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ELECTRICAL AND MECHANICAL ENGINEERING

DESIGN AND FABRICATION OF MORPHING DRONE

A PROJECT REPORT

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PESHAWAR ROAD, RAWALPINDI

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ABSTRACT

This paper describes a novel quadcopter design that has the ability to morph i.e., change its shape. It uses rotary joints to quickly change the shape of its wings without the need for extra actuators. The normally rigid connections between the quadcopter's arms and its central body have been replaced with spring hinges that allow the arms to fold down when the propellers aren't generating close to maximum thrust. This makes the largest dimension of the drone about 50% smaller. The drone can change its size while it is flying, but to achieve this maneuver pilot must have solid grip over quadcopter controls. This makes it possible for the quadcopter can fit through gaps that a quadcopter that doesn't change size couldn't. The quadcopter is designed such that existing quadcopter controllers and algorithms for making and predicting trajectories can be used while also reducing the amount of time it takes to switch between configurations and fly with utmost stability.

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CHAPTER 1

INTRODUCTION

When referring to unmanned aerial vehicles, the term "drone" is often used. However, in Europe, it is more generally referred to as Remotely Piloted Aircraft Systems (RPAS). Another way of saying this is a type of aircraft that does not require an onboard pilot to fly. There have been several uses for drones from their first use in the mid-1800s, including photography, security, safety and environmental protection. Defense-related robots might have a huge influence on everyday operations including transportation, communication, agriculture, disaster relief, and environmental preservation. These robots are commonly connected with military applications. In spite of this, combat is to be credited for the advancement of drone technology. A number of countries' militaries were among the first to realize the advantages that drones may bring to military operations, and they immediately began pushing to grow the drone business.

As far back as the mid-1800s, military forces throughout the world have been using drones for everything from training and target practice to airstrikes and bomb detection. The Austrian Navy captured Venice in 1849 by using 200 incendiary balloons. In the early 1900s, the US military began investigating the use of drones to construct training targets [1].

There were unmanned airborne warfare vehicles written about by Nikola Tesla in 1915. A.M. Low built the first self-propelled drone for use as an aerial target in 1916. The first pilotless torpedo was developed by the Dayton-Wright Airplane Company during World War I. [2] An unmanned aerial torpedo and the Hewitt-Sperry automatic plane, both developed after World War I, helped propel drone technology ahead. Before 1935, most of the military's work on remotely flown vehicles was done, but actor and model aviation enthusiast Reginald Denny was the first civilian to do it [3]. drones were used by both Allied and German troops to teach aero plane gunners during World War II [4]. Drone designers began employing jet engines after World War II in technology like the Australian GAF Jindivik and the Model 10001 produced by Beechcraft for the U.S. Navy [5]. They were accurate in 1960, when Ernesto "Che" Guevara wrote these remarks, “One of the favorite arms of the enemy army, supposed to be decisive in modern times, is aviation. Still, it had no use during the time that guerrilla warfare is in its starting stages, with lesser men in rugged places. The utility of aviation lies in the systematic destruction of visible and organized defenses; and for this there must be large concentrations of men who construct these defenses, something it is nonexistent in such warfare.” [6]

The idea of intervening into the places as inhospitable as irradiated zones, in the depths of the sea, or on distant planets without danger propagated after the discovery UAVs. In 1964, the engineer John W. Clark produced a study of “remote control in hostile environments”: “When plans are being made for operations in these environments, it is usual to consider only two possibilities: either placing a machine in the environment or placing a protected man there. A third possibility, however, would in many cases give more satisfactory results than either of the others. This possibility employs a vehicle operating in the hostile environment under remote control by a man in a safe environment.” A remote-controlled machine or what Clark coined an uncomfortable neologism from ancient Greek origins may be used in place of deep-water divers or autonomous devices “telechiric machines,” or “technology of manipulation at a distance.” [7]

After scanning the situation from above, the drones were able to quickly identify the anti-aircraft batteries and communicate that information to the Israeli fighter jets, who promptly destroyed them. Other uses for the drones included: After a terrorist bomb detonated in October 1983, the [U.S.] Marine Barracks in Beirut was devastated, and General Kelley travelled discreetly to the site. There was no advance notice of his presence. Live television photos of Kelley's arrival at the barracks were viewed by Israeli intelligence operatives across the border. It was so close that they could see the hair on his bald head in the cross hairs. The stunned Marine general heard the audio being played back by Israelis in Tel Aviv hours later. They said that a Mastiff RPV hovering above the barracks was transmitting the scene [8] “To me, the robot is our answer to the suicide bomber.” Bart Everett [9]

Former CIA director Leon Panetta said of armed drones, "It is very precise, and it is very limited in terms of collateral damage." [10] "Collateral damage" and "discrimination" are frequently cited as reasons why drones are more effective than conventional weapons. 2 There is a genuine nest of mental confusions under that cliché. "It's imperative that we do this methodically and precisely."

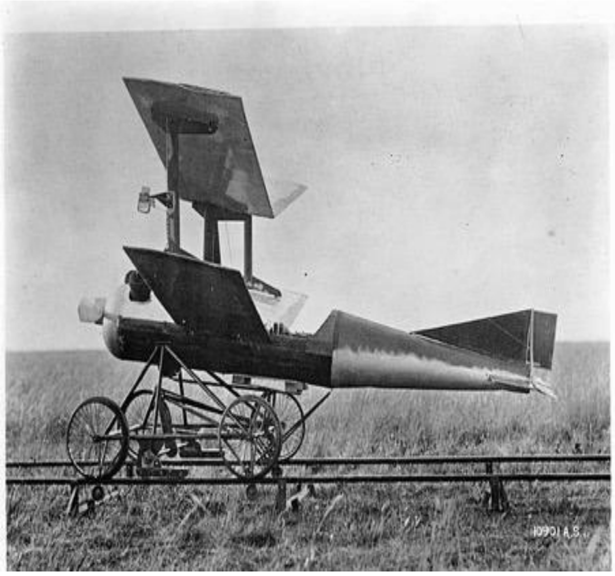


Figure 1 First Pilotless Torpedo

Figure 2 American U-2 spy plane

US. Air Force began employing unmanned aircraft to reduce pilot casualties over hostile terrain in the early years of Vietnam War [11]. After the Soviet Union shot down an American spy plane in 1960, investors continued to pour money into drone technologies [12]. US government invested in and employed in Vietnam drone technology to help with naval missions by the late 1960s, however most of these missions were classified. As a result of all the pilots who had gone through those missions, it was a good notion to employ unmanned aerial vehicles at that time period. All of the pilots who were going to be involved in the reconnaissance flights would have been saved if the planes could be remotely controlled instead of being flown by the pilots themselves.

Till 1980 and 90, that the U.S. military began heavily investing in the technology. The U.S. Defense Department told the AAI Corp and Israeli Malat contracts in 90s decade to develop new drone technology, which produced less costly technologies. In the mid-90s, the U.S. government began The Predator program, which resulted in the MQ-1 Predator [13], equipped with a Hellfire anti-tank missile on its wings. It paved the way for the MQ-9 Reaper in 2007.

The first use of drones for non-military ventures started in 2006, the same year the Federal Aviation Administration issued its first commercial drone permit [14].Government agencies quickly began testing drone technologies for disaster relief and border surveillance while corporations began using them for commercial applications like pipeline inspections, crop evaluation, and security. Further advances allowed a drone with 4 or more rotors to be controlled by adjusting the speed of individual rotors. Improving the stability of multirotor aircraft opened new possibilities for them to be used in several ways.

Quadcopters were among the first VTOLs (Vertical take-off and landing) aircraft. Earlier helicopters used tail rotors to counterbalance the torque generated by a single, main rotor [15]. This was ineffective and wasteful. To solve the problems that helicopter pilots had with performing vertical flights, engineers developed quadcopters. The first quadcopter was the Omnichen 2. It was invented by Etienne Omnichen in 1920. This aircraft flew a recorded distance of 360 meters and made over 1000 successful flights [16]. The Convertawings Model A quadcopter appeared in 1956. This quadcopter was designed by Dr. George E. Bothezat. The Convertawings Model A quadcopter was the first to use propulsion to control an aircraft’s yaw, pitch, and roll. In 1958 the Curtis Wright Company developed the Curtis Wright V27 [17].

Technology has advanced quads and drones dramatically. In the past ten years, companies such as Heli-Max, Blade, Walker, Parrot, and DJI have produced micro and nano drones that use up-to-date computer technology for aerial photography and flight control. Remote-controlled drones and quadcopters have qualities that make them popular among enthusiasts and they gain new qualities almost every day.

Quadcopters have the characteristics of co-axial and pitched helicopters. Pitched helicopters are wind resistant and agile and co-axial helicopters are more stable because they depend on two layers of rotors. Quadcopters are a comfortable combination of both. Three-axis gyro technology stabilizes many of the latest quadcopters. Quadcopters are agile, but steady and they are perfect devices for aerial operations.

Figure 3 A common quadcopter design

A wide range of sectors are being disrupted by quadrotors, from agricultural and transportation to security, infrastructure, entertainment and search and rescue. They are able to move through intricate constructions, assess damaged buildings, and even explore subterranean tunnels and caverns because of their mobility and hovering capabilities. Current quadrotors, on the other hand, do not have the flexibility to adapt to a variety of flight circumstances and duties, as is the case with birds [18]. drone shows a simple quadcopter while to the five she was at DJI Mavic drone. This Mavic drone specializes in surveillance and quiet operation. it is easily available in the market. It has been used in the army as well as by drone enthusiasts for the purpose of reconnaissance, recreation, or simple learning of flight controls of drone.

Figure 4 DJI Mavic drone structure

This would provide useful in complex scenarios, such as rescue and rescue missions or inspection of complex structures. For example, pigeons and swifts adapt their wing surface by folding to optimize gliding efficiency over a broad range of speeds. Pigeons have also been shown to choose different morphologies of their wings to negotiate gaps of unusual sizes: they fold the wings upward to negotiate relatively large vertical gaps and fold them tight and close to their body to traverse narrower gaps [18]. In a similarly drone could fold only when it has to fly in very cluttered environments [19]. In this way negotiation of narrow gaps can be achieved without miniaturizing the drone with consequent trade-offs in terms of flight time and payload. However, morphing quadrotors where the relative position or orientation of propellers can be or the use of tiltable. modified during flight in order to extend the flight envelope remains a largely unexplored topic. The optimization of the relative orientation of the propellers [20]. rotors have been investigated to increase the controllability of hovering platforms [21]. Although these approaches facilitate the execution of complex trajectories and manipulation tasks, they do not entail significant shape change of the frame.

