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Senior Design Project Report

3D PRINTED DRONE

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Declaration.

We hereby declare that the thesis titled “Design and Development of 3D PRINTED DRONE for Mechanical Applications” is submitted to the Department of Mechanical Engineering partial fulfillment of the Bachelor of Science in Mechanical Engineering. This work was not submitted elsewhere for the award of any other degree or any other publication.

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Abstract.

Nowadays, there is a growing need for flying drones with diverse capabilities for both civilian and military applications. There is also a significant interest in the development of novel drones which can autonomously fly in different environments and locations and can perform various missions. In the past decade, the broad spectrum of applications of these drones has received most attention which led to the invention of various types of drones with different sizes and weights. In this review paper, we selected a drone was ready designed on solid work as conceptual design. We reviewed the design and noticed that there are a lot of mistakes that could be developed and enhanced to make the drone work with better efficiency and more flight time with less power consumption. As we also made huge changes in the way of working. We also changed some parts or canceled some to make the best possible design. We will test each part and provide the data sheet and how it was affecting the drone efficiency.

Acknowledgment.

First of all, we would like to express our appreciation to our advisor Dr. Nassim Khalid for his unlimited support for our project and his encouragement. Also, we express thanks to Dr. Faramarz Djavanroodi, chair of the Mechanical Engineering Department at PMU, for his continued encouragement. Finally, we thank our parents for their endless support, and attention.

List of Acronyms (Symbols) used in the report:

Symbol	Symbol Description
ϕ	Roll angle
θ	Pitch angle
ψ	Yaw angle
RPM	Revolutions per minute
F	Actual thrust applied plus weight of rotor.
C	Thrust rating from chart for 106 revolutions of life.
Y	Bearing thrust factor from chart
N	RPM of motor.
CI	Lift coefficient
V	Speed of moving object
ρ	Density of fluid
A	Area of the wing
KV	Constant velocity of a motor

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Chapter 1: Introduction.

Unmanned aerial vehicles (UAV) are another name for Drone. drone is a flying robot. Sometime featured with GPS, the flying machine may be remotely controlled or can fly autonomously by programmed controlling flight systems. Drones are most often used in military services. However, it is also used for weather monitoring, firefighting, search and rescue, surveillance and traffic monitoring etc. In recent years, the drone has come into attention for a number of commercial uses. In late 2013, Amazon announced a plan to use unmanned aerial vehicles for delivery in the nearby area's future. It is known as Amazon Prime Air; it is estimated to deliver the orders within 30 minutes inside 10 miles of distance. So, it is clear that domestic usage of UAV has vast future possibility in different fields rather than military usage.

Drones for military use were started in the mid-1990s with the High-Altitude Endurance Unmanned Aerial Vehicle Advanced Concept Technology Demonstrator (HAE UAV ACTD) program managed by the Defense Advanced Research Projects Agency (DARPA) and Defense Airborne Reconnaissance Office (DARO). This ACTD placed the base for the improvement of the Global Hawk. The Global Hawk hovers at heights up to 65,000 feet and flying duration is up to 35 hours at speeds approaching 340 knots and it costs approximately 200 million dollars. The wingspan is 116 feet and it can fly 13.8094 miles which is significant distance. Motherland security and drug prohibition are the main needs Global Hawk was designed for. Another very successful drone is the Predator which was also built in the mid-1990s but has since been improved with Hellfire missiles. "Named by Smithsonian's Air & Space magazine as one of the top ten aircraft that changed the world, Predator is the most combat-proven Unmanned Aircraft System (UAS) in the world". The original version of the Predator, built by General Atomics, can fly at 25,000 feet for 40 hours at a maximum airspeed of 120. As we know all these names of drone and how powerful it is. Drone was classified into 4 major types.

1. Multi Rotor Drones
2. Fixed Wing Drones
3. Single Rotor Helicopter
4. Fixed Wing Hybrid VTOL

Multi Rotor Drones is classified also into types based on how many motors is attached to it.

- 1- Tricopter (3 rotors).
- 2- Quadcopter (4 rotors).
- 3- Hexacopter (6 rotors).
- 4- Octocopter (8 rotors).

We have selected the Quadcopter as to be designed, tested, and modified in our project.

1.1: Project Definition.

Quadcopter is a kind of unmanned aerial vehicle (UAV). UAV can generally be defined as a device used or intended to be used for flight in the air that has no onboard pilot. These devices are sometimes referred to as drones, which are programmed for autonomous flight, and remotely piloted vehicles (RPVs), which are flown remotely by a ground control operator. This fact in many cases can result in high maintenance and deployment costs particularly speaking in the industrial domain applications. Some applications implement an autonomous flight mode, however the autonomy here is intended as a simple path planning through several given points. Quadcopter can be used in applications such as aerial recognition, search-and-rescue, industrial monitoring missions among others. Dimensions of quadcopters can vary from the size of an insect to a size of a professional aerial vehicle. Dimensions differ according to the type of application in which this UAV are going to be implemented and the equipment they are taking., quadcopter needs to be equipped with sensors (in most cases they are light) so the quadcopter can be small., where the quadcopter needs to be equipped with camera, sensors, and sometimes weapons, quadcopter needs to be much larger. Camera and adequate software can be used to provide imaging-based automatic inspection and analysis for such applications as automatic inspection, process control, and robot guidance in industry. A quadcopter is a multirotor UAV that is lifted and propelled by four rotors. Quadcopters are classified as rotorcraft, as opposed to fixed-wing aircraft, because their lift is generated by a set of rotors (vertically oriented propellers).

1.2: Project Objectives.

The objective from designing the Quadcopter and make research & consider problem solving and start to do several experiments to approach:

- Develop a wing equipped with legs to be more valuable and more stability to the design that can sit with different application under one design.
- Maximize the flight time for drone with low cost and minor changes in design to develop a better usage for those who are using the drone for long time such as monitoring proposes.
- Understand the design of propeller angels and numbers can create a change in the drone flight efficiency, which can help those are working with the drone to deliver packages or unexpected increase of weight.
- Improve Sensors selection optimization & Analysis of the performance requirements of Quadcopter.
- Studying the changes in the system and get the best valuable result in improving the design based on the experiment that will implements will help the future researcher or drone manufacturers make their drone project with based data can guide them to make the best design without studying the project from zero and make their testing just for the data.

1.3: Advantages of Quadcopter.

There are several advantages to Quadcopter. First, Quadcopter do not require mechanical linkages to vary the rotor blade pitch angle as they spin. This simplifies the design and maintenance of the vehicle. Secondly, the use of four rotors allows each individual rotor to have a smaller diameter, allowing them to possess less kinetic energy during flight. This reduces the damage caused should the rotors hit anything. For small-scale UAVs this makes the vehicle safer for close interaction. Some small-scale Quadcopter have frames that enclose the rotors, permitting flights through more challenging environments, with lower risk of damaging the vehicle or its surroundings.

1.3.1: Environmentally.

Recently, many countries are going in using the 3D printed drone technology. The benefits that drones offer the fields of environmental monitoring and conservation are being realized by an ever-increasing number of researchers, students and environmental engineers. Drones offer quick, easy and cost-effective insights, on demand. Their application meanwhile varies widely. So, we can see United States is the first one of the biggest countries in the world in manufacturing drone.

