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GROUND TARGET TRACKING UNMANNED AERIAL VEHİCLE (UAV)

FOTO DOMINIQUE PARFAIT KOFFI

MASTER'S THESIS

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Special thanks to my advisor Prof. Bogrekci, who has been a tremendous mentor and a great help to me since the day I arrived at this university. Once again, I would like to thank him for encouraging me in this particular research.

Thanks to Associate Dr. Erdem for allowing me to use his materials while building the UAV. Last but not least, thanks to my dear friends Neslihan and Hilan for their assistance provided while I needed a safe place to keep all the electronics.

Foto Dominique Parfait KOFFI

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LIST OF ICONS AND ABBREVIATIONS

A : Ampere

BDC : Brushed Direct Current Motor

BLDC : Brushless Direct Current Motor

C : Celsius

CCW : Counter Clockwise

CFD : Computational Fluid Dynamics.

CW : Clockwise

DC : Direct Current

FoV : Field of View

FWD : Fixed Wing Drone

g : Grams

GPS : Global Positioning System

LiPO : Lithium-Ion Polymer

m : Mass

MRD : Multi Rotor Drone

RPM : Revolution Per Minutes

RPV : Remotely Piloted Vehicle

SRD : Single Rotor Drone

UAV : Unmanned Aerial Vehicle

V : Volt

VTOL : Vertical Take Off and Landing

W : Watt

ν : Poison’s Ration

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YER HEDEF TAKİP İHA'LARI

Koffı F.D.P. Aydın Adnan Menderes Üniversitesi, Fen Bilimleri Enstitüsü, Makine Mühendisliği Bölümü, Yüksek Lisans Tezi, Aydın, 2022.

İnsan toplumunun gelişmesi ve yeni teknolojilerin tanıtılmasıyla birlikte yeni ihtiyaç türleri, isyankar tehditler veya kontrol dışı durumlar ortaya çıkıyor. Yeni neslin bu sorunlarını ele almak için kolluk kuvvetlerinin, film endüstrisinin veya ordunun ihtiyaçlarına hizmet etmek için birçok seçenek değerlendirildi ve hala değerlendiriliyor.

Orta Afrika'nın bazı ülkelerindeki kırsal hastanelere erişmek ve tedarik etmek çok zordur. Yol altyapısı sorunları, çok tehlikeli yolculuklar veya uygun uçuş seçeneklerinin olmaması. İHA'ların, bu bölgelerdeki muhtaç nüfusa yardım etmeye devam etmenin en hızlı, en kolay, en uygun fiyatlı ve en etkili yolu olduğu gösterilmiştir. Amerikan ordusunun Viet Nam ile olan çatışması sırasında, düşman pususunda öldürülen Amerikan askerlerinin büyük kayıpları, düşürülen helikopterler ve kara antipersonel mayınları, bilim adamlarını dünya çapındaki düşmanları az kayıpla yenmek için yeni bir strateji araştırmaya ve oluşturmaya sevk etti.

Bu nedenle, son birkaç on yılda insansız hava araçlarına (İHA'lar) çok fazla ilgi var, bunun nedeni muhtemelen İHA'ların uçabilmeleri nedeniyle birçok avantajı olmasıdır. GPS ve kameralar gibi gerekli yerleşik elektroniklerin dahil edilmesi, amaçlanan hedeflerin gerçekleştirilmesini kolaylaştırır.

Geleneksel yöntemler kullanmak yerine, atanan gözetim görevleri sırasında seçilen bir yer hedefini izlemek için bir VTOL (Dikey Kalkış ve İniş) RPV (Uzaktan Pilotlu Araç) oluşturulur.

Anahtar Kelimeler: Asi, Gözetleme, İHA, Uzaktan Kumandalı Araç, VTOL.

ABSTRACT

GROUND TARGET TRACKING UAV

Koffi F.D.P. Aydın Adnan Menderes University, Graduate School of Natural Sciences, Mechanical Engineering Department, Master's Degree Thesis, Aydın, 2022.

New types of needs, rebellious threats, or out-of-control situations emerge along with the development of human society and the introduction of new technologies. Many options—whether to serve the needs of law enforcement, the film industry, or the military—have been and are still being considered in order to address these issues of the new generation.

Rural hospitals in some nations of central Africa are tough to access and supply. Road infrastructure issues, too dangerous commutes, or a lack of convenient flight options. UAVs have been shown to be the quickest, easiest, most affordable, and most effective way to keep helping the needy population in those areas. During the American military's conflict with Viet Nam, the enormous losses of American soldiers killed in enemy ambushes, helicopters shot down, and ground antipersonnel mines prompted scientists to look into and create a new strategy for defeating foes worldwide with few casualties.

Thus, there has been a lot of interest in unmanned aerial vehicles (UAVs) over the past few decades, which is probably because UAVs have a lot of advantages because they can fly. Including necessary onboard electronics like GPS and cameras make it easier to realize the intended objectives.

Instead of using conventional methods, a VTOL (Vertical Take Off and Landing) RPV (Remotely Piloted Vehicle) is created to track a chosen ground target during assigned surveillance missions.

Keywords: Piloted Vehicle, Rebellious, Remotely Surveillance, UAV, VTOL.

1. INTRODUCTION

Unmanned aerial vehicles (UAVs) as shown in Figure 1.1. can make movements that are impractical for humans to carry out in inhabited vessels. With such amazing capabilities, it only seems sense to create a UAV that can monitor ground targets. In this study, we investigate the design of an autonomous quadrotor that can carry out the assigned task and provide surveillance intelligence.

Figure 1.1. Unmanned Aerial Vehicle (UAV).

1.1. Background

1.1.1. Use of UAVs for Surveillance

Prior to the development of UAV technology, surveillance was typically conducted with a single manned aircraft or spacecraft. Large, expensive manned aircraft are frequently risky in hostile circumstances, and operator weariness from time-consuming operations may endanger a pilot’s life. Satellites and other space assets are likewise exceedingly expensive and have limited uses. While this is going on, the advantages of UAVs, such as their flexibility to operate in a variety of time and space configurations and the lack of a human on board, offer major chances to develop an unwarned gathering capability and concentrate resources on the immediate issue.

UAV aerial sensing can offer superior coverage to survey vast regions at a rapid speed without being constrained to a specific ground navigation route than ground surveillance sensors like video cameras positioned at fixed sites. Additionally, they have the ability to immediately respond from the air to the specified situation and target while also obtaining fast information, which is a necessity in cases of emergencies like oil leaks in gas pipelines, natural disasters and accidents. Thus, the usage of UAVs for surveillance and tracking missions is highly necessary.

Target detection methods through air patrol and behavior analysis of obtained live or recorded surveillance data are naturally necessary for the UAV surveillance system. For example, UAVs having an onboard visual moving target indicator radar enable quicker and reliable identification of potential threats by accurately estimating a huge number of moving targets. When surveillance data is combined with visual mosaic techniques, target trajectories and movements can be shown on a map. This greatly improves the operator's situational awareness. However, in order to identify suspicious activities, the operator must still understand and analyze the surveillance data that is produced.

The most difficult challenge in ground traffic is identifying potentially dangerous vehicles disguised as legitimate traffic, such as those used for weapons and personnel smuggling, terrorist target reconnaissance, roadside bomb planting, and suicide bombers, among others. The majority of these risky driving behaviors involve occasional deviations from the motion characteristics of legal traffic.

In the face of a flood of data and information, this behavior analysis necessitates the use of multiple adequate human operators, too costly and unsustainable. In addition, current UAV research has focused on the development of specific algorithms, such as sensing and modeling, multi-sensor management and information fusion, or the guidance and control required for ground traffic surveillance.

However, these research findings are rarely incorporated into a system to aid in situation assessment. As a result, there is a strong need to develop an integrated high-level analysis algorithm to process target information and detect anomalous behaviors in order to reduce the workload of the human operator.

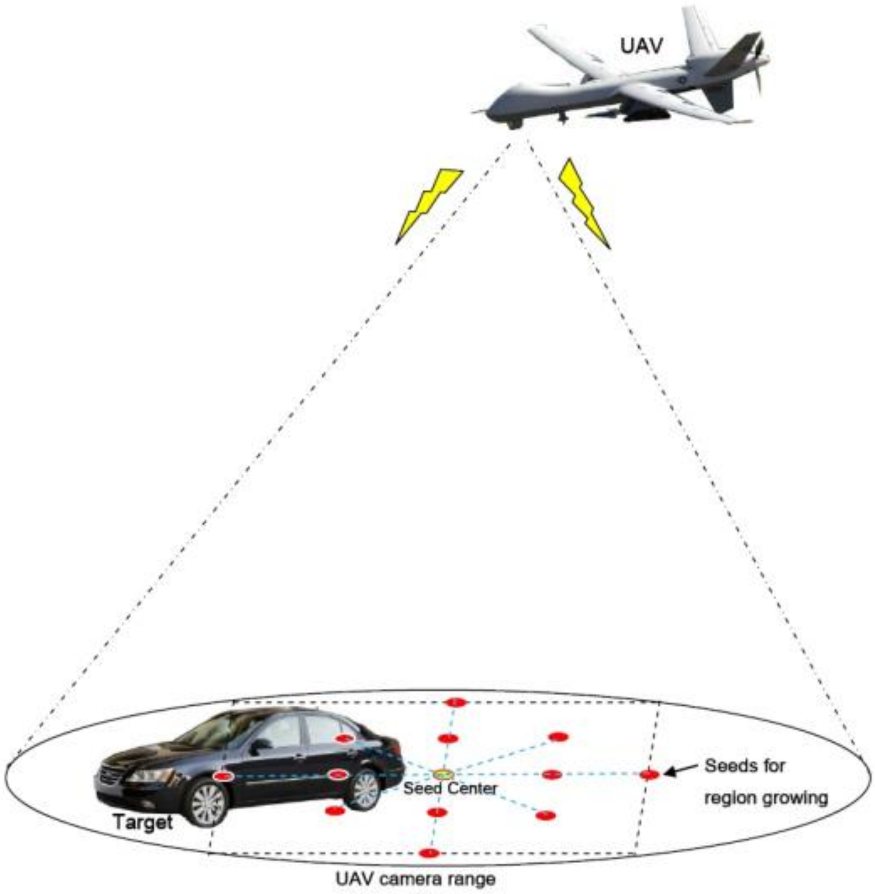


Figure 1.2. Field of View.

1.1.2. Monitoring Multiple Targets Using Several UAVs

If multiple moving ground vehicles are identified as targets of interest by surveillance systems, schemes for deploying multiple UAVs to consistently follow them must be developed. Keeping all targets in the sensor's field of view (FOV), as shown in Figure 1.2, becomes more difficult as a result of acceleration, deceleration, and possibly deliberate evasive maneuvers. To ensure reliable tracking, multiple platforms could be used, anticipating different turns at intersections and affecting the hand-off of a target from one UAV to another as needed. Several methodologies for multi-target tracking with multiple UAVs have been investigated. However, in light of the recent inflation, this thesis concentrated on developing a single UAV.

1.2. Purpose

This study, which aims to investigate the use of small and low-cost drones for autonomous target tracking/aerial surveillance, is the first in a series of studies that will eventually allow the development of a fully automatic surveillance drone.

1.3. Thesis Layout

We now have a clear view of our goal and the different applications associated. What is a UAV and how does it work? How is it made? What is the Surveillance Algorithm to achieve our goal?

This thesis is organized to answer these questions:

Chapter II describes the general information about UAVs, giving a basic overview of their working principles. Chapter III describes in detail our UAV/drone. Chapter IV describes the control technique. Chapter V discusses the problems encountered. In Chapter VI, we test and comment the results obtained and finally, Chapter VII concludes the challenges encountered while carrying out this research and discusses the potential for future improvements.

2. LITERATURE REVIEW

There has been a significant increase in interest in Unmanned Aerial Vehicles (UAVs) over the last ten years, which is likely due to the fact that UAVs have come a long way since their early remote-controlled days. UAVs can now take off, fly, and land almost completely autonomously. Following this trend, global production of unmanned aerial vehicles (UAVs) has increased as well: in 2004, global production of unmanned aircraft systems (UAS) produced 477 different types of UAVs, some civilian but mostly military, and by 2007, that figure had increased nearly by 65 percent to 789 [International, 2007].

Some of these platforms are quite impressive: they address a wide range of issues, including flying capabilities, airspace integration, airworthiness, and operational capabilities.

However, they appear to be missing something crucial: autonomy. There is a common misconception that a UAV is autonomous because it can fly by itself during some parts of its mission. The distinction should be made right away: on one hand, automatic flight provides a system with the ability to perform actions according to a set of predefined rules in a highly predictable environment, with the automatic pilot being a classic example. True autonomy, on the other hand, requires a drone to be able to act without supervision in a changing environment with a wide range of conditions.

An autonomous system should provide a high-abstraction-level interface through which the user can command the aircraft to "Explore (Area)" or "GoTo (City)," and the system can be left to perform these tasks completely unsupervised. To get an idea of the level of autonomy that modern UAVs provide, consider that the plan for most aerial platforms produced today is to command the aircraft to go to some deserted area and perform circles until communication is reestablished or until all fuel is consumed and the aircraft hard lands. (Panagiotis Theodorakopoulos 2019)

2.1. Unmanned Aerial Vehicle (UAV)

An **Unmanned aerial vehicle (UAV)**, a military aircraft that is guided autonomously, by remote control, or both and that carries sensors, target designators, offensive ordnance, or electronic transmitters designed to interfere with or destroy enemy targets. Unencumbered by crew, life-support systems, and the design-safety requirements of manned aircraft, UAVs can be remarkably efficient, offering substantially greater range and endurance than equivalent manned systems.

It can fly using inertial sensor and navigation technologies, either remotely or autonomously, with pre-determined flight destinations (Limnaios et al., 2012). A ground control system (GCS) as illustrated in Figure 2.1 usually remotely monitors the line of flight in order to intervene if an emergency situation occurs. Fixed and rotary wing UAVs, lighter-than-air UAVs, lethal aerial vehicles, decoys and targets, alternatively piloted aircrafts, and uninhabited combat aerial vehicles are all classified as "UAVs" (Ma et al. 2013). See Figure 2.2.

Figure 2.1. MQ-1 Predator unmanned aerial vehicle (Master Sgt. Steve Horton/U.S. Air Force).

Figure 2.2. Unmanned aerial vehicle (Dave Cbley 214th Reconnaissance Group/U.S. Air Force).