Quadrotors with frames that morph during flight have been investigated by Zhao et al. [22], Desbiez et al. [23], Riviere et al. and Zhao et al. [24] in order to negotiate narrow gaps or grasp objects, each with their own advantages and trade-offs. For example, the robots of Desbiez et al and Riviere et al can only fold into a narrow and elongated configuration, which allows flying through narrow vertical gaps, but hampers the negotiation of tight horizontal gaps. Another example is the morphing aerial vehicle composed of four serially connected links equipped with propellers proposed by Zhao et al, this robot is specifically conceived to wrap around objects and grasp them without the need of additional gripping device.

Figure 6 River et el drone

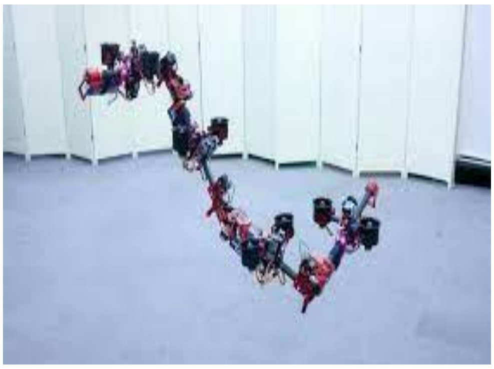


Figure 5 Zhao et el drone

A variety of morphologies are depicted in Figure 6 and Figure 5 Zhao et el. Quadrotor applications can be broadened through the use of simple morphing processes and adaptive control systems. Research in this area might be shifted toward developing unique morphing aerial vehicles. However, there are still a number of unanswered research concerns, including autonomous morphology selection, exploiting morphology for superior high-speed flying, bio-inspired mechanical designs, and employing morphology to attain high altitudes or regions where conventional drones cannot take off. The proposed design is focused on a drone that can be morphed mid-air for the purpose of midair deployment. It is designed to be encapsulated so that it can be launched by a mortar or a carrier.

1.1 T,H & O Morphologies

There is some work being done on the morphological design with the drones already, which includes some morphologies which are in the X(horizontal) plane. Quadrotor with morpho-functional folding capabilities. These transitions are done by folding the arms in the horizontal plane by the use of a large number of actuators which not only adds weight and complexity to the control the drone, but it also makes the drone unstable and less responsive the sudden changes in the control. This design was still a huge innovation in the field of drone technology as they allow the drone to be moving through narrow gaps and showing the possibility of the operation of drones while working on two wings, and at complex orientations. There are several task-specific morphologies that the drone may adopt from its typical X form:

i. To fly over tight vertical gaps, the H design is used.
ii. flying across horizontal gaps in a completely folded drone form.
iii. T-shape for vertical surface examination in close proximity.

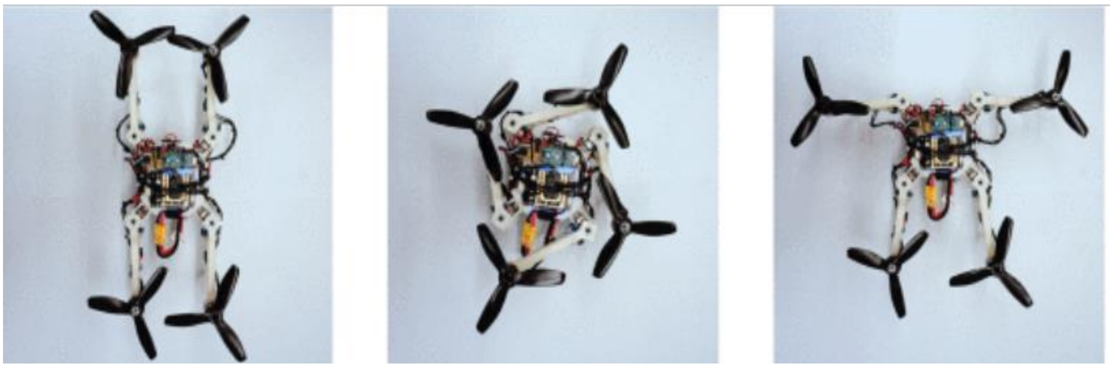


Figure 7 T,H & O Morphologies (from left to right)

The first parameter we are interested in is the flight time each configuration can provide. Since flight in dynamic conditions is highly influenced by the kind of trajectory the vehicle flies, we performed our tests in hover conditions. In this regard, we let the vehicle autonomously hover while logging the battery voltage. We performed 10 trials for each configuration using a fully charged, 3-cells, Li-Po battery. It is well known that the discharge curve for LiPo batteries is linear only within a certain region [25]; therefore, we only considered such a region to compute the flight time. As expected, the X configuration can provide the best results and allows the vehicle to hover on average for 253 s. Changing the morphology of the drone causes a drop in the hover time of around 17%, 23%, and 63% for the H, T and O configurations, respectively. In the H configuration, this loss of endurance is partially due to the overlap between propellers. As shown in [30], when two propellers overlap, the thrust produced by the lower one depends on the vertical offset with respect to the upper one and the percentage of overlap. Our foldable quadrotor has a vertical offset between propellers of 2 cm. In the T and H configurations, the overlap is around 30% of the propeller radius, resulting in a loss of thrust for the lower propeller of around 5% [26]. The reduced flight time of the T configuration does not depend on propeller overlap, but rather on the robot geometry. In hover, rotors 1 and 2 need to rotate faster than rotors 3 and 4 due to their smaller distance to the COG along the x_b axis. This leads to a higher power consumption in hover with the T configuration, since in near-hover conditions the power required by each motor scales with the cube of its rotational speed [31]. Finally, in the O configuration, the flight time is reduced even more because each propeller has a 30% overlap with the main frame.

The morphology would be useful in complex scenarios, such as rescue and rescue missions or inspection of complex structures. For example, pigeons and swifts adapt their wing surface by folding to optimize gliding efficiency over a broad range of speeds. Pigeons have also been shown to choose different morphologies of their wings to negotiate gaps of unusual sizes: they fold the wings upward to negotiate relatively large vertical gaps and fold them tight and close to their body to traverse narrower gaps.[26] Similarly, a large drone could fold only when it has to fly in very cluttered environments. In this way, negotiation of narrow gaps can be achieved without miniaturizing the drone with consequent trade-offs in terms of flight time and payload. However, morphing quadrotors where the relative position or orientation of propellers can be modified during a flight to extend the flight envelope remains a largely unexplored topic.

1.2 Flight Controls

Learning Quadcopter Flight Controls is one of main objectives. Figure 8 below shows all the basic movement and control parameters of the drone. Pitch fluctuates like the lid of a box. Roll is the opposite of yaw, which goes left and right like a hinged door. The following is a quick rundown on how to operate a drone at the most basic level.

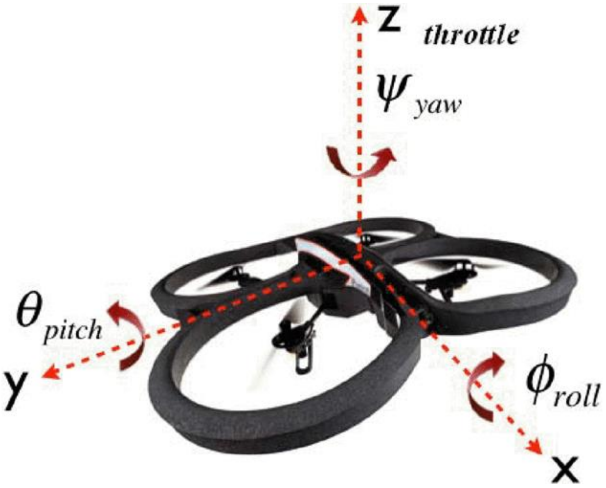


Figure 8 Basic drone controls and axes

1.2.1. Roll

Roll moves the drone left or right. It’s done by pushing the right stick on the controller to the left or to the right. It’s called roll because it rolls the drone. Figure 9 and Figure 9 Drone rolling right show roll left and right of the drone.

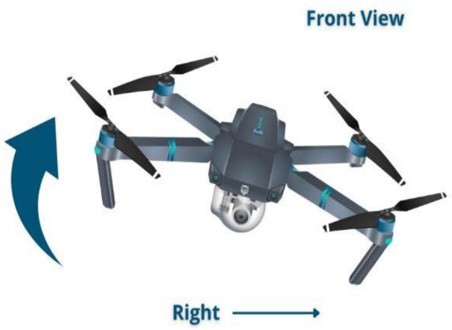


Figure 9 Drone rolling right

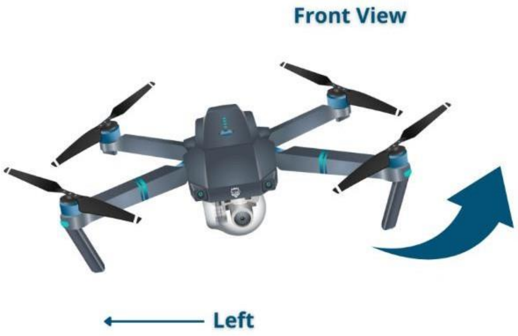


Figure 10 Drone rolling left

When stick is pushed left, the propellers will be pushing air to the right, forcing the drone to fly to the left. If the stick is pushed right, the propellers will be pushing air to the left, forcing the drone to fly to the right.

1.2.2. Pitch

Pitch is done by pushing the right stick on the controller forwards or backward. This will tilt the drone, resulting in forwards or backward movement.

Figure 11 Drone pitching forward

Figure 12 Drone pitching backwards

When the right stick is pushed forward, the back of the drone will pitch up causing the air to push the drone forward. If the right stick is pulled backward, the front of the drone will pitch up causing the air to push the drone backward.

