{1.39}$$

The Jacobian matrix $J(\eta)$ from ν to is

$$J\ (\eta)\ = J = W_n^T I W_n \tag{1.40}$$

$$= \begin{bmatrix} I_{xx} & 0 & -I_{xx}S_\theta \\ 0 & I_{yy}C_\phi^2 + I_{zz}S_\phi^2 & (I_{yy} - I_{zz})C_\phi S_\phi C_\theta \\ -I_{xx}S_\theta & (I_{yy} - I_{zz})C_\phi S_\phi C_\theta & I_{xx}S_\theta^2 + I_{zz}S_\phi^2 C_\theta^2 + I_{zz}C_\phi^2 C_\theta^2 \end{bmatrix} \tag{1.41}$$

Thus, the rotational energy E_{rot} can be expressed in the inertial frame as

$$E_{rot} = (1/2)\, \upsilon^T I_\upsilon = (1/2)\, \ddot{\eta}^T J \ddot{\eta} \tag{1.42}$$

The external angular force is the torques of the rotors. The angular Euler-Lagrange equations are

$$\tau = \tau_B = J\ddot{\eta} + \frac{d}{dt}(J)\,\dot{\eta} - \frac{1}{2}\frac{\partial}{\partial \eta}\left(\dot{\eta}^T J \dot{\eta}\right) = J\ddot{\eta} + C(\eta, \dot{\eta})\,\dot{\eta} \tag{1.43}$$

In which the matrix$C(\eta, \dot{\eta})$ is the Coriolis term, containing the gyroscopic and centripetal terms. The matrix$C(\eta, \dot{\eta})$ has the form, as shown in [9],

$$C(\eta, \dot{\eta}) = \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} \tag{1.44}$$

$$\begin{aligned}
&C_{11} = 0 \\
&C_{12} = (I_{yy} - I_{zz})(\dot{\theta}C_\phi S_\phi + \dot{\psi}S_\phi^2 C_\theta) + (I_{zz} - I_{yy})\dot{\psi}C_\phi^2 C_\theta - I_{xx}\dot{\psi}C_\theta \\
&C_{13} = (I_{zz} - I_{yy})\dot{\psi}C_\phi S_\phi C_\theta^2 \\
&C_{21} = (I_{zz} - I_{yy})(\dot{\theta}C_\phi S_\phi + \dot{\psi}S_\phi C_\theta) \\
&C_{22} = (I_{zz} - I_{yy})\dot{\phi}C_\phi S_\phi \\
&C_{23} = -I_{xx}\dot{\psi}S_\theta C_\theta + I_{yy}\dot{\psi}S_\phi^2 S_\theta C_\theta + I_{zz}\dot{\psi}C_\phi^2 S_\theta C_\theta \\
&C_{31} = (I_{yy} - I_{zz})\dot{\psi}C_\phi S_\phi C_\theta^2 - I_{xx}\dot{\theta}C_\theta \\
&C_{32} = (I_{zz} - I_{yy})(\dot{\theta}C_\phi S_\phi S_\theta + \dot{\phi}S_\phi^2 C_\theta) + (I_{yy} - I_{zz})\dot{\phi}C_\phi^2 C_\phi + I_{xx}\dot{\psi}S_\theta C_\theta - I_{yy}\dot{\psi}S_\phi^2 S_\theta C_\theta - I_{zz}\dot{\psi}C_\phi^2 S_\theta C_\theta \\
&C_{33} = (I_{yy} - I_{zz})\dot{\phi}C_\phi S_\phi C_\theta^2 - I_{yy}\dot{\theta}S_\phi^2 S_\theta C_\theta - I_{zz}\dot{\theta}C_\phi^2 S_\theta C_\theta - I_{xx}S_\theta C_\theta
\end{aligned}$$

Equation (I.44) leads to the differential equations for the angular accelerations which are equivalent with Equations (I.45).

$$\ddot{\eta} = J^{-1}(\tau_B - C(\eta, \dot{\eta})\dot{\eta}) \tag{1.45}$$

1.6.4.3 Aerodynamical effects

The preceding model is a simplification of complex dynamic interactions. To enforce more realistically behavior of the quadcopter, drag force generated by the air resistance is included [23].

$$\begin{bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix} = -g \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} + \frac{T}{m} \begin{bmatrix} C_{\Psi} S_{\theta} C_{\phi} + S_{\Psi} S \\ S_{\Psi} S_{\theta} C_{\phi} - C_{\Psi} S_{\phi} \\ C_{\theta} C_{\phi} \end{bmatrix} - \frac{1}{m} \begin{bmatrix} A_x & 0 & 0 \\ 0 & A_y & 0 \\ 0 & 0 & A_z \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix} \tag{1.46}$$

In which Ax, Ay and Az are the drag force coefficients for velocities in the corresponding directions of the inertial frame. Where:

$K_{d,x} = \frac{A_x}{m}$, $K = \frac{A_y}{m}$ $K_{d,z} = \frac{A_y}{m}$

Several other aerodynamical effects could be included in the model. The influence of aerodynamical effects are complicated and the effects are diffcult to model. Also some of the effects have significant effect only in high velocities. Thus, these effects are excluded from the model and the presented simple model is used [33]

1.7 Conclusion

The main components of the quadcopter as well as their applications in several fields such as military and agriculture are well discussed in this chapter. Moreover, we have presented the mathematical modeling of the quadcopter taking into account the frame, kinematics as well as the physics mouvements. Moreover, the forces and the accelerations as well as the effect of the airodynamics are also discussed. The next chapter will deal with the main components which are used to construct the quadcopter as well as the appropriate softwares to control and supervise its mouvements.

Chapter 2

Hardware and realisation of the DJI 450 quadcopter

2.1 Introduction

Building a quadcopter is always difficult. It can be a difficult task that takes up a lot of time and resources. This difficulty is generally caused by a lack of knowledge about the proper selection of good and non-adaptable components. Furthermore, the flight controller, which is the quadcopter's brain, is critical before any prior construction. As a result, in this chapter, we will walk you through the process of building a quadcopter based on the DJI F450 frame. The Pixhawk controller will be implemented and thoroughly explained.

2.2 DJI F450

The DJI F450 quadcopter presented in the Figure 2.1 is a vehicle that can be used for both fun and creating professional aerial views. The multirotor is actually designed as a frame which makes it extremely light and versatile, given the fact that owners can add or remove certain technical elements [24].

FIGURE 2.1 : DJI 450 Quadcopter

2.3 Wiring diagram

The wiring diagram for building the DJI450 is given in Figure 2.2.

FIGURE 2.2 : Wiring Diagram

2.4 Components used for quadcopter

2.4.1 Frames

Frames made up of various materials are present out there like Plastic, Glass Fiber and Carbon Fiber. The type of frame to choose depends upon the application of the quadcopter. The first thing on your mind should be the materials when picking the best frame. The materials play a significant role in determining the drone's stability and efficient performance. Note that vibration is increasingly a nuisance in many drones, and if not managed well, it could lead to poor quality aerial images and possible damage to the electronic components shown in Figure 2.3 [25].

FIGURE 2.3 : Quadcopter Frame

2.4.2 Motors

The motors are the main drain of battery power on your quad, therefore getting an efficient combination of propeller and motor is very important. Motor speed is rated in kV, generally a lower kV motor will produce more torque and a higher kV will spin faster. There are many aspects to motor performance aside from raw thrust, high among these is how much current the motor draws from the battery. Remember to check the specs of your motors for their maximum amp draw, and ensure that your ESC's are rated to withstand this amperage. The brushless motors that are most commonly used on a quad have 3 wires, it's really matter which of the 3 output terminals these are connected to on the ESC, swapping any of the 3 will change the direction of rotation. Note : to ensure that the motor mounting screws are not too long and that they do not touch the stator windings of the motor. This contact can cause a short in the windings, spelling the end for your motor, also make sure that any grub screws are fitted and tightened look at the Figure 2.4 [25].

FIGURE 2.4 : Motor Speed is Rated in kV

2.4.3 Electronic speed controller (ESC)

An ESC is an electronic circuit which is used to change the speed and direction of brushless motor. Basically, an ESC converts DC battery power into 3-phase AC for driving brushless motors. It is the interface between the Motors and Flight Controller.While the selection of ESC, the current rating must be higher than the ampere drawn by all motors and other components. Normally an ESC has 5 inputs but these days an ESC comes with 4 input terminals, where 2 inputs terminals are for Ground and PWM signals coming from the Flight controller and other 2 are for battery input supply, these 2 inputs carry the high current to the ESC to supply the motor presented in the Figure 2.5 [25].

Figure 2.5 : Electronic Speed Controller

2.4.4 Propellers

The propeller acts as wings of the flight. It pulls the air downwards and makes your drone fly. Almost, in every size, there are different types of propellers are available. Propellers largely affect the quadcopters flying speed, it's load and the speed at which they can manoeuver. According to these attributes, you can decide the length and pitch of the propellers. The pitch is the shape and slant of the propeller. Longer size propellers provide stronger lift at lower RPM but it takes time to speed up and slowdown. Shorter size propellers quickly change the speed of quadcopter and produce better manoeuvering capabilities. As compare to longer propellers, it requires more energy/current to spin. This causes excess strain on the motors, which may lead to a shorter life span for the motors shown in Figure 2.6 [25].

Figure 2.6 : Propellers

2.4.5 Battery

To power on your quadcopter, we need Lithium polymer (LIPO) battery. Flight time of the quadcopter depends on the battery capacity. Generally, the LIPO batteries are rating with its capacity in mAh, the number of cells in series (like 3S, 4S) and it's C rating (30C/40C). The battery is the single heaviest component of your drone, just because using bigger size battery doesn't mean it will fly longer. So we need to choose the battery according to its size, capacity, C rating, its voltage etc look at the Figure 2.7 [25].

Figure 2.7 : Battery of Drones

2.4.6 Transmitter & receiver

Radio Transmitter is an electronic device that uses radio signals to transmit commands wirelessly via a set radio frequency over to the Radio Receiver, which is connected to flight controller of quadcopter being remotely controlled. Radio transmitters and receivers manipulate electricity resulting in the transmission of useful information through the atmosphere or space. The transmitter sends a signal over a frequency to the receiver. The transmitter has a power source, that provides the power for the controls and transmission of the signal. Simply, it is a Remote Controller which use to control altitude, speed, the orientation of the drone. Radios are usually come paired with their compatible receiver. There are a variety of RC transmitters available in the market. You can choose one of them which matches your specification presented in the Figure 2.8 [25].