UAVs are descended from target drones and remotely piloted vehicles (RPVs) employed by the military forces of many countries in the decades immediately after World War II. Modern UAVs debuted as an important weapons system in the early 1980s, when the Israeli Defense Forces fitted small drones resembling large model airplanes with trainable television and infrared cameras and with target designators for laser-guided munitions, all downlinked to a control station. Rendered undetectable by their small size and quiet engines, these vehicles proved effective in battlefield surveillance and target designation. Other armed forces learned from the Israeli success, notably the United States, which purchased some of the early Israeli models or produced them under license. The most important American tactical UAV—and one that is representative of trends in the development of these aircraft—is the MQ-1 Predator, which first flew in 1994 and entered service the following year. The Predator, with a length of 26 feet 8 inches (8 meters) and a wingspan of 41 feet 8 inches (12.5 meters), is powered by a piston engine driving a pusher propeller. It flies at 80 miles (130 km) per hour and has an endurance of 24 hours. In addition to visible and infrared television, it carries synthetic aperture radar and passive electronic sensors, and it can also carry antitank missiles. Control inputs and sensor outputs are transmitted via communications satellite. A larger, turboprop-powered derivative of the Predator, the MQ-9 Reaper, has improved performance and carries a larger ordnance load.

Both the Predator and the Reaper have been used in the conflicts in Iraq and Afghanistan and have been purchased by allies of the United States. (John F. Guilmartin 2017)

Figure 2.3. Winston Churchill, David Margesson and others wait to watch the launch of a de Havilland Queen Bee target drone, 6 June 1941 (Imperial War Museums 1990).

2.1.1. Target Tracking

Target tracking assesses the current state of a target and predicts its future state based on measurements from sensors that detect the target. (Bar-Shalom and Li, 1993; Blackman and Popoli, 1999).

Filtering, dynamic target modeling, fusion, and data fusion are all topics in target tracking. The target in this task is a stationary or moving ground vehicle, especially if the vehicle is assumed to be on a known road network. Because the sensor in this study is a vision sensor, the tracking model is only a reference model consisting of two angles that describe the direction to the target based on a tracking sensor platform. When monitoring multiple targets, pairing issues become a problem. However, because the scheduling problem is the main focus of this paper, the related problem is ignored despite its many purposes. Instead, several attempts have been made to model the performance of road vehicles and sensors.

2.1.2. Classification of Drones

Based on the different aerial platform, as shown in Figure 2.4., there are four major types of UAV (drone)

- Single Rotor Drone (SRD)
- Multi Rotor Drone (MRD)
- Fixed Wing Drone (FWD)
- Fixed Wing Hybrid Vertical Take-off Landing (VTOL)

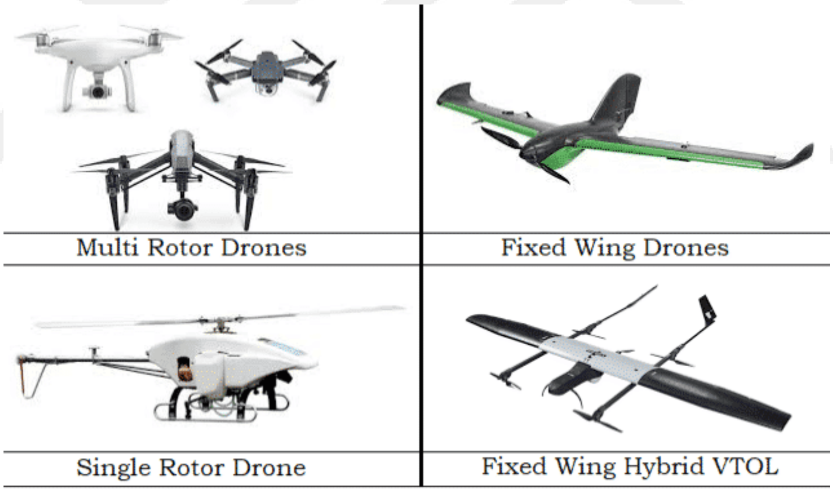


Figure 2.4. Drone classifications (Anonymous, 2022a).

2.1.3. Types of Rotary Wings Multi Rotors UAVs

Their number of Propellors determines their kind. More propellers improve drone stability and load capacity, but they require more battery power to operate more motors. The common are the quadcopters.

➢ Two-propeller bicopter

- Three-propeller triplecopter
- Four-propeller quadcopter
- Six-propeller hexacopter
- Eight-propeller octacopter

UAVs with four motors are called quadcopters, they are very adequate for surveillance mission both in terms of maneuverability and energy consumption.

The four propeller motors are mounted to the frame's cross-shaped end beam. To rise off the ground, two motors rotate clockwise and two revolve counterclockwise. (Figure. 2.5)

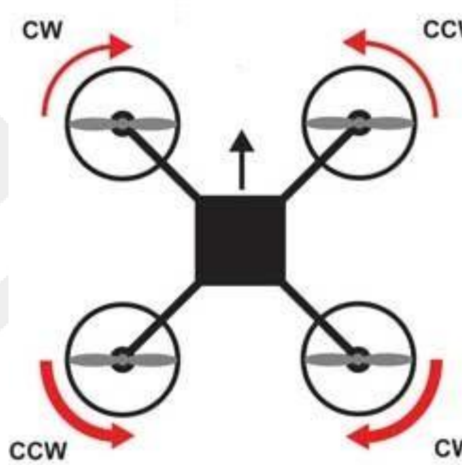


Figure 2.5. Motors configuration (Anonymous 2022b).

Every fixed motor generates the necessary amount of thrust and torque in rotational motion, and these forces are used to properly move and hover the quadcopter. Coordination of these motors in terms of revolving direction cancels all forces and keeps the speed constant.

To fly a quadcopter in the desired direction, specific points must be recalled when hovering (lifting up).

If the speed of motors 1 and 3, as shown in Figure 2.6, is held constant but motors 2 and 4 rotate at a faster speed, a 'Yaw' in direction is created. As a result, the other two movements, 'Roll' and 'Pitch,' are produced by altering the speed of the motors. These terminologies are clearly covered in Section 3.

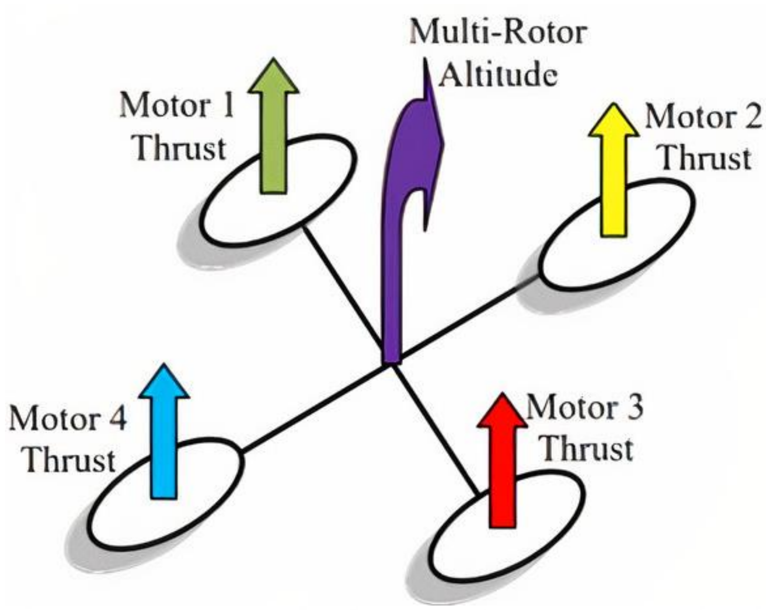


Figure 2.6. Motor arrangement in quadcopters.

Reconnaissance and tactical planning are two common uses for unmanned aerial vehicles (UAVs). This technology can now be used to assist crew members in emergency situations. UAVs can be employed for a variety of reasons, including military and commercial ones, depending on their altitude range, endurance, and weight. Laptop computers and other components small enough to be taken along with the aircraft in tiny vehicles, boats, or backpacks are commonly used for ground control stations for smaller unmanned aerial vehicles (UAV).

2.2. Subjects for Quadcopter

A UAV's knowledge and development can be affected by a wide range of factors. An application's design is influenced by a number of different variables, including as the propeller's aerodynamic shape, weight, and strength, as well as telemetry, radio transmitters, and software interfaces on mobile devices and computers for data monitoring and analysis.

Aerodynamics:

The forces operating on a quadcopter's body can be determined using fluid dynamics.

The propeller's design, size, and speed are all determined by aerodynamics.

The airflow dynamics over drones are helped by CFD modeling.

The amount of thrust generated by propellers must be calculated using CFD modeling of turbomachinery.

Validation of CFD data still requires wind tunnel testing of airfoil blades.

Mechanical Design

Drone motion and forces analyzed using rigid-body dynamics.

Durability (the strength of the material used).

Drone materials are lightweight and appropriate.

Electronics and Electrical Components:

Electronic Speed Controller, Flight Controller Unit and computer processors require a brushless electric motor to operate propellers.

Radio transmission and reception

Low-weight, high-wattage batteries are essential.

Software-based mobile or computer data collecting and analysis. (Cfdflow Engineering 2015)

2.3. Working Principle

Quadcopters have four propellers.

For balance and mobility, each propeller’s speed and direction are individually controlled.

Traditional quadrotors have evenly spaced rotors. One pair of rotors rotates clockwise and the other anti-clockwise to maintain balance. All rotors must spin fast to hover. Varying rotor speed moves the drone forward, backward, and side-to-side.

2.4. Forces in Acting on a UAV

The thrust $(\boldsymbol{F_T})$**,** which defies gravity and enables hovering, is one of the main forces operating on an unmanned aerial vehicle (UAV). Everything on earth is subject to the gravitational acceleration known as the Weight $(\boldsymbol{F_W})$. The drag force $(\boldsymbol{F_{DV}})$ that the air around you, applies to everything moving through it is the last but not the least. Figure 2.7.

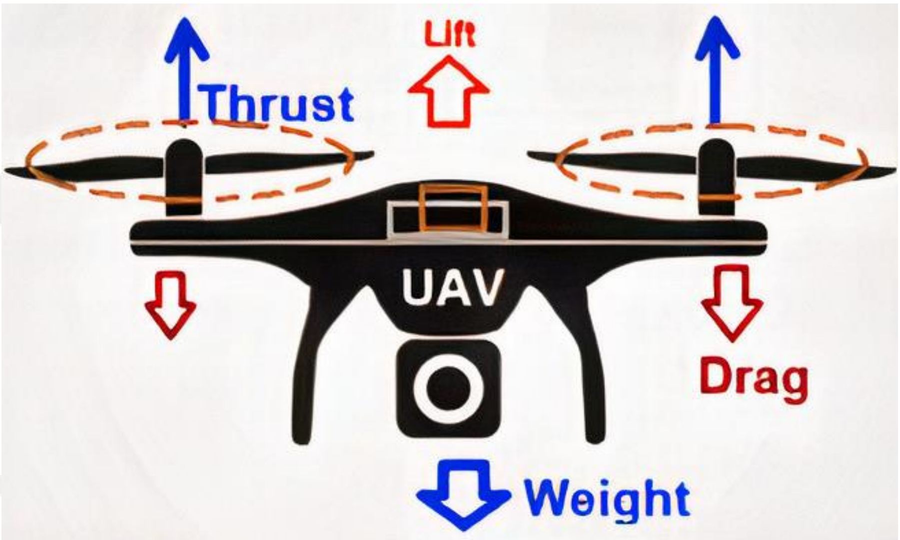


Figure 2.7. Forces applied cfdflow engineering 2015.

As shown in Figure 2.7, various forces act on a moving vehicle in the air. The forces that result will determine its movement.

To become airborne, a drone must overcome its weight $\boldsymbol{W}$ *or* $\boldsymbol{F_W}$ and drag $\boldsymbol{F_{DV}}$. The weight of a drone is the product of its mass times gravity, and drag is the force that resists the drone's motion through the air and is affected by reference area, air density, and flow velocity.

The propellers provide thrust $\boldsymbol{T}$ or $\boldsymbol{F_T}$ to lift and fly the drone. At hover, the propellers' combined thrust equals the drone's weight.

Maximum propeller thrust should be twice the hovering thrust for excellent control authority. Racing quads feature a higher thrust-to-weight ratio.

3. MATERIALS AND METHODS

This chapter describes in detail the parts needed in the construction of the UAV and their costs.

3.1. Material Selection

Aluminum alloys, titanium alloys, high-strength steels, and composites make up over 90% of airframe weight.

The UAV's frame is comprised of glass fiber and polyamide nylon as shown in Table 3.1.

Table 3.1. Material properties.

Material	Density (g/cm^3)	Young's Modulus (Mpa)	Tensile strength (Mpa)	Poisson's ratio ν	Melting temperature (˚C)
PA66GF30	1.370	15000	160	0.36	263
Glass Fiber	2.56	4000	3,445	0.25	$\cong 1200$

3.1.1. Polyamide Nylon (PA)

Nylon is a thermoplastic polyamide. Its characteristics make it a good choice for many applications. Below are the material's pros and downsides.

Advantages

- High abrasion resistance (resistance to mechanical wear) Good thermal resistance (nylon can melt at 300°C)
- Good fatigue resistance makes it perfect for gears.
- High machinability.
- Nylon effectively dampens sounds.

Disadvantages

- Water absorption lowers mechanical characteristics. Nylon 6/12 is moisture-resistant.
- Nylon is weak against acids and bases.

3.2. Choose The Right Components

3.2.1. The Motors

The specified S500 frame can only support three brushless motors based on its configuration among which: 2212 KV1400, 2216 KV880 KV900. Quadcopters frequently use brushless direct current (BLDC) motors. These motors are composed of a permanent magnet that rotates around a fixed armature and have numerous advantages over brushed DC motors, including improved torque, less noise, high dependability, longer battery life, and increased efficiency for less power and weight. A motor with a rating of 1 kV will rotate at 1000 RPM for every 1V applied to it. Each BLDC motor may provide up to 1200 g of thrust force depending on the kV rating (Table 3.2). The motor’s kV rating is utilized to select it.

Table 3.2. Theoretical Comparison of suggested motors based of 1045 propellers on 4S 11.1 V LiPo Battery.

Motors	Weigh (g)	Voltage (V)	Current (A)	Thrust (g)	Efficiency (g/W)
2212 KV1400	60	11.1	20	1,200	5.3
2216 KV880 KV900	68	11.1	30	1,400	4.99

This table shows that the 2212 KV1400 is lighter and has a satisfying thrust and good efficiency.

The 2216 KV880 and KV900 motors have also very satisfying weight to thrust ratio. With a relatively low mass, these motors combined could theoretically produce roughly 4,600 g of thrust/lift at the top of their capacity. Enough to hover and fly the UAV with a pre-estimated total mass of 1,800g.

3.2.1.1. Electronic Speed Controllers (ESCs)

The main factor to consider when selecting an ESC is its ability to deliver the motor's peak current. In our case, we do not expect our motor to draw more than 30 A, so our ESC will perform admirably. It can supply a constant current of up to 30 A. This gives us a bit of a safety margin because the motor will not be fully throttled, so this ESC is a good fit for our drone.

