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DESIGN AND CONCEPT OF GENERAL-PURPOSE DRONE

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I. Abstract

A drone is defined as an aerial vehicle which uses aerodynamic forces to provide vehicle lift, can be recoverable or expandable, can be piloted remotely or fly autonomously, does not carry a human operator, and can carry a non-lethal or lethal payload. Beforehand, drones were used only for military applications like spying on both international and domestic threats because they do not put the life of a pilot at risk in combat zones. In addition, they do not need rest, which enables them to fly if there is fuel in the craft. Currently, the developed drones can be used in a vast number of applications, such as deliveries, policing, monitoring flooded areas, and many others that were discussed in this report. The mechanism described in this report targets multiple disciplines that fall under the Mechatronics umbrella, which comprises mechanical, electrical, and digital components. This project focuses on designing and developing a general-purpose drone that can be used in different applications, specifically in deliveries. The developed drone design has been simulated using different software, including MATLAB, SolidWorks, Gazebo, and Proteus. Different analyses were made on the drone to choose the best available material, guarantee its longevity, and ensure its safety. A propeller was analyzed as well to determine the air pressure and velocity impact on it. Besides, the flight dynamics of the system and the reasons why each component was chosen were explained in detail. In addition, mathematical equations to better understand the system's flight dynamics and electrical calculations to determine the flight autonomy were clearly shown and explained.

Keywords: Drone, delivery, mechatronics, propeller, SolidWorks

II. Introduction

A drone is defined as an aerial vehicle which uses aerodynamic forces to provide vehicle lift, can be recoverable or expandable, can be piloted remotely or fly autonomously, does not carry a human operator, and can carry a non-lethal or lethal payload. Beforehand, drones were used only for military applications like spying on both international and domestic threats because they do not put the life of a pilot at risk in combat zones. In addition, they do not need rest, which enables them to fly as long as there is fuel in the craft. Currently, the developed drones can be used in a vast number of applications, such as deliveries, policing, monitoring flooded areas, and many others that were discussed in this report. The mechanism described in this report targets multiple disciplines that fall under the Mechatronics umbrella, which comprises mechanical, electrical, and digital components. This project focuses on designing and developing a general-purpose drone that can be used in different applications, specifically in deliveries. The developed drone design has been simulated using different software, including MATLAB, SolidWorks, Gazebo, and Proteus. Different analyses were made on the drone to choose the best available material, guarantee its longevity, and ensure its safety. A propeller was analyzed as well to determine the air pressure and velocity impact on it. Besides, the flight dynamics of the system and the reasons why each component was chosen were explained in detail. In addition, mathematical equations to better understand the system's flight dynamics and electrical calculations to determine the flight autonomy were clearly shown and explained.

A quadcopter is a simple flying mechanism also known as a quadrotor that has four arms, which each one of them has a motor that is attached to a propeller. In the quadcopter, two of the rotors turn counterclockwise (CCW) while the two others turn clockwise (CW) [1].

aerodynamically, quadcopters are not stable which require a flight controller to send information to the motors through their electronic speed control (ESC) to make a desired motion. In the figure below is an example of how a quadcopter drone looks
UAV technology (drone) has gained a lot of interest in the last couple of years. It is one of the fastest growing sectors related to IT. The concept of using drones to hover around crime scenes to collect information and evidence to speed up remote investigations and to provide fast-response units is already implemented in the United States [2].

Figure 1: An Example of a Quadcopter Drone
Nowadays, drones can use sensors such as laser, infra-red, and optical sensors to keep track of their environment from multiple angles to imitate the human eye. By taking advantage of this technology, a drone can navigate on its own to accomplish any task that it was set to perform. With the advancements in technology, more precisely intelligent systems, it is now possible to customize and increase the autonomy of drones [3].
This amazing advancement of astonishing technology in drones has produced and developed applications that led to new fields. Now, drones can be used for several purposes in various areas. Drones can be utilized as a guiding unit for disabled people for navigation purposes. They are also used in the architectural sector to map buildings and check their compliance with safety regulations. Below are some other drone applications' common areas [4].

- Agriculture
- Engineering applications
- Search and rescue
- Ariel surveillance/photography
- Shipping and delivery
- Military
- Explorations and many more

III. Background of the study.

In a paper published in 2004 by Newcome [5], he explained that unmanned aviation started almost the same time as the manned one; thus, drone technology has existed for a century, but it is rooted to its testing done in the first world war while its success was noted by most scholars in the second world war [6].
The main uses of the UAVs were applied in aerial photography, safety inspection building, deliveries shipments, monitoring of crops precision, thermal sensor drones which are applicable for rescue operations as well as information collection for border and law enforcement surveillance, disaster management, storm tracking, tornado forecasting and hurricane [7].

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According to the figure below, the estimated investment in drone hardware in government, consumer, and enterprise has been increasing since 2015.