1.3.2: Economically.

In economic side, our system helps to save money & time by increasing the quality on usage which the most needed in the companies in current time such as marketing delivery. Moreover, it will as replacement of traditional works.

1.4: Project Specifications.

This project is applicable to Quadcopter drone types such as Multi Rotor Drones, Fixed Wing Drones. The parts have been selected for this project which has the specifications as listed in table 1.1.

Table 1.1: The system measurements

Item	Name	Quantity	Weight in grams
1	Lower body	1	251
2	Upper body	1	270
3	Motor holder	4	400
4	Propeller	4	44
5	Lithium Polymer Battery 6000 mAh	1	439
6	Brushless motors	4	124
7	Flysky FS-i6x transmitter	1	18
8	CAM ESP Wi-Fi Bluetooth	1	7
9	Flight controller FC Built-in TCMRC F4	1	26
10	Mini PDB - Power distribution board	1	12
11	TTL Adapter board - Cam Adapter	1	4
12	bolts	4	92
		Total estimated weight	1687 g

How to select our part in the drone?

We have 4 different models; the selection of models will be based on the application of done usage. To select the application, we should know the two words.

- 1- Weight force: is the force of gravity. It acts in a downward direction—toward the center of the Earth. This will be about two part (Model weight and object weight)
- 2- Thrust force is opposite direction of the weight force and in the same direction of the fan (Propeller).

The main component of the drone and the model e used:-

- 1- Brushless DC motor: Crazepony 4pcs BLHeli_32 35A ESC 2-5S Dshot 150/300 / 600/1200 for FPV Drone Quadcopter Multicopter
- 2- Propeller: RCGEEK Compatible with DJI Mavic 2 Pro Carbon Fiber Propellers
- 3- Electronic speed controller: Crazepony 4pcs BLHeli_32 35A ESC 2-5S Electronic Speed Controller
- 4- Lipo battery : Zeee 3S 11.1V 60C 6000mah RC
- 5- Flight controller kit : TCMMRC F4 10V 2-5s
- 6- PDB : ICQUANZX V3.1
- 7- RC (Transmitter & Receiver).: Flysky FS-i6X

Selection of the weight component will assure you the flight of drone. Here important note that total weight shall not exceed the thrust force required.

How we calculate and know the thrust force for motor and propeller?

By Pinch test, the manufacturer will conduct this test on the many propeller and will give you the thrust on each propeller.

The Main parameter affecting the thrust force:

- 1- 3 Parameter in the propeller (Pitch, Diameter, material)
- 2- One Parameter in the Motor (RPM)
- 3- One parameter in the atmosphere. (Air)

I will start with

- 1- RPM:

RPM will be function in two things

A -KV

B -volt in the battery.

This will let me know the RPM for the motor. For example, 600 KV motor powered by 11.1, the max RPM= $11.1 \times 600 = 6,660$ RPM.

- 2- Propeller

The size of propeller will contain two number example 10 x 4.5 inch that mean 10 is diameter of propeller and 4.5 is the pitch. In the theory the diameter is related to Thrust force, if the diameter increased the Thrust force will increase. Also, the pitch related to the speed of the

drone, if we increased the pitch the speed will be increased but the problem if we increase the pitch the turbulent will occurred.

Flight time

Before procured any battery, 3 you need to know

- 1- mAh
- 2- number of C which is the maximum discharge rate can produce by battery
- 3- the Volt, we should know this number to multiply with KV to get the Max RPO like example above.

How we can select the battery?

The main information that you need to know to select the write battery:

- 1- Lip Cells: example in the batter we have 3s that meat 1 Cell = 4.7V so, 3 Cells= $4.7 \times 3 = 11.1V$. that mean you can't apply more that 11.1 volt in this battery.
- 2- Maximum Current: X Number of Motor = Max Ampere required (Battery must deliver this Ampere which is mentioned in the data specification)

HOW TO CALCULATE FLIGHT TIME

$$\text{Flight time}_1 = \frac{\text{battery's capacity in amp hours}}{\text{average amp draw}} \times 60$$

We Land Vehicle at (20%) of battery cap.

AVARAGE FLIGHT TIME = FLIGHT TIME 1 x 0.8

1.5: Applications.

There many purposes of the applications for the project are to be used on:

- Research Platform: Quadcopter are a useful tool for university researchers to test and evaluate new ideas in a number of different fields, including flight control theory, navigation, real time systems, and robotics.
- Investigating Purpose: Since Quadcopter is small in size and light in weight, they can get into places, where people cannot get into like caves, holes and tunnels.

- Shipping and delivery: Major companies in favor of drone delivery. Drones could save a lot of manpower and shift unnecessary road traffic to the sky. Besides, they can be used over smaller distances to deliver small packages, food, letters, medicines, beverages and the like.
- Geographic mapping: Available to amateurs and professionals, drones can acquire very high-resolution data and download imagery in difficult to reach locations like coastlines, mountaintops, and islands. They are also used to create 3D maps and contribute to crowd sourced mapping applications.
- Search and rescue: Drones are able to discover the location of lost persons and unfortunate victims, especially in harsh conditions or challenging terrains. Besides locating victims.

Chapter 2: Literature Review.

2.1: Project background.

Drone now a days has become the future of many businesses and took a huge place to be used by individuals and the government. It still needs a lot of permissions to be used and there is limitation in Saudi Arabia to use it specially inside the city. The challenges start when a company or an individual think of using a drone or test it without official permit which will Cause him to be stopped immediately. Another challenge is when wanting to program the Arduino by the individual himself, he will need a high skill in programming plus a WIFI Arduino which could be unavailable in Saudi Arabia. All the boards and the digitals equipment's that are related to the drones are not available in Saudi Arabia. All equipment's should be bought from amazon or another web site which will take more time to provide all the needed equipment. Batteries are not allowed to be shipped in normal ways; it should be shipped by airplane which will add some extra cost for shipping. Another challenge is having all our connection done in the right way so we don't connect the wrong voltage in the wrong port which can damage the board.

This is the main body which is formed of two main parts upper and lower. it was scaled up in a way that fits the 3D printer to be printed as one piece. To have a dimensions of 30 cm X 40 cm. we avoided making it larger due to the limitation of the printing machine the company will use. If it was going to be larger that mean it will be made into halves then it will be glued which we didn't accept in our prototype.

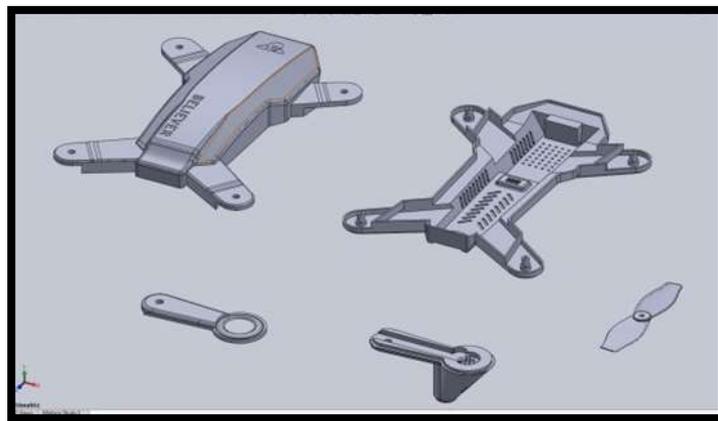


Figure 1

Figure 1 show the body design, that we used before modification

it will be the joint that connect the motor fan with the body to make them fly as one solid part. It was modified to be lighter and empty from inside. The original leg was designed wrongly by not respecting the motor base bolts and the motor shaft area. Also, it didn't consider the weight of it as it was designed to have an unneeded large gear which will add weight on the drone and add load on the shaft. That's why it was modified to work without a gear.