The ESC's sole job is to control the motor speed by receiving the flight controller's Pulse Width Modulation (PWM) signal. The input signal is altered when it receives power from the battery. It has a voltage reducer sensor that supplies the required voltage output from the battery to the FS-i6 receiver and flight controller.

The current rating of the motors determines the ESC choices. They are step-down devices that reduce the voltage from the battery to the receivers. The ESCs use PWM signals from the flight controller to control the motor speed. The ESC is attached to the motor's signal and power wires, and the remaining two wires from the ESC's other end are soldered to the PCB boards for powering up. Four 30A speed controllers are used in the proposed quadcopter prototype.

3.2.1.2. Battery Made of Lithium-Ion Polymer (LiPo).

Lithium-Ion Polymer (LiPO) batteries are used in quadcopters. For the BLDC motors, the batteries have 3.7V cells in each cell and can deliver tremendous current. These batteries are rated using C-ratings. For a full charge, it takes about two hours. A completely charged battery can run a quadcopter for up to 20 minutes, depending on the weight. As a result, it can deliver 75A of source power. It is impossible to use LIPO batteries at less than 80% of their rated capacity.

3.2.1.3. Radio Transmitter and Receiver

The Fly Sky FS-i6 is a 2.4 GHz receiver with 10 channels. It is coupled to the control board of the quadcopter. This receiver's job is to deliver a signal to the controller depending on the radio control transmitter's stick movements, enabling the quadcopter's motion to be controlled as required. Depending on the application, the radio transmitter's range may extend to several kilometers.

3.2.1.4. Flight Controller

We analyzed one of the top drone controllers on the market by gathering information for factors such as:

1. Affordability
2. Source-Based Firmware
3. Autonomous performance
4. Linux-based or microcontroller-based setting
5. Common frame size
6. Popularity (Higher popularity means more online resources and help)
7. Processor

The PIXHAWK

Pixhawk PX 2.4.8 hardware is entirely open-source and may be utilized for drone applications.

Many manufacturers can produce and sell the boards, but the architecture is constant.

The PIXHAWK's many IO ports make it easy to interface with a raspberry pi.

It's easy to find and buy. Most PIXHAWK kits contain GPS, magnetometer, buzzer, LiPo power module, etc.

Figure 3.1. Pixhawk PX 2.4.8 flight controller

Advantages:

- Open-source software projects support this popular drone board.
- Interactable with another computer.
- Famous, YouTube has PIXHAWK tutorials.
- It’s cheap for its usefulness.

Disadvantages:

It’s an older flight control board

3.2.2. Materials

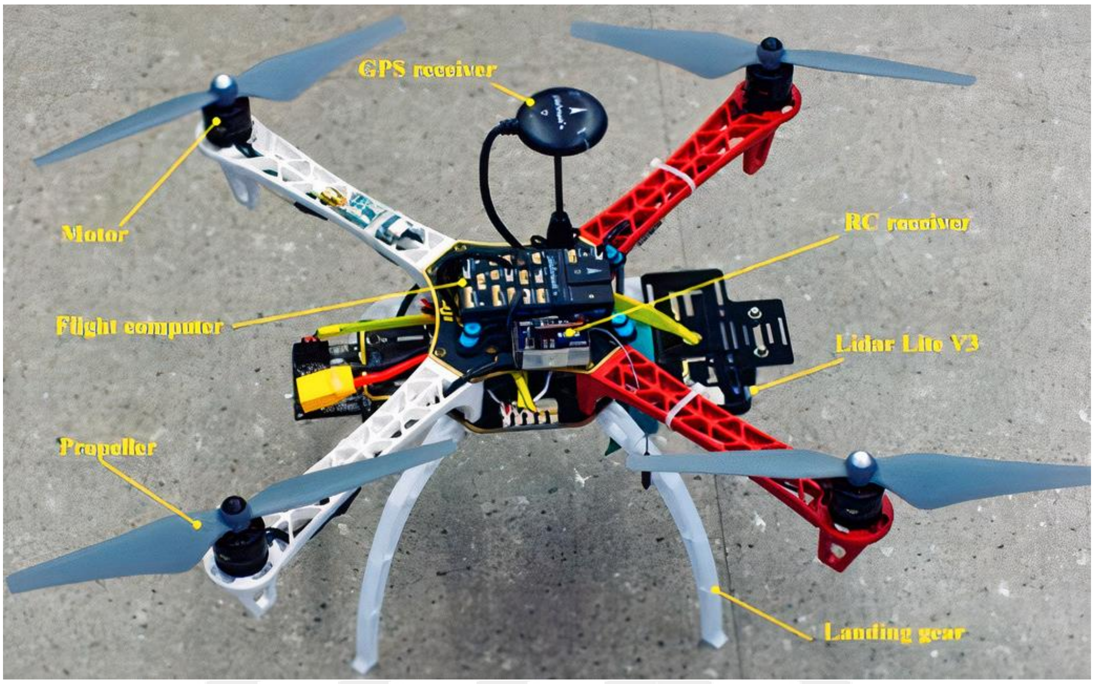


Figure 3.2. Built S500 drone.

Table 3.3. Main components required.

Name	Description	Image
Frame	Max. Takeoff weight (with battery): 2KG Weight: 635g	
ESC	Input voltage: 2-4S Lipo battery BEC (5V regulator output) Can support up to 30A instantaneous (10s)	

Table 3.3. Main components required (continue).

Name	Description	Image
Motors	KV (rpm/V): 1400 Voltage: 7.4-14.8V Load current: 15.6A Pull: 1065g Power: 231W Weight: about 66g	
Propellers	CW and CCW	
Flight Controller	PIXHAWK 168 MHz 256 KB RAM 2 MB Flash 32-bit	
Video & Transceiver	DC12V FPV5-17V Frequency: 5.8Ghz Transmission Distance: 600mW=2km	

Table 3.3. Main components required (continue).

Battery	Voltage: 11.1V Capacity: 6200mAh Discharge Value: 45C Weight: 431 g	
GPS Module	M8N GPS module	
Remote Control	Transceiver RF Range: 2.4055-2.475GHz Range: 500-1500 m	
Telemetry Radio	433MHz Telemetry Radio / 915MHz Telemetry Radio	

Table 3.3. Main components required (continue).

Power module	Input voltage: 6 ~ 30V (2 ~ 8S) Output voltage: 5.3V ± 0.1V Maximum output current: 3A Maximum current: 90A Maximum voltage: 30V	
Connectors	XT60 Connectors (12 couples)	
	Banana Connectors (3.5 mm) (1 couple)	

3.2.3. Cost Evaluation

Table 3.4. Project cost evaluation.

Parts	Quantity	Unit Cost	Cost
Frame	1	78.99	78.99
ESC	4	15.99	95.94
Motors	4	16.99	101.94
Propellers set	2	15.99	31.98
Flight Controller & GPS Module	1	339.25	339.25
Camera System	1	35.99	35.99
Battery	1	108.12	216.24
Video & Image receiver System	1	69.99	69.99
Radio Control	1	144.78	144.78
Power Module	1	20.00	20.00
Connectors	26	0.8	20.8
Total Cost			**1,156.8 $**

3.3. UAV Dynamic Modeling

Modeling is important to create a realistic quadcopter model.

The quadcopter's movement is classified based on the four propellers: Throttle, Pitch, Roll, Yawn

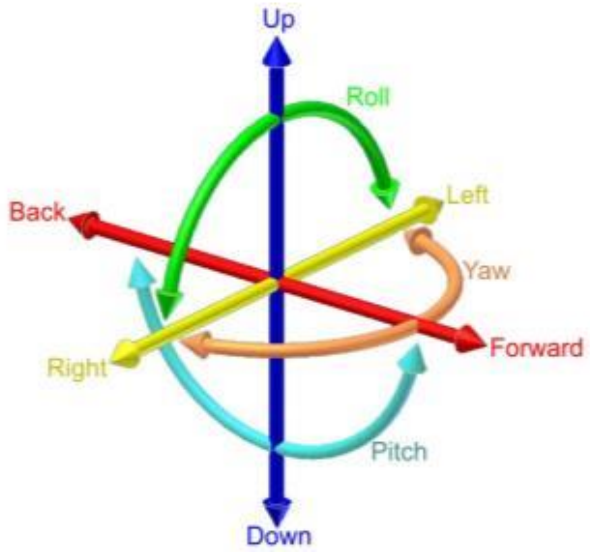


Figure 3.3. Quadcopter dynamics

Hover: quadcopter up-and-down movement.

If all four propellers spin normally, the drone will descend.

When all four propellers spin faster, the drone rises. Quadcopter hovering.

Pitch: forward or backward movement of a quadcopter about a lateral axis.

High-speed rear propellers move the drone forward.

When two front propellers spin fast, the drone moves backward.

Rolling motion involves a drone's longitudinal axis.

When two right propellers spin fast, the drone moves left.

When two left propellers spin fast, the drone moves right.

Yawn: rotating the drone's head about the vertical axis (left or right).

When two right-diagonal propellers spin fast, the drone rotates counterclockwise.

When two diagonal propellers spin fast, the drone rotates clockwise.

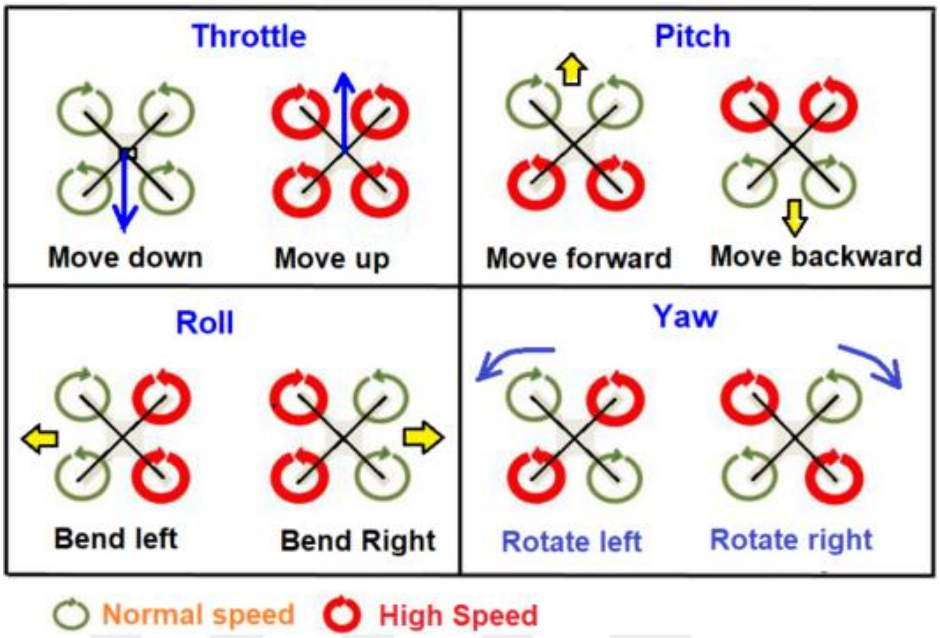


Figure 3.4. Quadcopter motion.

3.3.1. Drone Design loop

The circular nature of the drone engineering process is called a 'design loop.' Our first surveillance drone is based on assumptions that will change as components are chosen and the design is finalized.

The designer examines how the first version of the design differs from the assumptions, then returns to the start (figure 3.5).

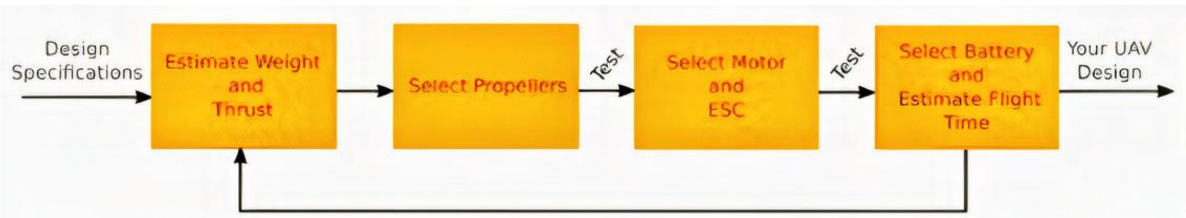


Figure 3.5. Design loop for drones.

3.3.2. Flight Time Calculation

Battery capacity and propulsion power determine flight time. Many factors are involved.

$$\text{Flight time (min)} = \left(\frac{E_{Battery} \times Discharge\ Rate\ C}{Average\ Amp\ Draw}\right) \times 60s$$

Where E is the capacity of the battery in mAh.

3.3.3. Efficiency

Output/input equals efficiency. The propellers create thrust by converting the mechanical work.

$$\boldsymbol{Efficiency\ (N/W) = \frac{Thrust\ (N)}{Mechanical\ Power\ (W)}}$$

where $Mechanical\ Power\ (W) = Torque\ (N/m) \times Angular\ Velocity\ \omega\ (rad/s)$

Because we’ve chosen the motor and propeller, we can determine the battery’s discharge (C rating) specifications. If our motor draws more current than our battery can supply, it will degrade or overheat.

Battery current draw formula:

$$Current\ (A) = C \times E$$

Where Current (A) = C rating X Capacity (Ah)

3.3.4. Weight Estimation of The UAV

Due to the drone’s mass, body mass force always acts downward.

Increasing the drone’s weight requires more power for it to fly.

$\boldsymbol{F_T}$ is the total weight of the drone with a payload, which pulls it down due to gravity, $\boldsymbol{F_{DH}}$ and, $\boldsymbol{F_{DV}}$ are drag forces caused by horizontal and vertical airflow disruptions.

F_T is the thrust produced by the rotating propellers of the drone; it opposes the weight and drags to maintain the drone's altitude and velocity. Figures 3.6 (a) and (b) depict, respectively, the total forces experienced by a drone flying vertically at constant speed V_v and horizontally at constant speed V_h. In both instances, the thrust equals the sum of the weight and drag.

F_W , F_{DH} and F_{DV} are modeled by the following (1):

$$F_W = (m_d + m_p)g \quad (1)$$

where m_d and m_p are the mass of the drone and payload, respectively, and g is the gravity acceleration.