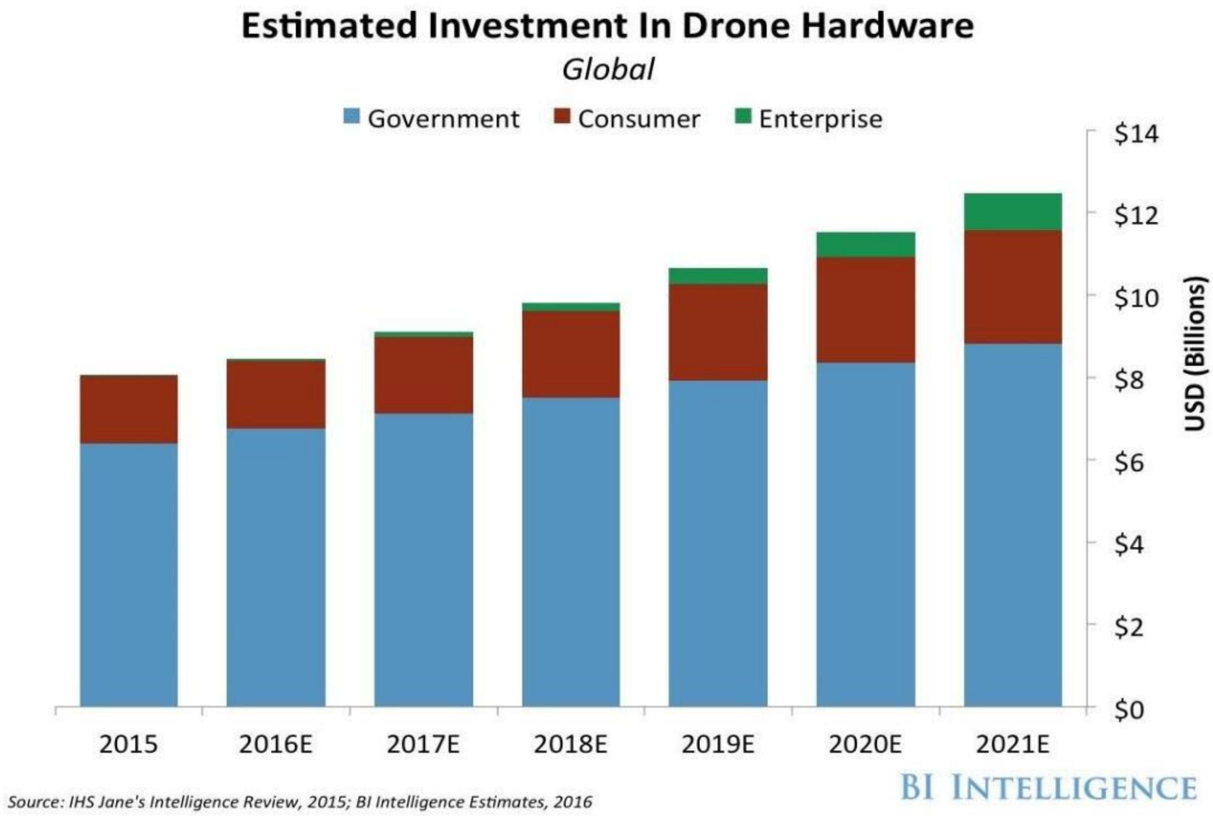

Figure 2: The Estimated Investment Growth in Drone Hardware [7]

These small drones have a limitation, which is they need pilots who are highly skilled. In addition, an already built-in access to data wireless link or maps is required for semi- autonomous drones as well. Researchers in some higher education institutions like Zurich's Federal Institute of Technology are working on making drones more independent (autonomous) [8].

Undeniably, it was disclosed by research that human help is still required for the drone technology to start operating in new spaces. Currently, there are two types of drones. The former does not need a GPS as it hinges on a highly skilled person to keep full control of it; in other words, it relies on visual tracking to determine orientation as well as position. As for the latter, it contains GPS technology, which at first was reserved only for military purposes. Then, when they start allowing the use of this type of drone, many doors have opened for new fields of applications. It allows the drone to have multiple functions; for instance, it allows it to remain in a fixed position with respect to location and latitude. Another function is returning home, which allows it to remember the spot at which it took off and automatically returns to it, and this is made by pressing on a button called “return”. Clearly, this type of technology does not require any human pilot as it uses the autopilot concept by following the trajectory given by a set of GPS points, which is a way the autonomous flight predetermines the path of the drone [9].

Literature records that currently UAVs are applied to the building’s construction surveillance, road maintenance, and building inspection. From all the mentioned aspects, the predetermined GPS points are followed by the drone technology within and without a building, and this is allowed by a functionality of the drone called waypoints. Besides, for the inspection roles in closed areas, the drone’s controller system accords a larger capacity to the camera, which sends signals like pictures for example. It was also shown that navigation and drone technology expand dramatically in terms of range of use, utility, and application.