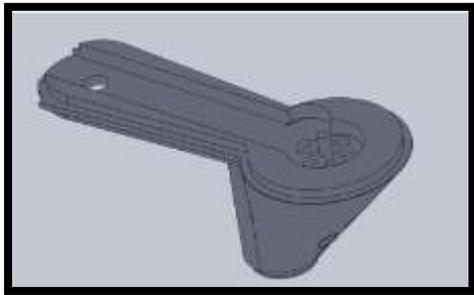


Figure 2

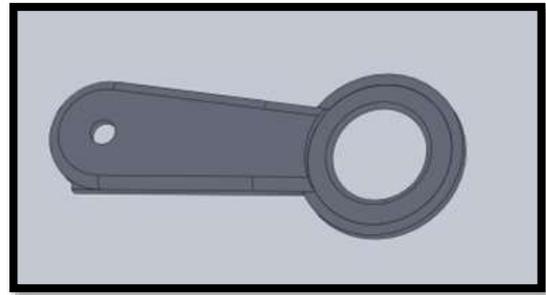


Figure 3

Figure 2 & 3 show that the design of the body holder which we called body leg #1.

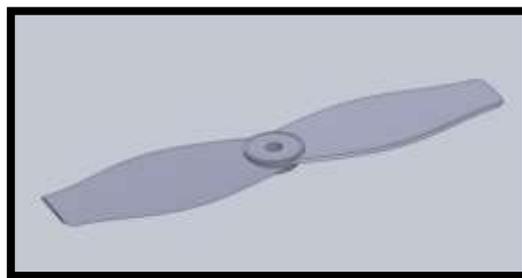


Figure 4

Figure 4 show the propeller was designed to fit in the gear. The central area was modified to be attached directly to the shaft of the motor.

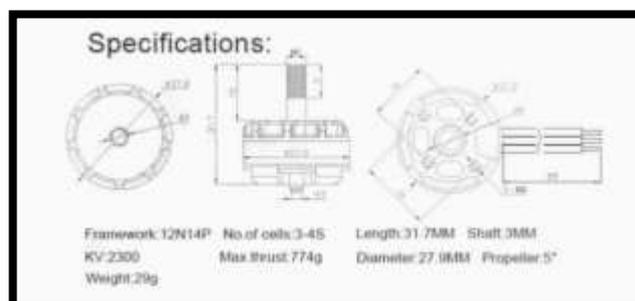


Figure 5

Figure 5 shows the specification for the brushless motor we will use in our drone.

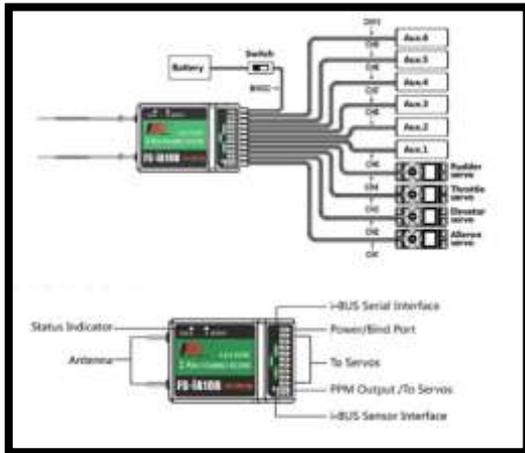


Figure 6

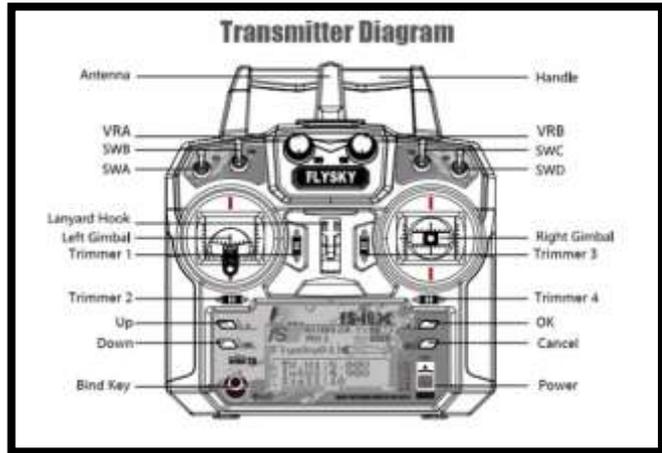


Figure 7

Figure 6 & 7 show that the transmitter and receiver we will use to control the drone

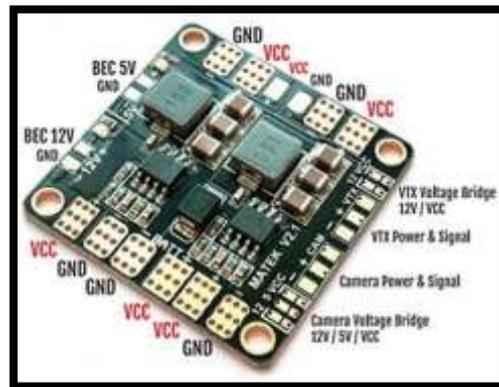


Figure 8

Figure 8 show the board we will use to reduce the power consumption and see how it is going to affect the flight time and drone efficiency.

2.2: Modelling of a Quadcopter dynamics.

This section presents the basic Quadcopter dynamics. The basic idea of the movement of the Quadcopter is shown in the following figure. It can be seen from the figure that the Quadcopter is simple in mechanical design compared to helicopters. Movement in horizontal frame is achieved by tilting the platform whereas vertical movement is achieved by changing the total thrust of the motors. But Quadcopter arise certain difficulties with the control design.

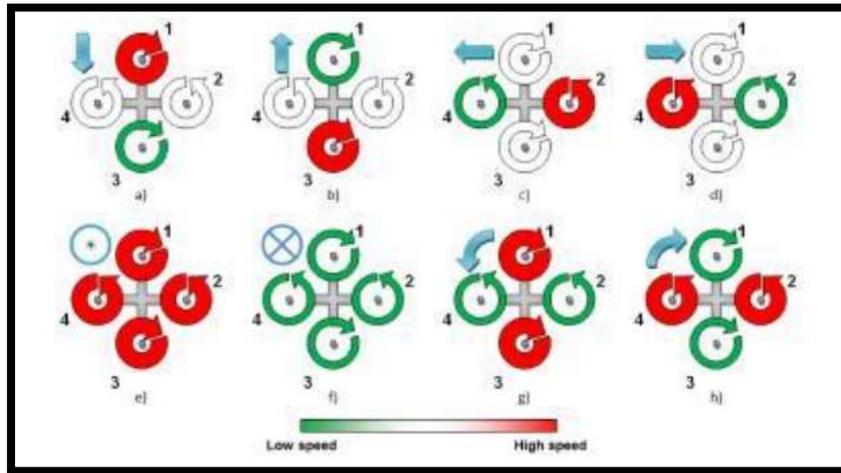


Figure 9: Basic Flight movements of a Quadcopter

A coordinate frame of the Quadcopter is shown in the figure below.