FIGURE 2.8 : Radio Transmitter

2.4.7 Flight controller

The flight controller is the brain of the Quadcopter. This is a small computer board with various sensors which understand the movement of the craft. It has sensors like Gyroscope, Accelerometer, Barometer and Magnetometer. According to the signal comes from the transceiver, it controls the motors and craft. Flight controllers configured with computer software. It uses computer software like Cleanflight, Betaflight, Mission planner etc. Selecting the flight controller is just a personal choice in many ways. As per your quadcopter requirements, you can choose the affordable, reliable flight controllers which work with most components easily. To understand different types of the flight controller, check below tutorial [25].

2.4.7.1 Selecting a drone flight controller

There are seemingly limitless drone flight controller choices on the market today. While this is true, there is only a select amount of drone controllers that are right for your build. Once you have clarity of your drone build, the list of potential autopilot boards decreases drastically, making your decision less daunting [25].

Best flight controller boards

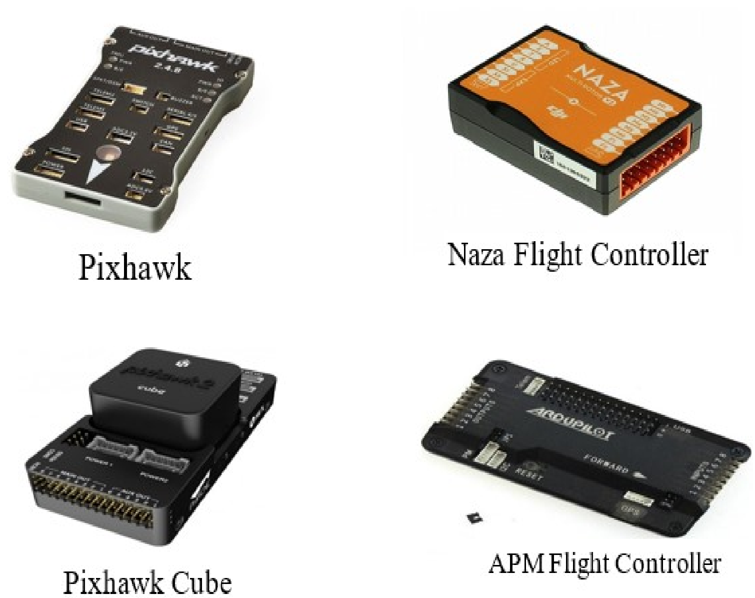


FIGURE 2.9 : Best Flight Controller Boards

In our work , we have used the Pixhawk 2.4.8. Hence, a brief overview of its main characteristics is given in what follows ;

2.5 Pixhawk 2.4.8

Pixhawk is 3DR's advanced autopilot system. It is transparent for hardware and easy to re-create. Pixhawk integrates two advanced processors, STM32F103 backup failsafe

32-bit co-processor with manual recovery and its own power supply if one processor fails, delivering incredible performance, flexibility, and reliability for controlling any autonomous vehicle. Users can also customize the Pixhawk configurations for different vehicles based on their intended use and hobbies. Pixhawk, as one of the cores of autopilot systems, has gained widespread popularity among developers and hobbyists in recent years due to its practicality, ease of use, and low cost [26].

2.5.1 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 auxiliary, high-powercompatible).

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

• Integrated backup system for in-flight 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.

2.5.2 Interface layout

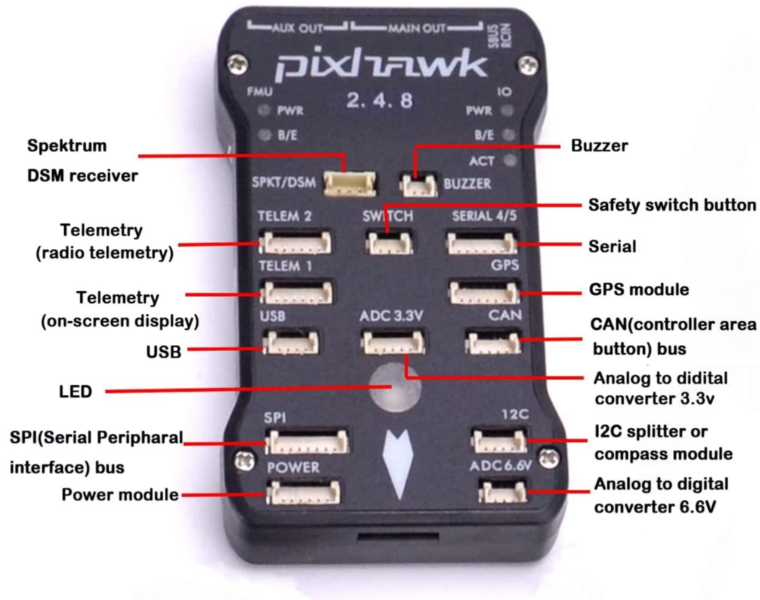


FIGURE 2.10 : Interface Layout

2.5.2.1 Internal layout

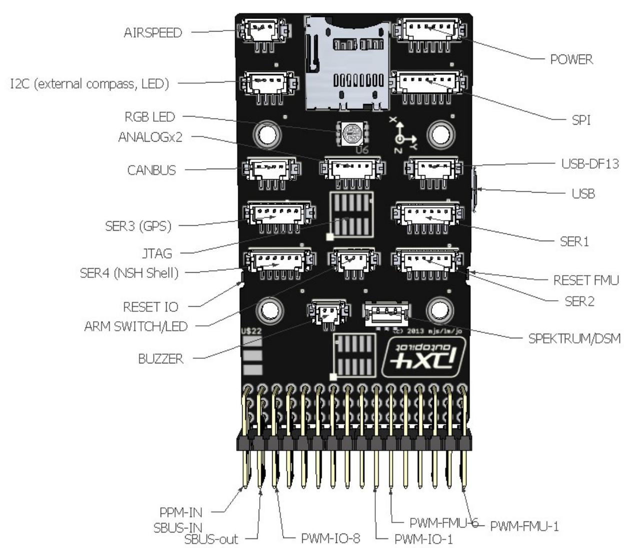


FIGURE 2.11 : Pixhawk Connector Diagram Internal Layout

Figure 2.12 : Pixhawk Connector Diagram Interface Layout

2.5.2.2 Outputs connections

Connect each signal wire from the PDB to the main output signal (S) pins by motor number. Connect one wire for each motor to the corresponding pin shown in Figure 2.13.

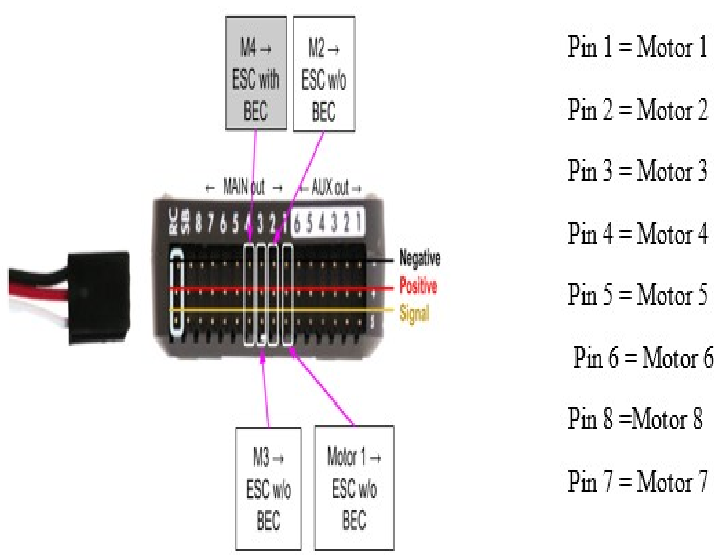


Figure 2.13 : Output Connections

2.5.2.3 Pixhawm other elements connections

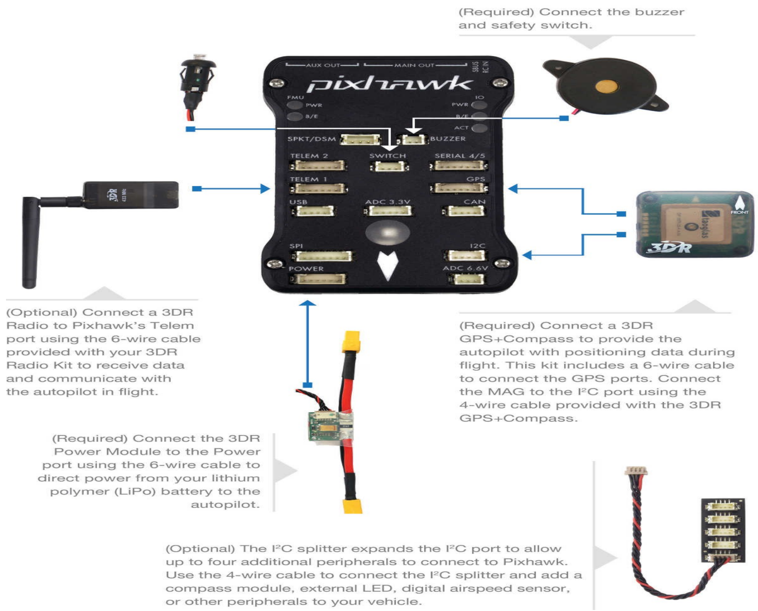


FIGURE 2.14 : Pixhawk Other Elements Connections

2.6 Mission planner

In order to control and visualise the quadcopter mouvement, we need a tool or software to do this task. Several softwares can be found which are open source and free to use. The most advanced one is called mission planner.

2.6.1 Install mission planner

To download the Mission Planner from [27]Once installation is complete, open Mission Planner by clicking on its system icon. Once the installation of Mission Planner and driver is done, there will several pop-ups when you opentheMPat the first time. The first pop-up clicks Yes and the others click NO. There are six Menu Button in main menu.

Flight data : flight attitude and data will show in real time on MP

Flight plan : planning the flight mission [28-29].

2.6.2 Intial setup

First, you have to upgrade the firmware you need when you the first time ready to use

Pixhawk . -Radiolink Pixhawk is default with quadcopter firmware, you have to install the right firmware if you use the other frame drone presented in the Figure 2.15 [28-29].

