Design and Development of Quadcopter

Deo Raj Biswa[1*], Dawa Tshering[2], Tshering Dargay [3], Tandin Wangchuk[4], Bir Bahadur Duklung Rai, Dechen Dorji[5], Bir Bahadur Rai[6], and Dechen Dorji[7]

[1-7]*Department of Electronics and Communication Engineering, Jigme Namgyel Engineering College, Dewathang*
[*]*Corresponding author: deoraj.jnec@rub.edu.bt*

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Abstract

This project basically deals with the design and development of a quadcopter using a readily available flight controller which has inbuilt and integrated components such as an inertial measurement unit (IMU). These Sensors are crucial for developing any drones as they provide data related to acceleration, gyroscope, and magnetometer which plays a vital role in obtaining drones orientation, angular velocity, and acceleration, and maintaining stability and control. A lithium polymer battery, which provides high current density and has a capacity of 11 powers, the quadcopter.1V and a discharge capacity of about 66A.

Keywords— UAV, quadcopter, BLDC motor, Electronics Speed Controller, Technology

1 Introduction

Drones where humans cannot enter, such as high temperature and high-altitude surveillance in various industries, and rescue missions can perform many tasks. Drones use four propellers, driven by motors, to generate the thrust needed for flight. We also call a drone a quadcopter. The basic principle behind the quadcopter is that the two motors will rotate in a clockwise direction. The quadcopter will ascend vertically by rotating its other two wings anticlockwise. A Quadcopter being recovered after photographing the Head of the Charles regatta in Cambridge, Massachusetts. A quadcopter, powered by four rotors, lifts and propels itself up as a multi-rotor copter. People classify quadcopters as rotorcraft, rather than fixed-wing aircraft, because a set of rotors (vertically oriented propellers) generates their lift [1].

Drone technology has ushered in a new era of problem-solving across various sectors, including agriculture and disaster relief. Equipped with advanced sensors and high-resolution cameras, these versatile aerial devices offer unprecedented access to remote or hazardous areas, enabling efficient data collection and analysis. Drones provide cost-effective and efficient solutions to traditionally challenging tasks, such as agricultural monitoring, health surveillance, disaster damage evaluation, and infrastructure inspection.

Moreover, human interventions are greatly reduced by advancing technology in drones and quadcopters, which is visible significantly in the medical, agriculture, and defense sectors. There is a significant rise as they can perform any task with greater precision and consistency as they can withstand any risk zones, reach the unreachable areas by human, and cover the area is short time, resulting in high productivity. Therefore, with the changes, there must always be an augmentation in the approaches that are prevailing, so are the industries adopting and innovating drone technology and signaling a future of drones being an integral part of any industries.

This project has presented us with an invaluable educational opportunity and inspired us to delve deep into such trending technology. The development of quadcopter drone has provided us an opportunity to gain hands-on experience and practical knowledge, such as to use 3D machine, CAD software to design its parts, programming, circuit design, circuit connection and troubleshooting. Overall, we got an experience of a real-world scenario.

Through this project it allowed us to bridge the various gaps between modules that are taught in the class as individual subjects. For example, we could understand how we can control the flight which relates to control system and controllers, how sensor and actuators work relates to analog and digital electronics, Instrumentation engineering. We applied our knowledge of communication systems to the flight transmitter. Finally, to integrate them together, we are using our programming skills derived from programming subjects such as C, C++ and assembly programming.

We are all aware of the fact that His Majesty King Jigme Khesar Namgyel Wangchuk emphasizes the importance of youths and their engagement in technological fields such as AI, IoT, Blockchain, data mining and other trending technology. In fact, His majesty stated in coronation speech, The future of our nation depends on the worth, capabilities and motivation of todays youth. Therefore, I will not rest until I have given you the inspiration, knowledge and skills so that you will not only fulfill your own aspirations but be of immense worth to the nation. This is my sacred duty. A strong motivated young Bhutan guarantees a strong bright future. [2]. Similarly, we hope to find our interest in this area and inspire the youngsters.

2 Literature Review

2.1 Thrust-to-weight ratio

The thrust-to-weight ratio is one of the fundamental ratios in the design of quadcopters. It is the ratio that determines the drones dynamics and capabilities. We basically define it as the ratio of total thrust generated by the propulsion system to the total weight of the copter. With TWR, we can predict:

1. Quadcopters ability to Take-off and landing.
2. Maneuverability.
3. Carry payload.
4. Stability.

A properly defined TWR ratio is essential for quadcopters to function efficiently. Applications such as aerial photography, surveying, and surveillance strongly require this. Having low TWR makes the drone sluggish and loses it stability otherwise. Therefore, it plays a crucial role in maintaining the TWR, which is typically 2:1 to 3:1.

2.2 Calculating the TWR

We have TWR formula as presented below:

TWR = Total thrust produce/Total weight

Where, total trust is obtained from all the motors connected, and weight includes the mass of the copter and payload We show the differences between a high TWR and a low TWR here.