Each component's mass must be accounted for when calculating the empty weight and total weight.

$$m_d = W_F + W_M + W_{ESC} + W_{Batt}$$

Where, W_F *is the weight of the frame*

W_M *the weight of the motors (4)*

W_{ESC} *the weight of the ESC (4)*

W_{Batt} *the weight of the battery*

m_p *the payload, which consists of the propellers, camera, and receivers.*

Motors: 66 g

Propellers: 17.3 g

Other components (camera, frame, ESC, etc.): 740 g

Battery mass: 793 g

The calculations of weight estimation are shown in the formula below:

Based on these new values, we estimate the total mass $m_T = 1{,}800\ g$ and

$$F_W = 1.8\,kg \times 9.81\,m/s^2.$$

$$F_W = 17.658\,N$$

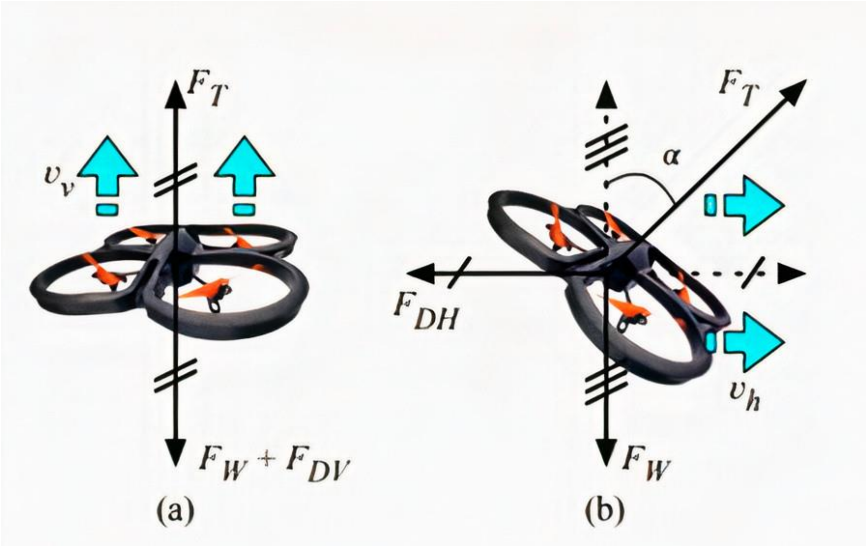


Figure 3.6. Overall forces when a drone moves vertically at a constant speed and flies horizontally at a constant speed.

3.3.5. Drag

Due to air resistance, drag is the force acting on the drone in the opposite direction of motion.

This may be the result of pressure variations and air viscosity.

The definition of drag is as follows:

$$\boldsymbol{F_D = \frac{1}{2}\rho A C_d V^2} \qquad (1)$$

This divides into its vertical component, $\boldsymbol{F_{DV}}$, and horizontal component, $\boldsymbol{F_{DH}}$.

$$\boldsymbol{F_{DV} = \frac{1}{2}\ \rho A_t C_d V_v^2\ ,\ F_{DH} = \frac{1}{2}\ \rho A_f C_d V_h^2} \qquad (2)$$

$\boldsymbol{A_f}$ and $\boldsymbol{A_t}$ are the horizontal and vertical cross-sectional areas, $\boldsymbol{C_d}$ is the drag coefficient, and is the air density.

3.3.6. Thrust

The definition of thrust is the force required to drive or propel a quadcopter through the air. It is generated by a motor with a particular angular velocity. The thrust generated by a rotor is depicted in (3).

While hovering, thrust is entirely vertical. Depending on the thrust angle, the drone will tilt forward or backward.

This force is required to maintain the drone's speed in the desired direction.

As shown in Figure 3.7, the thrust to oppose the weight and drag is obtained by induced air passing through a rotating propeller. The following is a basic thrust formula:

$$\boldsymbol{F_T = \rho A_p V_i^2} \qquad (3)$$

Where ρ is real-time air density (kg/m3),

$\boldsymbol{A_p = \pi (2r)^2 = 4\pi r^2}$ is the disk area of the propellers,

and $\boldsymbol{V_i}$ is the induced airflow velocity.

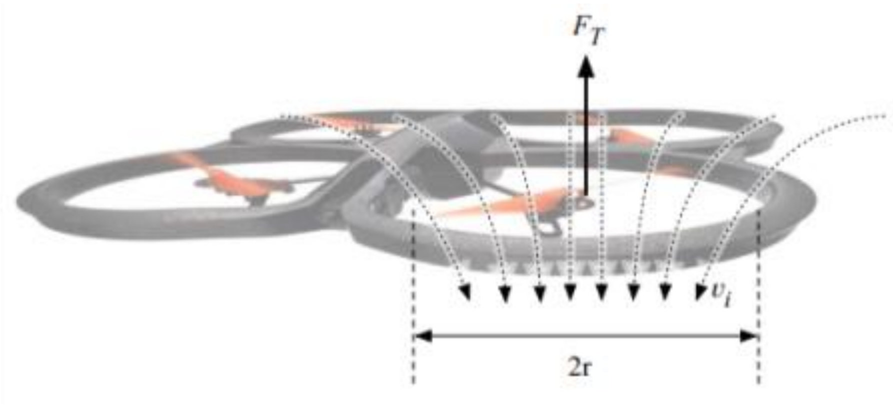


Figure 3.7. Thrust by rotating propeller.

The maximum motor power is calculated as follows: (3).

$P = V.I$

where voltage (V) = 11.1 V and the current of the battery I= 3.5 A.

$Power\ (P) = 38.9$ watt

The selection of ESCs [3.1.2.b] is based on (4).

$$(Number\ of\ ESC's\ \times Ampere\ rating\ of\ ESC)\ must\ be\ higher\ that\ (C \times I) \quad (4)$$

where C is the Li-Po battery's discharge rate.

$4 \times 30A > 25 \times 3.5$

3.4. UAV Dynamic Modeling

The S500 frame was chosen for our UAV because of its low weight and high strength. The X geometry of the S500 frame allows us to mount additional components on the UAV. Using the frame dimensions, the frame is modeled in AutoCAD 2021 and SOLIDWORKS 2021, with consideration for safety requirements, smooth operation, and optimal utilization of propellers, motors, and electrical equipment.

The central hub, spars, and arms are designed separately prior to assembly, as shown in the diagram below.

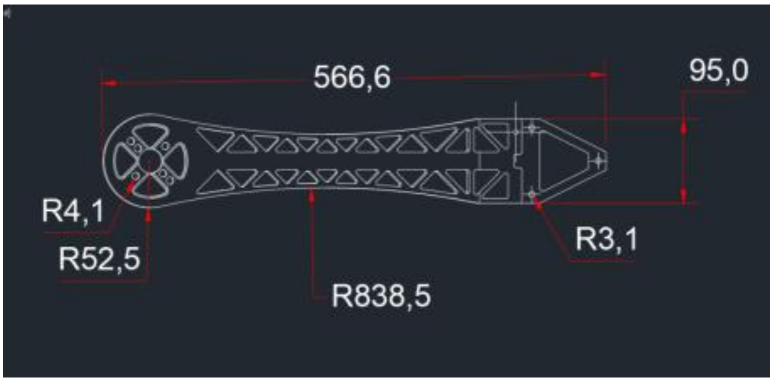


Figure 3.8. UAV arm's AutoCAD sketch.

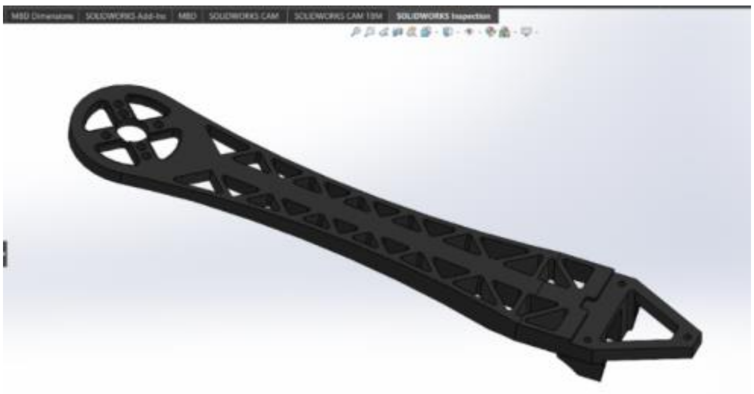


Figure 3.9. UAV arm's SOLIDWORKS isometric view.

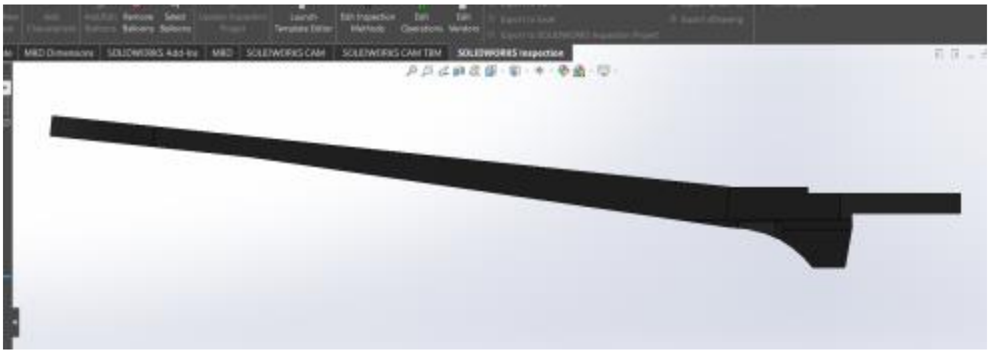


Figure 3.10. UAV arm’s SOLIDWORKS side view.

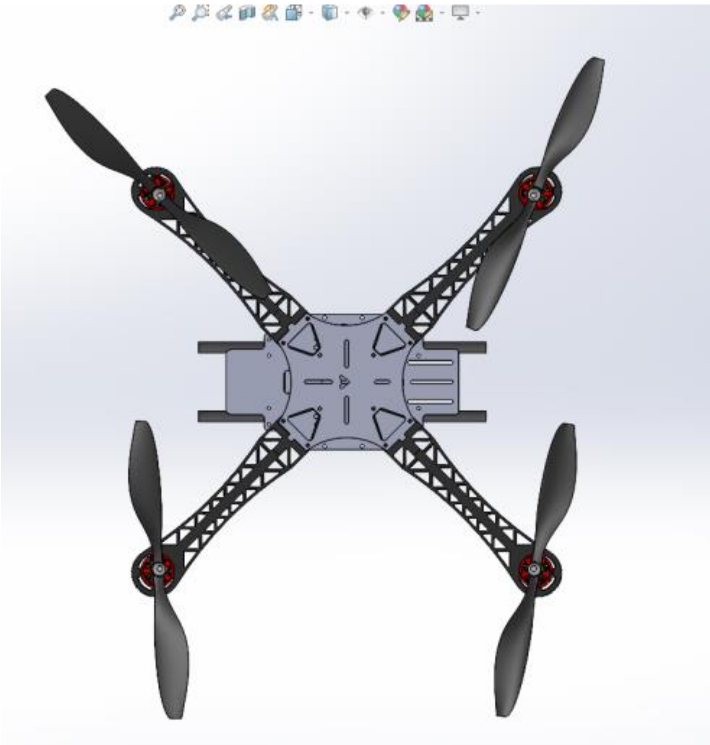


Figure 3.11. Assembly of UAV frame in SOLIDWORKS.

Figure 3.12. Side View

Figure 3.13. Isometric View

3.4.1. Frame

The design of the UAV is divided into two parts. The first is aerodynamics, while the second is mechanics. Aerodynamics will include selecting the appropriate propeller, calculating the lift and drag for the frame, calculating the total drag induced by the entire UAV, and calculating the lift-to-drag ratio for the UAV, as stated in section 3.2.

The mechanics section will use several calculations to determine the strength, maximum shear, bending of the various structures, and whether or not the suggested material is strong enough to withstand the forces acting on the structure. This will be followed by aerodynamics and mechanics for the frame, rods to hold the motors, and finally vibration.

3.4.2. Mechanics

Because the weight limit is strict, it is critical to use the lightest material possible that can withstand the forces experienced during flight. This section discusses the mechanics and physics required to ensure a secure structure.

3.4.3. Bending

Understanding how a beam or rod bends is critical for designing a strong structure. The equations differ depending on how the force is applied. When a weight is hung from the edge of a rod, the force is concentrated to a single point, resulting in a deflection that looks like:

$$\boldsymbol{w} = \frac{\boldsymbol{PL^3}}{\boldsymbol{3\mathcal{E}I}}$$

P is the force applied.

L is the length of the rod.

Ɛ is the Youg Modulus, which describes the stiffness of a material.

$\boldsymbol{I}$ is the area moment of inertia, which is the structure’s resistance to deflection.

3.4.4. Shearing

This is important to calculate because a material can only be bent so far before breaking. It is carried out using the formula for maximum normal stress.

$$\boldsymbol{\sigma} = \frac{\boldsymbol{M}}{\boldsymbol{\omega_b}}$$

Where M is the maximum bending moment in the structure, and $\omega_{\boldsymbol{b}}$ is the rotational resistance.

3.4.5. Vibrations

Vibrations in aircraft can be problematic. Understanding where and how it happens is essential for knowing how to avoid it. Buffer, flutter, and noise are the three main types of vibration.

Flutter can cause an airplane to crash. Unsteady aerodynamics cause an aircraft’s natural frequencies to oscillate. This causes unstable flutter. Use a portable vibration analyzer to prevent flutter during routine aircraft maintenance.

Buffet is a common type of air turbulence vibration. Aerodynamic excitation causes buffet. Buffet has random vibration and separated airflow. When an aircraft’s speed brakes extend, they disrupt airflow.

Noise is a vibration that excites and vibrates the air. Random vibrations produce unmusical, confused noise. Harmonic vibrations sound like a whistling drain or musical instrument.

Buffer or flutter vibrations are insignificant due to the UAV’s low speed and altitude. At Mach 0.8 (950 km/h) and 6000 meters, these issues appear.

3.5. Structural Analysis of Quadcopter

Quadcopter frames bear the most weight. High tensile and compressive loads make it appealing. ANSYS 17 analyzes the frame’s structure.

3.5.1. Von-Mises’s Base Plate Analysis

The properties required for static structural analysis are listed in Table III. The meshing resolution employed is adequate for producing precise results. 160 MPa is the ultimate tensile strength of the base plate material (PA66GF30). Figure 3.14 demonstrates that the maximum equivalent stress obtained is 5.99 MPa. Consequently, the base plate is able to withstand the loads.

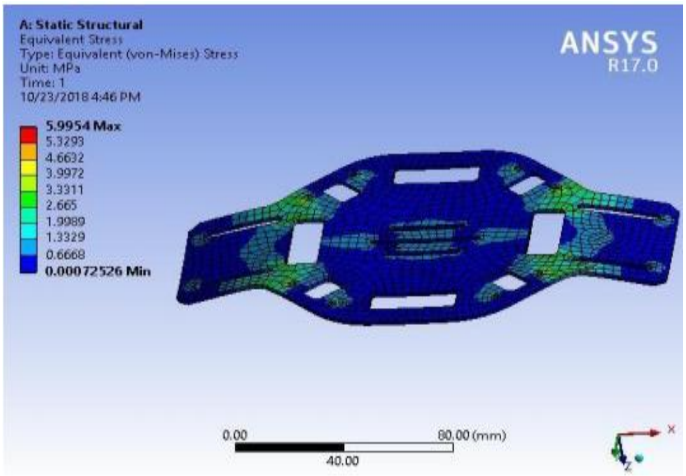


Figure 3.14. Von-mises stress analysis on a base plate subjected to a tensile load of 20N.