FIGURE 2.15 : Connect With MP and Pixhawk

2.6.3 Download and install firmware

Please connect your Pixhawk and computer via USB cable. Open the Mission Planner and select theright COM port drop-down on the upper-right corner of the screen (near the Connect button) shown in Figure 2.16 [28-29].

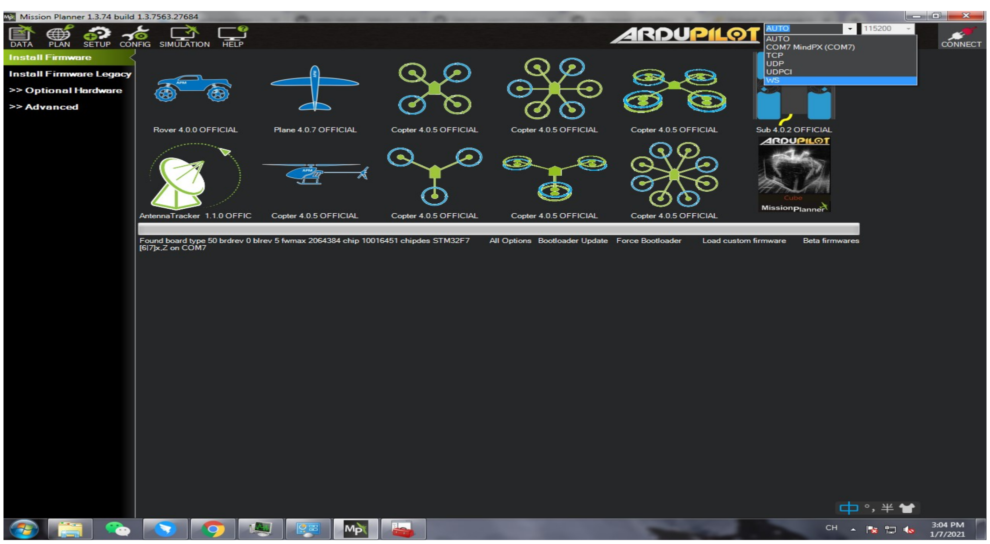


FIGURE 2.16 : Install Firmware

Attention

• Do not click Connect before you upload the new firmware, please click DisConnect if you have connected successful before. Upload new firmware will be not success if you have connected already.
• Please do not upload new firmware by wireless data transmission because it has missed thereset signal.
• If there's without firmware version number, it means failed upload new firmware. It may causeof network problem, please re-upgrade firmware until shows the version.
• Click "Yes" to install the firmware, Disconnect the USB cable, click OK and then reconnect USB cable immediately (Pay attention : Pixhawk will have failed to connect if there are more than one COM, please remove other equipment if disconnect). Red status LED means the Pixhawk is loading the firmware look at the Figure 2.17.

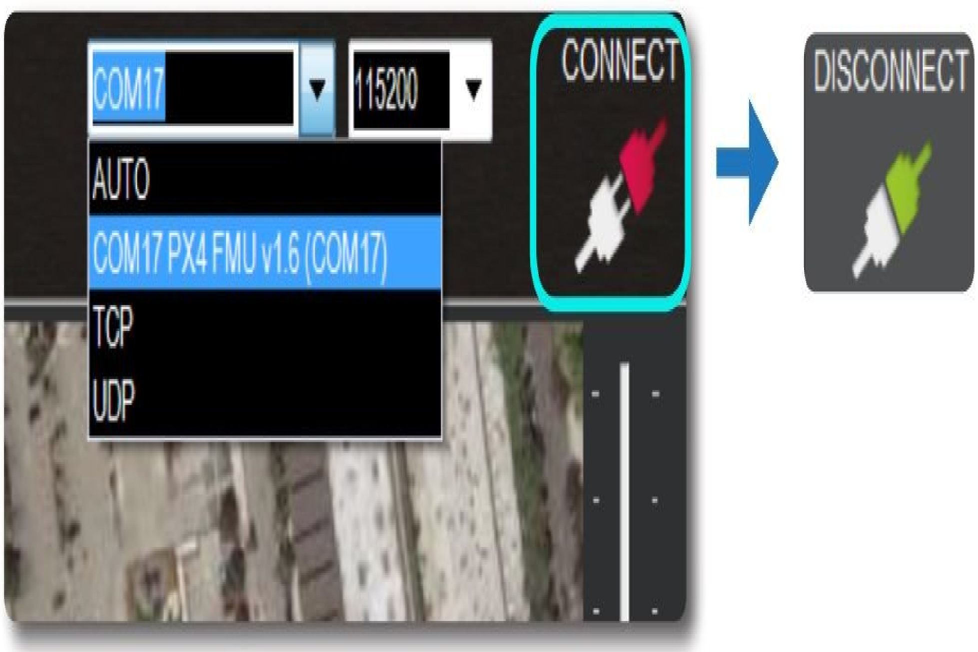


FIGURE 2.17 : Choose the COM

2.6.4 Frame types

Please setup as below :

1. Initial setup
2. Mandatory hardware frame type

3. Choose quad or hexa or other frame types as you need

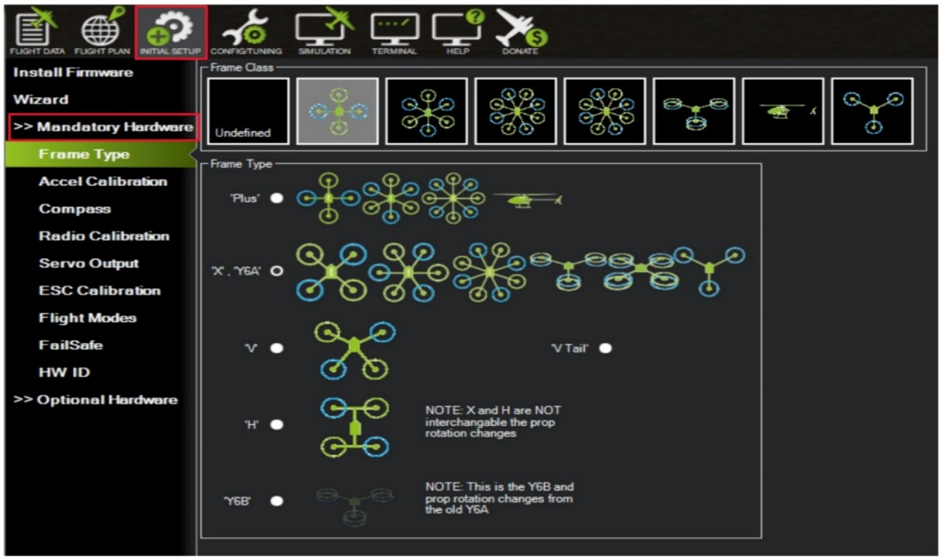


FIGURE 2.18 : Choose The Type of Drone

2.6.5 Accelerometer calibration

Accelerometer calibration or in other words defining to the board different level or sides, to start the process, press the Calibrate Accel button, MP will ask you to put the vehicle (or the pixhawk) in different calibration positions, press any key to indicate that the vehicle is in position, keep through until MP displays calibration successful, according to ardupilot.com, here are a few tips to execute a good accelerometer calibration . The level position is the most important to get right as this will be the attitude that your controller considers level while flying shown in Figures 2.19 & 2.20 [28-29].