1.2.3. Yaw

This is done by pushing the left stick to the left or to the right. Yaw is typically used at the same time as throttle during continuous flight. This allows the pilot to make circles and patterns.

1.2.4. Throttle

Throttle gives the propellers on your drone enough power to get airborne. When flying, the throttle is engaged continuously. To engage the throttle, the left stick is pushed forward. To disengage, pull it backwards.

1.3 Flight Controllers

A flight controller (FC) is a small circuit board of varying complexity. Its function is to direct the RPM of each motor in response to input. A command from the pilot for the multi-rotor to move forward is fed into the flight controller, which determines how to manipulate the motors accordingly.

Majority of flight controllers also employ sensors to supplement their calculations. These range from simple gyroscopes for orientation to barometers for automatically holding altitudes. GPS can also be used for auto-pilot or fail-safe purposes. More on that shortly. With a proper flight controller setup, a pilot’s control inputs should correspond exactly to the behavior of the craft. Flight controllers are configurable and programmable, allowing for adjustments based on varying multi- rotor configurations. Gains or PIDs are used to tune the controller, yielding snappy, locked-in response. Depending on your choice of flight controller, various software is available to write your own settings. Many flight controllers allow for different flight modes, selectable using a transmitter switch. An example of a three-position setup might be a GPS lock mode, a self- leveling mode, and a manual mode. Different settings can be applied to each profile, achieving varying flight characteristics. Following were the locally available controllers.

1.3.1. Arduino

Arduino is an open-source electronics platform that uses simple hardware and software to make it easy to use. Arduino boards can take inputs - such as light from a sensor, a finger on a button, or a Twitter tweet - and convert them to outputs - such as turning on an LED, triggering a motor, or posting anything online. By providing a set of instructions to the board's microcontroller, you may tell it what to do. The Arduino programming language (based on Wiring) and the Arduino Software (IDE) (based on Processing) are used to do this.

Arduino was created at the Ivrea Interaction Design Institute as a simple tool for rapid prototyping intended for students with no previous experience with electronics or programming. As soon as it gained a larger following, the Arduino board began to evolve to meet new demands and problems, evolving from simple 8-bit boards to solutions for IoT, wearables, 3D printing, and embedded settings.

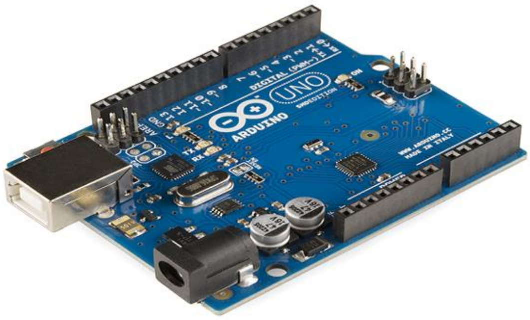


Figure 13 A generic Arduino board

1.3.2. Raspberry Pi

The Raspberry Pi is a small, low-cost computer the size of a credit card that connects to a computer display or television and utilizes a conventional keyboard and mouse. It's a powerful small gadget that allows individuals of all ages to learn about computers and programming languages like Scratch and Python. It can do everything a desktop computer does, including accessing the internet and watching high-definition video, as well as spreadsheets, word processing, and gaming.

Figure 14 A generic Raspberry Pi

1.3.3. Ardu pilot/APM

ArduPilot is an open-source autopilot system that supports a wide range of vehicle types, including multicopters, conventional helicopters, fixed-wing aircraft, boats, submarines, rovers, and more. A huge group of experts and hobbyists work on the source code. ArduPilot facilitates the construction and deployment of safe, self-driving unmanned vehicle systems for the common good. ArduPilot offers a broad set of tools that may be used with nearly any vehicle or application. It is continually growing as an open-source project based on quick feedback from a vast community of users. ArduPilot offers a large online community committed to answering questions, solving difficulties, and providing answers to users.

Figure 15 Ardu pilot/APM compact board

The ArduPilot project is an open-source autopilot software system that is powerful, full-featured, and dependable. It can manage practically any type of vehicle, including traditional and VTOL planes, gliders, multirotor, helicopters, sailboats, motorized boats, submarines, ground vehicles, and even Balance-Bots. APM Planner 2.0 is a free ground station program for MAVlink-based autopilots such as APM and PX4/Pixhawk that runs on Windows, Mac OSX, and Linux, allowing autonomous vehicle control, configuration and calibration or creating a mission using GPS waypoints and events.

1.3.4. KK2.15

An Atmel Mega644PA 8-bit AVR RISC-based microprocessor with 64k of memory lies at the core of the KK2.1.5. Extra polarity shielded header has been provided for voltage sensing. When activating and deactivating the board, a convenient piezo buzzer provides

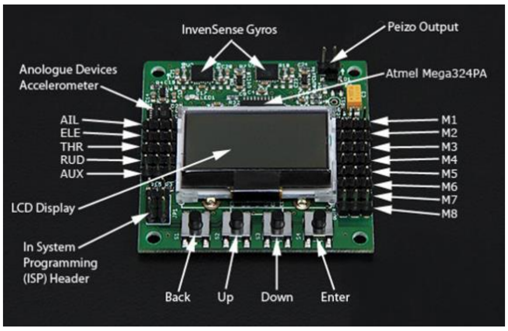


Figure 16 KK2.15 flight controller

an auditory warning. In case something was unintentionally connected wrong, the KK2.1.5 included polarity protection to the voltage sensing header and fuse protection to the buzzer outputs.

1.3.5. Open pilot

OpenPilot GCS is a configuration and ground control station for the OpenPilot series of open-source flight control, telemetry modem, and autopilot boards. Firmware uploading, configuration, control, and telemetry monitoring are all possible with this program. All OpenPilot boards are supported by the application.

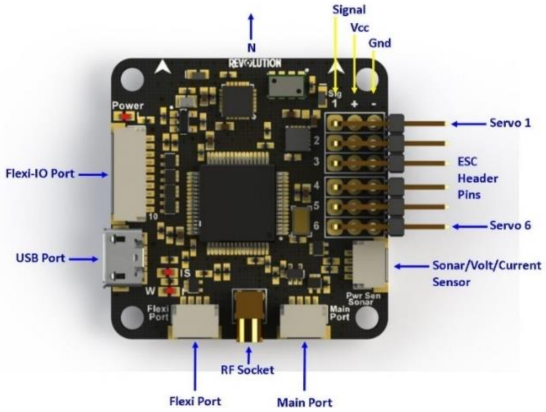


Figure 17 Open pilot flight controller

1.3.6. Pixhawk Flight Controller

Shown in fig 24, the Pixhawk is the most recent version of the flight controller, and it has a smaller footprint and twice as much RAM as its predecessors. More features include updated sensors with improved temperature stability, integrated vibration isolation, and additional ports for further integration and growth. Real-time operating system is based on sophisticated processing technology and provides an extraordinary level of performance, flexibility, and dependability. Biggest disadvantage of using Pixhawk is that it is very costly

Figure 18 Pixhawk Flight Controller board

and then and not readily available in the market. Additionally, it adds weight to the drone because it allows for telemetry kit and a number of other accessories to be attached with a drone frame, thus adding weight.

1.4 Forces Model and FBD

The system is modeled as five coupled rigid bodies: the four arms and the central body of the vehicle torques shows the internal and external forces and torques acting on a single arm and the central body. The body-fixed frame B is defined to be at the center of mass of the central body, and the arm fixed frame A is defined to be at the center of mass of arm. P denotes the propeller and H denotes the hinge joint.

The internal reaction forces and torques acting at the hinge are defined as f_r and τ_r respectively. The propeller attached to the arm produces thrust force f_p and torque τ_p in the z' direction. We assume that the torque produced by each propeller is linearly related to the propeller thrust force by $\tau_p = \kappa_p f_p$, where the sign κ_p is determined by the rotation direction of propeller [12].

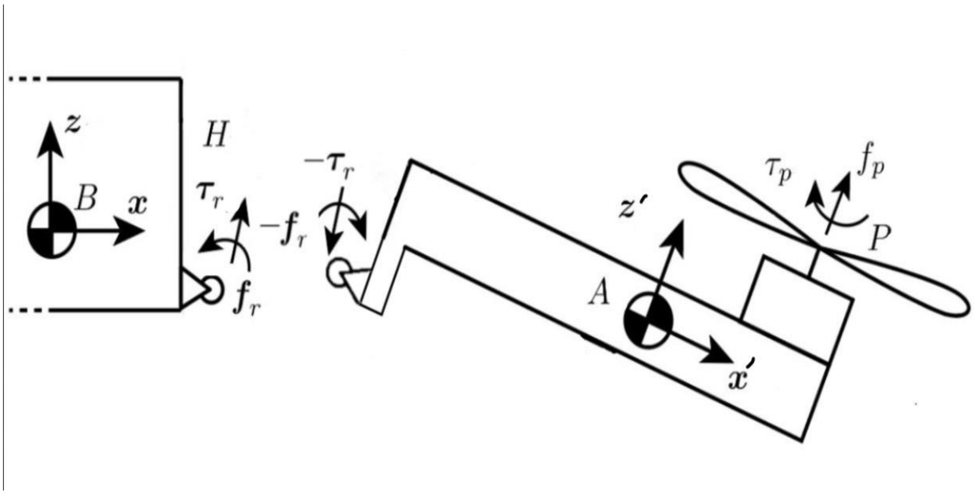


Figure 19 Free-body diagram showing the forces and torques

H shows the hinge and the when the connection is removed, existing reaction force and torque are shown in Figure 20 FBD. f_r and τ_r show the reaction force and reaction torque. Reaction forces acting downwards, and the reaction torque is in the direction which pushes the wings in the opposite direction of thrust generated by the wings.