Table 3.5. Boundary Conditions.

Material	Density (kg/m3)	Young's Modulus (MPa)	Strength (MPa)	Poisson's ratio
PA66GF30	1370	15000	160	0.36

3.5.2. Von-Mises Stress Analysis of The S500 Frame's Top Plate

The top plate material (PA66GF30) has an ultimate tensile strength of 160 MPa. The maximum equivalent stress obtained is 2.255 MPa, as shown in Figure 3.15. As a result, the top plate is capable of withstanding the loads. The maximum equivalent stress is 23.0 MPa, as shown in Figure 3.16. As a result, the S500 frame is capable of withstanding the loads.

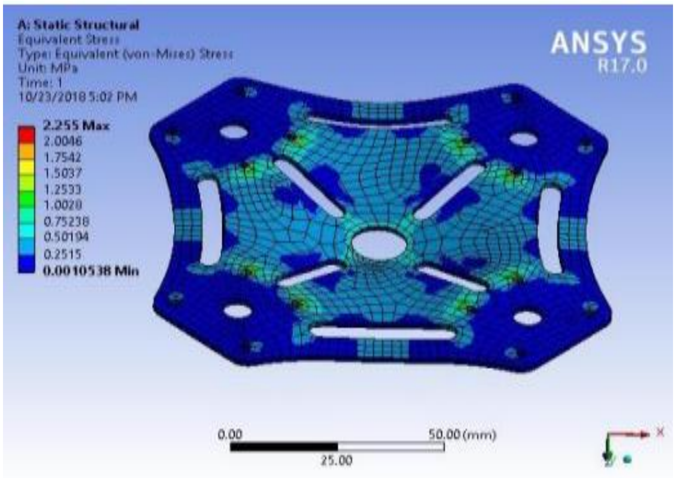


Figure 3.15. Von-Mises's stress analysis on the top plate for a tensile load of 20N.

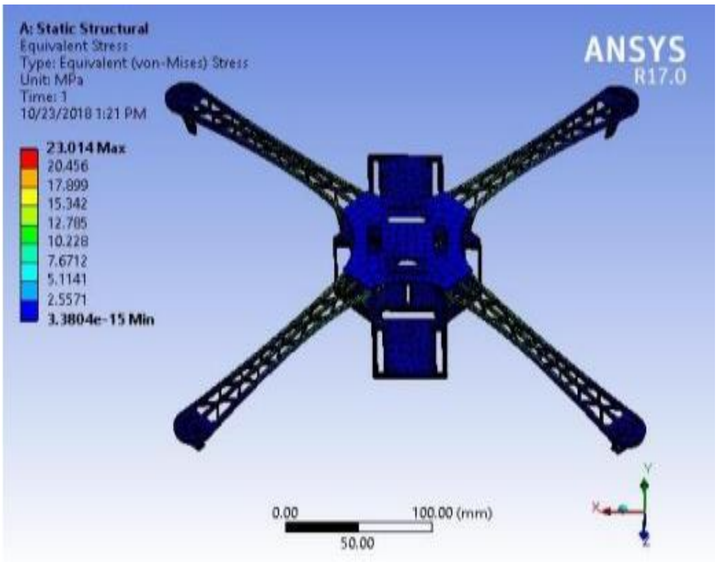


Figure 3.16. Von-mises stress analysis on the S500 frame for a tensile load of 20N.

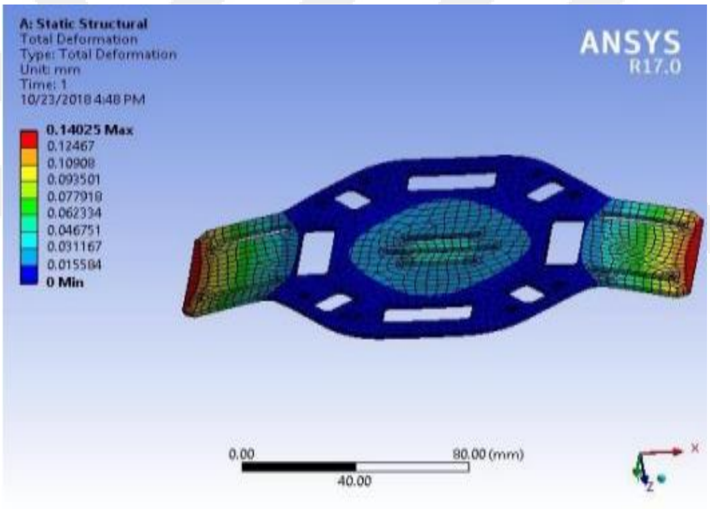


Figure 3.17. Total deformation analysis of the base plate under a tensile load of 20 N.

3.5.3. Comprehensive Analysis of Base Plate Deformation

As shown in Figure 3.17, the base plate's total deformation ranges from 0 mm to 0.14025 mm.

3.5.4. Analysis of Total Deformation of The Top Plate on The S500 Frame

As shown in Figures 3.18 and 3.19, the total deformation obtained for the top plate and S500 frame ranges from 0 mm to 0.0097 mm and 4.13 mm, respectively. On the quadcopter prototype frame (S500), a static structural analysis is performed to determine frame deformation when a load is applied. In comparison to the tensile strength of PA66GF30 material, the obtained results are within the acceptable range. Therefore, the frame is safe and capable of withstanding collisions.

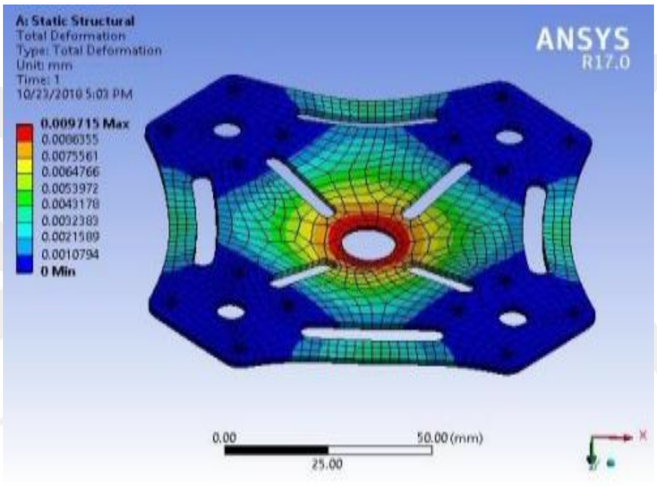


Figure 3.18. Analysis of total deformation for a 20 N tensile load on the top plate.

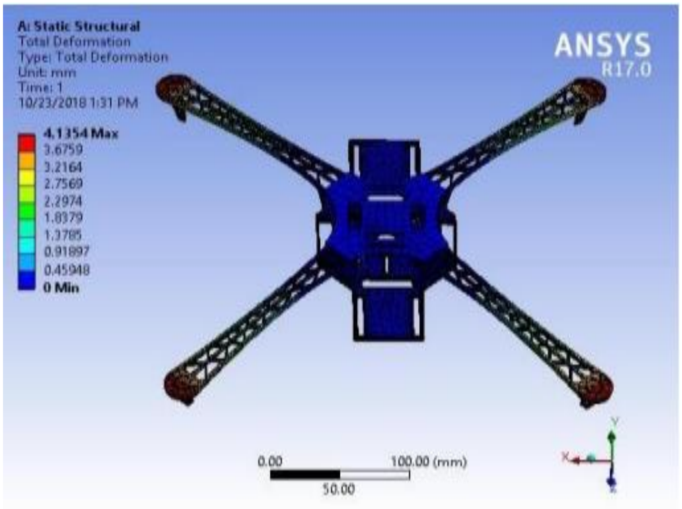


Figure 3.19. Analysis of total deformation for a 20 N tensile load on an S500 frame.

4. RADIO CONTROL

The controller operates by transmitting a radio signal from the remote control to the drone containing instructions for its operation.

The radio transmitter on the drone controller transmits and the radio receiver on the drone receives radio signals.

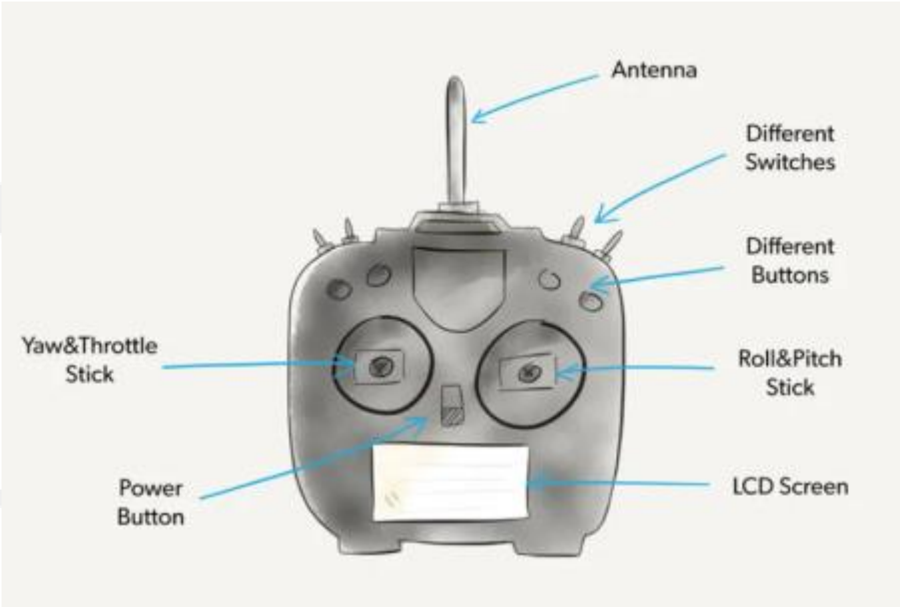


Figure 4.1. Drone controller.

4.1. Parts of a Controller

(See figure 4.1.)

The primary controller components are:

Right Stick

This is the right stick, and it controls the Roll and Pitch movements.

Left Stick

This is the left stick that is perpendicular to the right stick. It controls the yaw and throttle.

Antennas

These are the transmitters responsible for transmitting radio signals to the drone.

4.2. Basic Drone Movements

In the preceding sections, we discussed the primary maneuvers of a drone. In this section, we'll examine what happens when the controller's analog sticks are pushed. (See Figure 4.2.)

Figure 4.2. Sticks and their roles.

This is the point at which the altitude of the drone changes. In this instance, all motors are rotating at the same speed. Figure 4.3 illustrates that the higher the drone travels, the faster the propellers spin.

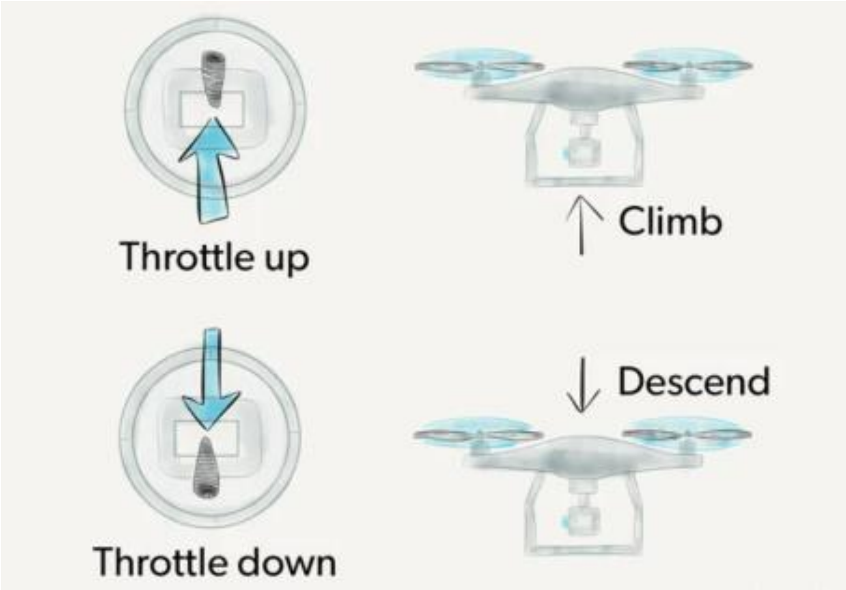


Figure 4.3. Throttle.

Yaw – This is where the drone rotates clockwise along the top-to-bottom Yaw axis. Left-stick controller left/right. The ESC reduces motor power diagonally. figure 4.4.

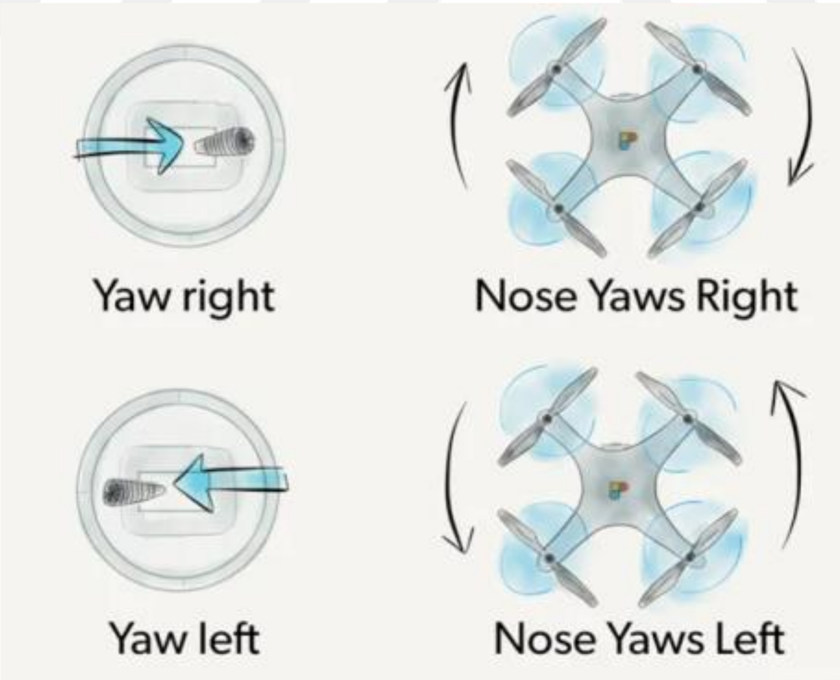


Figure 4.4. Yaw.

Pitch – A drone uses this movement to move along the Pitch x axis. The right stick is used. To speed up the front motors, the ESC reduces the power of the rear propellers. The drone’s front section tips downward when it accelerates. figure 4.5.