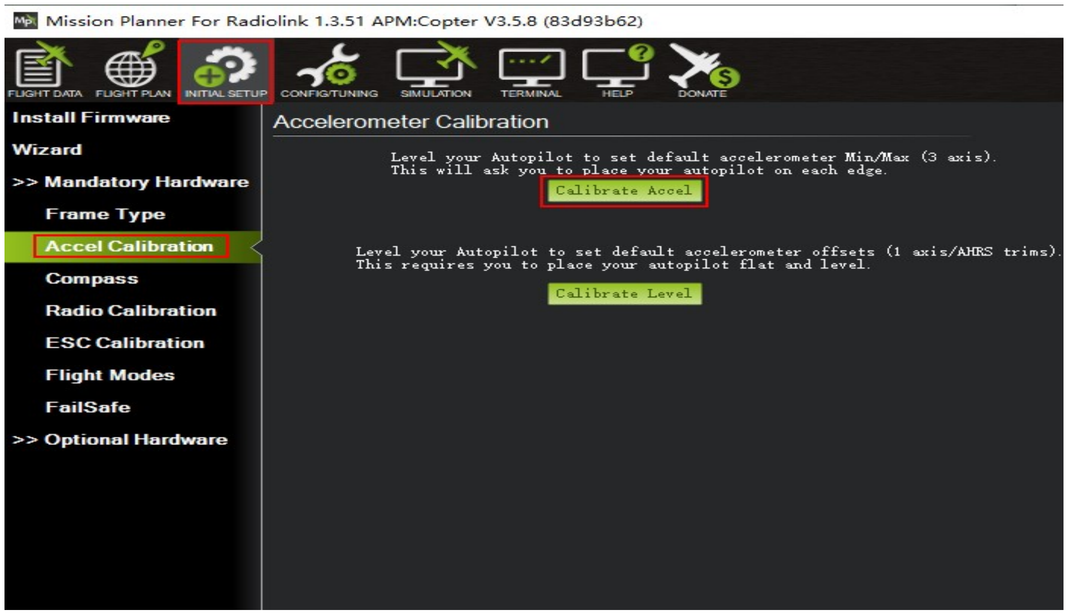


FIGURE 2.19 : Accelerometer Calibration

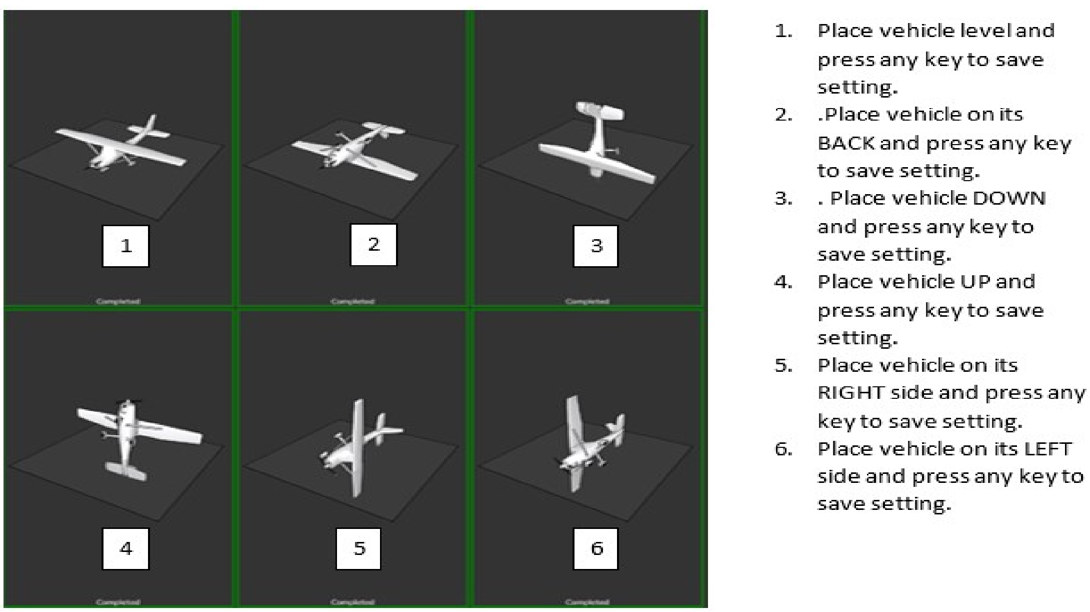
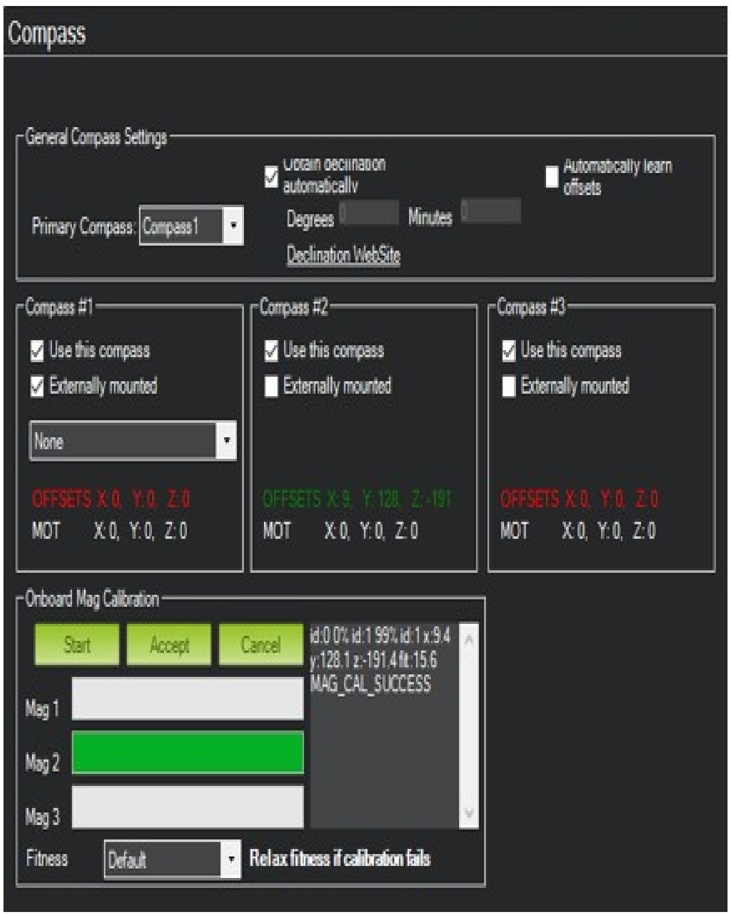


FIGURE 2.20 : Defining to The Board Different Level of Drone

2.6.6 Compass calibration

Please fixed Pixhawk , then click “Start” and turn Pixhawk till the progress bar of Mag 1 and Mag 2 to the end. Calibrate the compass as these steps below : Hold the vehicle in the air and rotate it slowly so that each side (front, back, left, right, top and bottom) pointsdown towards the earth for a few seconds in turn so it will result in six full 360-degree turns with each turn pointing a different direction of the vehicle to the ground, as the vehicle is rotated the green bars should extend further and further to the right until the calibration completes if compass calibration succeed you should hear three rising tones and MP will ask you to reboot your pixhawk look at the Figure 2.21 [28-29].



The mission planner will keep recording the data that collected by the compass sensor and the progressbar and the percentage will keep change when you calibrate the compass, if the percentage have not changed, please check if the compass is connect success. The mission planner will remind you when the compass has calibrated success.

FIGURE 2.21 : Compass Calibration

2.6.7 Radio calibration

This memoire shows how to perform radio control calibration using Mission Planner. RC transmitters are used to control vehicle movement and orientation. Copter and Plane minimally control throttle, pitch, roll and yaw. Calibrating each of the transmitter controls/-channels is a straightforward process - simply move eachof theenabled sticks/switches through their full range and record the maximum and minimum positions.There are two main transmitter configurations : Mode 1 : left stick controls pitch and yaw, the right stick will control throttle and roll. Mode 2 : left stick controls throttle and yaw ; the right stick will control pitch and roll. Copter default channel mappings are presented in this Figures 2.22 & 2.23 [28-29].

Channel 1: Roll

Channel 2: Pitch

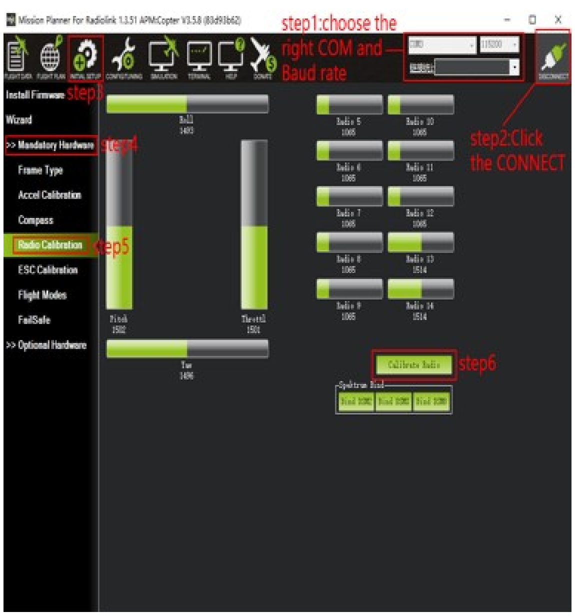
Channel 3: Throttle

Channel 4: Yaw

Channel 5: Flight modes

Channel 6: (Optional) In flight tuning or camera mount (mapped to transmitter tuning knob) Unused channels can be mapped to control additional peripherals .

FIGURE 2.22 : Radio Calibration



Radio Calibration Steps:

1. Open Mission Planner
2. Choose the right COM and Baud rate .
3. Click the CONNECT .
4. Choose INITAIL SETUP Mandatory Hardware—Radio Calibration .
5. Click "Calibrate Radio".

FIGURE 2.23 : Radio Calibration Steps

There are two tool pop-ups after you click “OK”, one for make sure both your transmitter and receiver are powered on and connected, and the motor of your drone does not have power and without propeller. And then click “OK” and move all RC sticks and switches to their extreme positions so the red bars hit thelimits shown in Figures 2.24 & 2.25.

Figure 2.24 : Security System

CH1: low position = roll (towards the left),up position= roll (towards the right).

CH2:low position =pitch(forward), up position = pitch(backwards).

CH3: low position =reduced speed, up position =speed up.

CH4: low position = yaw (towards the left), up position = yaw (towards the right.

Figure 2.25 : How to Calibrate The Radio

2.6.8 ESC calibration steps

Most ESCs need to be calibrated to make sure that the motors run at the required speed and direction, this process will identify to the ESC the minimum and maximum PWM values that the pixhawk will send, there are many ESC calibration methods based on the brand, some of them can be done manually without the need of a GS, and some of them require a GS with software like MP, as it is the case with the Semi-Automatic ESC-by-ESC Calibration which can be performed following these steps [28-29].

- set the ESC calibration.
- Disconnect the battery and USB cable so the autopilot powers down
- Connect the battery.
- The arming tone will be played (if the vehicle has a buzzer attached).
- If using a safety button press it until it displays solid red.
- You will hear a musical tone then two beeps.
- A few seconds later you should hear a number of beeps (one for each battery cell you're using) .
- and finally a single long beep indicating the end points have been set and the ESC is calibrated.
- Disconnect the battery and power up again normally.

2.7 Conclusion

Before any use of the quadcopter, the step by step realisation as well as the component selection should be studied. The type of frame, the designed materials as well as other electronics plays a big role for the smooth flies of the quadcopter. In addition, mission planner software is used in our work in order to prepare the quadcopter for the mission lunch and its analysis, which will be discussed in the next chapter.

Chapter 3

Mission analysis and results discussion

3.1 Introduction

Building a quadcopter is an important step. However, driving it takes a long time and it is hard to learn manually. Moreover, it is not used for professional tasks. Hence, programming and launching automatic control and mission achievement is an important task after building any kind of quadcopters. In this chapter, we will try to test a mission flight in the region of Laghouat, Algeria and analyze the quadcopter response and its stability .

3.2 Flight modes

Pixhawk has 20 flight built-in flight modes, 10 of which are regularly used. There are modes to support different levels/types of flight stabilization, a sophisticated autopilot, a follow-me systemetc. Flight mode share controlled through the radio (via a transmitter switch), via mission commands, or using commands from a ground station (GCS) or companion computer. You can setup six flight modes once and max setupeight [29].

3.3 Flight modes setting steps

1. Connect Pixhawk and receiver (connect the RC port of Pixhawk, and make sure receiver work as SBUS signal).
2. Make sure transmitter bind to receiver success.

3. Make sure Pixhawk connect to Mission Planner success and click Initial Setup—Mandatory Hardware—Flight modes, you can setup the flight modes you want in this menu.

4.In flight modes menu, it's very clear that the flight modes, the PWM numerical interval of six flight modes you have set and choose Simple Mode/Super Simple Mode or not. Most of the RC fans setup the flight Mode 1 is Stabilize, the other five flight mode will be setup according to users' flight habit. First, you have to setup flight mode in transmitter. The setting steps as below look at the Figure 3.1 [29].