Literature shows that drone technology is amongst the ten technological innovations that will lead a major change to the people’s lives and the world forever [10]. Obviously, at this present moment

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drones can capture pictures at different angles even in 360 degrees angle of a desired place, environment, or the world at large.
After making my investigation about my capstone project by reading articles and books, two terminologies have triggered and captured my attention, which are UAVs which stand for either Unmanned Aerial Vehicles or rarely as Uninhabited Aerial Vehicles, and the other one is Remotely Piloted Air System RPAS. UAVs are meant to occur autonomously while RSPA control is meant to occur outside of the aircraft. The application key of the drone used by the civilian's authorities and military hinges on discharging security, policing, or safety duties which will rely on intelligence gathering network as well as surveillance conduct.
The drone's future is to give assistance in many operations that could be risky for both the members of the military and public such as spying, forest fire fighting, and navigating rooftops. Also, a critical strategy can be formed by drone technology to enhance both the speed of logistics and efficiency of the delivery companies. Law enforcement agencies documented and implemented resulting impacts and practical applications of the drone [11].

IV. STEEPLE Analysis

To make a good project plan, it is imperative that both the factors which can have an impact on it and the external and internal elements to be analysed. Even some prominent organizations and companies use the commonly analysis strategy tools, which include STEER, SWOT, PESTLE, STEEPLE, and so on and so forth. All these are methods to help analyse the effect of a certain product before taking any informed decision. The difference between them is only in the variants they incorporate [12]. In this report, I will cast some light upon the STEEPLE implications of my project as well as the analysis, design, testing, and implementation, which make it the key factors of my capstone process.
This latter analysis permits entities to foresee imminent trends by taking into consideration the variables that are external in which any organization operates and enables it to figure out the different factors that would impact it after. STEEPLE analysis is assessed as one of the well-known methods for the operational activities of corporations and business examination and is considered as more sophisticated and practical than SWOT analysis [13].

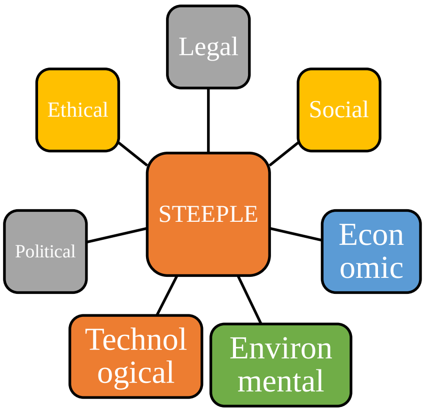

Figure 3: STEEPLE Acronym

STEEPLE analysis of the project:

1. Social: This drone type quadcopter will assist students as a starting point to evolve it so that they can design or develop their own applications. Another help that it would provide is it would arouse the creativity of students and open the doors for them to have a new aid on which they can hinge on to set their systems, so that they can make a new contribution to society's improvement. In the case of adding a camera to the drone, society's acceptance of it will vary greatly. Some will think of it as an attempt to spy on people and manage the information that is displayed to the public while others will see it as an extension to their security and safety which will be our main intention.

2. Technological: The technologies that are essential for the drone's deployment already exist, which makes it feasible. Many people have already managed to create drones; however, meticulous study needs to be done with the components in mind, which are available and eventually give it a personal touch.
3. Economic: I still have not envisioned the economic model in depth; nevertheless, it is thought that this system has a great impact on the Moroccan economy and society. More than that, I am planning to use the laser cutter for the drone's frame and 3D print any other possible parts, which make it economical.
4. Environmental: this system does not have any deleterious effect on the environment in any way, but on the contrary, it helps cut down the emissions of the carbon dioxide if used to execute given tasks that customarily require deliveries or transportation [14].
5. Political and Legal: According to the Moroccan government, it is not permissible to use the drones in the country and this has been banned through a Royal decree [15]. However, as I said previously my focus on the project is to create a drone without a camera at first, and this would not be a problem since it cannot be used to spy or harm anybody; thus, this makes it permissible. Nonetheless, if time allows and I intend to add one by the end, I will make sure to fill in and submit any proper work to the authorities.
6. Ethical: The use of the drone is ethically controversial. As it all depends on the user's intention, which can lead to dire consequences if the user has bad aims. It can be used for surveillance to track victims by criminals. Nonetheless, this should not stop the advancement and development of this technology and its different applications to serve society.

V. Engineering Design Process.

1. Objective Tree

Objectives for design of a quad copter	Cost	Drone should be economically friendly.
	Durability	The drone needs to withstand all the seasonal weather, so it can fly in different areas and places
	Performance	Lifts the appropriate weight
		Flies in 3 dimensional axis
		Precise in landings and Take-offs
	Apperance	Asthetics
		Appropriate dimensions
	Technology	The system needs to monitor and supply power to manipulate the drone to meet the users' needs
	Environment	Safe for humans
		Minimal environment effect

Figure 4: Objective Tree

2. System Requirement

Requirements are important because they establish a foundation for product scope, vision, schedule, and cost. They eventually should target the quality and performance of a finished product. Requirements supply stakeholders like electrical engineering, marketing, software engineering, and mechanical engineering with one uniform set of goals and vision. Each stakeholder holds realistic expectations after understanding the requirements of the final product. No surprises should occur from the final product in terms of functionality and design, which will yield a profitable and a successful product launch [16].to determine the project well requirements, I made a hierarchical decomposition of a quadcopter as shown below.