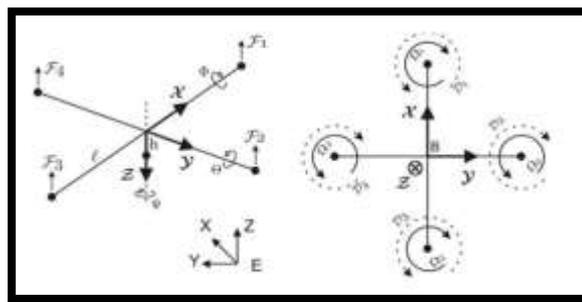


Figure 10: Quadcopter coordinate system

The Quadcopter is designed on the following assumptions:

- The structure is supposed to be rigid.
- The Centre of Gravity and the body fixed frame origin are assumed to coincide.
- Thrust and drag are proportional to the square of the propeller's speed.
- The propellers are supposed to be rigid.
- The structure is supposed to be axis symmetrical
- Rotation matrix defined to transform the coordinates from Body to Earth co-ordinates using Euler angles ϕ - roll angle, θ - pitch angle, ψ - yaw angle.
- About by ϕ , by θ and by ψ

Special attention should be given in the difference between the body rate measured p, q, r in Body Fixed Frame and the Tait- Bryan angle rates expressed in Earth Fixed Frame. The transformation matrix from $[\phi \ \theta \ \psi]^T$ to $[p \ q \ r]^T$ is given by:

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & 0 & -\sin \theta \\ 0 & \cos \phi & \sin \phi \cos \theta \\ 0 & -\sin \phi & \cos \phi \cos \theta \end{bmatrix} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

Moreover, the rotation matrix of the Quadcopter's body must also be compensated during position control. The compensation is achieved using the transpose of the rotation matrix.

$$R(\phi, \theta, \psi) = R(x, \phi)R(y, \theta)R(z, \psi)$$

$$R(x, \phi) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \phi & -\sin \phi \\ 0 & \sin \phi & \cos \phi \end{bmatrix}$$

$$R(y, \theta) = \begin{bmatrix} \cos \theta & -\sin \theta & 0 \\ \sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R(z, \psi) = \begin{bmatrix} \cos \psi & -\sin \psi & 0 \\ \sin \psi & \cos \psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Chapter 3: System Design.

3.1: Design Constraints and Design Methodology.

When we started our design and plan for the project, we faced some challenges that are lack of the parts and hard to have them in short period for our project such as special type of motors and control system to assist the lifting of the design. Moreover, most of parts have been bought from out of kingdom due to they are not available in local market, Furthermore, the different companies that refuse to work in making the design , because they do not have official authority to make it. Finally, one company accept to do the design in shape only without making any programming for the control system and we informed them, that design was requested from PMU for the student of senior graduation project and all experiments will be done inside the campus of the university for developing the movement of drone. However, we should take considerations on the weight of design and focused on the thrust strength of the motor to rise the design without cause any over load so, we can fly it in easily method.

3.1.1: Sustainability.

We may face a problem in terms of sustainability due to chance of little vibration Because the thickness & angle of the blades of the fan and to avoid this problem, we used smaller fan with high efficiency to be suitable with the motor movement in the thrust.

3.1.2: Safety.

One of the important of our system is safety of parts. keeping the motor running not over loaded, this will increase the efficiency of the quadrat rising and keep the movement of the fan stable.

3.1.3: Ethical.

This project almost looks like the previous kind of works. So, we searched to get some general ideas to improve the design by our own ideas in terms of safety, economically, and sustainability.

3.2: Design Engineering Standard.

Engineering standards should be followed in each components of our system. In this section, we described each component that have been selected for our project.

Component	Engineering standards	Details
Lithium Polymer Battery 6000 mah	Capacity of 6000 mah - cell number 3S	Power supply for our drone
Brushless motors	2300kv with 1025 MAX thrust	Motors to rotate the propeller and left the drone
Flysky FS-i6x	2.4 ghz : 10 Channels	To control the drone wirelessly.
Electronic speed controller	35 a	Speed controller
Flight controller FC Built-in TCMMRC F4	10V, 2-5s.	To monitor the drone operations
Propellers	5 inch glass made propellers	To generate the thrust power.
CAM ESP WIFI Bluetooth	2MP	To transfer the vision
Mini PDB - Power distribution board	3-6s - 5 and 12 Volt	To reduce the power consumption

3.3: Theory and Theoretical Calculations.

The calculation of the Quadcopter based on seven factors which given as:

1. Force and moments.

$$F_i = K_f \times \omega_i^2$$

$$M_i = K_m \times \omega_i^2$$

$$M_y = (F_1 - F_2) \times L$$

$$M_x = (F_3 - F_4) \times L$$

$$\text{Weight} = mg$$

2. Newton's second law of motion.

* for linear motion:

$$\text{Force} = \text{mass} \times \text{linear acceleration.}$$

* for rotational motion:

$$\text{Torque} = \text{Inertia} \times \text{angular acceleration}$$

3. Hover condition.

$$mg = F_1 + F_2 + F_3 + F_4$$

$$\text{All Moments} = 0$$

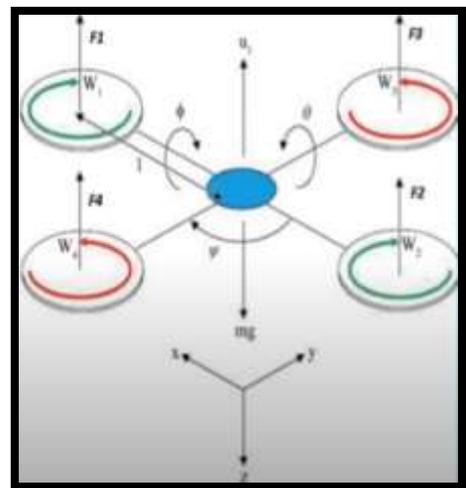


Figure 11

4. Rise motion.

$$mg < F_1 + F_2 + F_3 + F_4$$

$$\text{All Moments} = 0$$

5. Drop motion.

$$mg > F_1 + F_2 + F_3 + F_4$$

$$\text{All Moments} = 0$$

6. Yaw motion.

$$mg = F_1 + F_2 + F_3 + F_4$$

$$\text{All Moments} \neq 0$$

7. Pitch and Roll motion.

$$mg < F_1 + F_2 + F_3 + F_4$$

$$\text{All Moments} \neq 0$$

3.3.1: Thrust Application.

Thrust is the force which moves an aircraft through the air. Thrust is used to overcome the drag of an airplane, and to overcome the weight of a rocket. Thrust is generated by the engines of the aircraft through some kind of propulsion system.