High TWR: A quadcopter with high TWR, strong trust to its weight defines i.e., *TWR>3:1*. It mostly finds its application that needs high and rapid acceleration, sharp maneuvers, and fast takeoff and landing, such as racing drones.

Low TWR: Alternatively, a Quadcopter with a low TWR, a *TWR <2:1*, might be more stable but would lack the agility required for dynamo flight. For applications where stability is a prime requirement, like aerial photography or surveillance, quadcopters with a lower Thrust-to-Weight Ratio are the typical choice [3].

2.3 PI Controlling Setup

It allows to modify the Roll, Pitch, and Yaw control loop feedback parameters. An output value proportionate the proportional term (P generates to the current error value). For a given change in the error, a high proportional gain causes a significant change in the output. If the proportional gain is set too high, the quadcopter will overshoot and begin to oscillate. An excessively high P gain because will produce a high frequency oscillation the control loop corrects for faults 400 times per second. It will be difficult to control the quadcopter if the proportional gain is too low since the control action will be too slow to react. Therefore, it is crucial for us to set the P gain value is such that it simply makes the quadcopter oscillate.

Both the error's magnitude and duration have a direct correlation with the integral term's (I). The integral provides the cumulative offset that ought to have been fixed earlier in a PI controller, which is the sum of the instantaneous errors over time. The quadcopter will begin to oscillate if the integral term is excessively high. Since the Integral term is correlated with the error's length over time, an excessively large I gain will cause a low frequency oscillation to emerge. And if the Integral term is too low, the Integral gain will result in a less locked in feeling.

2.3.1 PI gain adjustment process

- To set the Roll, Pitch and Yaw values to zero, we use transmitter trims by selecting Receiver and Test menu through the flight remote controller.
- Turn off the self-level.
- Select Integral value as zero for all movement, i.e. Roll, Pitch and Yaw.
- Hover the Quadcopter and move on one axis (Roll, Pitch or Yaw) and quickly center the TX control stick.
- Increase Proportional gain till the quadcopter oscillates.
- Thereafter, we decrease proportional gain gradually to remove oscillation.
- Repeat the steps for all three axes.
- Increase the Roll and Pitch Integral gain until it flies straight forward/sideways without pitching up or down. It should feel more locked in.
- Increase the Yaw Integral gain until Yaw feels locked in.

Keep in mind that if you have a gain set and you fly your quadcopter on the ground, some motors will begin to accelerate while others will slow down. This is the Integral term trying to make up for long-term mistakes, but it can't move the quadcopter to make up for the error when it's on the ground or in your hand (without any propellers, of course).

The motor can use up to a certain percentage (PI limits) to apply correction. For example, a limit of 20 (20% motor power to apply the correction) will allow 80% of motor power to be used for commanding a change in direction from the receiver [4].