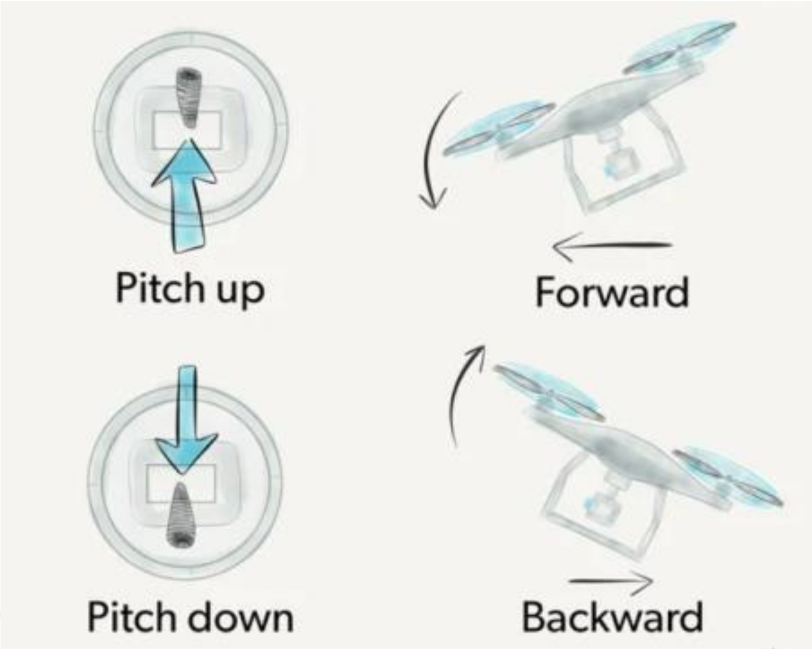


Figure 4.5. Pitch.

Roll allows the drone to move right or left along the front-to-back roll axis. The right stick is used. The ESC reduces one side's motor power to make the drone roll (left or right). figure 4.6

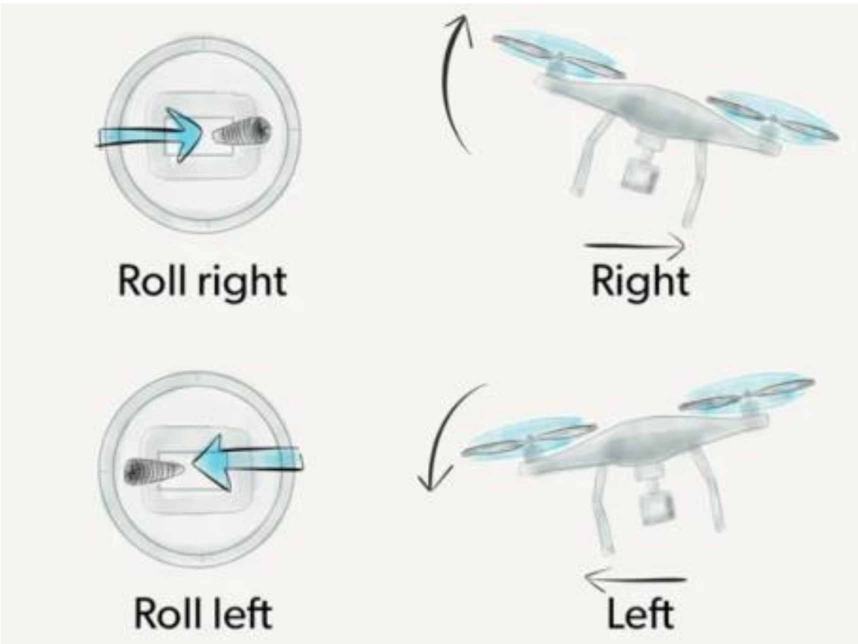


Figure 4.6. Roll.

4.3. Communication Between The UAV and The Controller

Below are drone and controller communication channels.

4.3.1. Radio Waves

This is a common way drones talk to their controllers. Radio waves are invisible electromagnetic waves. I've already described the transmitter and receiver.

All drones must be "tuned" to the same frequency to communicate. What if another device uses the same range and frequency? RFID helps here.

RFID (Radio Frequency Identification) identifies drone-controller communication. The drone only responds to that specific RFID signals.

Lower frequencies can operate over longer distances, allowing the drone to move further from the controller. Low frequencies require large antennas. Most drones, including ours, operate between 800 and 900 MHz for balance.

4.3.2. Wi-Fi

Most drones with an app and camera have Wi-Fi. Wi-Fi enables real-time drone streaming.

Wi-Fi operates at 2.4 to 5.8 GHz, unlike radio. High frequencies.

4.3.3. Global Position System (GPS)

GPS helps drones navigate. Stabilization, Return to Home, and No-Fly zones help achieve this.

How do GPS-enabled drones talk to their controllers? You send the drone's GPS the coordinates.

Some drones are designed to avoid No-Fly zones, but the app handles communication. Modern drones can follow waypoints in the form of coordinates. Land surveying often requires aerial images of a target.

4.3.4. Satellite Link

This advanced mode of communication is only used by military drones like the Hawk, Predator, “Bayraktar TB3”, and “Kizilelma”. Satellite communication lets the military control drones thousands of miles away. Takeoff and landing still require a ground station in the drone’s operating area.

5. PROBLEMS ENCOUNTERED

5.1. Battery Running Out Too Fast

One of the main issues we encounter while building drone is the flight time. The commonly used LiPo battery are too heavy. While trying to increase the flight time, heavier batteries have to be mounted. This in return requires stronger motors to counter the weight. Strong motors pull more current leading the batteries to run our too fast. In a nutshell, it is difficult to escape from this vicious circle. Further studies have to be made to solve this substantial problem.

Add to that, the ordered Pixhawk power module malfunctioned causing a short circuit any time an attempt to connect is carried out.

Figure 5.1. Burned power module.

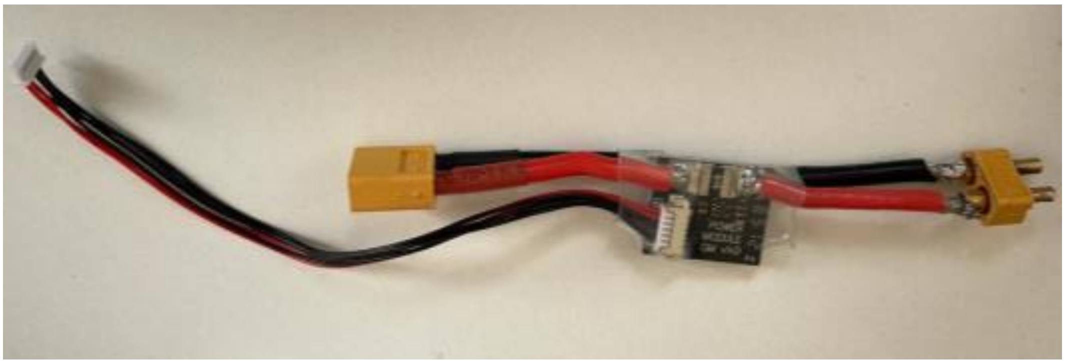


Figure 5.2. Malfunctioning power module.

5.2. Signal Interference

Some areas have a high level of electromagnetic interference, which may interfere with the controller’s connection to the drone. If the drone connects to the controller and takes off, the connection may be lost while the drone is in flight.

5.3. Controller Range Too Low

The controller’s range was intentionally kept low for this experimental step (3000 meters). This allows us to keep our UAV within visual range (VLOS). As a result, we maintain constant visual contact with the drone.

6. ASSEMBLY, TEST, RESULT, AND COMMENTS

6.1. Assembly

6.1.1. Pins of The Flight Controller

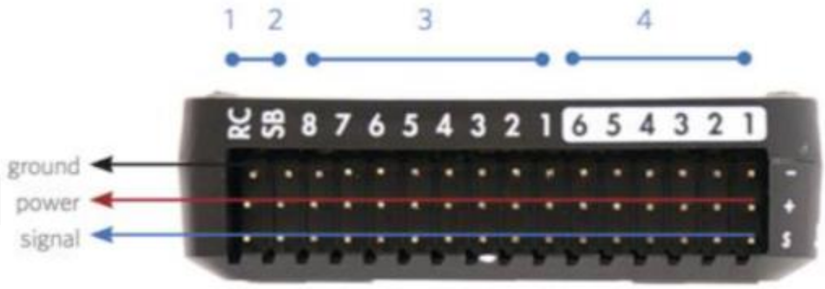
Before digging into the complete assembly of our UAV, let get to know the pins of our flight controller and what should be connected on it for the purpose of this study.

1. Spektrum DSM receiver	9. Serial
2. Telemetry (on-screen display)	10. GPS module
3. Telemetry (radio telemetry)	11. CAN (controller area network) bus
4. USB	12. I2C Splitter or compass module
5. SPI (Serial peripheral interface) bus	13. Analog to digital converter 6.6 V
6. Power module	14. Analog to digital converter 3.3 V
7. Safety Switch Button	15. LED indicator.
8. Buzzer	

Figure 6.1. PIXHAWK top ports.

1. Input/Output reset button
2. SD card
3. Flight management reset button
4. Micro-USB port

Figure 6.2. Side ports.



1. Radio control receiver input
2. S.Bus Output
3. Main Outputs
4. Auxiliary Outputs

Figure 6.3. Main and AUX pins.

6.1.2. Wiring of our Pixhawk Flight Controller

Figure 6.4. PIXHAWK wiring.

All the motors are connected the pins 1 to 4 of the MAIN OUT.

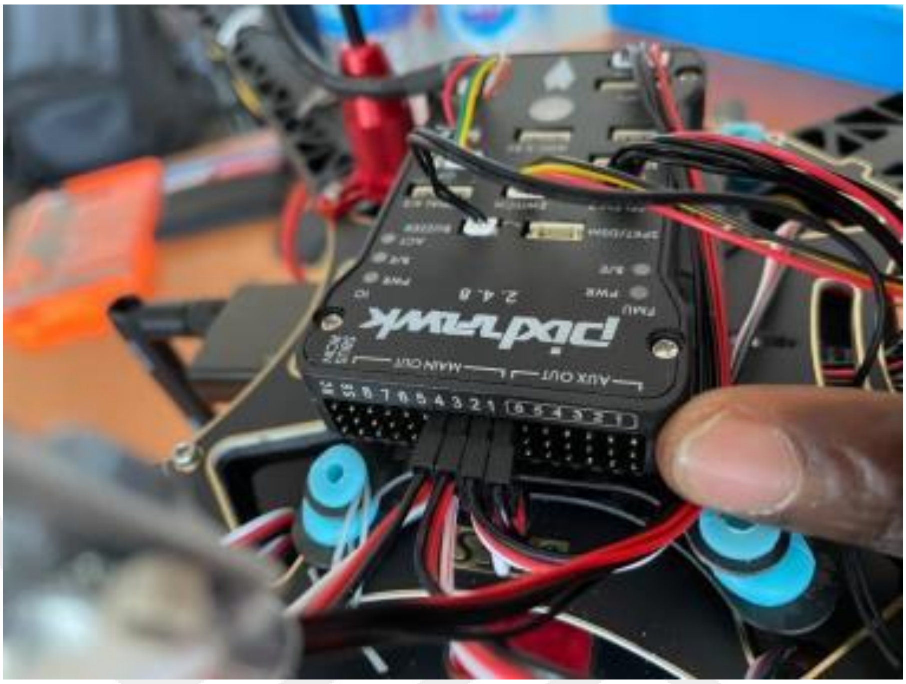


Figure 6.5. Connection of the motors to the PIXHAWK.

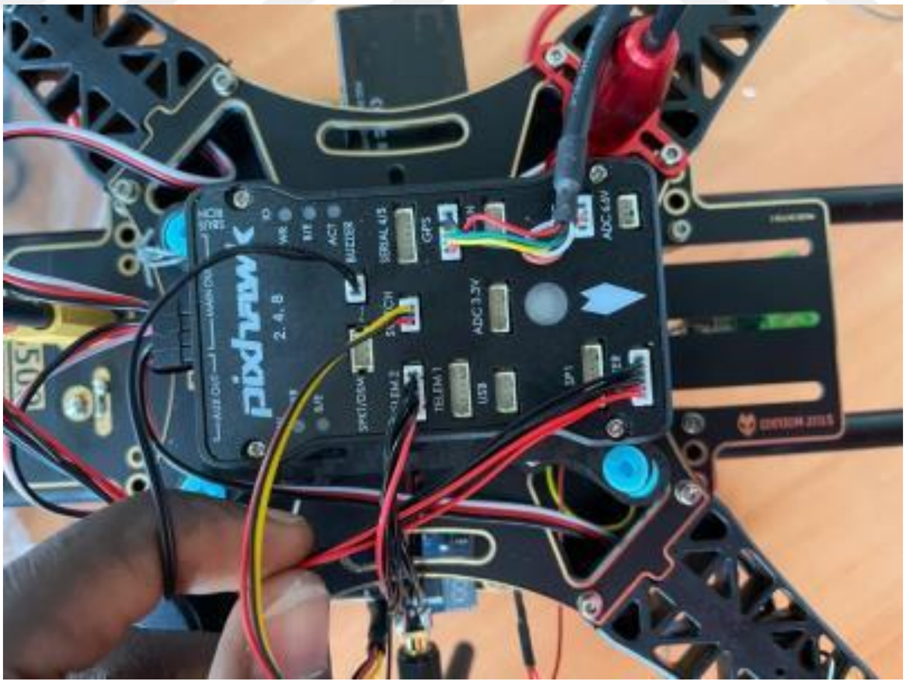


Figure 6.6. Onboard Flight Controller

Figure 6.7. ESC to Motor connection using Banana connectors.

Figure 6.8. Camera module.

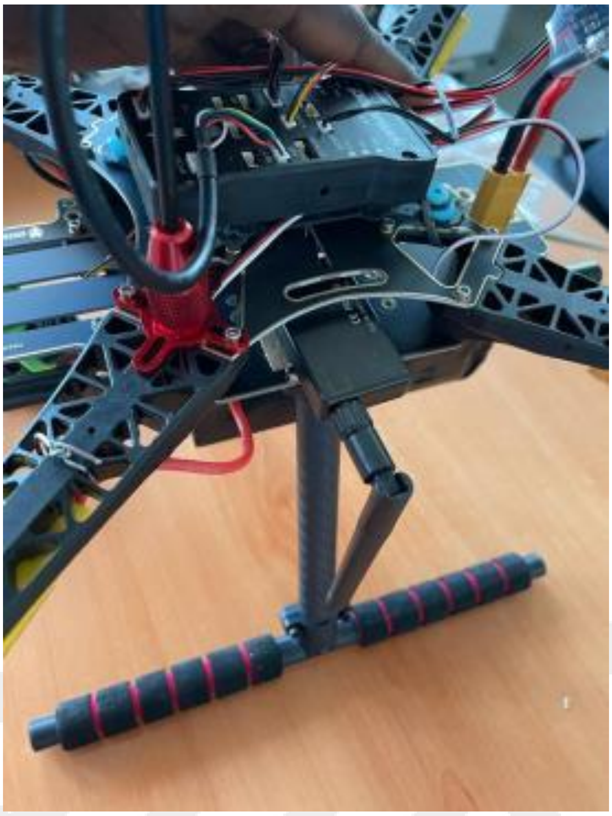


Figure 6.9. GPS module stand attached to the frame.