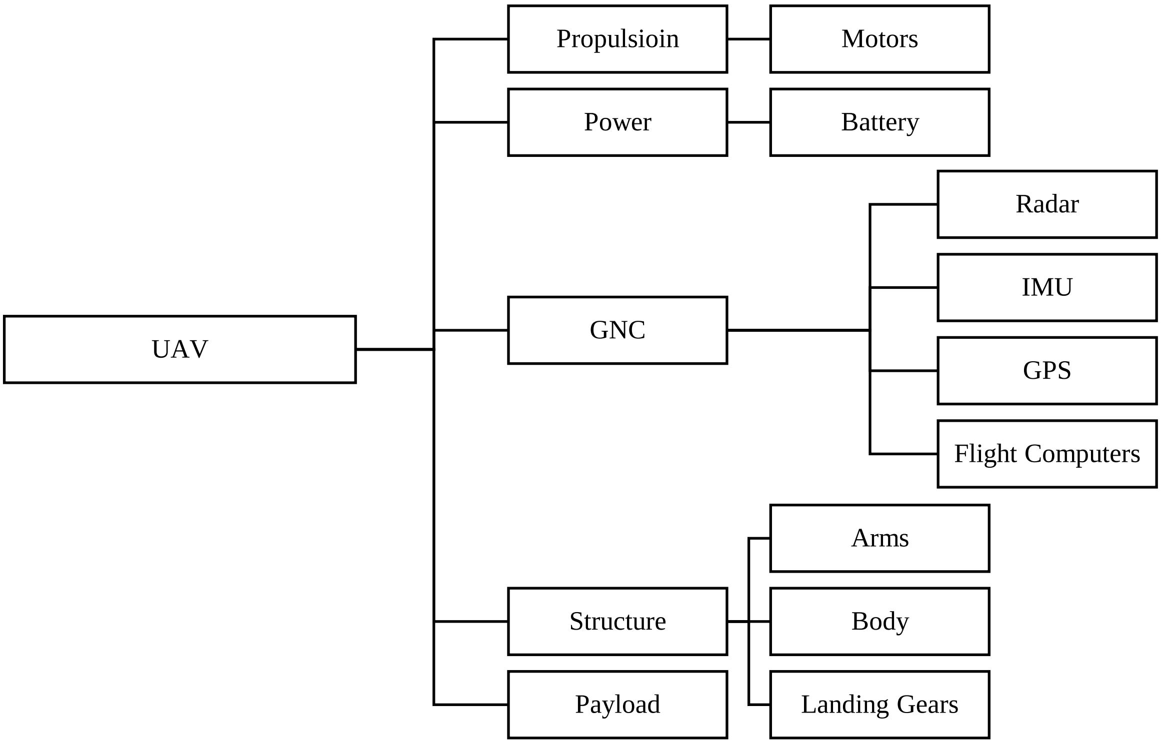

Figure 5: Hierarchical Decomposition of a Quadcopter
Figure 5 describes a hierarchical decomposition of a simplified model of a quadcopter drone by dividing it into two tiers. The first one has five primary subsystems, which consist of power, propulsion, structures, GNC, propulsion, and payload. As for the second one, it comprises battery, IMU, flight computer, radar, motors, GPS, body, arms, and landing gear [17].

The table below shows the quadcopter's requirements along with their descriptions.

Requirements		Description
1	The drone should fly remotely	The user should control the drone by using a handheld controller. The user should be able to fly the drone in any. direction and at any height up to the maximum altitude.
2	The drone should fly to a maximum height of 500 meters	The drone should be able to fly at any altitude up to 100 meters.
3	The drone should carry a load up to 2kg	The drone should be able to carry a 2 kg load in the payload while flying. It should be controllable and stable while. delivering whatever is inside.
4	The drone should fly left, right, back, forward, up, and down	The user should be able to fly the drone at any direction.
5	The drone should fly up to 600 meters away from the user	The drone should be controllable up to 600 meters from the user by operating it with the remote controller.
6	The drone should fly with the maximum payload for at least 15 minutes	The drone should provide a stable flight while carrying the maximum payload for a minimum of 15 minutes.
7	The drone should spin both CW and CCW	The drone should be able to spin while flying when the user needs it to. The spin needs to be in both directions.
8	The drone's frame should be designed to provide a payload and an enough room for all components.	The drone's frame should have enough room and support for an Arduino, flight controller, BLDCs, LiPo battery, ESCs, and any sensor. Also, a payload is required so that it can lift any object to deliver.
9	It should be a medium size	The drone's design should be compact (500 mm at most).
10	Propellers of high thrust are needed	Propellers need to be 10 inch into 4.5 pitch to have enough thrust to lift the drone in such size.