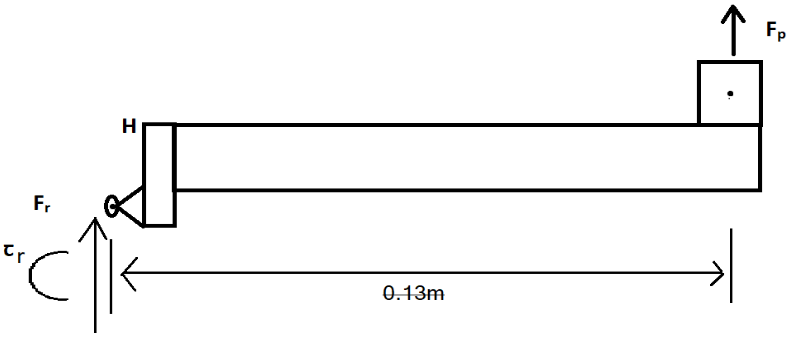


Figure 20 FBD diagram of the wing

Free body diagram shows unfolded position of drone where the angle between the arm and the drone body is 0 degrees, and the local coordinate system and global coordinate system are essentially the same. Using $f_p = 13$ N (as thrust is 1.3kg for each rotor propeller set) and applying equation of motion and summation of torque, we get

$$\Sigma Fy = fp = -fr \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \text{ (1)}$$

$$\Sigma \tau H = -\tau r + fp * 0.13 = 0$$

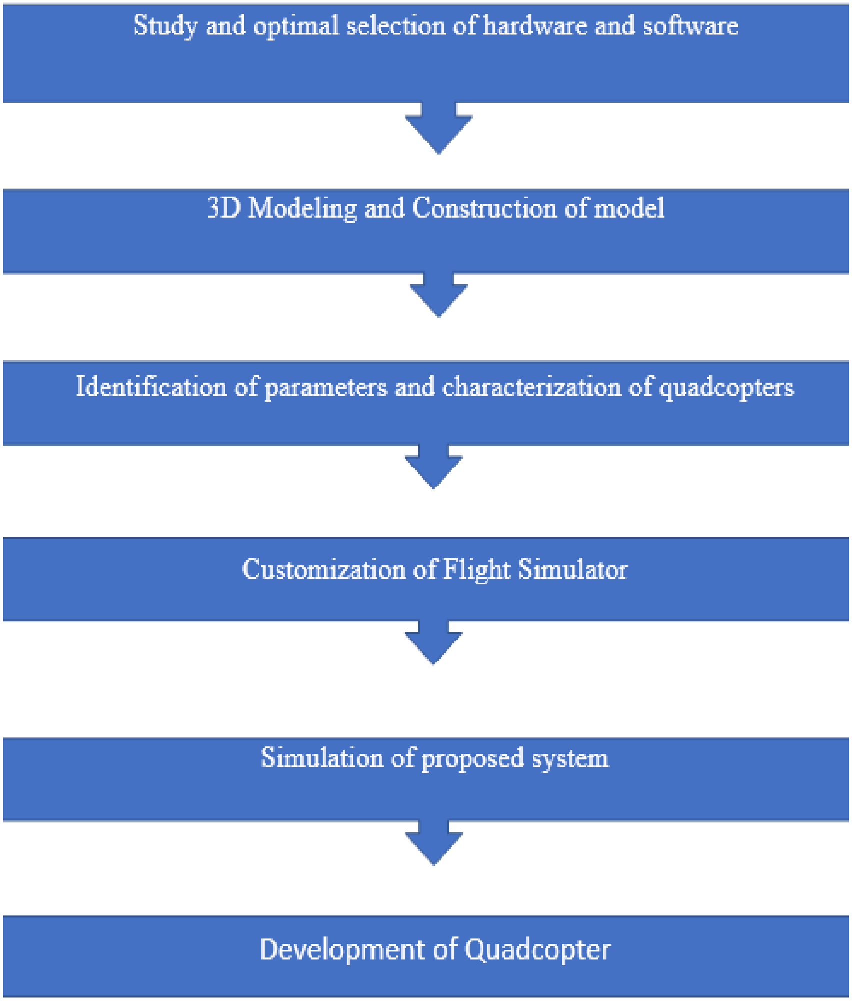
$$\boldsymbol{\tau r = 1.69\ N.m\ \&\ fr = 13\ N.}$$

The angle between the body of the drone and the arm increases the reaction torque remains essentially the same, but the reaction force is divided into X&Y components in the global coordinate of the body frame. Since the angle is increasing from zero degrees till 90 degrees (which is the maximum rotation possible with the hinge design), The component of force in the global z direction of the body starts to decrease and becomes 0 when the arm reaches 90-degree angle. the component of course in the global X direction starts to increase as the angle starts increasing from 0 to 90 degrees and becomes maximum when the arms of the drone are in complete folded position.

CHAPTER 2

METHODOLOGY & THE PROPOSED DESIGN

A flowchart was designed that showed, how the project will be undergone and what will be the constraints, which were decided mainly by budget and time limitations. The long and tedious process was divided into simple and small steps and a flow diagram was created. starting with the study of hardware and software of our project he went on with 3D modeling and then continued with the construction of model and then depending on market we customize that design and tailored it to our needs. we also used simulation software like "Beta Flight Controller", to understand the behavior of our motors and ESC, along with thrust control and transmitter receiver testing.



Depicted in Figure 21 Quadcopter Structure with components [33] are the basic components of a drone. The diagram also shows the basic locations of all these components, and it does not vary for all of the quadcopters although some components are optional and not required for the basic functioning of the drone like GPS kit and canopy. These however add to the features and safety of drone. The other components the building blocks of drone without which it cannot fly.

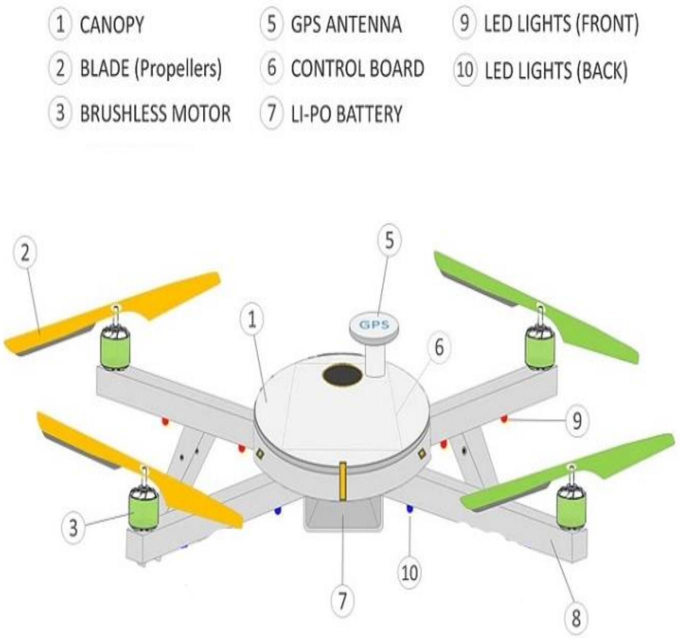


Figure 21 Quadcopter Structure with components [33]

2.1 Frame Size

The size of propellers that may be used and the size of the engine that can be put on a drone is determined by the frame type. The size of a drone or quadcopter is a major factor in determining the motor size. It must be known what size drone is desired to build, what size propellers it can run, and which batteries can be used in order to choose the proper arrangement. How fast is it? A Drone for Intelligence Gathering? Or are we constructing a weapon-carrying aircraft that also achieves the highest feasible altitude? The F330 frame size was chosen after taking into account all of these criteria, as well as market availability. It is a little light that can be easily customized and is offered at a low cost. In addition, its wings may be chopped, which is ideal for the specific application because the hinge must be fit into it.

Stator/K_V combinations are as varied as the sorts of motors that may be used with them. The ultimate objective is to create a system that is well-balanced and meets the needs of the pilot, the drone, and the size of the drone. Longer flight durations, longer equipment life, less wear and tear, and lower temperatures may all be achieved with the right motor size. Considering the purpose, the DJI F330 frame was selected as it was easily available, cheap and right according to size that can fit into a missile, mortar or carrier after being folded. Its arms are made of rigid plastic while central base is made of fiber glass.

2.2 Stator Size

Next step is to select the stator size. For a 7" Propeller a motor of stator size 2206-2210 is recommended, still a 2212 stator size is used because of ease of availability. A good start is to use the following guide show in Table 1:

Table 1 Motor Stator Selection Guide

Frame Diameter	Prop Size	Stator Size	Lowest Kv	Highest Kv
<150-150mm	3"	1306	3000	4000
150-250mm	4"	1806	2600	2800
190-220mm	5"	2204-2206	2300	2600
220-270mm	6"	2204-2208	1960	2300
350mm	7", 8"	2206-2210	1450	1600
450mm	8", 9"	2212	1000	1200
>450mm	9", 10"	2214-2216	900	1000

2.3 Propeller Size

The size of the frame will dictate the size of the props. A DJI F330 frame was used since it was built for 7"/8" propellers. The Propellers are made up of plastic because plastic provides higher thrust. Propellers made of carbon fiber were having less stress and higher cost. Additionally, they were exceptionally durable, but they did not suit our application.

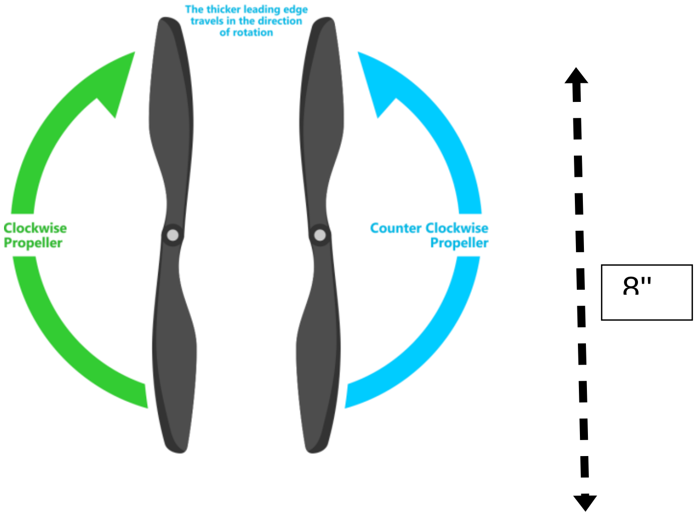


Figure 22 CW/CCW Propellers (8-inch size)

Although Plastic propellers have weaker strength and get easily broken on crashes but in terms of thrust and price, they are better option than carbon fiber propellers. The angle of the blasé so the propellers is 15 degrees.