How to calculate thrust for motors?

Basic Life Formula - Ball Bearings

$$\text{Life in Hours} = (C/P)^3 * 10^6 = (C/FY)^3 * 10^6$$

Terminology:

- C = Thrust rating from chart for 10^6 revolutions of life.
- F = actual thrust applied plus weight of rotor.
- Y = Bearing thrust factor from chart
- N = RPM of motor.

Theoretical calculation for selecting out motors thrust power:

Weight of Drone = 1700 g

Calculated weight = 2 X 1700g = 3400g

Total weight = 3400 + 20% = 4080 g

Thrust for each motor = 4080 / 4 = 1020

So each motor must be able to generate a thrust power of 1020 g

Based on our calculation

We have selected the motors with the required thrust specification which is equal to 1024g. see figure 12

Specification
KV: 2300kv
Weight: Approx. 30g with wires
Wire AWG: 20AWG
Stator Diameter: 22mm
Stator Height: 5mm
Shaft Diameter: 3mm
Configuration: 12N14P
Motor Diameter: 27.9mm
Motor Height: 31.7mm
Prop Adapter Shaft Thread: M5
Input voltage: 3S-4S (12.6 - 16.8v)
KV2300 With HQ5045 BN Max.thrust:1024g
Package included
2 * EMAX R52205 2300KV Brushless Motor (CW)
2 * EMAX R52205 2300KV Brushless Motor (CCW)

Figure 12

DUCTING EFFECT ON PROPELLER EFFECIECNKY AND THRUST

According to Bernoulli's equation, the pressure is low where the airspeed is high, and high where the airspeed is low in the case of a flat sheet or aero-foil. In the case of aero-foil, the speed of the air passing at the upper portion is high causing the pressure drop as compared to the bottom portion of aero-foil where the pressure is higher. This effect causes the aero-foil lift due to pressure difference.

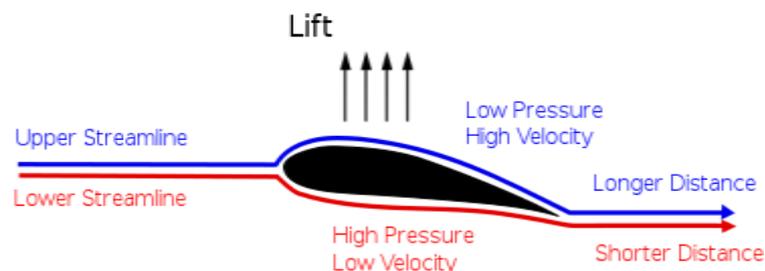


Figure 13: Aero-foil design and profile

The construction of the propeller consists of several blades that are attached to the hub or boss. The attachment is done by either forging or welding. The blades/ aero-foils are at an inclined angle and organized in such a way that the blades are rotated in any direction depending upon the way the thrust should come out. These blades behave like a wing moving through the air causes lift when the air streamlines passing through wing air will be deflected down and the reaction will cause lift of a wing. Propeller works on the principle of Newton's third law of

motion that “Action and reaction are equal in magnitude but opposite in direction”. According to Bernoulli, the air passing at the top portion of the aero-foil moves quickly as compared to lower portion causes the pressure drop at the top portion.

This effect is another cause of aero-foil lift. Propeller blades block the flow of air moving from top to bottom and spinning due to centrifugal force. When the air from the higher pressure region (bottom portion) to the lower pressure region (top portion) it causes the vortex creation at the tip of aero-foil where the high and low-pressure mixes and causes heated the air and noise is created due to molecular movement of air, hence making noise, and a large amount of energy is wasted. To prevent the formation of vortex we provide a fence against the blades, prevent the mixing of high-pressure air with low-pressure air. However, the energy that is previously wasted into vortex creation is now used in the lifting of aero-foil, because of protecting it from mixing and causes stronger lift. There are two ways of increasing the efficiency of the propeller by placing it in a duct.

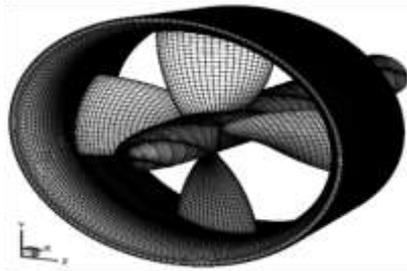


Figure 14

When the propeller is placed inside the tube it will prevent vortex formation because the gap between the tip of the aero-foil and the wall of the tube is very small and little leakage occurred. Due to this construction the efficiency of the propeller in a duct increase. Therefore, the propeller operating in the duct is more efficient than the propeller working in the free region. The second way is to make a curved portion at the edges of the duct, hence causing more lift. The curve portion looks like an annular wing at the top of the duct. The air passing through the annular wing/ curve portion is very quick causes the low-pressure region near the curve. The pressure behind the curve portion of the duct is normal atmospheric pressure because no air is moving behind the curve portion. Due to the pressure difference, the whole duct will move forward and causes it to lift the whole duct. It will cause the aero-foil lift in the forward direction as that of the propeller itself without any expense, no input energy is used, and get more free energy thus increasing the efficiency of the propeller. The combination of lip (Annular wing) and the duct itself increases the performance of the propeller. If the clearance between the duct and the tip of the blade is too much it will cause the turbulent flow around the tip of the blade and hence much power is a loss. This gap should be kept very small.

3.3.2 : Brushless motor and reason for using it instead of normal motors.

Brushed DC motors depend on a mechanical system to transfer current, while AC and brushless DC gear motors use an electronic mechanism to control current. We used brushless motor instead of normal motors due to the following:

- 1- Motor Construction: see figure 15 for more explanation

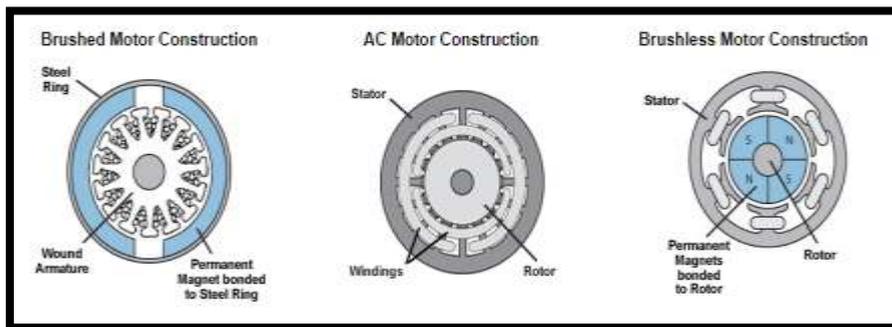


Figure 15: shows the motor construction

- 2- Efficiency: in figure 16, we can see the different efficiency between DC & AC motors.