Table 2: System Requirements

3. System Block Diagram

A block diagram is a high-level and specialized flowchart used in engineering. It is used to describe and improve existing systems or to design new ones. The block diagram's structure provides a high-level overview of important working relationships, key process participants, and major system components [18]. Below is the overview of the major quadcopter components [19] represented as block diagram.

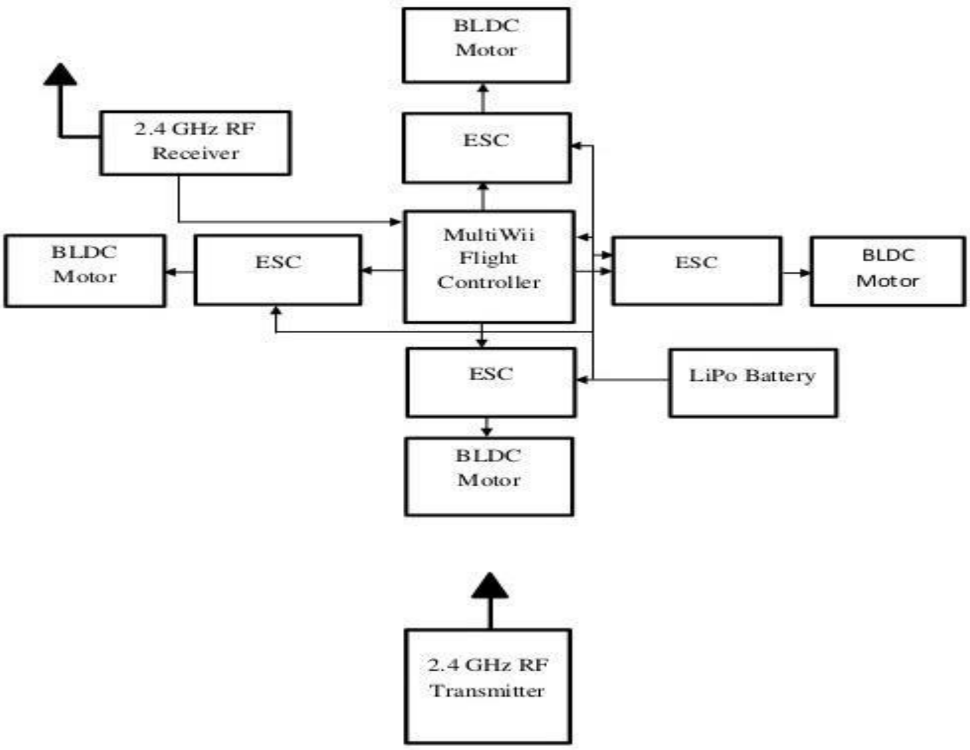

Figure 6: Block Diagram of a Quadcopter

4. Technical Specifications

The drone's technical specification is nothing more than a document that through technical data makes a clarified description for the drone's specific use, functionality, or performance levels.

We should hence abridge the previous concept by claiming that the quadcopter's technical specification is a set of key performance indicators (KPIs), which is able to describe the performance competence of a quadcopter.

The set of significant technical data or the technical specification plays a crucial role when it comes to making a formal decision about choosing the ideal drone; especially, when making a comparison between different quadcopter models. Nonetheless, when acquiring the right indicators of the technical specifications is not always easy for two reasons. The first one because some fundamental parameters are hidden by some manufacturers as they are not optimal when compared to the rivalry [20]. The second one is because the specifications are not the same reported by all manufacturers. For instance, producer A can report his drone's maximum tangency quota; on the other hand, producer B can only omit this data in the technical specs.

After reviewing my system requirements, the figure shown below describes the specifications that my quadcopter should meet.

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Metric	Value
Dimensions	405mm x 371mm x 70mm
Weight	1000 g
Power	200 W
Rotors	4
Propellers	10” x 4.5” (10 inches in diameter and 4.5 inches in pitch).
Battery	3300 MAh (C) 3S LiPo 35C (Max)
Controller	Arduino uno
Payload Mass	150 g
Diagonal Size (Propellers excluded)	520 mm
Motors (for medium size quadcopter 500mm)	A2212 brushless outrunner dc motor, 1000kv. No load current @ 10V: 0.5A Thrust @ 3S with 1045 propeller: 800gms approx.
Current Capacity	12A/60s
Motor Dimensions	27.5 x 30mm
ESC Specification	18A (30A Recommended)
Propellers RPM	7536 RPM
Input Voltage	11.1V
Pitch Speed	32.1 MPH (51 KMH)
Efficiency	80%
Weight that the drone can lift	2 kg or more
Flight Time	Up to 15 minutes

Table 3: Table of specifications

VI. The Flight Dynamics

Before talking about the 6-DoF and start deriving the quadcopter’s dynamics, two frames in which we will operate need to be introduced. The first one is called the inertial frame and is defined by its position that is with respect to the ground along with the gravity pointing in the negative z-direction. The latter is called the body frame which is defined by the quadcopter’s different orientation. The figure below illustrates my explanation [21].