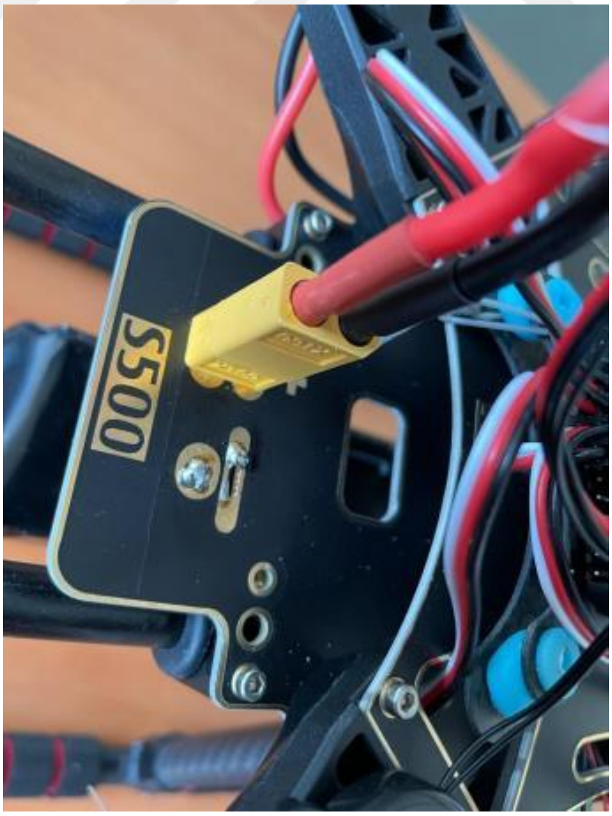


Figure 6.10. Soldering of the power module XT60 connector.

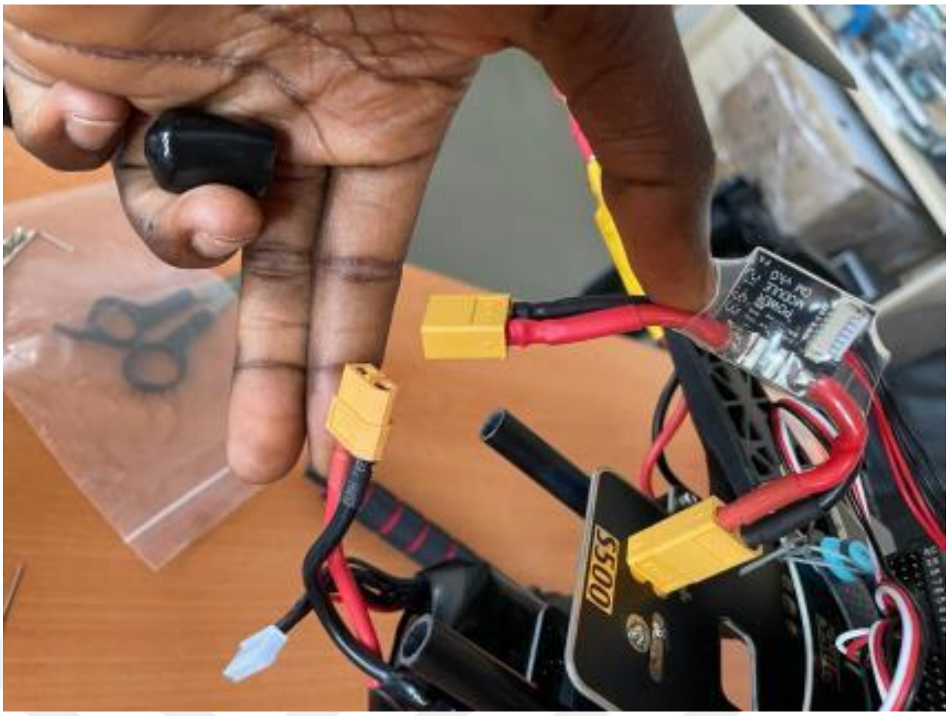


Figure 6.11. Power module and lipo battery XT60 connection.

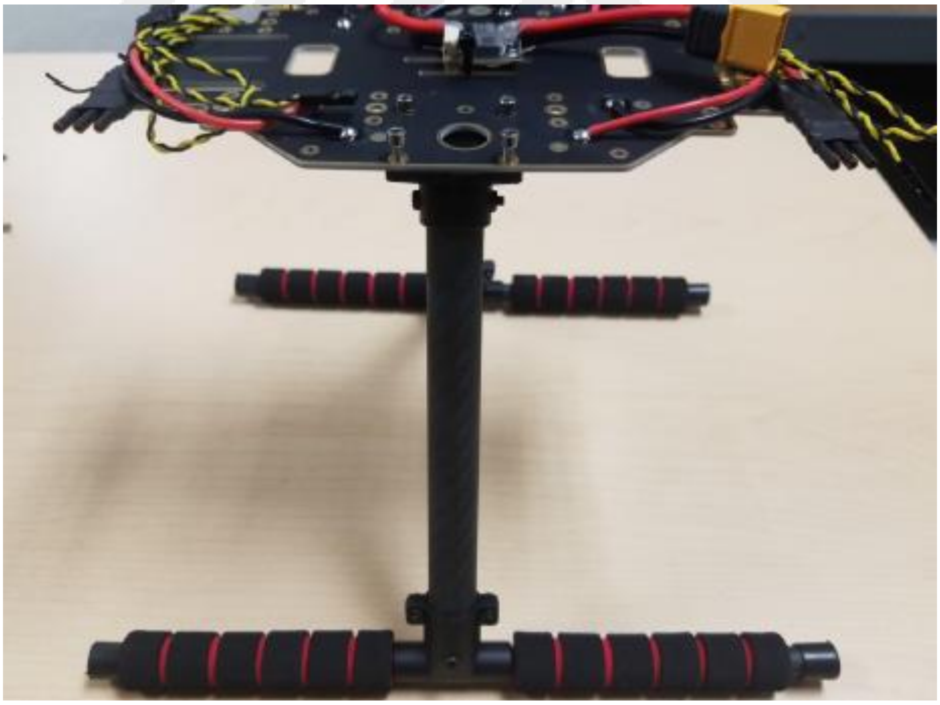


Figure 6.12. Power Module – Lower Plate connection

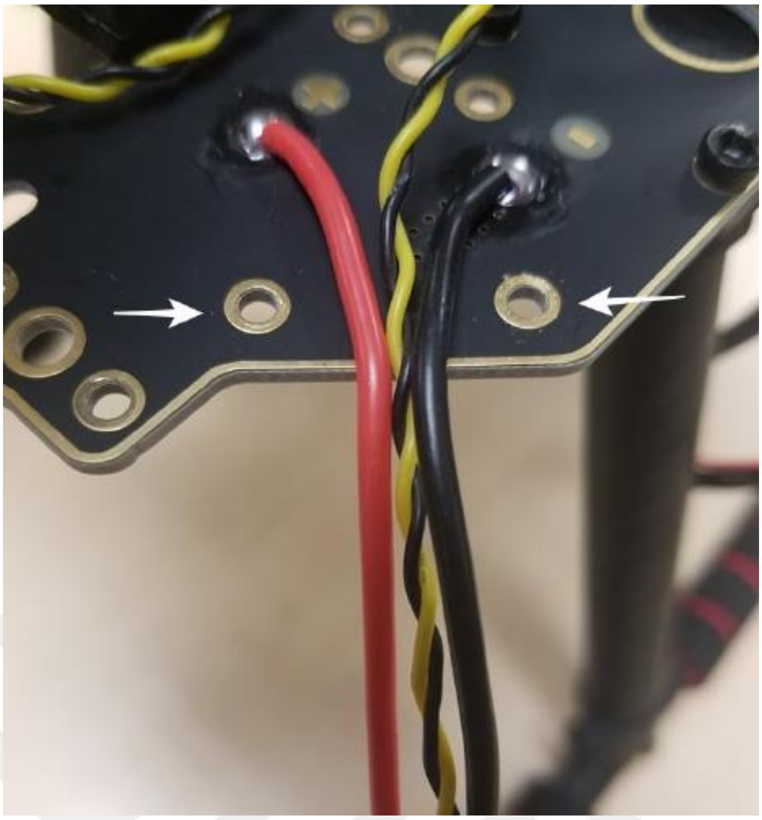


Figure 6.13. Connecting ESCs to the plate.

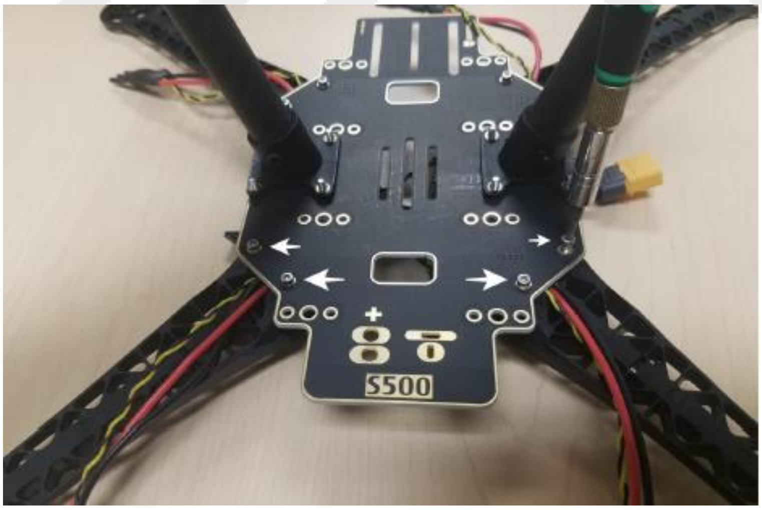


Figure 6.14. Lower Plate Polarities

Figure 6.15. Assembly side view.

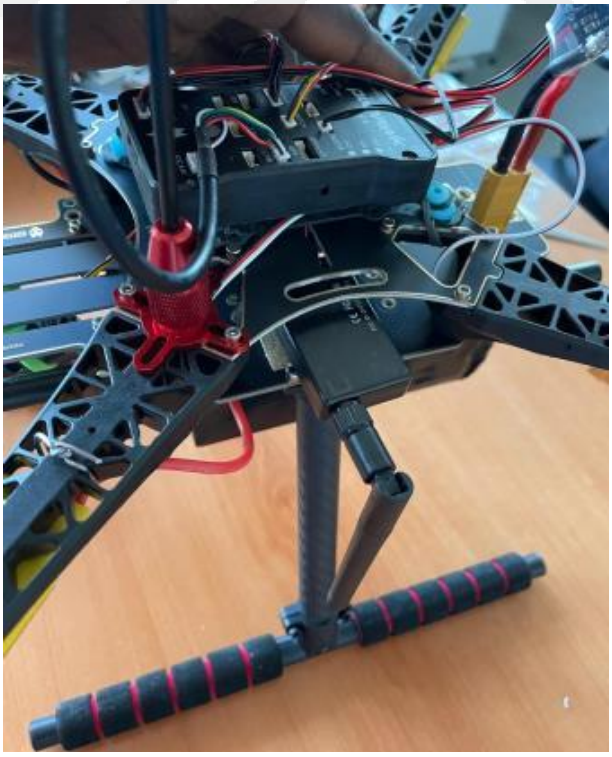


Figure 6.16. Telemetry installation.

Figure 6.17. Ongoing assembly

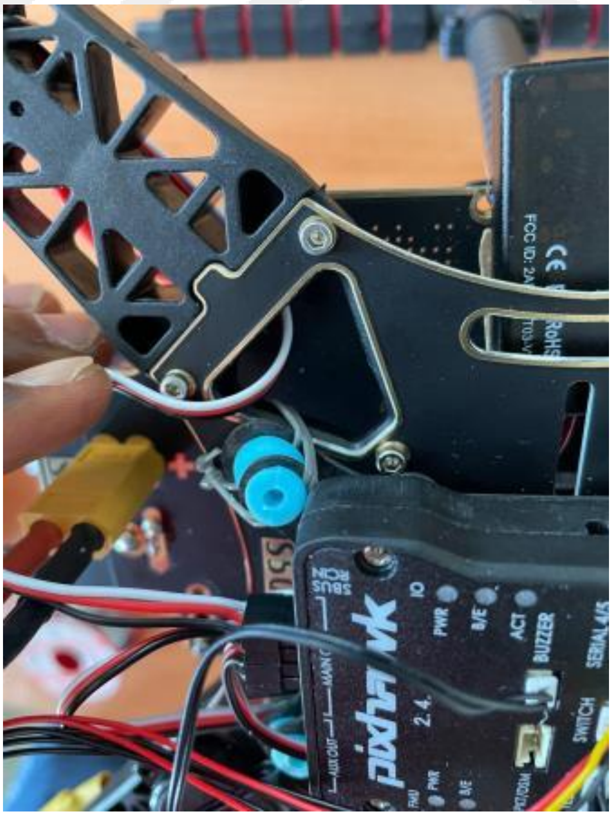


Figure 6.18. F.C. Stabilizer

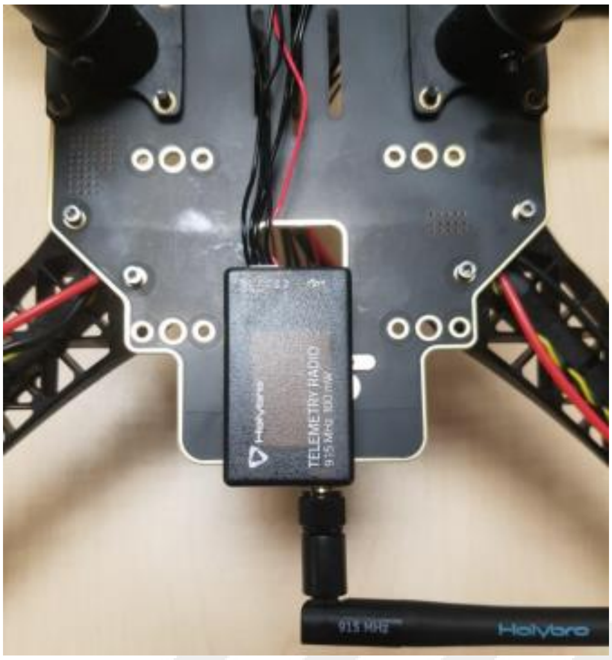


Figure 6.19. Lower plate and Telemetry Radio

7. EXPERIMENTATIONS

7.1. Calibration

We start by calibrating our flight controller, compass, GPS and the radio controller in ArduPilot program. For that, we connect the mounted copter’s flight controller to the computer using a USB cable as shown below.

Figure 7.1. Calibration.

The calibrated drone gives the exact global positioning.

Figure 7.2. Global Positioning of the drone.

7.2. Tracking Trajectory

Figure 7.3. Tracking trajectory for a static target over our test field. In the center of the field, the target is stationary and seated. The experiment's rendezvous point is represented by the red dots in the upper right corner.