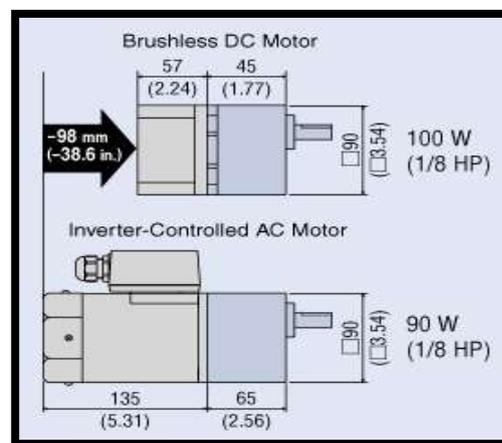


Figure 16

- 3- Service and Maintenance:
- 4- Speed Stability.
- 5- High Speed Operation: As shown in figure 17

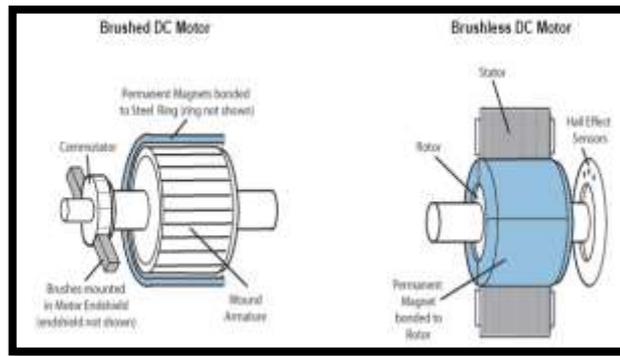


Figure 17

3.3.3: Calculation thrust for motors.

Thrust for motors is calculated by following procedure:

1. First of all, calculate the weight of drone including the objects that will drone carry during its flight. Multiply the weight of drone by two to determine the minimum thrust. Again add 20% of this calculated weight to get total weight.

$$\text{Calculated weight} = 2 \times [\text{weight of drone} + \text{weight of carried objects}]$$

$$\text{Total weight} = 2 \times [\text{weight of drone} + \text{weight of carried objects}] + [0.2 \times \text{calculated weight}]$$

2. And finally divide total weight by number of motors

$$\frac{\text{calculated weight} + [0.2 \times \text{calculated weight}]}{\text{Numbers of motors}}$$

3.3.4: Power Lift Calculation.

When a body move through a fluid, fluid always apply a force on the surface of the moving body. Lift is one component of that applied force. Lift always applied perpendicular to the direction of motion of the object. On an airfoil shape moves through the air, the stream lines on the upper side of airfoil are closer than the lower side of the airfoil. According to the where streamline are closer, pressure will be lower. This pressure difference creates a lift. Power of lift is calculated by the following formula:

$$\text{Power of Lift} = CI \times \frac{\rho \cdot V^2}{2} \times A$$

Where 'CI' is lift coefficient, ρ is density of fluid, V is speed of moving object and arear of wing.

3.3.5: Flight time calculation formula for our drone.

Time of flight can be calculated by using following formula

$$\text{Time of flight of drone} = t = \frac{\text{Battery capacity} \times \text{Battery discharge}}{\text{Average amp.}}$$

Where 't' is the time of flight in hours. To get time of flight in minutes divide it by 60.

Average Amp are amperes of batteries.

$$\text{Time of flight of drone} = t = \frac{\text{Battery capacity}(60) \times \text{Battery discharge}(11.1)}{\text{Average amp}(100)} = 6.6 \text{ hours}$$

3.3.6: Relation of Power consumption in drone and number of propellers blades.

Number of propellers blade vary according to the situation of carried load. Higher number of propellers blades will make an addition to the carried load. As weight of drone increases the power consumption of drone will also increase. Smaller blades are installed on smaller motors having high KV rating. Larger fan blades are installed with motors which have low KV rating.

In figure 18, it explains how the propellers works in the drone.

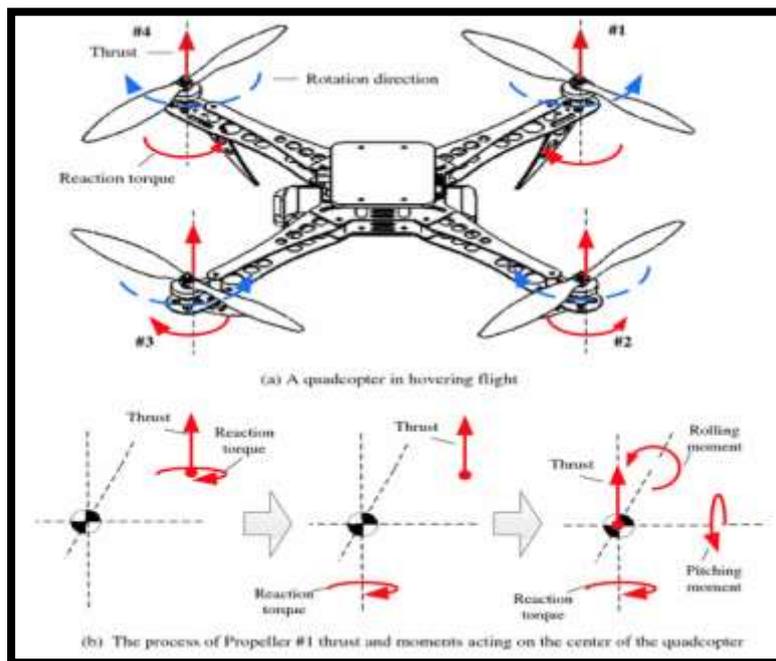


Figure 18

3.3.7: making graph and data table of thrust power and power consumption to get flight time data.

Power consumption of a drone can be calculated by the following formula:

$$\text{Power consumption} = \text{Battery capacity} \times \text{Battery discharged}$$

By taking power consumption on y-axis and average amperes on x-axis a graph can be drawn.

The slope of this graphs will give time of flight of that drone.

3.3.8 Stability and body rigidity.

When building drone, two rules should be taken in consider having a stable flight.

- 1- The first rule is to have a rigid body.

If the body were fixable. Flying won't be stable and the drone will face a lot of unbalanced movement and angular movement.

A rigid harness support should be added to the drone if the body were fixable as it is low cost solution and highly increasing the stability and rigidity.

- 2- The harness support we used in our drone is designed as X shape. Made of Fiberglass and has a 5 mm thickness. It is two supports one on the top and the other one is at the bottom all tightened through the fixable plastic drone body by long 8 bolts.
- 3- The second rule is to have the flight controller board installed and attached completely in the body where it doesn't move or tilt while flying and moving the drone, because once it tilt slightly it will react by increasing the motor power to be in the level that it was celebrated in.

Chapter 4: System analysis and testing.

4.1 Programming and celebration.

This is the celebration of the fly sky shown in the flight controller using beta flight program.

- 3D model simulation should be stable as you can test and simulate the controlling of the drone here in this window in Figure 19.