Figure 7: The Relative Orientation Between Inertial-frame and Body-frame of a Quadcopter in 3D Space

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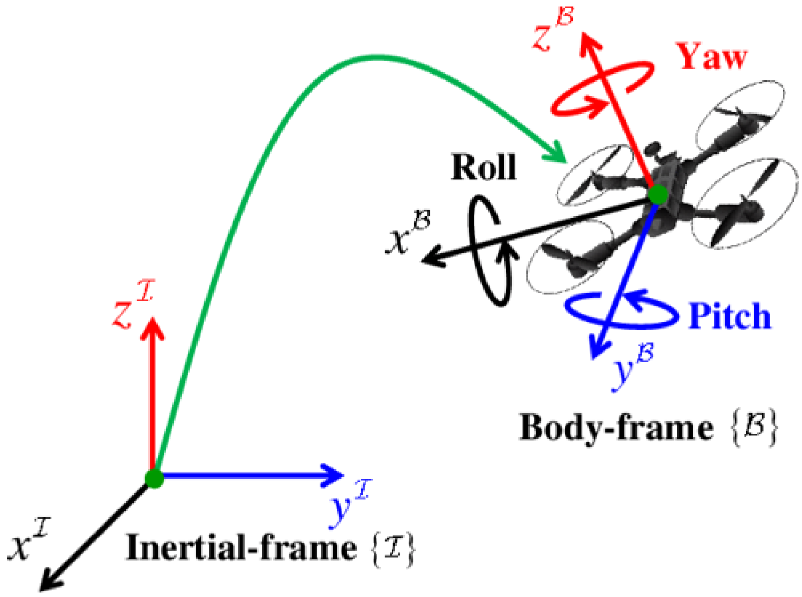

The quadrotor's position and attitude can be controlled by changing the speed of each motor to a desired value. Some moments and forces are performed on the drone such as: the thrust produced by the rotation of the motors, the rolling and pitching moments produced by the thrust of the difference of the four rotors, the gyroscopic effect which only appears in the drone construction lightweight, the gravity, and the yawing moment which may be cancelled out when 2 rotors rotate in the opposite direction.

Hence, the propellers and motors are split into two parts, which in each group have two diametrically opposite motors. Thanks to their rotation's direction, we can distinguish as shown in figure 8 that left and right propellers (number 1 and 3) are rotating clockwise while rear and front ones (number 2 and 4) are rotating counter clockwise [22].

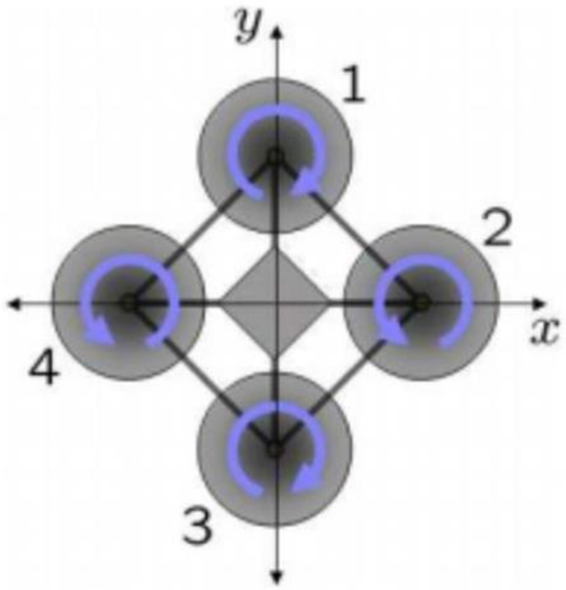

Figure 8: Direction of Propeller's Rotation

1.Six degrees of freedom (6-DOF)

Six degrees of freedom are required to describe any time space motion of a rigid body and can be divided into two groups, which are the barycentre and the movement around it. There are three barycentre movements named as three translation motions that make the quadcopter move longitudinally (forward and backward), vertically (upward and downward), and laterally (right and