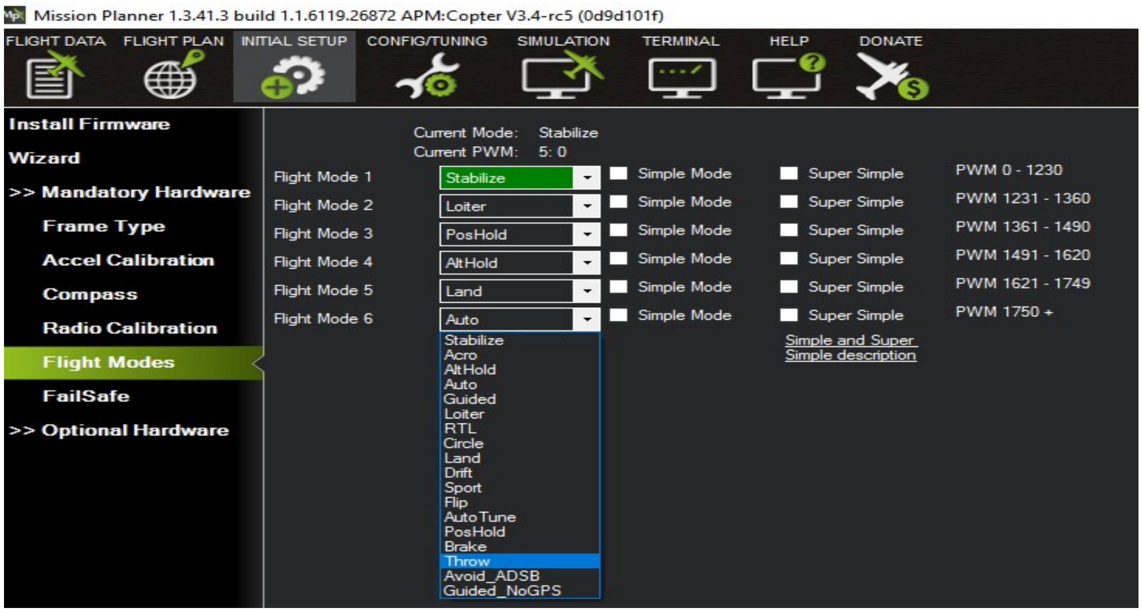


FIGURE 3.1 : Flight Modes Setting Steps

3.3.1 Stabilize mode

Stabilize mode allows you to fly your vehicle manually.

(1) Pilot's roll and pitch input control the lean angle of the copter. When the pilot releases the roll and pitch sticks the vehicle automatically levels itself.

(2) Pilot will need to regularly input roll and pitch commands to keep the vehicle in place as it is pushedaround by the wind.

(3) Pilot's yaw input controls the rate of change of the heading. When the pilot releases the yawstick thevehicle will maintain its current heading.

3.3.2 Altitude hold mode

In altitude hold mode presented in the Figure 3.2, copter maintains a consistent altitude while allowing roll, pitch, and yawto becontrolled normally. This page contains important information about using and tuning AltHold. Automatic altitude hold is a feature of many other flight modes (Loiter, Sport, etc.) so the information here pertains to those modes as well.

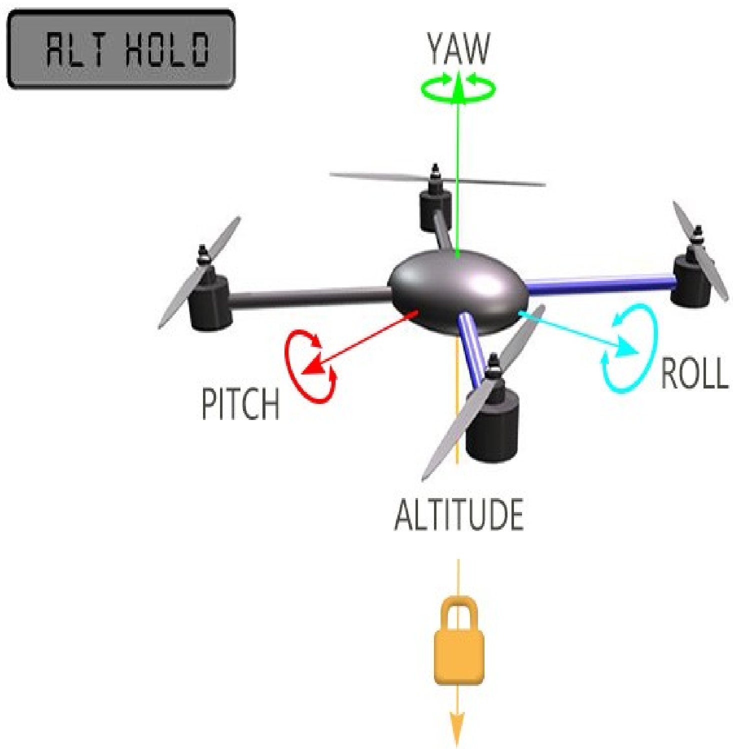


FIGURE 3.2 : Altitude Hold Mode

3.3.3 RTL mode

This very simple flight mode simply stops the vehicle as soon as possible using the Loiter controller. Onceinvoked, this mode does not accept any input from the pilot. This mode requires GPS. RTL mode (Return to Launch mode) navigates Copter from its current position to hover above the homeposition. The behavior of RTL mode can be controlled by several adjustable parameters. When RTL mode is selected, the copter will return to the home location. The copter will first rise to RTL_ALT before returning home or maintain the current altitude if the current altitude is higher than RTL_ALT. The default value for RTL_ALT is 15m. RTL is a GPS-dependent move, so it is essential that GPS lock is acquired before attempting to use this mode. Before arming, ensure that the APM's blue LED is solid and not blinking. For a GPS without compass, theLED will be solid blue when GPS lock is acquired. For the GPS+Compass module, the LED will be blinkingblue when GPS is locked. In RTL mode the flight controller uses a barometer which measures air pressure as the primary meansfor determining altitude ("Pressure Altitude") shown in Figure 3.3 .

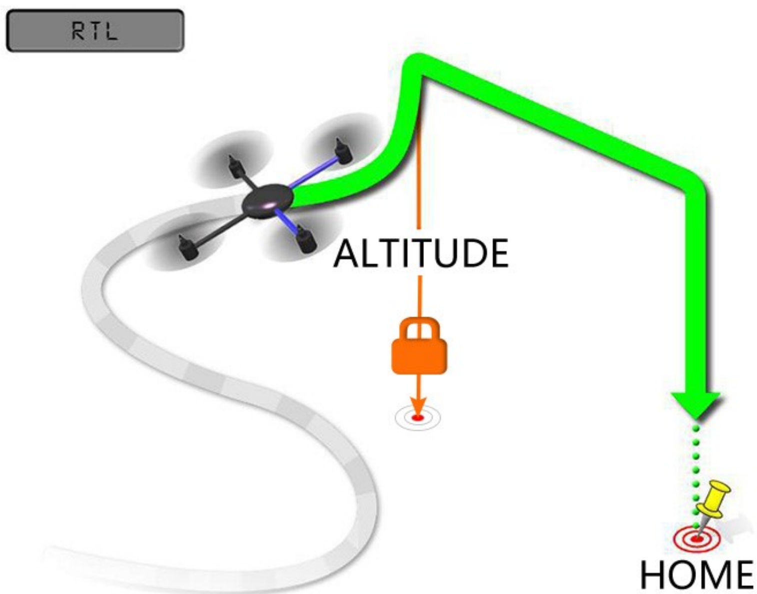


FIGURE 3.3 : RTL Mode

3.3.4 Auto mode

In Auto mode the copter will follow a pre-programmed mission script stored in the autopilot which is made up of navigation commands (i.e. way points) and "do" commands (i.e. commands that do not affect the location of the copter including triggering a camera shutter).

Auto mode incorporates the altitude control from AltHold mode and position control fromLoiter mode and should not be attempted before these modes are flying well. All the same requirements apply including ensuring that vibration levels and compass interference levels are acceptable and that the GPSis functioning well.

Auto should be set-up as one of the Flight Modes on the flight mode switch. Make sure that the GPS is positioning first : The LED of Pixhawk is green. The LED of GPS and compass module is blinking. If starting the mission while the copter is on the ground the pilot should ensure the throttle is down, the switch to the Auto flight mode, then raise the throttle. The moment that the throttle is raised above zero, the copter will begin the mission. If starting the mission from the air the mission will begin from the first command the moment that the flight mode switch is moved to Auto.

If the first command in the mission is a take-off command but the vehicle already above the take-off command's altitude the take-off command will be considered completed and the vehicle will move onto the next waypoint. At any time, the pilot can retake control from the autopilot by returning the flight mode switch to another flight mode such as Stabilize or Loiter. If the pilot then switches to Auto again, the mission will restart from the first command.

During the mission the pilot's roll, pitch and throttle inputs are ignored but the yaw can be overridden with the yaw stick. This allows the pilot to for example aim the nose of the copter (which might have a hard-mounted camera on it) as the copter flies the mission. The autopilot will attempt to retake yaw control as the vehicle passes the next waypoint look at the Figure 3.4 .

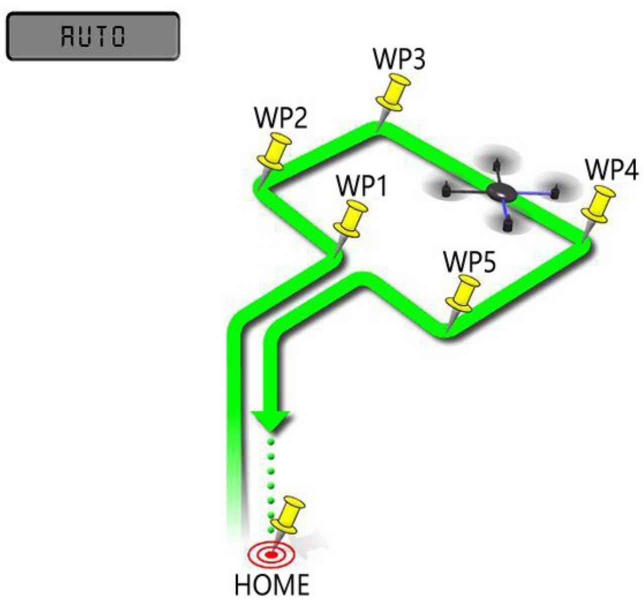


FIGURE 3.4 : Auto Mode

3.3.5 Guided mode

Guided mode is a capability of Copter to dynamically guide the copter to a target location wirelessly using a telemetry radio module and ground station application .

3.3.6 Loiter mode

Loiter Mode automatically attempts to maintain the current location, heading and altitude. Thepilot may fly the copter in Loiter mode as if it were in a more manual flight mode but when the sticks are released, the vehicle will slow to a stop and hold position .

3.3.7 Circle mode

Circle will orbit a point located Circle_Radius centimeters in front of the vehicle with the nose of the vehicle pointed at the center .