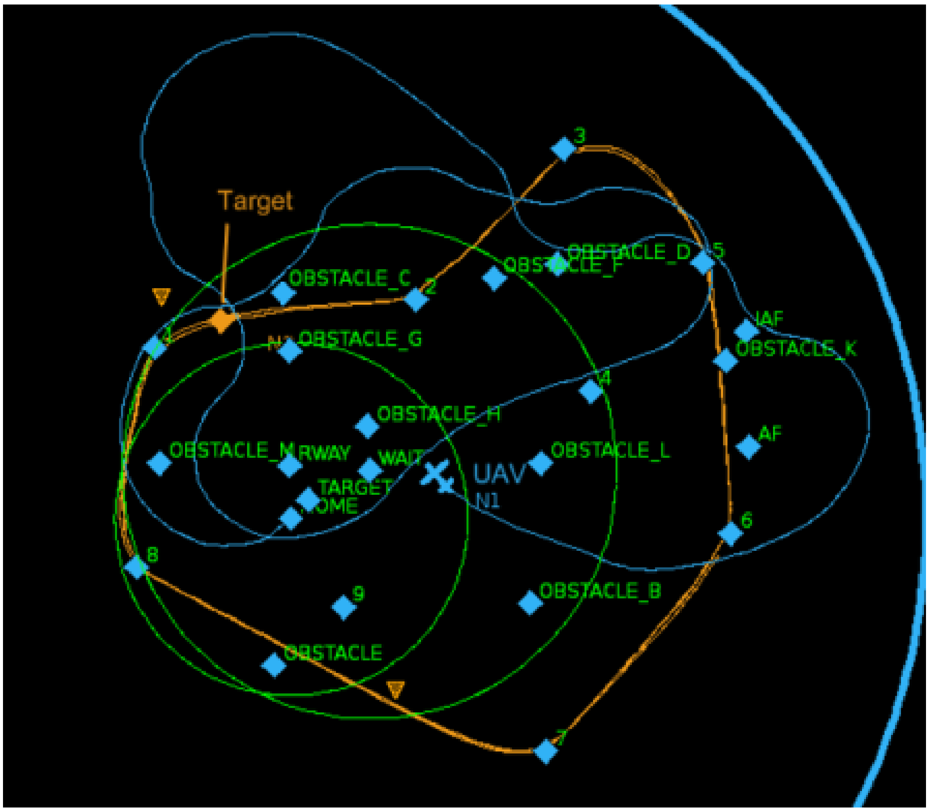


Figure 7.4. UAV chasing a target on the road.

Figure 7.5. Target visualization.

The design UAV successfully detected a rat on the ground at a distance of almost 100 meters. Figure 7.5. shows the target in the field of view of the onboard camera. Various test carried out on different target showed:

Table 7.1. Observation distance

Target Size	UAV's Altitude in meters	Distance in meters
10 – 20 cm	15	25
20 – 50 cm	50	95
50 – 100 cm	100	250

7.3. Flying Test

Flying the UAV helped in knowing the ideal altitude to effectively track a ground target undetected is between 50 to 100 meters. At this distance, the low sound dB produced by the spinning motor propeller couple is dissipated and cannot be heard by the target.

Figure 7.6. Starting the motors.

Figure 7.7. Hovering UAV.

Figure 7.8. UAV in the air.

Figure 7.9. Flying UAV.

Figure 7.10. View 1.

Figure 7.11. View 2.

7.4. Thrust Test

The test was essentially directed towards the brushless motor's ability to produce lift through a thrust test conducted with a servo tester, the LiPo battery, one ESC and a highly sensitive balance.

The circuit used is as the following Figure 6.12

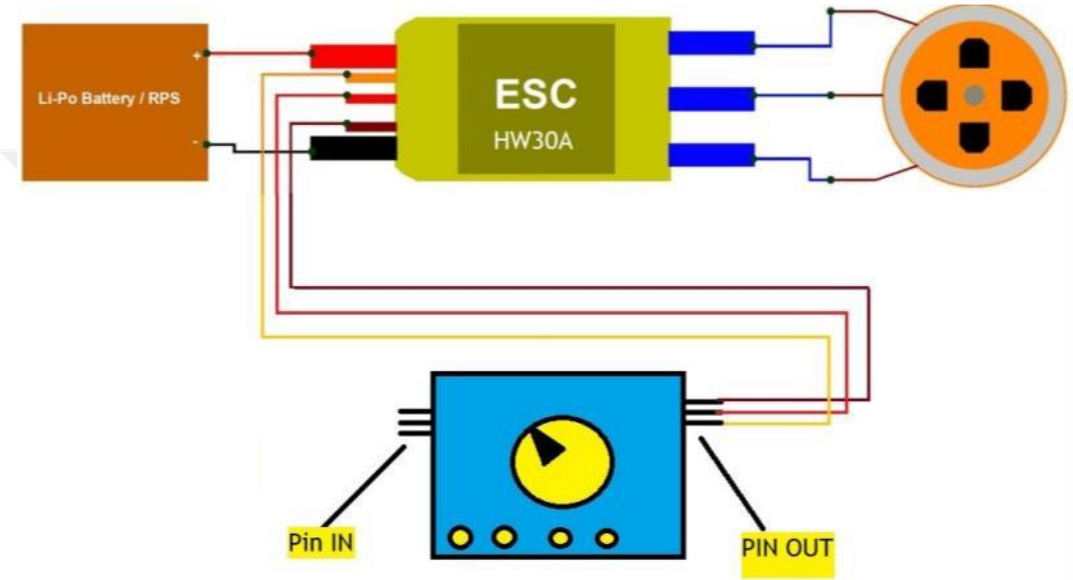


Figure 7.12. Thrust test using a servo tester circuit.

Table 7.2. Thrust results.

Propellers	Motor	Thrust (kg)	Voltage (V)	Pull-Current (A)	Power (W)
8 x 4.5	A 2212	1.418	16	27	432
9x 4.5		1,605	15.90	31	493
10x4.5		982	17	30	510

Figure 7.13. Maximum thrust

Initially set to be mounted on the X2216 motors, the 10x4.5 propellers came out to be a liability on the A2212 motors.

As shown in Table 6.1, the most suitable propeller for this application is the 8x4E also known as 8045.

Capable of withstanding a maximum current of 30A, our ESCs wouldn't be able to support the massive current pull of the other two (2) propellers. On contrary, the lift produced with the 8045 propeller and its current pull are perfectly suitable for the proposed UAV for a longer flight time. The lift produced can be calculated to be:

$$F_T = 4 \times 1400\ (g)$$

$$F_T = 5600\ grams\ or\ 5.6\ kg$$

The resulting lift more the twice higher than the total weight $\boldsymbol{F_W}$ estimated to around 2kg.

8. CONCLUSION AND FUTURE STUDIES

Despite all of the difficulties, primarily financial, encountered prior to and during this time, we are grateful that this study enabled us to have a clear vision of our goal, the first parts required to successfully develop a ground stationed RC drone, and to understand the fundamentals of UAV applications, particularly in the field of target tracking/surveillance. We have presented one of many possible drone designs. With an estimated flying time of around 30 minutes, our UAV is capable of providing intelligence from the assigned task. Despite its inability to provide high-resolution images, the install camera allows us to see all of the targets in the field of view (FOV).

While we would like to be able to get more autonomous control out of this system, as previously stated, future research on this project will focus on transforming our UAV into a fully autonomous flying machine. This will necessitate the incorporation of a flying algorithm alongside a preplanned flight path. In obstacle detection, a Lidar laser scanner unit/laser-range sensors or stereo-vision cameras will be added, allowing our drone to detect potential obstacles such as buildings, cranes, trees, and even high voltage electric wires from a distance. Using optical flow maps from the previous frame, we will develop the drone's movement in a specific frame.

A Raspberry Pi will be added, along with many other new components, to receive AI programming and autonomous decision making. Battery life must be increased to at least 24 hours, with our UAV being able to land at one of the secret charging stations to recharge its batteries while providing information to the control teams.

Recent advances in computer technology and drone systems make it exciting to see what the future holds. Recent advances in computer technology and drone systems make it exciting to see what the future holds.

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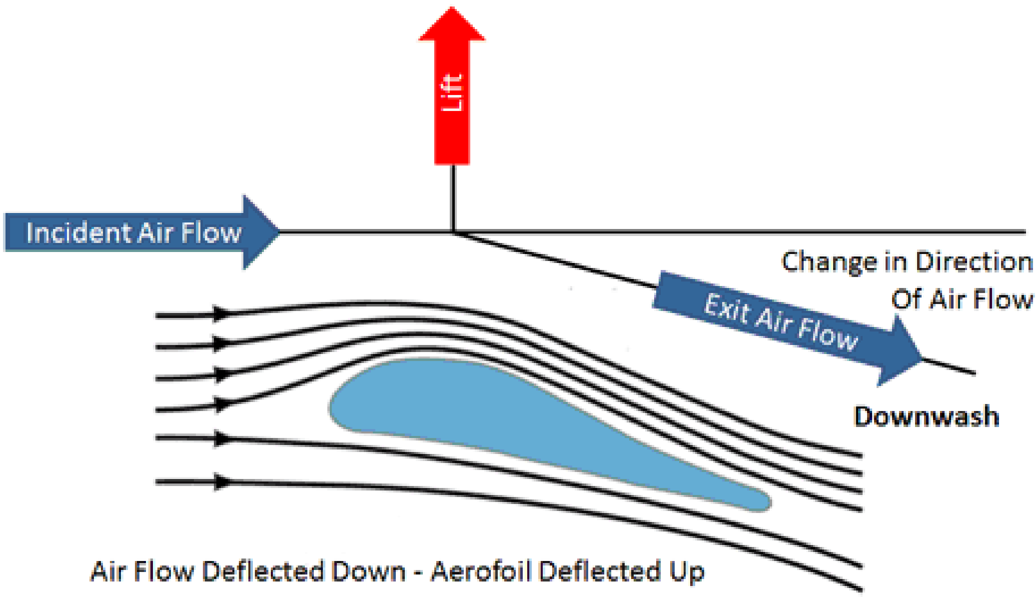
APPENDICES

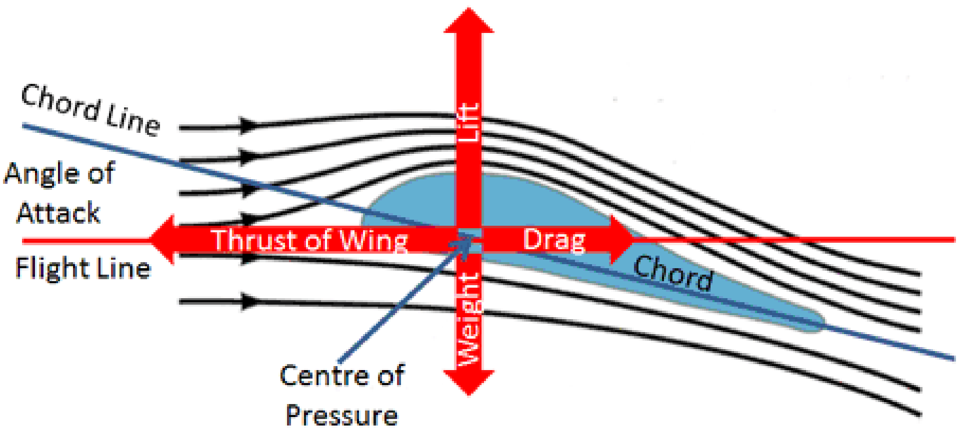
Annex 1. Principle of Lift Generation

Aerodynamic Lift – Explained by Newton's Laws of Motion



Lift occurs when a moving flow of air is turned by a solid object.
The flow is turned in one direction, and the lift is generated in the opposite direction, according to Newton's Third Law of action and reaction.
For an aircraft wing, both the upper and lower surfaces contribute to the flow turning or the downwash.

Aerofoil Lift and Drag – Aircraft Wings



Drag Equation

- Coefficient of drag, C_d
  - Determined experimentally
  - Combines several factors
    - Shape
    - Angle of attack

$$C_d = \frac{2 \times D}{A \times \rho \times v^2}$$

Alternate format

$$C_d = \frac{D}{q \times A}$$

$C_d = Coefficient\ of\ Drag$

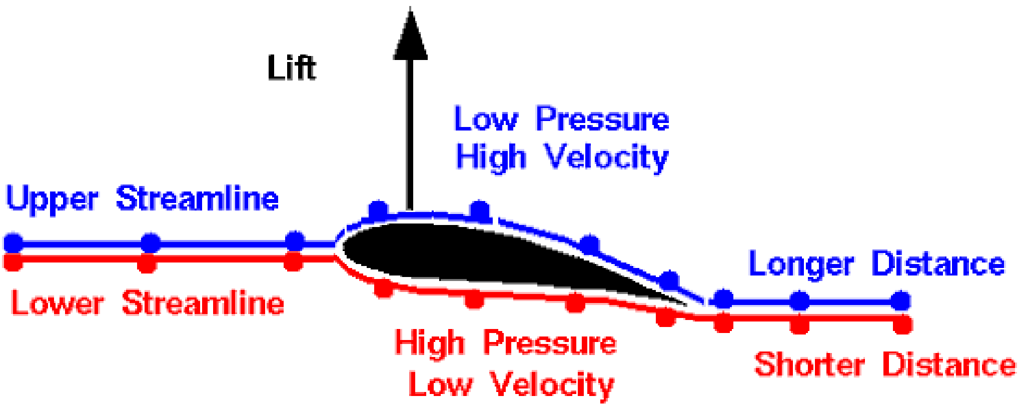
$D = Drag\ (N)$

$A = Wing\ Area\ (m^2)$

$\rho = Density\ \left(\frac{kg}{m^3}\right)$

$v = Velocity\ \left(\frac{kg}{m^3}\right)$

$q = Dynamic\ Pressure (Pa)$



"Longer Path" or "Equal Transit" Theory

T.C.
AYDIN ADNAN MENDERES ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ

BİLİMSEL ETİK BEYANI

YER HEDEF TAKİP İHA başlıklı Yüksek Lisans tezimdeki bütün bilgileri etik davranış ve akademik kurallar çerçevesinde elde ettiğimi, tez yazım kurallarına uygun olarak hazırlanan bu çalışmada, bana ait olmayan her türlü ifade ve bilginin kaynağına eksiksiz atıf yaptığımı bildiririm. İfade ettiklerimin aksi ortaya çıktığında ise her türlü yasal sonucu kabul ettiğimi beyan ederim.

Foto Dominique Parfait KOFFI

…/…/2022

ÖZ GEÇMİŞ

Soyadı, Adı : Foto Dominique Parfait KOFFI

Yabancı Dil : İngilizce, Fransızca, Türkçe

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Derece	**Kurum**	**Mezuniyet Tarihi (Yıl)**
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