2.4 Build Factors

2.4.1. Weight

A lighter motor is going to have a faster spin-up & slow down and will yield a faster change in speed. A heavier motor will take longer to spin up and slow down and will yield a slower change in speed. A lighter motor will most likely feel more precise in the air. lighter motors are more prone to damage upon impact, so beginners might be better off with heavier motors.

2.4.2. Efficiency

Efficiency is measured in grams/Watt so it can be taken as thrust/power required. Motor efficiency can affect flight times, voltage sag, and battery life. A motor is to be chosen that is most efficient throughout the range of operation, not just at the highest RPM. The battery used will have to be able to support whatever amp draw is at WOT, and the smaller the battery, the less capability it has to flow high currents. A higher KV motor can tend to be more efficient in the high rpm ranges but at the expense of torque.

2.4.3. Power

A lighter quad with motors that have less thrust can feel just as good in the air as a heavy quad that has motors that output max thrust. In the end, it has to be assured that enough thrust is available to perform the morphing operation and fly well. A good rule of thumb for a conventional quadcopter is to aim for a 4:1 power to weight ratio. It is double to 8:1 or more in racing quads. A high power to weight ratio near 8:1 was required for better morphing operation.

To figure power to weight ratio, the max static output of the motors was calculated and divided by the weight of the quad. Max thrust provided by a single DJI2212 motor with 8x4.5inch propeller and 3S 1500mAh battery is 650gms, and with 4S 2600mAh battery is 1200gms. Total thrust is 2600gms/4800gms. Table two shows the total weight of the drone combined, where weight of all the components is added up. Power to weight ratios or calculated by dividing the thrust generated by four wings and dividing them by total weight of the drone.

Table 2 Net Drone Weight

Ser No	Part	Weight
1	F330 Frame	170gms
2	Battery (3S 1500mAh)/ (4S 2600mAh)	115gms/248gms
3	Motors (4 x DJI 2212 53gms)	212gms
4	ESC (4 x 15A)	100gms
5	Flight Controller (CC3d)	30gms
6	Propellers (4 x 8 x 4.5)	-
	Total	627gms/760gms

$$Power\ to\ weight\ Ratio\ 3s\ Battery: 2600/627 = 3.97: 1$$

$$Power\ to\ weight\ Ratio\ 4s\ Battery: 4800/627 = 7.7: 1$$

2.4.4. Torque

Torque can affect the time it takes the propeller to reach a desired speed so a motor with higher torque will be easier to tune and will make the quad feel more precise in the air. Stator size effects the torque output, and larger stators tend to produce more torque, while smaller stators produce less. Another factor is K_v. It is typically thought of as RPM per volt. K_v can help us understand the current requirements of a motor to produce a certain amount of torque. The torque constant K_t is the inverse of K_v. So as K_v goes up, K_t goes down.

$$Kt \propto \frac{1}{Kv} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Torque τ_p can be calculated using current and K_t, the inverse of K_v. I=13 A, K_t=1.47

$$\tau p = Kt\ x\ I \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

$$= \mathbf{19.14\ N.m}$$

Current, torque and K_v are all related, Lower K_v motors require less current to spin heavy props and therefore have more torque, but loose efficiency at high rpm vice- versa, High K_v motors require higher currents to spin heavy propellers but can run at high rpm more efficiently. In other words, high K_v motors require more current than lower K_v motors to produce a certain amount of torque.

2.5 Electronic Speed Controllers

Next step is to select the ESC according to need of current being drawn from batteries. ESC is an electronic speed controller which receives the throttle signals from the flight controller and run the brushless motor at its desired speed. The superior quality ESC gives a reliable and smooth flight experience. There is a number of factors that are considered while selecting the ESC and they are as,

2.5.1. Current Rating

The first thing to consider when selecting an ESC is the current rating or ampere rating. Motors draw current when they spin, if we draw more current than our ESC capacity then it will start to overheat and eventually damage. The current rating of the ESC is decided after selecting a suitable motor size for our requirement. Following can increase the current draw of our ESC,

i. High K_v ratings of the motor

ii. Larger propellers (length & pitch)

iii. Larger motor size (stator width & height)

There are 2 current ratings of ESC, and they are continuous and burst. The continuous current rating indicates the maximum continuous current which ESC can handle safely. The burst rating means the maximum current that ESC can handle for a short period of time (e.g.,10 seconds) without damaging the ESC itself.

2.5.2. Input Voltage Rating

The voltage rating of an ESC is the maximum amount of voltage that the ESC can handle safely. Some of the ESCs supports for 3S-4S battery voltage, while others can support to 6S battery voltage. Here, it was made sure that they were compatible with the LiPo battery voltage. Powering ESC with excessively high voltage will damage the ESC as well as the motor.

2.5.3. Weight and Size

The weight and size of an ESC are dependent on ESC current rating. It is challenging to make ESC with lighter and smaller size without losing its performance and effective cooling. Mostly, single standalone ESCs are designed with the weight around 4gram to 6gram and the 4 in 1 ESC weights around to 12gram to 15gram. Generally, the lighter ESC’s has lower heat dissipation, which leads to concerns of overheating.

2.5.4. With or Without BEC

BEC stands for Battery Elimination Circuit. The BEC provides the constant current at a specific voltage. It has 5V output for powering the flight controller, a radio receiver

(RX) and other 5V components. The ESC without BES is known as Opto ESC. Without the 5V BEC, the Flight controller and RX will require a separate power source.

2.5.5. Connection of ESC with motor

ESC uses a LiPo battery to power up. The signal receives from the flight controller control the speed of the motor. A Brushless ESC has 3 wires which directly plugs or gets soldered to the 3 wires of the motor. The below image shows the single standalone ESC with LIPO battery, RC receiver and brushless motor.

2.5.6. Chosen ESC

Considering the above-mentioned factors, 15A ESC is selected with a battery elimination circuit as it is not supported without it. Figure 23 ESC shows the actual image of the ESC while circuit shows the connection circuit of the ESC between the battery and the motor.

Figure 23 ESC E300

Figure 24 ESC Connection circuit

2.6 Selected controller (APM)

Ardu pilot/APM was selected as it allowed stability and functionalities similar to Pixhawk Flight Controller and was cheaper in price. Also, the space occupation and weight were much less as compared to Pixhawk Flight Controller. The additional shock absorber kit added to stability of the drone and accelerometer.

2.7 Block Diagram

In Figure 25 Block Diagram of Drone Circuit, all the elements are shown to be attached as they are to be in the real drone circuit. Black lines show the connections of electric wires whereas the signals show that wireless connection is being made between the two components. Pixel controller located at the core of our circuitry controls all the components and is powered by the battery where the 3S or 4S. The wireless connection is between telemetry kit and the transceiver circuit.

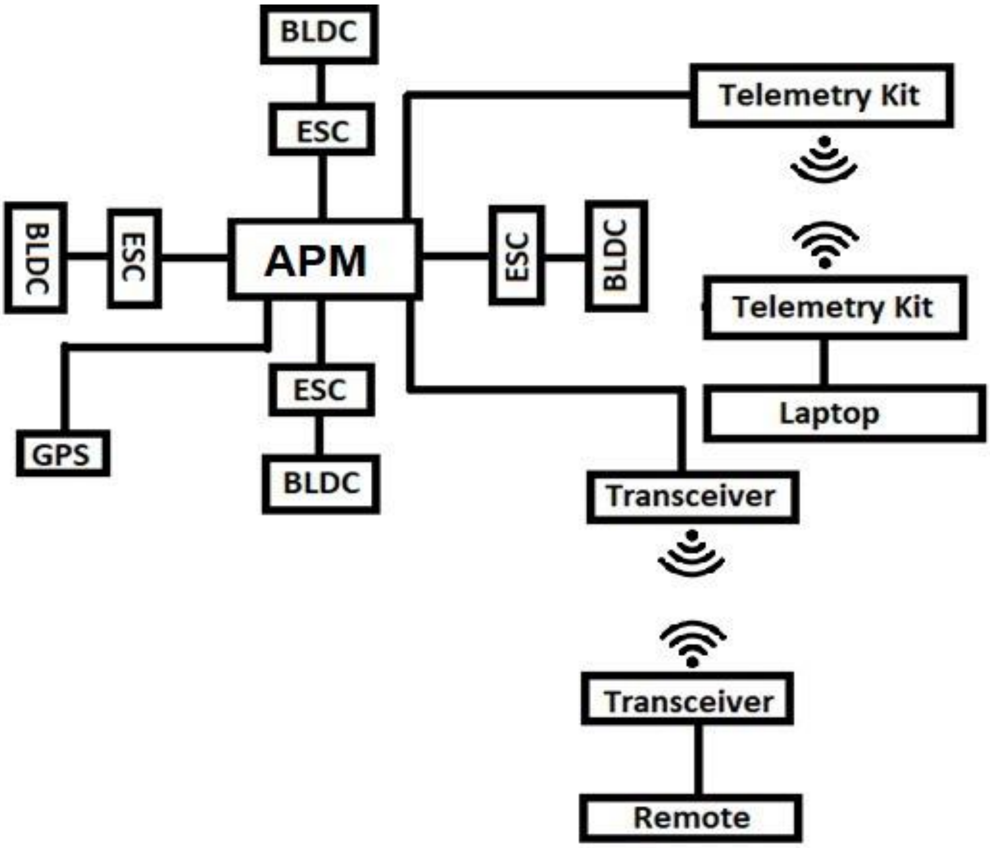


Figure 25 Block Diagram of Drone Circuit

CHAPTER 3

MODELLING, ANALYSIS & FABRICATION

3.1 3D Creo Model

The 3D model of the drone was made in Creo Parametric 7.0 Software. The software was used to design the mechanical hinges which are the main component for the operation of morphology. Fig 28 shows the main body of the quadcopter.