3.3.8 Sport mode

Sport Mode is also known as "rate controlled stabilize" plus Altitude Hold. Flip Mode : Vehicle will flip on its roll or pitch axis depending upon the pilot's roll and pitch stick position. Vehicle will rise for 1 second and then rapidly flip. The vehicle will not flip again until the switch is brought lowand back to high .

3.3.9 Autotune

Autotune attempts to automatically tune the Stabilize, and maximum rotational accelerations to provide the highest response without significant overshoot. Copter needs to be "basically" flyable in AltHold mode before attempting to use AutoTune as the feature needs to be able to "twitch" thecopter in the roll and pitch axis .

3.3.10 Land mode

Land Mode attempts to bring the copter straight down.

3.3.11 Break mode

This very simple flight mode simply stops the vehicle as soon as possible using the loiter controller. Once invoked, this mode does not accept any input from the pilot. This mode requires GPS .

3.3.12 Throw mode

This slightly dangerous flight mode allows the pilot to throw the vehicle into the air (or dropthevehicle) in order to start the motors. Once in the air, this mode does not accept any input fromthe pilot. Thismode requires GPS. Avoid_ADSB : for ADS-B based avoidance of manned aircraft.

3.4 Mission results

Our objective is to test a mission achievement for our build quadcopter. Hence, we have selected the region of Laghouat, Algeria to do this task. Several tests are done and the best results are shown in what follows .

3.4.1 Laghouat city

Located in the heart of the country 400 km south of the capital Algiers, the wilaya covers an area of 25,000 km^2. The Wilaya is distinguished by two zones : the zone of the Saharan Atlas characterized by altitudes ranging from 1000 to 1700 m made up of old forest massifs, the zone of the high plateaus and Saharan plateaus characterized by altitudes ranging from 700 to 1000 m. The wilaya conceals a rich and varied history, in particular with the existence of prehistoric tools, cumulus of dry stones, shelters under the rocks proving the presence of a human community since prehistory, vestiges and historical sites of an autochthonous sedentary population which was concentrated at the level of Oued M'Zi [31].

3.4.1.1 Laghouat map

FIGURE 3.5 : Laghouat Location on The Map

3.4.1.2 Climate of Laghouat

Laghouat is one of the warmest region in Algeria with an average daily high temperature of 26 degrees centigrade. Several months of the year it is warm to hot at temperatures continuously above 25 degrees centigrade, sometimes up to 40 degrees [32].

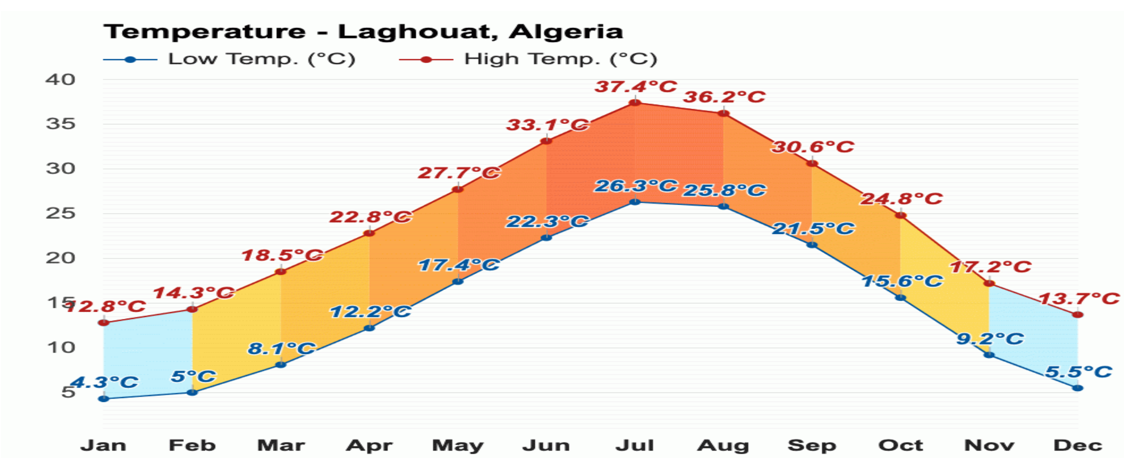


FIGURE 3.6 : Average Temperature Laghouat

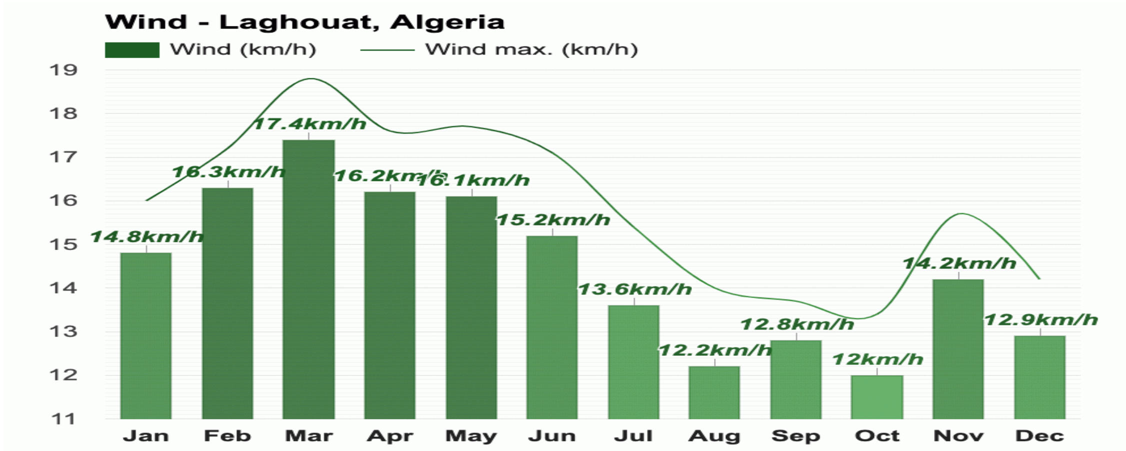


FIGURE 3.7 : Average Wind Speed Laghouat

Note

All climate graphs are the result of data collected from the official meteorological station in Laghouat at an altitude of 763 meters above sea level. This information was taken on 05/19/2022.

3.4.2 Quadcopter mission location

We conducted our work in The New Compus (Amar Thelidji Univeristy), Laghouat.

FIGURE 3.8 : The New Compus (Amar Thelidji Univeristy), Laghouat

3.4.3 Quadcopter mission trajectory

The elaborated mission trajectory for our work is constructed using mission planner as shown in Figure 3.9.

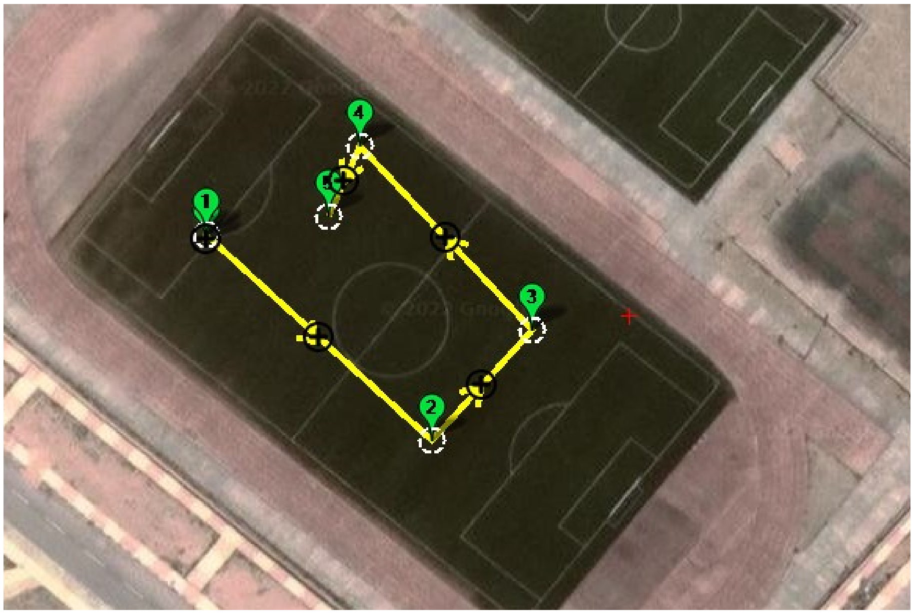


FIGURE 3.9 : Quadcopter Mission Trajectory

The mission waypoints are summurized as follows :

- **Waypoint "1" :** TakeOff ;
- **Waypoint "2" :** Waypoint ;
- **Waypoint "3" :** Waypoint ;
- **Waypoint "4" :** Waypoint ;
- **Waypoint "5" :** Land.

FIGURE 3.10 : Mission waypoints

3.5 Results of the mission

For smooth flight and mission follow, we have used the following PID tuning parameters In what follows, we will give the results of the planned mission of the desired output and the quadcopter output for achieving the mission. The data is driven from the pixhawk.

The main controllers to be discussed are the ones relating to the pitch, the roll and the yaw.These three controllers are the most important because they guarantee that the realised pitch, roll and yaw is the same as the one demanded.

It is therefore necessary to give the right PID gains to obtain the expected behaviour. In this work, there was initially a bit of trial and error in the assisted mode in order to ensure that the quadcopter has acceptable handling qualities.

The optimal gains are give in the following Table3.1 :

First, we gave some reference altitude for each way point , so the quadcopter will follow. Figure 3.11 show the reaction of the quadcopter altitude against the given waypoint reference altitudes.

Table 3.1: The optimal PID gains for the quadcopter.