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left). In addition, there are three rotation motions along three axes which make the drone move rotationally among each axis to produce roll, pitch, and yaw movements.
These motions, when combined, generate what we call six degrees of freedom. The quadrotor's yaw motion is realized by the rotor that produces a reactive torque. The reactive torque's size is relative to the speed of the rotor. When the speed of the four rotors is the same, the reactive torques will balance with each other and hence the quadrotor will not rotate. However, when the speed of the four rotors is not absolutely the same, there will not be a balance in the reactive torque; thus, the quadrotors will start to rotate.
To control the quadrotors, its modelling process assumptions were made such as: its symmetric structure, its rigid body, and its ground effect is ignored. The quadrotor's four basic movements which allow it to reach a certain altitude and height depending on each propeller's speed of rotation are shown below along with their descriptions [22].
•**The Throttle Movements:** This movement is provided by decreasing or increasing the speed of all the propellers with the same amount, which leads to a vertical force with respect to the body frame that lowers or raises the quadrotor. The vertical direction of the body frame coincides with the one of the inertial frames when the quadcopter is in a horizontal position. Otherwise, the inertial frame's both the horizontal and vertical accelerations are generated by the thrust provided. The throttle movement in the quadcopter sketch is shown in figure 9. The propellers speed Ωi, $i = 1, \dots, 4$ is equal in this case to $\Omega H + \Delta A$. For each. The ΔA (rad/s) is a variable (positive one) that represents with respect to the constant value an increment. The ΔA should not be too big because the quadrotor would ultimately be affected by saturations or non-linearities.

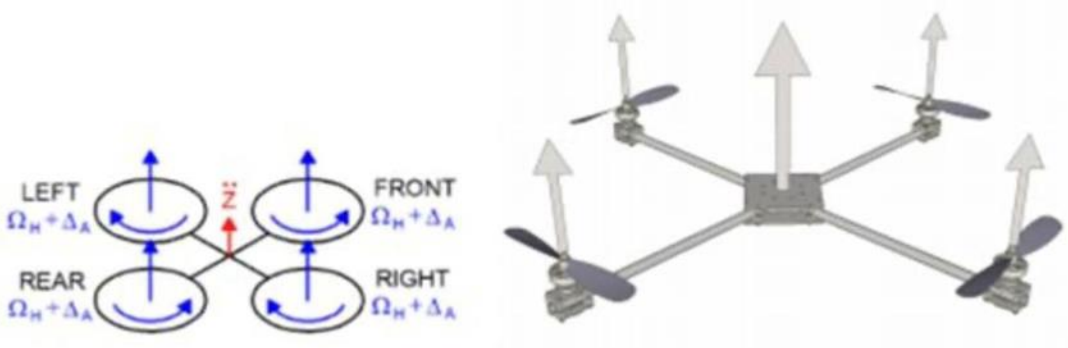

Figure 9: Throttle Movement
•**Roll Movements:** This movement is provided by decreasing or increasing the left and right of the propellers' speed. With respect to the x- axis, this leads to a torque (figure 10), which makes the quadcopter tilt side to side (left or right). In hovering is the same as the overall vertical thrust; thus, this movement yields only to a roll angle acceleration. Figure 10 shows the roll movement on a quadrotor sketch. The ΔB positive variable is chosen so that the vertical thrust is remained unchanged. Like the previous case, it should not be too big because the quadrotor would ultimately be affected by saturations or non-linearities.

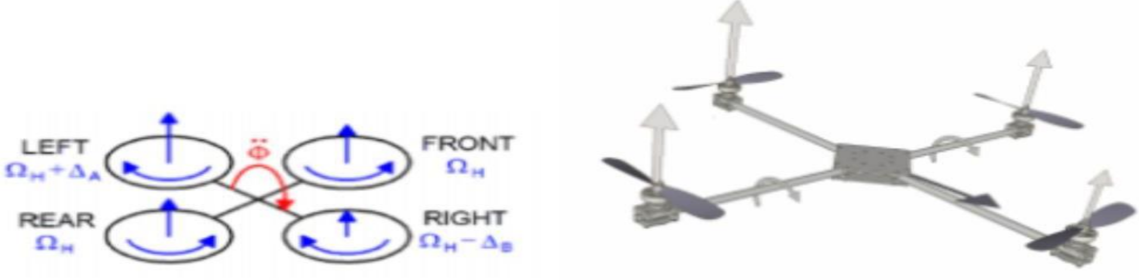

Figure 10: Roll Movement

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•**The Pitch Movements:** This movement is very similar to the roll one and is provided by decreasing or increasing the rear and front of the propellers' speed. With respect to the y- axis, this leads to a torque (figure 11), which would make the quadcopter tilt up and down from front to back. In hovering is the same as the overall vertical thrust; thus, this movement yields only to a pitch angle acceleration. Figure 11 shows the pitch movement on a quadrotor sketch. Like the previous case, the ΔC positive variable is chosen so that the vertical thrust is remained unchanged and cannot be too big.