Figure 27 Hinge part A design

Figure 26 Hinge part B design

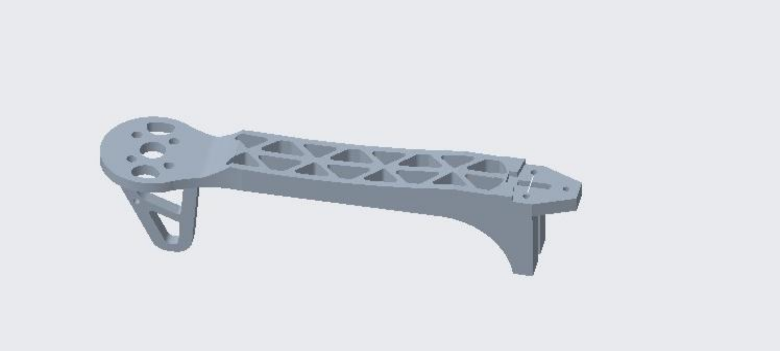


Figure 29 Drone arm design on CREO

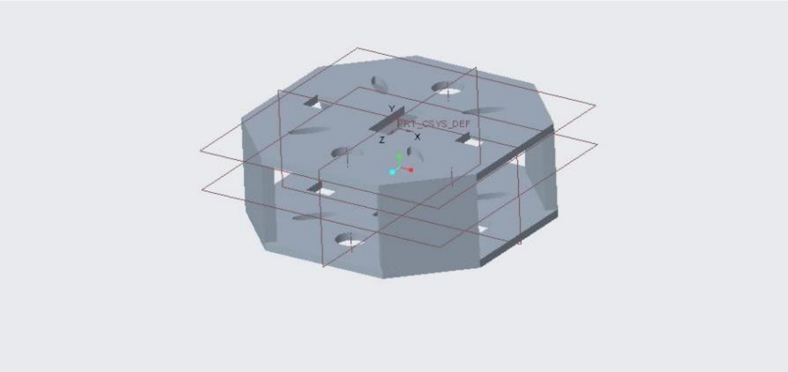


Figure 28 Main body design on CREO

The drone body is basically consisting of two disks that are connected by 4 walls. The disks are perforated to make them lightweight and also allow the passage of wires that are connecting different parts of the drone circuitry. The hinge is so designed that it fits into each other, and then it will be installed between the body of the drone and the wing of the drone. both parts are made with 5% clearance so that 3D printing would be feasible and the parts were fit into each other without getting stuck.

3.2 **Morphological Design**

The foremost important objective is to design a morphological drone, for the sole purpose a mechanical hinge is designed. The proposed design uses hinge joint to rotate the arms of the drone. The movement is one degree of freedom movement which allows the rotation of the arms in vertical axis. The joint is activated by the use of thrust of the motors thus no additional actuators are used. This reduces the weight of drone by not using actuators increasing power to weight ratio. Hinge part A and B are the two parts of hinge, they would exactly fit into each other. Part A and B of hinge are attached from one side to the drone body and on the other side to the wing. These two hinge parts will be installed on all four wings.

The area of the drone is at maximum in unfolded configuration. In folded configuration, the area has been reduced to almost 50%. The attachment of the bottle beneath is to insure two things; the battery can be installed in the bottle and the center of gravity to be lowered and to make sure that the wings do not collide with each other when they are in folded positions.

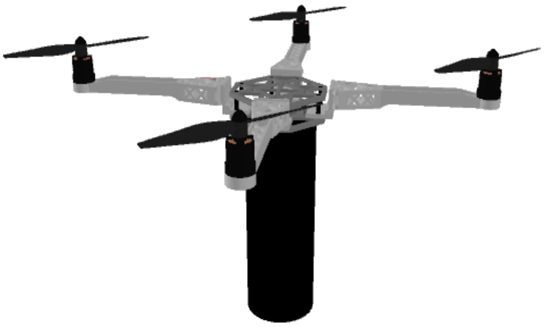


Figure 30 Quadcopter configuration unfolded

Figure 31 Quadcopter configuration unfolded

3.3 ANSYS analysis of hinge part

3.3.1. Finite Element Analysis

Structural elements such as hinge can be modeled using FEM techniques. A proper finite element model of the hinge has been developed. The 3d model of the hinge has been modeled on PTC Creo Parametric and then imported to Ansys to model the hinge using beam elements.

3.3.2. Material Selection

Our actual hinge has been fabricated using ABS (Acrylonitrile Butadiene Styrene). The material has very close properties to PLA (polylactic acid). The main properties of ABS are shown below.

Table 3 Properties of ABS material

Material	ABS
Modulus of Elasticity	1 – 2.65 GPa
Poisson's Ratio	0.340 – 0.380
Tensile Strength	4100 psi
Yield Strength	29.6 - 48 MPa

3.3.3. Model

As mentioned before, the model has been created on Creo 8.0.2. The design was then saved in .step file format and then imported to ANSYS.

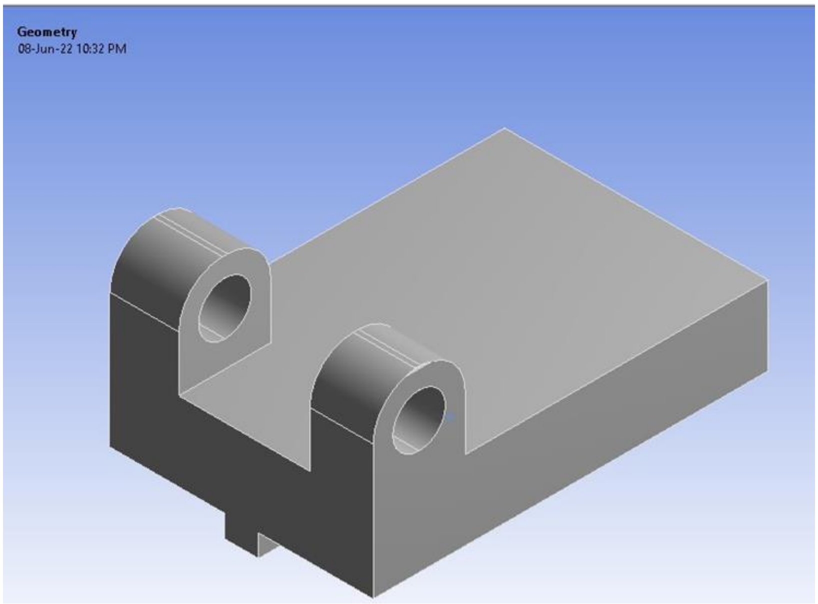


Figure 32 Hinge part imported at ANSYS

3.3.4. Meshing

The software breaks down the CAD model into smaller pieces called elements. The process of this breakdown is known as Meshing. When the mesh is of higher quality, the mathematical representation of the model will be more accurate. The meshing is done using 10 node tetrahedral element as shown below.

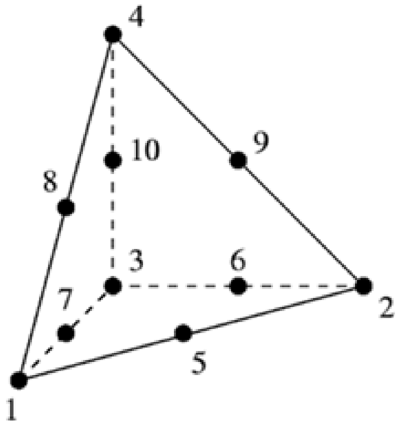


Figure 33 Ten node tetrahedral element for meshing

After a high-quality meshing, the following meshed CAD model of the hinge was obtained. The part has been meshed into more than 28,000 nodes. That provided for a fine meshing and subsequent analysis brought accurate stress concentrated areas.

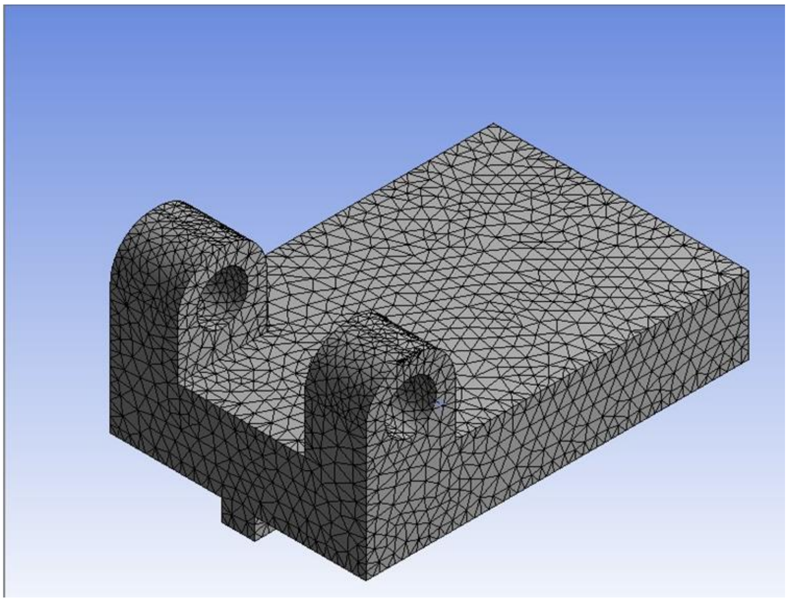


Figure 34 Meshed hinge part with ten node tetrahedral elements at ANSYS

3.3.5. Loading & Boundary Condition

Static forces load the hinge from the wing. Similarly, the thrust of the propeller is estimated at around 1.3kg or 13 N which will be distributed evenly throughout the hinge. The fixed supports are the points where the hinge is connected to the body of the drone. The hinge is around 5mm thick with 20mm wide and 30mm in length.

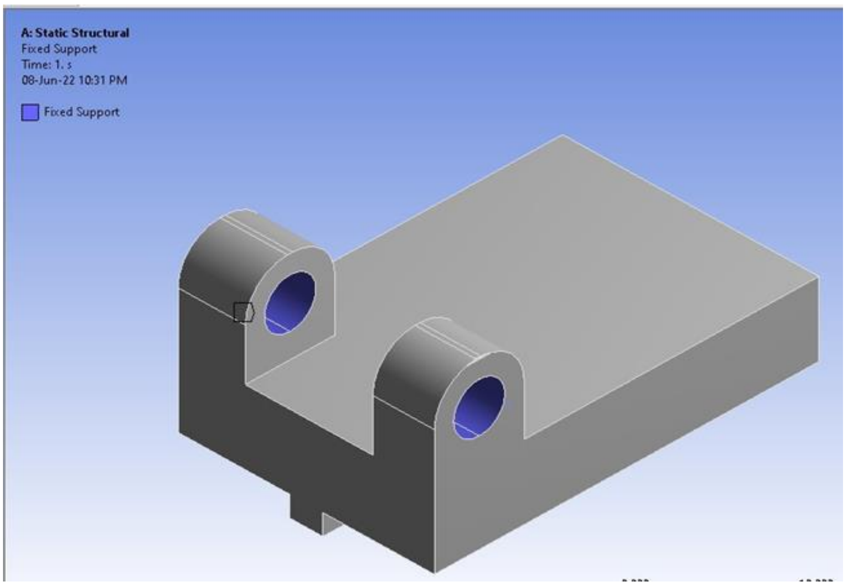


Figure 35 Highlighted areas showing Fixed Support points

3.3.6. Result of the Analysis

After the analysis, the maximum generated Von Mises stress on the hinge is around 2.7944 MPa. Similarly, around the hinge, the maximum generated Von Mises stress is somewhere between 0.465 and 2.7944 MPa.