	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

- **Altitude**

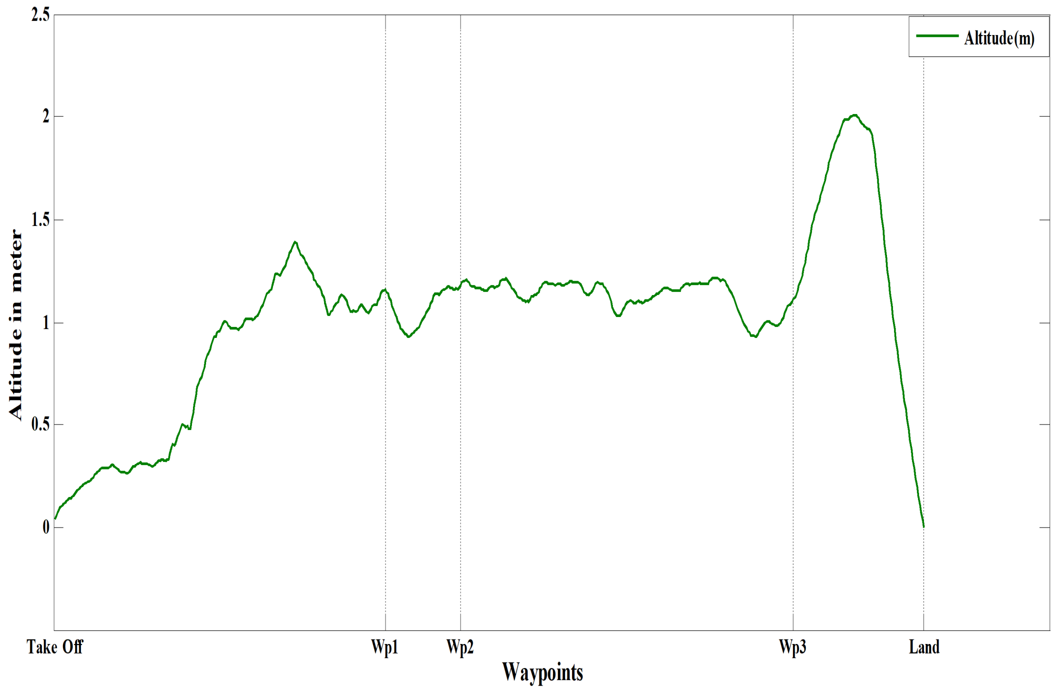


FIGURE 3.11 : The Desired Altitude for The Proposed Mission

We can see here that most of the time, the reference altitude follows the given scenario, but with some delay which is normal since it takes time to achieve any given altitude.

- **Pitch, roll and yaw**

The results of the roll, pitch and yaw and their desired references are given in Figs 3.12 & 3.13 & 3.14 :

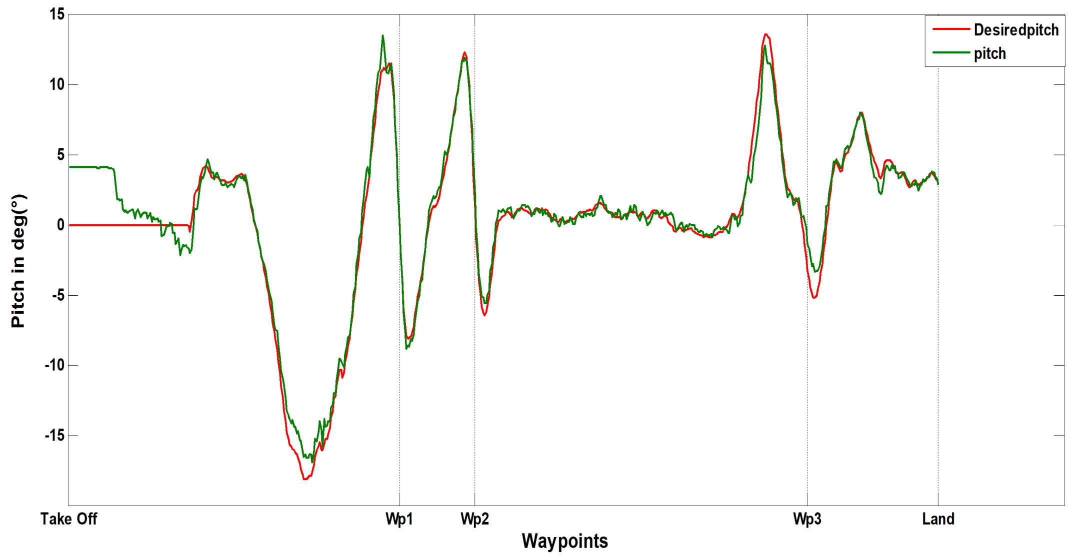


FIGURE 3.12 : The Desired and Output Pich Results.

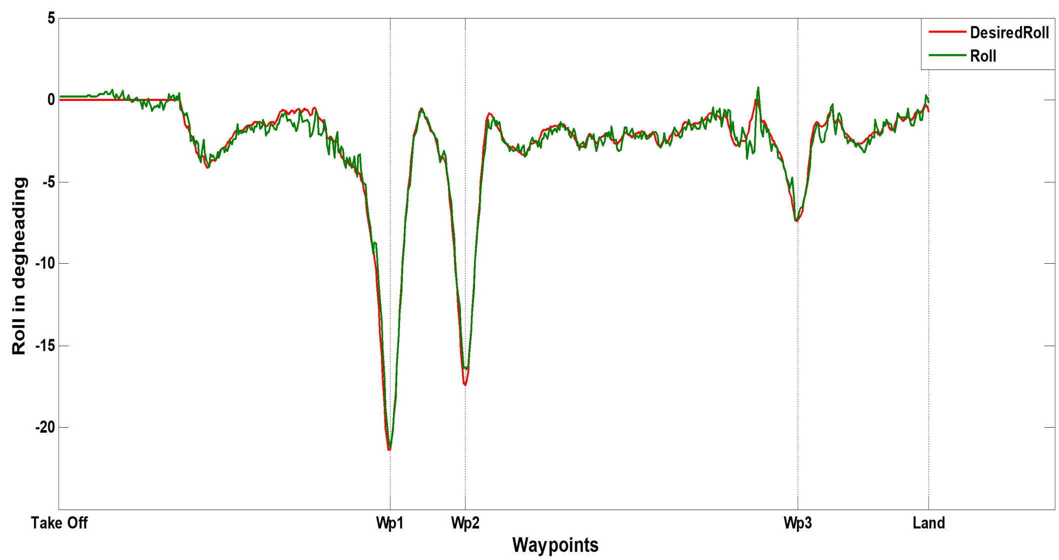


FIGURE 3.13 : The Desired and Output Roll Results.

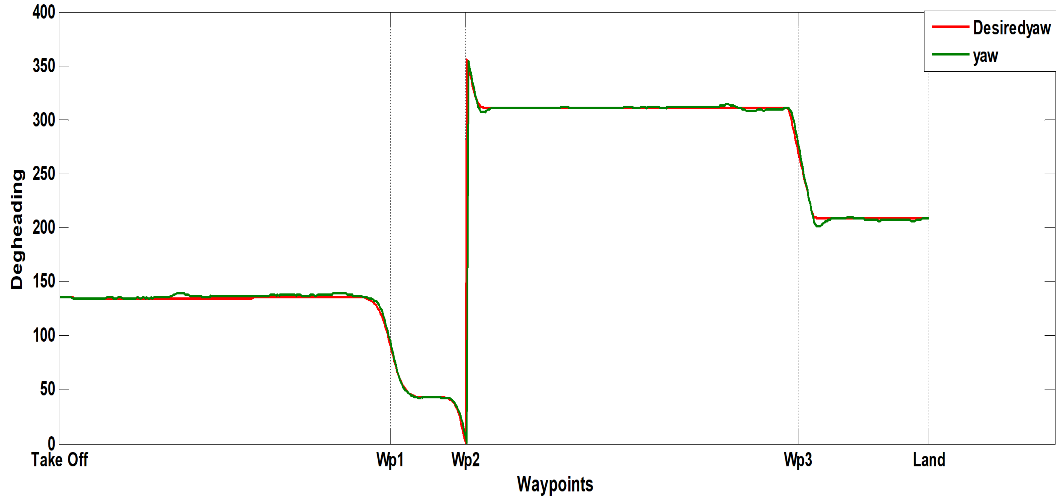


FIGURE 3.14 : The Desired and Output Yaw Results.

From these figures, we can clearly see the demanded and realized angle curves superimpose indicating that the control system is well tuned. The mission is almost rectangular, which is the reason why the quadcopter tends to turn to the same side. Some oscillations may occur due to some wind on the testing day.

- **Speed**

Moreover , the speed of the quadcopter is given in Figure 3.15

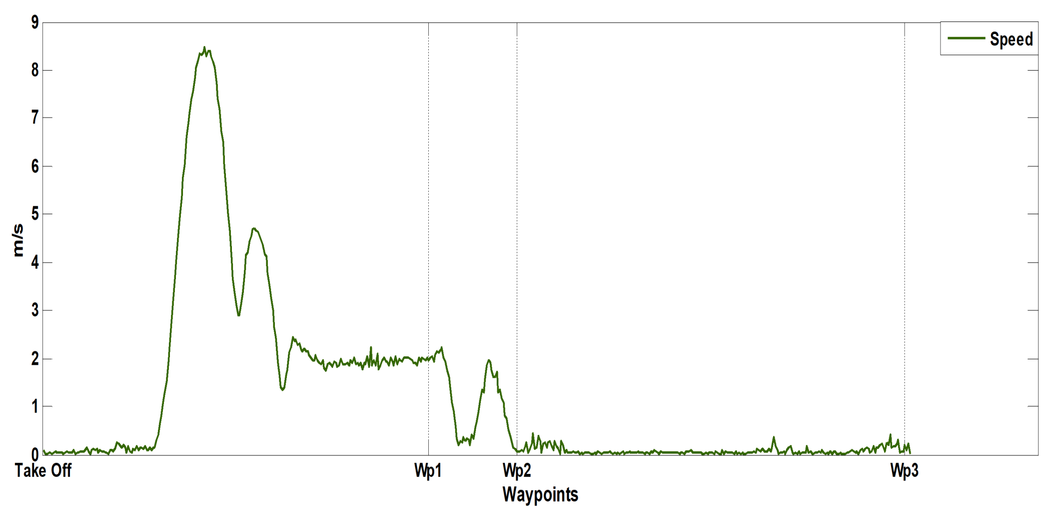


FIGURE 3.15 : The Speed of The Drone

We can see here clearly the speed change of the quadcopter before and after reaching each waypoint , ending with a 0 m/s speed when it finished the mission at land point.