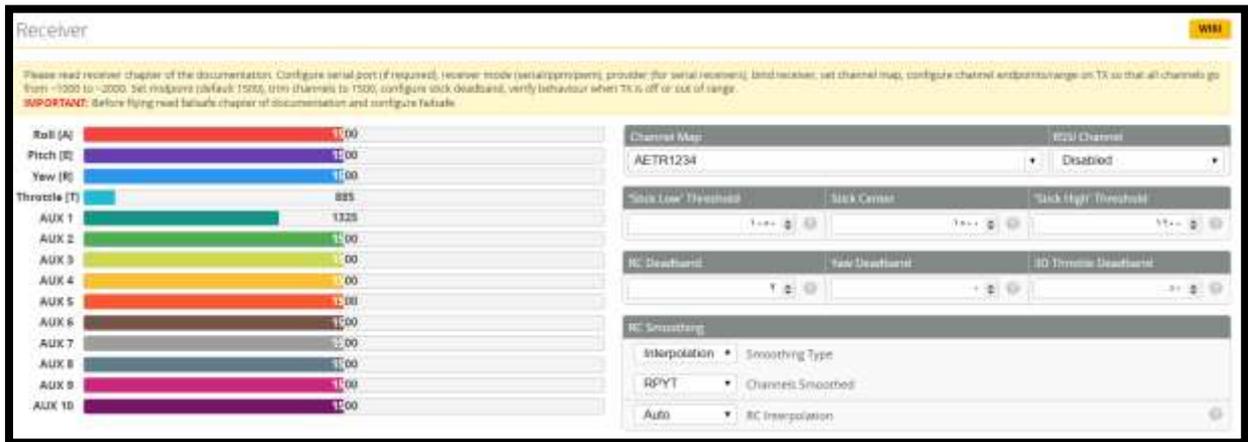


Figure 19: 3D model simulation can test and simulate the controlling of the drone

4.2 PID Profile setting.

After making the drone stable and test the simulation. Movement of the drone would be very fast and the sensitivity would react strongly. So the setting should be modified and calibrated as the user wishes to use the drone. If it was for racing and expert drones, keep the setting as shown in Figure 20.



Figure 20: setting modification and celebration that used in drone

But if it was for beginner users, we recommend to change the setting to the following data to make it easy to be controlled as shown in figure 21.

PID Profile Settings		Rateprofile Settings		Filter Settings	
	Proportional	Integral	Derivative	Feedforward	
Basic/Acro					
ROLL	±V	T=	I=	D=	F=
PITCH	±V	I=	D=	F=	
YAW	T=	I=	D=	F=	

Figure 21

Make sure your drone is on level and if it is not level. Press on calibrate to make the flight controller understand that this is the normal level for the drone to be land. See figure 22.

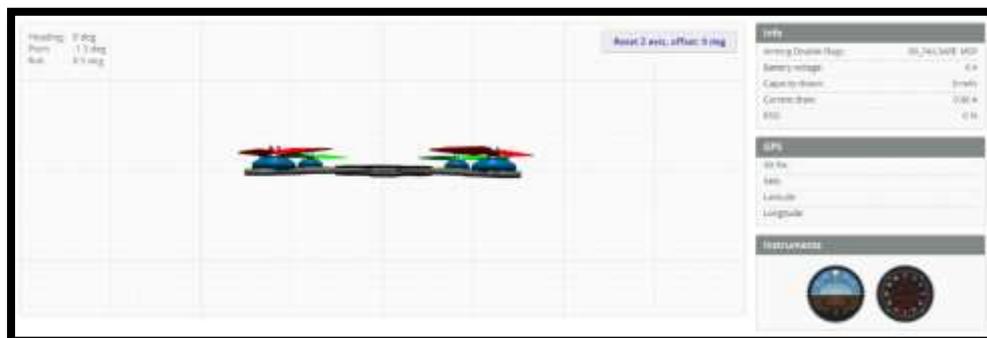


Figure 22:How to make balancing of the drone in on level

4.3: transmitter setting .

For using the transmitter Flysky, use the following set up to make it working with you receiver.
As shown in figure 23-1, 23-2 & 23-3

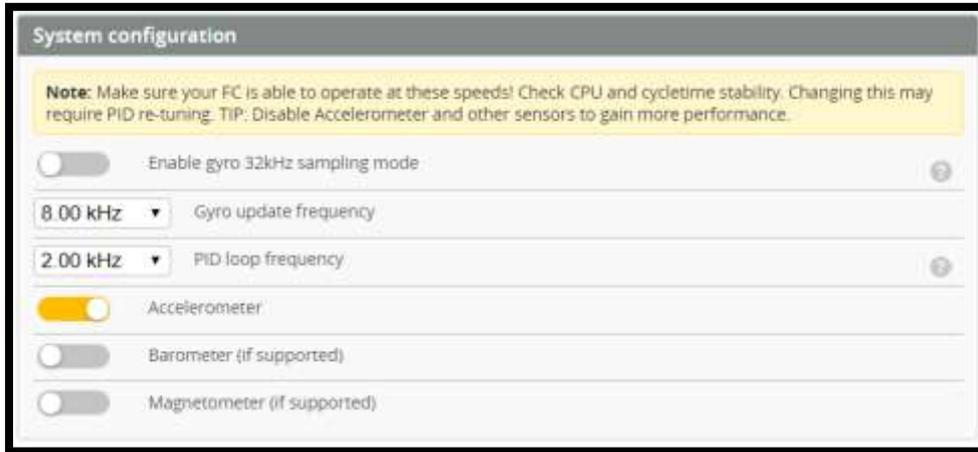


Figure 23-1

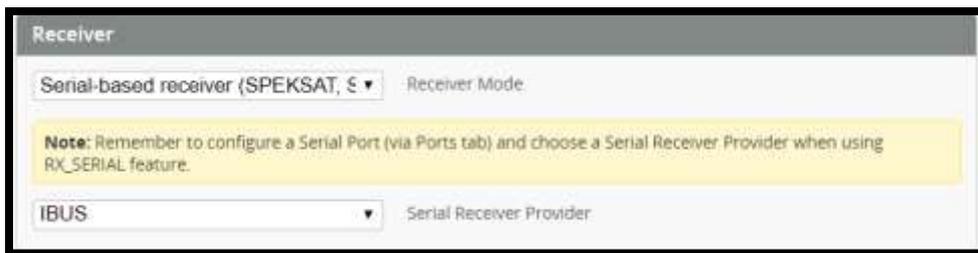


Figure 23-2

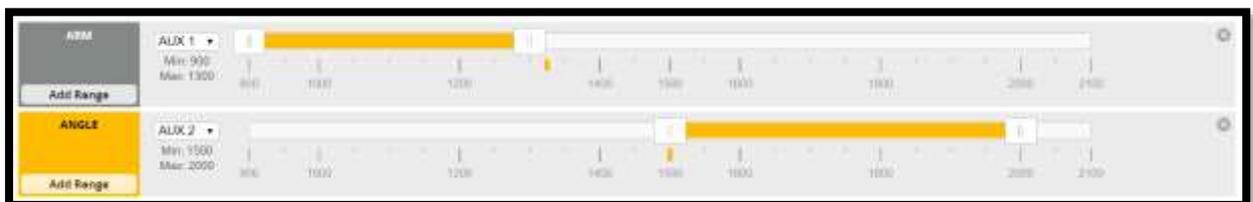


Figure 23-3

Chapter 5: Project Management.

The purpose of this words is to share experiences on our project in management part. begins by identifying some of the early issues examined and how these studies helped identify and explain some of the underlying managerial and theoretical foundations of project management.

5.1: Choosing the project.