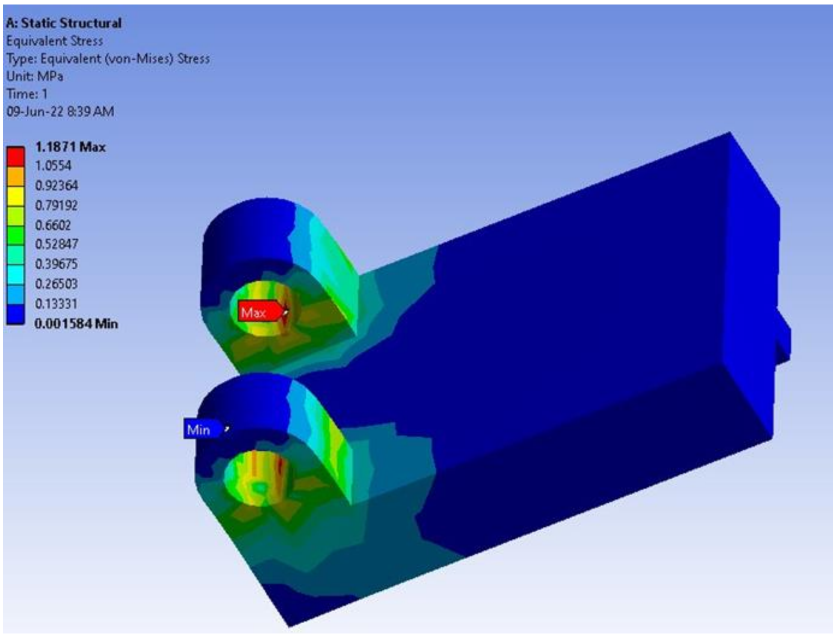


Figure 36 Equivalent Von Mises Stress color coded diagram

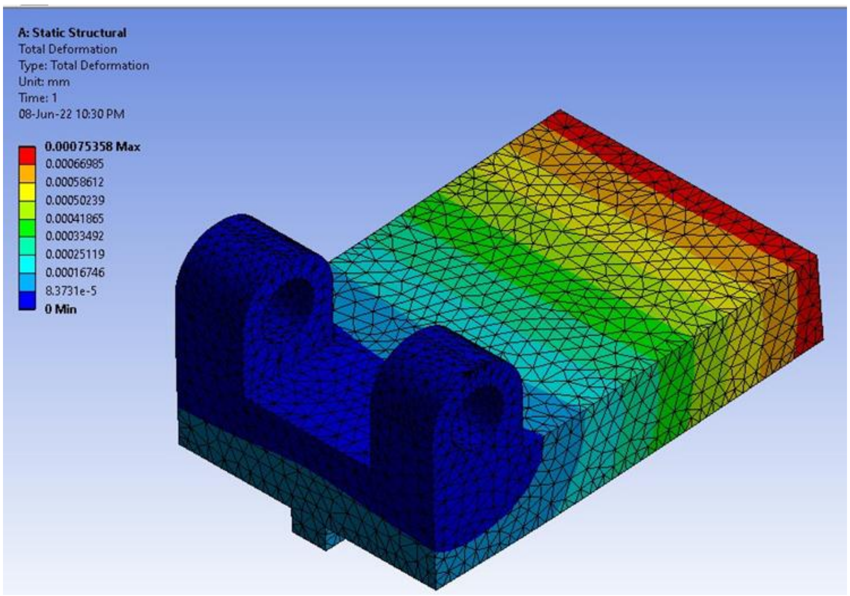


Figure 37 Total Deformation among the hinge part (mm)

3.4 3D printing

A CAD model or a digital 3D model is used to create a three-dimensional item known as 3D printing or additive manufacturing. [32] Computer-controlled deposition, joining, or solidification of materials can be accomplished in a variety of ways[33], often layer by layer, with various materials (such as polymers, liquids, or powder grains) being added together. Due to the simplicity with which polymeric materials can be manufactured and handled, 3D printing has traditionally relied on them for printing. A variety of materials may now be printed using 3D printing, including plastics[32], rubber[34], metals[35], and ceramics[36]. Wire frames and surfaces were used to generate three-dimensional models prior to the introduction of solid modelling in the late 1980s." the printer and material parameters govern layer thickness in all circumstances, though. [70]

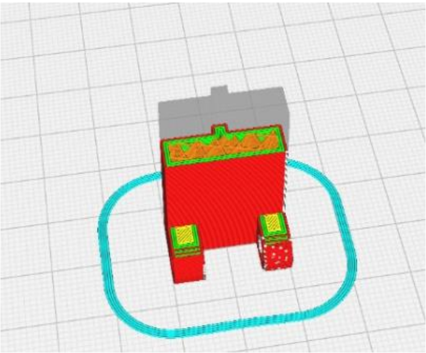


Figure 38 Hinge model on 3D printing software

The deposition rate of the three-dimensional material layer is regulated by the printer operator and saved in a computer file. Figure 38 shows the details of the 3D printing of the hinge using the standard quality of 0.2 millimeter, which also denotes the minimum nozzle size. For one hinge part, a total of 4 grams of PLA material was used and the time required was 36 minutes. since there were 4 iterations, 1 for each wing, the total time it was 2 hours and 24 minutes, and 16 grams of material was used.

3.5 Drone Circuitry

For the drone circuitry, amongst the countless number of flight controllers available we had to choose one. Not a lot of these controllers were available readily in the market, so we had to skip those and APM was chosen. The following are the other components in circuit:

3.5.1. GPS module

GPS navigation system, which stands for Global Positioning System uses transmitted signals from satellites throughout the world by GPS receivers. These signals may be used by the module to determine its current location, speed, and duration of movement. GPS uses the triangulation method, which typically requires three or four satellite signals, although certain drone GPS modules may latch on to up to seven or eight satellite signals for optimal performance. Having access to a greater number of signals and systems improves location accuracy, and hence all of drone's GPS-dependent capabilities. The position location precision of a conventional GPS drone is around a meter, but more modern GPS drones can have an accuracy of up to a cm. The drone can detect and retain its position at a fixed point when it can lock on to a GPS signal. This is also known as the ability to hover stably.

3.5.2. Telemetry kit

The telemetry kit links Smart App Autopilot to a ground control station wirelessly. This small, lightweight, and simple-to-install module establish a wireless network between your PC or laptop and the autopilot. Telemetry allows to track numerous aspects of the drone on the ground by retrieving flight data from the drone on onto the computer or radio control.

Figure 39 Telemetry kit and its components

3.5.3. Transceiver remote controller

As the remote control transmits a radio signal to the drone, it instructs it on how to carry out its task. Transmissions are made by the radio transmitter on the drone controller and received by the radio receiver on the drone. Since then, it has been referred to as the drone radio transmitter or controller by both of those terms.

The right stick lets you control the roll and pitch of your drone, allowing you to move the drone right/left as well as forward and backward. The left stick lets you control the yaw and throttle of your drone, allowing you to control the height at which you fly and letting you rotate the drone clockwise or counterclockwise in flight.

Figure 40 Transmitter module of Microzone MC6C

3.5.4. UBEC

A UBEC (universal battery eliminator circuit) is a device that converts high voltage (such as 25V from a 6S LiPo) to lower voltages, allowing the entire UAS to be powered by a single primary battery. Because most electronics require 5V, 6V, 8V, or 12V, this device is used to power these devices from much higher-voltage sources. Some ESCs include an inbuilt BEC that delivers this power; however, the electronics in the KDE Direct UAS ESCs are OPTO-isolated. The power for flight electronics is given via secondary electronics, such as a UBEC, to ensure isolation between electronics and keep any noise and interference from influencing flight performance, as is best practice for drones.

A linear regulator utilizes resistors to dump excess voltage as heat, which is inefficient, but a switching regulator, such as the KDEXF-UBEC22, employs high-frequency switching circuits to lower voltage effectively and without generating substantial heat or wasted energy.

Figure 41 UBEC, a switching regulator

CHAPTER 4

SIMULATION SOFTWARES AND TEST FLIGHT

A varied set of software was used for purpose-based simulations and testing, starting from test bench to study the rotational motion of the 3-D designed hinge, then beta flight controller to optimize and calibrate the flight of the conventional drone and finally, mission planner was used to calibrate APM microcontroller. Following is a brief description of the software used for different purposes.

4.1 Arduino IDE

Arduino IDE was used to operate a test bench to study the rotational motion of our hinge. The test bench included a single 2212 stator motor, 8inch propeller, Arduino UNO, 30Amp ESC, Breadboard and 10 K ohm Potentiometer. The test bench was also used to measure the thrust of propeller. Figure 42 and 43 show the circuitry of the test bench and its working.