- **Pressure and temperature**

In addition , we have to clearly monitor the health of the quadcopter, which is very important to finish the mission without any unpredictable errors. Hence, we have plotted the pressure as well as the temperature of the quadcopter as given in Figs 3.16 & 3.17 :

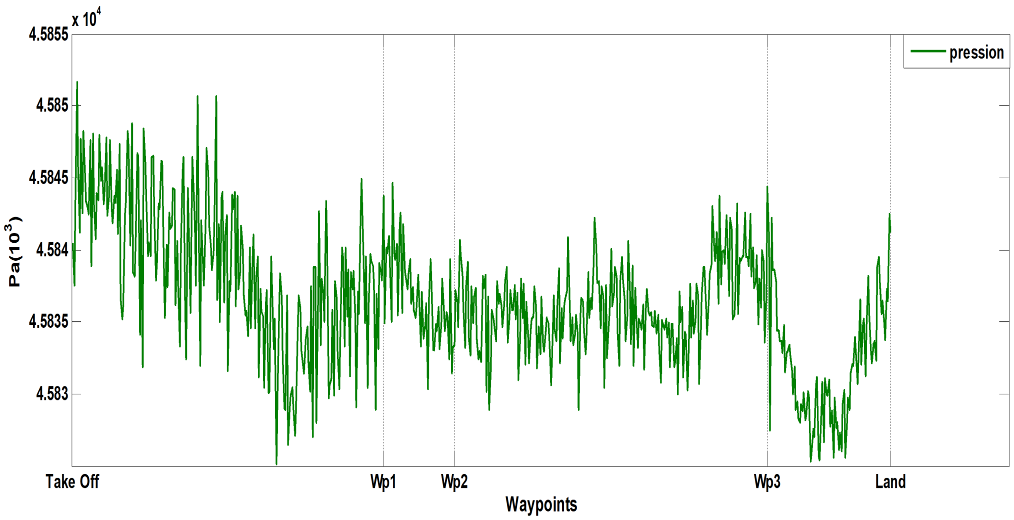


Figure 3.16 : The Output Pression of The Quadcopter.

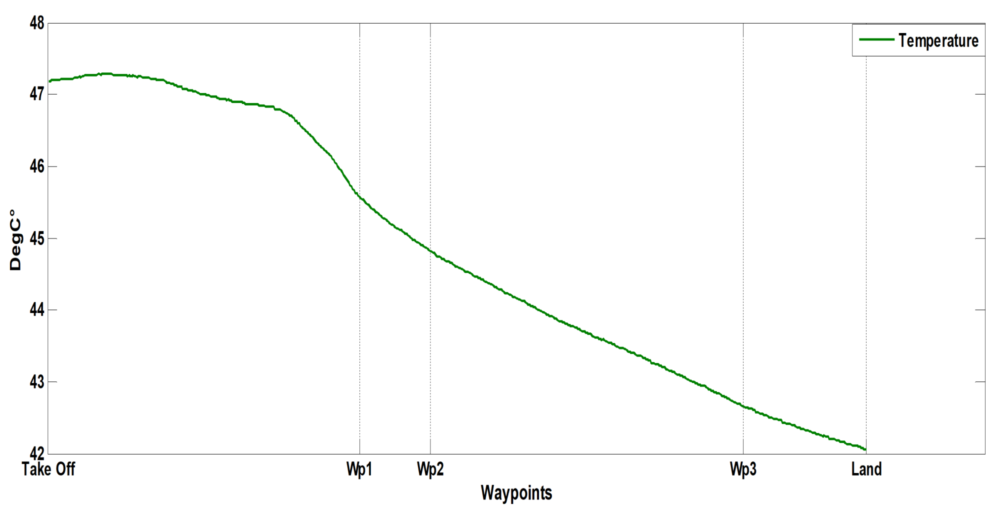


Figure 3.17 : The Output Temperature of The Quadcopter

From these figures, we can see how healthy the quadcopter is when achieving its mission with normal pressure and temperature values.

Finally, we can conclude here that the achieving mission depends on a lot of factors, especially the weather conditions as well as tuning of the PID parameters.

At the end of this chapter, we can see here some real footage for the tests of the mission outside shown in Figures 3.18. Note here that we have elaborated several tests under different conditions which are sometimes too hard especially in the presence of rain or wind.

FIGURE 3.18 : Real Footage for The Tests of The Mission Outside

3.6 Conclusion

In this chapter, the analysis of a mission for the quadcopter is achieved. A given set of way points are given in order to see the reaction of the quadcopter to finish the mission with less errors. The desired angles are well tracked by the quadcopter and the results are so satisfactory.

Conclusion general

The main objective of the present work is to design a mathematical model to estimate the behavior of flying robots with four motors (quadcopters) controlled by PID controller. Our aim is to test the stability of the quadcopter in automatic mission achievement in real time outdoor conditions. This research is about devising an autonomous takeoff and landing system for quadcopters.

From this study we can get some conclusions :

- An autonomous system would reduce the need of human supervision and would therefore increase the possible fields of use. This is a first step to develop a fully autonomous system that could be used for e.g. surveillance or search and rescue missions.

- 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. This is also essential for swarm robotics where it is not possible to control every unit in detail.

- The system is required to work in an outdoor environment and therefore a good GPS and barometer should be used for better results. The reason for using good components is because they measure air pressure and the turbulence from the quadcopter that may give unreliable results in the case of bad component selection.

Future works :

The system is also a first step to implement a custom mode that can be modified further in the future to implement more functions. The final goal for the quadcopters are to be able to land and take off to a specific height in unknown terrain, so no help such as markers or maps have been used.

A dynamic change of vertical speed should improve the altitude hold function to fine tune when approaching the target altitude. It should also improve the takeoff and landing time by reducing the speed only when close to the target altitude or ground.

When the system is working on one unit it should also be scalable to a swarm of multiple units to use its full potential. This could give rise to other problems such as interference between the quad copters and more that have to be taken into account.

Solving all these problems is the ultimate goal that would make it possible for quadcopters to without human supervision explore, search, or surveillance areas without being affected by exhaustion or human errors.

References

[1] IWM Sta, A Brief History of Drones | Imperial War Museums, IWM, 2018.

[2] A. Finn and S. Scheding, Developments and Challenges for Autonomous Unmanned Ve- hicles: A Compendium, Intell. Syst. Ref. Libr., 2010.

[3] P. Pounds, R. Mahony, and P. Corke, Modelling and control of a large quadrotor robot, Control Eng. Pract., 2010.

[4] K. M. Zemalache, L. Beji, and H. Marref, Control of an under-actuated system: application a four rotors rotorcraft, 2008.

[5] A. SINGHAL, IMPACT OF DRONE TECHNOLOGY ON HUMAN LIFE. International Journal of Research in Humanities, Arts and Science, Issue 1, E-ISSN: 2456-5571 , Vol. 5, January 2021 .

[6] P.Mátyás and N. Máté, "Brief history of UAV development." Repüléstudományi Közlemények 2019 .

[7] O.MACKENSEN, Journal of Economic Entomology , Experiments in the technique of artificial insemination of queen bees. Vol: 48, No: 4 ,E-ISSN: 418-421 1955.

[8] F.SABATINO. Quadrotor control: modeling, nonlinearcontrol design, and simulation, 2015.

[9] R.MAJOR, RQ-2 Pioneer: The Flawed System that Redefined US Unmanned Aviation. Air Command And Staff College Mawell AFB United States, 2012.

[10] F. MUNEYOSHI, A.Hideki Case Study of DJI, the Top Drone Maker in the World. Kindai Manag. Rev , Vol: 5, ISSN: 2186-6961, pp: 97-104, 2017.

[11] PANDIT, Vinay; POOJARI, Arun. A study on amazon prime air for feasibility and profitability: A graphical data analysis. IOSR Journal of Business and Management, Vol: 16, Issue: 11 pp:06-11,Nov 2014.

[12] J. Hawkins, Ehang's passenger-carrying drones look insanely impressive in first test flights, https://www.theverge.com/2018/2/5/16974310/ehang-passenger-carrying-drone-first-test-flight [accessed may, 18th, 2022] .

[13] B.VERGOUW. Drone technology: Types, payloads, applications, frequency spectrum issues and future developments. In: The future of drone use. TMC Asser Press, The Hague, p. 21-45, 2016.

[14] M.R .Dlleep , A study and analysis on various types of agricultural drones and its applications. Fifth International Conference on Research in Computational Intelligence and Communication Network) Nitte Meenakshi Institute of Technology, Bengaluru, India. IEEE, pp : 181-185 ,2020.

[15] ELIJAH, Thato, et al. A review on control and maneuvering of cooperative fixed-wing drones. International Journal of Dynamics and Control,Vol :9 ,No :4 E-ISSN : 1332-1349 , 2021.

[16] J.GONG, Comparison of Radar Signatures from a Hybrid VTOL Fixed-Wing Drone and Quad-Rotor Drone. Drones, , Vol:6, No:5, p:110, 2022.

[17] What is a MultiCopter and How Does it Work? https://ardupilot.org/copter/docs/what-is-a-multicopter-and-how-does-it-work.html [accessed april, 29th, 2022].

[18] K. M. Zemalache, L. Beji, and H. Marref, Control of an under-actuated system: application a four rotors rotorcraft, 2008.

[19] T. S. Venkatasundarakumar, R. Suwathy, T. M. Haripriya, and M. Venkatesan, Motion control analysis of a quadcopter system part II-Modelling, in 2016 IEEE International Conference on Computational Intelligence and Computing Research, ICCIC 2016, 2017.

[20] G. Homann, H. Huang, S. Waslander, and C. Tomlin, Quadrotor Helicopter Flight Dy- namics and Control: Theory and Experiment, 2012.

[21] J. Rauleder and J. G. Leishman, Measurements of organized turbulence in the dual-phase ow below a rotor, in 38th European Rotorcraft Forum 2012, ERF 2012, 2012.

[22] D. Gonzalez-Aguilera and P. Rodriguez-Gonzalvez, DronesAn Open Access Journal, Drones, 2017.

[23] FuzzyLogicTutorial,https://www.tutorialspoint.com/fuzzy_logic.htm ,2017,02/04/2019

[24] J. Brown, DJI F450 QUADCOPTER: A VERSATILE & ELEGANT MULTI-ROTOR, https://www.mydronelab.com/reviews/dji-f450-quadcopter.html [accessed may, 7th, 2022].

[25] Understanding Various Components Used for Quadcopter , https://robu.in/understanding-various-components-used-for-quadcopter-2/ [accessed may, 7th, 2022].

[26] PIXHAWK https://www.geeetech.com/wiki/index.php/PIXHAWK . [accessed may, 7th, 2022].

[27] http://www.radiolink.com.cn/firmware/MissionPlanner/MissionPlanner-latest.msi.

[28] PIXHAWK https://www.rcworld.co.za/downloads/pixhawk.pdf [accessed may, 7th, 2022].

[29] PIXHAWK http://radiolink.com.cn/doce/UploadFile/ProductFile/PIXHAWKManual.pdf [accessed may, 7th, 2022].