As part of PMU strategies in improving the development for the senior project that assign their doctors to make proposal for making researches and experiments by their students to show their achievement during the studying period in the university. Our project was guided by Assistant Professor Dr. Nassim Khaled and when we see the proposal of the project, it was very interested to us because this project has combined of our major that is mechanical Engineering and matching with the control system technologies in the same time which has recently a lot of usage in different application in the world.

5.2: Scheduling and Planning.

Each project to be implemented should have study plan and to be succussed must be developed, starting from the first step that will be taken. However, to process our project that have four members in the team and due to Covid-19 pandemic, we distributed the tasks between us as following:

Member name	Task
Abdullah Al-Hamdan (Group leader)	Review all activities that given to the members, follow the Gannt chart strategies, link between the members and our advisor, prepare online meetings to see and discuss where the member stands on. Make some Cad designs, Review the reports and make submission as the last station of the team.
Nedaal Bembi	Requesting materials, manage the budget, make communication with the companies to receive the parts. Make designing & report for the task that assign to him. Assigned to get course in control system and make knowledge transfer to the remain team to work together in programming of control system of the drone.
Abdul-Khaliq AL-Shamrani	Assist with Nedaal as back up, make the reports in part that assign to him, make Cad designing in some parts that needed. Fill the monthly progress reports and send it to group leader to be reviewed.
Ibrahim Al-Hayaz	Make reports in part that given to him and assigned to search for all calculation data of the drone to be used in our project and reliance on it in application mode while doing experiments references.

However, all the members were attended the experiments to get the result and see the progress inside PMU campus after we got the approval from mechanical engineering department as part of the planning and management due to the sensitivity of flying of the drone required government authority approval.

5.3: Project materials and Badgat.

In the table below, we can see the actual paid cost in SAR which is 7138.5 and our estimated cost for the project is 10,000 SAR.

item	name	price
1	Printing 3D model + modifications + rebuilding	5000
2	Lithium Polymer Battery 6000 mAh	300
3	4 Brushless motors x3	763
4	Flysky FS-i6x	64.5
5	Electronic speed controller x2	350
6	Flight controller FC Built-in TCMMRC F4	114
7	Carbon fiber propellers x2	198
8	5 inches glass propellers	68
9	CAM ESP WIFI Bluetooth	65
10	Battery charger	53
11	Weight scale	50
12	Mini PDB - Power distribution board x2	91
13	TTL Adapter board - Cam Adapter	22
total		7138.5

Chapter 6: Project Analysis.

6.1: Experiments and results.

6.1.1: EXP #1: using 5-inch propellers made from glass.

Experiment #1 shows Fail in lifting the drone and making it able to be flying and it shows a small high which is approximated by 0.25 m.

That is why we decided to change the propeller to 6 inches made from carbon fiber.

6.1.2: EXP #2: using 6-inch propellers made from glass.

Experiment #2 showed a good and significant lifting for our drone, but the drone was experiencing a rotation on its self as the celebration weren't completed and it showed a angler unbalanced lift due to the flexible body.

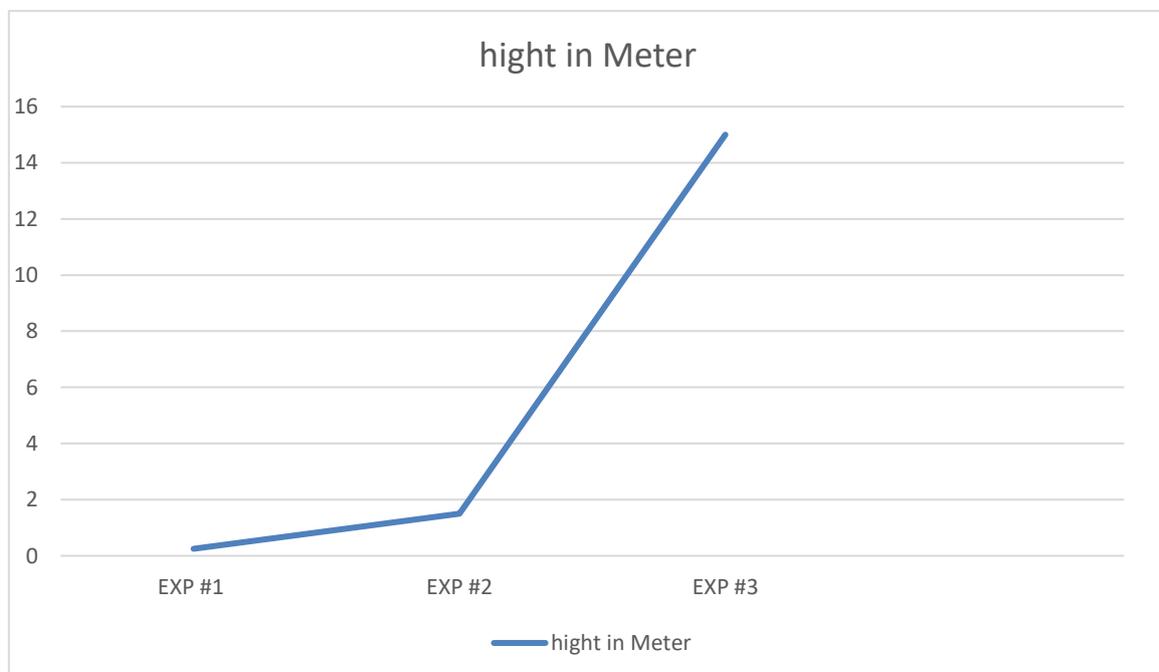
Due to that mistakes, our drone hit wall of the university when it was out of control.

6.1.3: EXP #3: using 6-inch propellers made from glass.

After recalibrating and adding the fiberglass supports to increase the rigidity, our drone fly into more than 13-meter-high and had a stable flight on the air.

But when it was landing it crushed and it experienced lots of damages.

So, we decided to celebrate the movement and to reduce the reacting sensitivity to make the controlling easier.



6.2: Lesson learn.

- Make sure to use the suitable length of motor base bolts. If the bolt were too long it might smash the winding wires inside the motor generating high heat or damaging the whole motor.
- Make sure to use open area for the motor to make it able to be cooled by the flow of air it generates from rotation.
- Make sure to use high melting temperature material on the motor area to prevent it from being melted due to the heat that comes from the motors.
- Do not use large propellers with high KV motors as it could burn the motor. Make sure to use the recommended size and to track and monitor the current it uses.
- Select Speed controller that is larger than the motor capacity by 5 to 10 A to prevent it from getting burned if the motor were working on its maximum efficiency.
- Avoid making threads using 3D printing - PLA plastic. It is very soft material where the threads.

Conclusion:

The main intention of our project is to familiarize ourselves with the complete design process from engineering requirement to finalize the product. our goal to make a design of a quadcopter which can be used in the market for commercial use. With the support of our advisor we have the resources and technical knowledge to complete this project successfully. We chose the quadcopter for our UAV design since it has interesting design elements and potential for marketable gains. At this point the project could go in a variety of directions since the platform seems to be as flexible. This flexibility allows changing the functions it performs and also allows integration of any technology that would prove to be useful. This project will clearly demonstrate the goals of proving that small scale UAVs are useful across a broad range of applications.

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