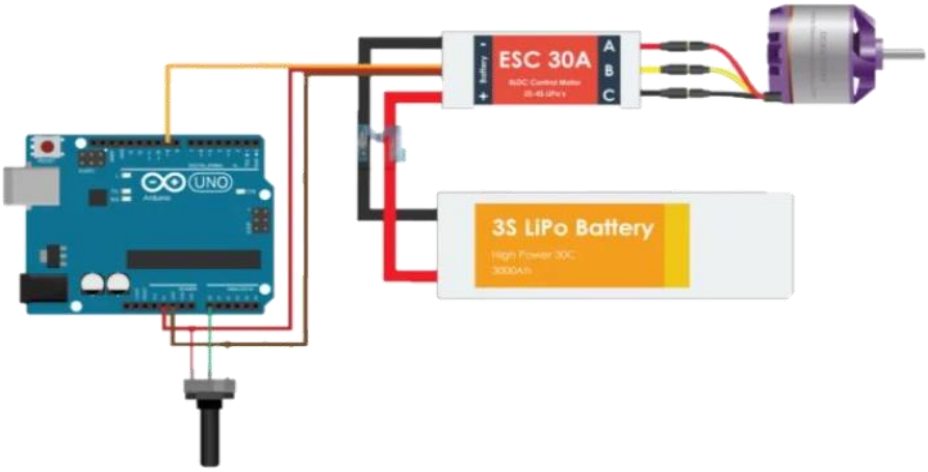


Figure 42 Motors Attached to ESC and Arduino Circuit

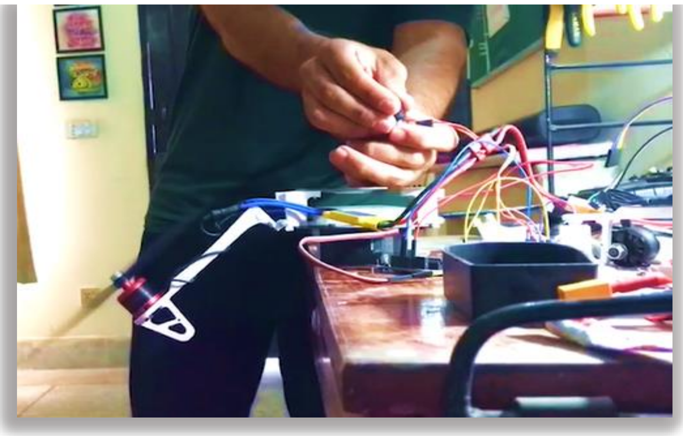


Figure 43 Test bench generating lift at wing and transiting from folded to unfolded folded position

Following is the coding of Arduino IDE used for test bench:

```
                         Arduino IDE Code
*/
#include <Servo.h>


Servo ESC;     // create servo object to control the ESC


int potValue;  // value from the analog pin


void setup() {
  // Attach the ESC on pin 9
  ESC.attach(9,1000,2000); // (pin, min pulse width, max pulse width in microseconds)
}


void loop() {
  potValue = analogRead(A0);   // reads the value of the potentiometer (value between 0 and 1023)
  potValue = map(potValue, 0, 1023, 0, 180);   // scale it to use it with the servo library (value between 0 and 180)
  ESC.write(potValue);    // Send the signal to the ESC
}
```

4.2 Beta Flight Controller

Beta Flight controller was used to simulate and tune Open Pilot CC3D Flight Controller. This flight controller was used in conventional drone in preliminary stages. The modules of the Beta Flight Controller used for calibration, setup(Left) and monitoring(Right) of the drone are shown in figure 44.

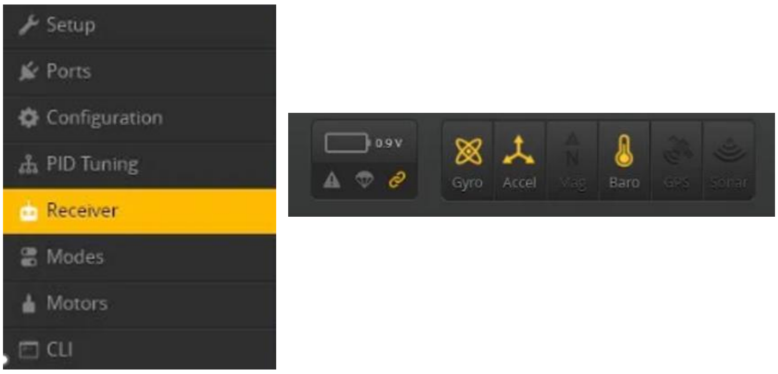
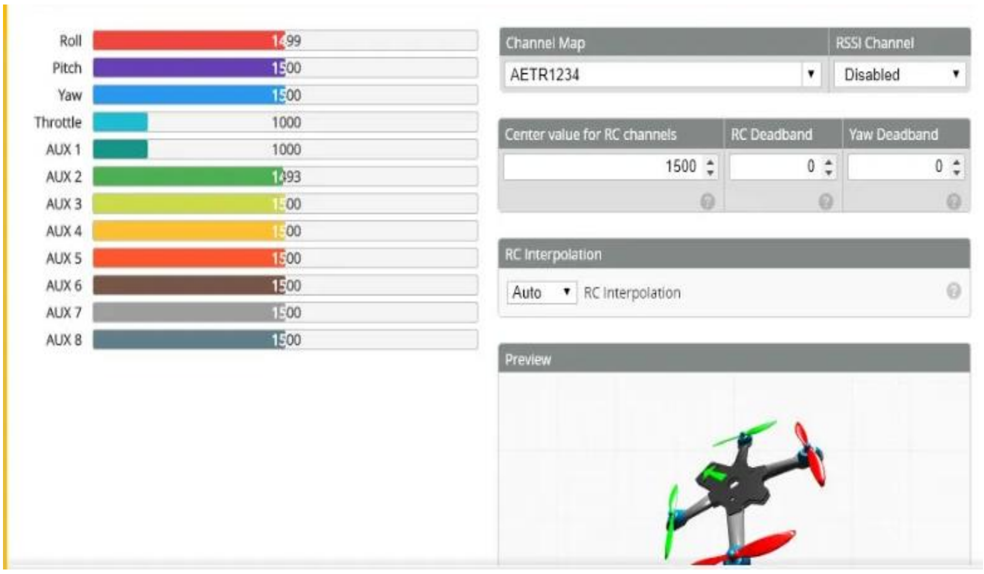


Figure 44 Modules and features used at BFC

Receiver calibration of the transmitter-receiver circuit/remote control is shown in figure 45. In addition to calibration, it also allows for miniature testing of drone using the throttle feature. Successful test flight of conventional drone was done was done after the use of this software with Open Pilot CC3D Flight Controller.



Roll 1499
Pitch 1500
Yaw 1500
Throttle 1000
AUX 1 1000
AUX 2 1493
AUX 3 1500
AUX 4 1500
AUX 5 1500
AUX 6 1500
AUX 7 1500
AUX 8 1500

Channel Map: AETR1234
RSSI Channel: Disabled
Center value for RC channels: 1500
RC Deadband: 0
Yaw Deadband: 0
RC Interpolation: Auto

Figure 45 Receiver settings of BFC

4.3 Mission Planner:

Without PID tuning the drone, equipped with rotary joints was unstable and was swaying in unannounced directions under the influence of wind and variable atmospheric conditions. Therefore, Mission Planner was used for the programming, simulation and analysis of APM, the flight controller .Mission Planner is a full-featured ground station application for the APM open-source autopilot project for planes, copters and rovers. Mission Planner can be used as a configuration utility or as a dynamic control supplement too. The morphing drone’s calibration and PID tuning were made possible by Mission Planner. Afterwards successful flight test was conducted that exhibited the rotary joints in its full working by the use of thrust of the propellers.

Altitude (m) 0.00

GroundSpeed (m/s) 0.00

Dist to WP (m) 0.00

Yaw (deg) 0.00

Vertical Speed (m/s) 0.00

DistToMAV 0.00

hdop: 0.0

Sats: 0

Figure 46 Topographic view and arming of drone using MP

CHAPTER 5

INSIGHTS GAINED

Teamwork was a major role in the successful completion of the project development cycle as the work was distributed equally and according to the skills of the project team. team members were incorporated according to their skill set and field of expertise. The supervisors kept a strict check and schedule regular weekly meetings for the update on progress and assigned next tasks. any delay in the project progress and timeline was checked and asked upon.

The first design of the hinge was based on 3D model only and not on ANSYS analysis. The result was not very good as the part broke upon the first landing of the drone during flight. Then the idea to resort to ANSYS became very helpful as the ANSYS analysis (shown in the chapter 3) made it very clear which part of the hinge was critical and under maximum stress. To cater for that stress added additional layers in 3D printing were added at that point and the density of the 3D printing was increased. This resulted in not only a much more reliable and sturdier hinge, but it also reduced the overall weight of the hinge to less than 4 grams as access material in places where strength was not required was removed. In addition to this with the help of ANSYS, a design was created that was a little wider at the stress concentration point and its edges were rounded to reduce the stress concentration factor.

Another lesson was the importance of a detailed literature review as it helped in making the decision of design selection. The study of previous morphologies in the horizontal plane and the associated complexities gave a fine idea of which mistakes not to repeat and which designs to avoid. The idea of not using any additional actuators also popped up from the study of these horizontal morphological designs as they had to use up to 10 channel transmitter receiver circuits to control these actuators and drones gained more weight, and the controls became more complex. Furthermore, whenever there was confusion about component selection or circuit connections, by referring to this literature an easy solution came up eventually.

CHAPTER 6

FUTURE RECOMMENDATIONS

Completion of a morphological drone of such type would open doors to a number of opportunities in the military sector disaster management and recreational drone activities. The size of the bottle is 70mm it can be successfully launched into the air to a long distance while just using the 80mm mortar. Also, a bigger and much sturdier folding drone model with aerodynamic changes can be used:

i. With slingshot like a fixed wing drone.

ii. In missile launched applications

iii. Dropped straight down from a bigger UAV or other aircraft

Thus, significantly increasing the range and reducing the launch time of the drone, while after separation of drone from missile after achieving desired height and range, drone can operate under remote or autonomous control through GPS.

CHAPTER 7

CONCLUSION

The goal to complete a novel drone that changes shape in the vertical direction and has the ability to reduce the largest dimension of drone from 56cm to 28cm has been achieved(50% size reduction). In addition, compared to previous aerial morphing vehicles, the mechanical complexity of this design is only modestly increased as only after detailed literature review, a design and a methodology for the morphological drone was established. The project development cycle started from conventional drone, then achieving stability in its flight. The second step was designing the hinge, its analysis on ANSYS and 3D printing, and in the last step, completing the morphological setup by incorporating the hinge onto the frame and conducting flight tests.

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