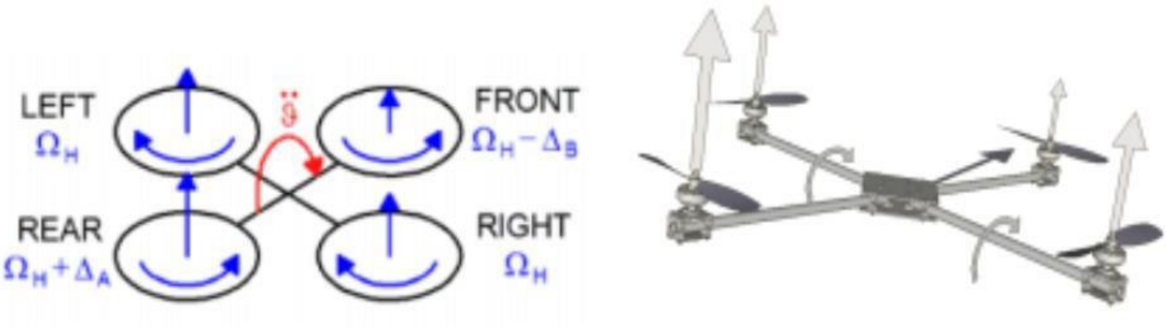

Figure 11: Pitch Movement

•**The Yaw Movements:** This movement is provided by decreasing or increasing the rear and front of the propellers' speed and by increasing and decreasing that of the right-left couple. With respect to the z- axis, this leads to torque, which makes the quadcopter move around in a counter-clockwise/clockwise rotation as it remains level to the ground. The fact that the rear- front propellers rotate counter-clockwise while the right-left ones rotate clockwise, generates yaw movement (figure 12). Therefore, has said previously, the quadcopter turns on itself when the overall torque is unbalanced. In hovering is the same as the overall vertical thrust; thus, this movement yields only to a yaw angle acceleration. Figure 12 above shows the yaw movement on a quadrotor sketch.

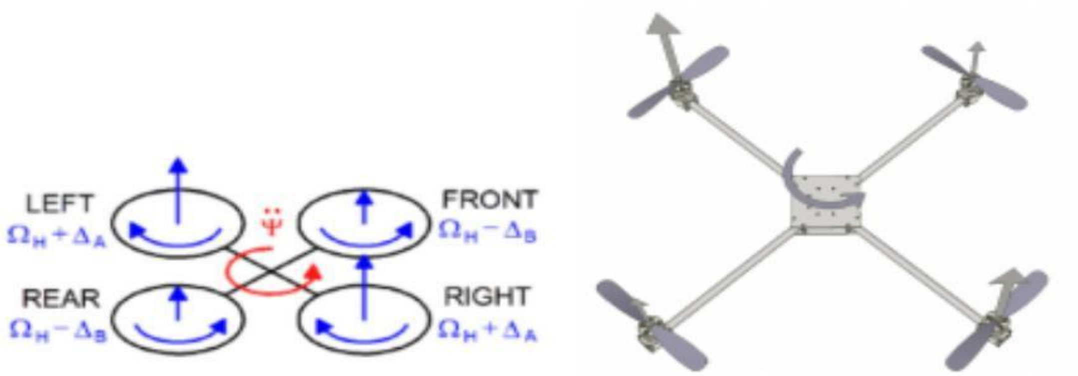

Figure 12: Yaw Movement

VII. Conclusion

This capstone project was one of the golden opportunities that prompted me not only to gain knowledge on different topics and learn a fair number of new technologies but also put them into practice. It was a great way for me to apply all the skills and knowledge I have acquired throughout my undergraduate degree in general engineering. I was able to apply the engineering development process on a real-life project. I managed to conduct a feasibility study, gathering requirements by prioritizing them, designing and implementing the project, and eventually testing it.

During this capstone project, I became much more familiar with the quadcopter flight dynamics and many software, such as SolidWorks, MATLAB, Gazebo, Proteus, and Multiweek. I used SolidWorks to work on the mechanical part of my project to determine the best available material to use and to see the air's velocity and pressure impact on the propeller. These were done by making different simulations and analyses, such as the linear static analysis (to generate the Von Mises stress,

displacement, strain and factor of safety), the drop test analysis (to see which material would withstand falling from a height of 100 meters), fatigue analysis (to determine the damage percentage and life cycles), and the flow simulation (to simulate the air flows through and around the propeller to calculate its capabilities and performance).
MATLAB was used to generate quadcopter thrust while flying along with its angular velocity and displacement. In addition, I made a sketch connecting the electrical components using Proteus so that I can upload the code from Multiweek to the software and simulate it. Finally, Gazebo was used to simulate virtually how my system would react in any environment. Not to mention that a quadcopter prototype has been successfully achieved.
I can never say I have learnt much or enough as I will always strive to learn more. Learning never ends and I do not see this project as complete. I aim to develop it further and once fully completed; a final version will be published online for free.
The principal work to be done next is to ensure the drone's smoothness and stability. Besides, the feasibility of using the image processing has been investigated. The idea is to enable the drone to avoid obstacles and recognize people's faces to identify missing people, civilians, and criminals. Thus, working on this will enable me to eliminate criminal activities; especially, that there is a massive increase in crime rate in Morocco and other countries.
In addition, this can be used in favor of many institutes to record attendance by detecting faces without wasting time or effort. This is only one of many other applications that this general- purpose drone could be used to accomplish, which could have a huge impact on societies.

VIII. Acknowledgement.

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