3 Methodology

3.1 Block diagram and Schematics

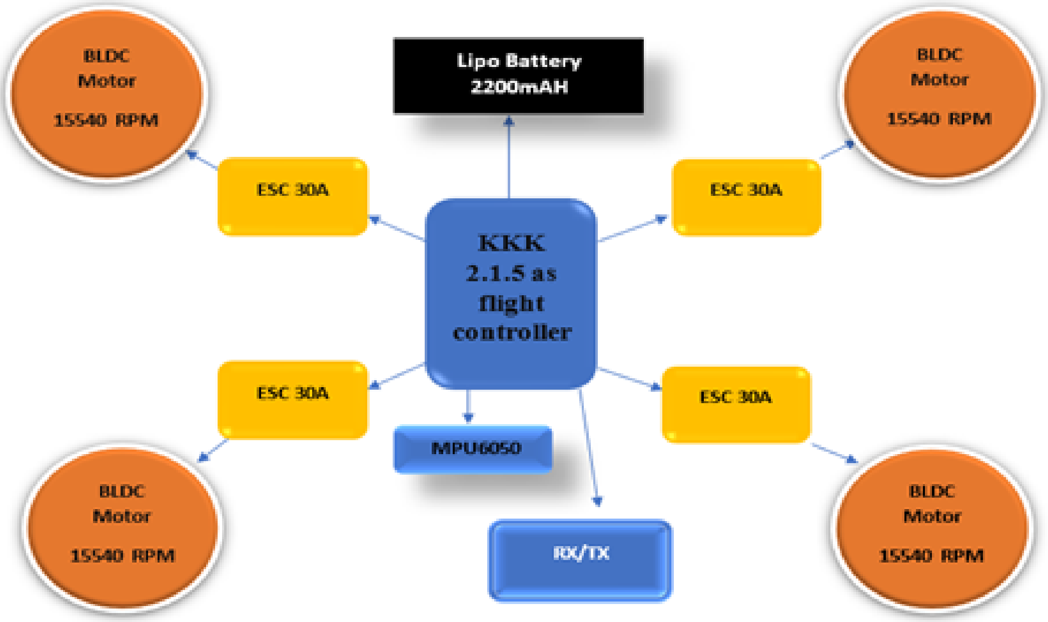

Figure 1: Block Diagram of our Proposed System Architecture

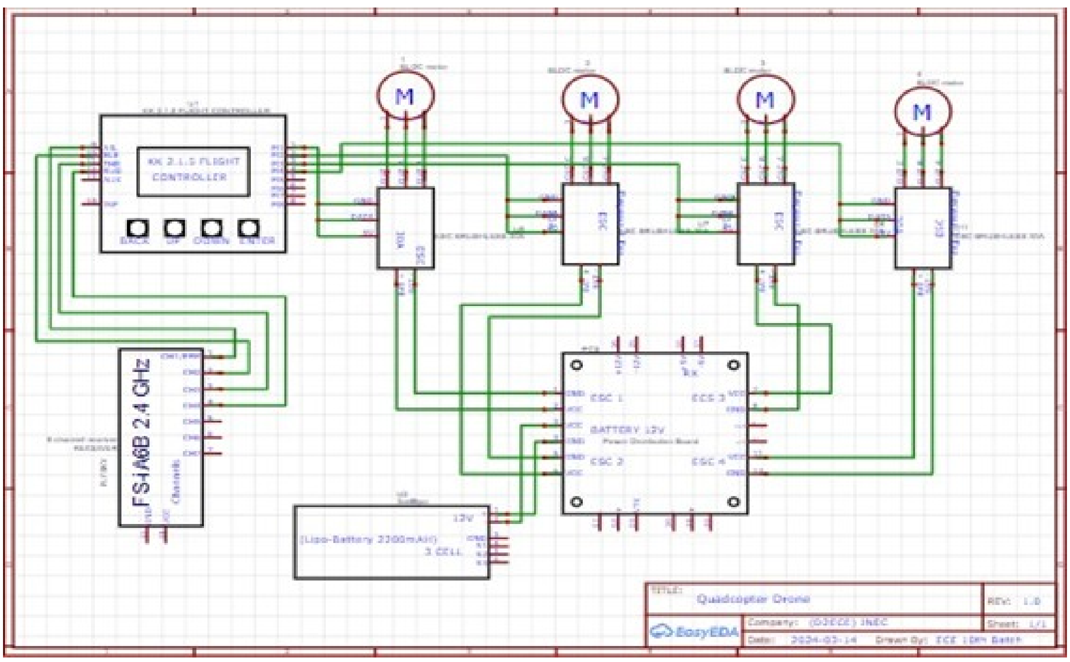

Figure 2: Schematic Diagram designed in EasyEDA

The figure 1 represents the block diagram of our proposed system, which includes key components such as BLDC motors, ESCs, a microcontroller, a LiPo battery, and a radio transmitter and receiver.

A KK 2.1.5 flight controller is used in the construction of our quadcopter, acting as the main control unit to oversee and stabilize the flying operations. This operation is supported by the integrated IMU sensor which provides data to find its acceleration, velocity, height and orientations. The ESC and Battery are responsible for controlling the motor and energizing it respectively. And radio transmitter and receiver is used to control the quadcopter remotely.

3.2 Wiring Connections for KK2.1.5 Flight Controller

1. KK2.1.5 Flight Controller: M1: ESC 1 (Motor 1)

   M2: ESC 2 (Motor 2)

   M3: ESC 3 (Motor 3)

   M4: ESC 4 (Motor 4)

2. Receiver (FS-iA6B 2.4 GHz): Channel 1 (Throttle): Channel 1 on KK2.1.5

   Channel 2 (Aileron): Channel 2 on KK2.1.5

   Channel 3 (Elevator): Channel 3 on KK2.1.5

   Channel 4 (Rudder): Channel 4 on KK2.1.5

3. ESCs (Electronic Speed Controllers): Power Wires: The Red Wire Positive Terminal of Battery The Black Wire Negative Terminal of the Battery

   Signal Wires: ESC 1 to M1 on KK2.1.5

   ESC 2 to M2 on KK2.1.5

   ESC 3 to M3 on KK2.1.5

   ESC 4 to M4 on KK2.1.5

4. Battery: 12V LiPo (3-cell, 2200mAh): The terminal of battery is connected to + and terminals of the Power Distribution Board (PDB). PDB distributes power to all the drivers. [4].

3.3 Flowchart

The KK2.1.5 Flight Control Unit (FCU) operates by receiving commands from a transmitter, which include throttle and directional inputs. It uses gyroscopic sensors to detect and measure rotational movements (pitch, roll, yaw) of the quadcopter, and an accelerometer to gauge linear acceleration and determine the quadcopter's orientation relative to gravity. Using Proportional-Integral-Derivative (PID) control algorithms, the FCU adjusts the speed of each motor through Electronic Speed Controllers (ESCs).

This adjustment is based on the data from gyroscopes and accelerometers to maintain stability and achieve desired flight orientations in both Rate mode (fixed rotational rates) and attitude mode (stable orientation based on stick inputs). The FCU's LCD display and navigation buttons allow pilots to configure settings, such as PID parameters and flight modes, directly on the unit.

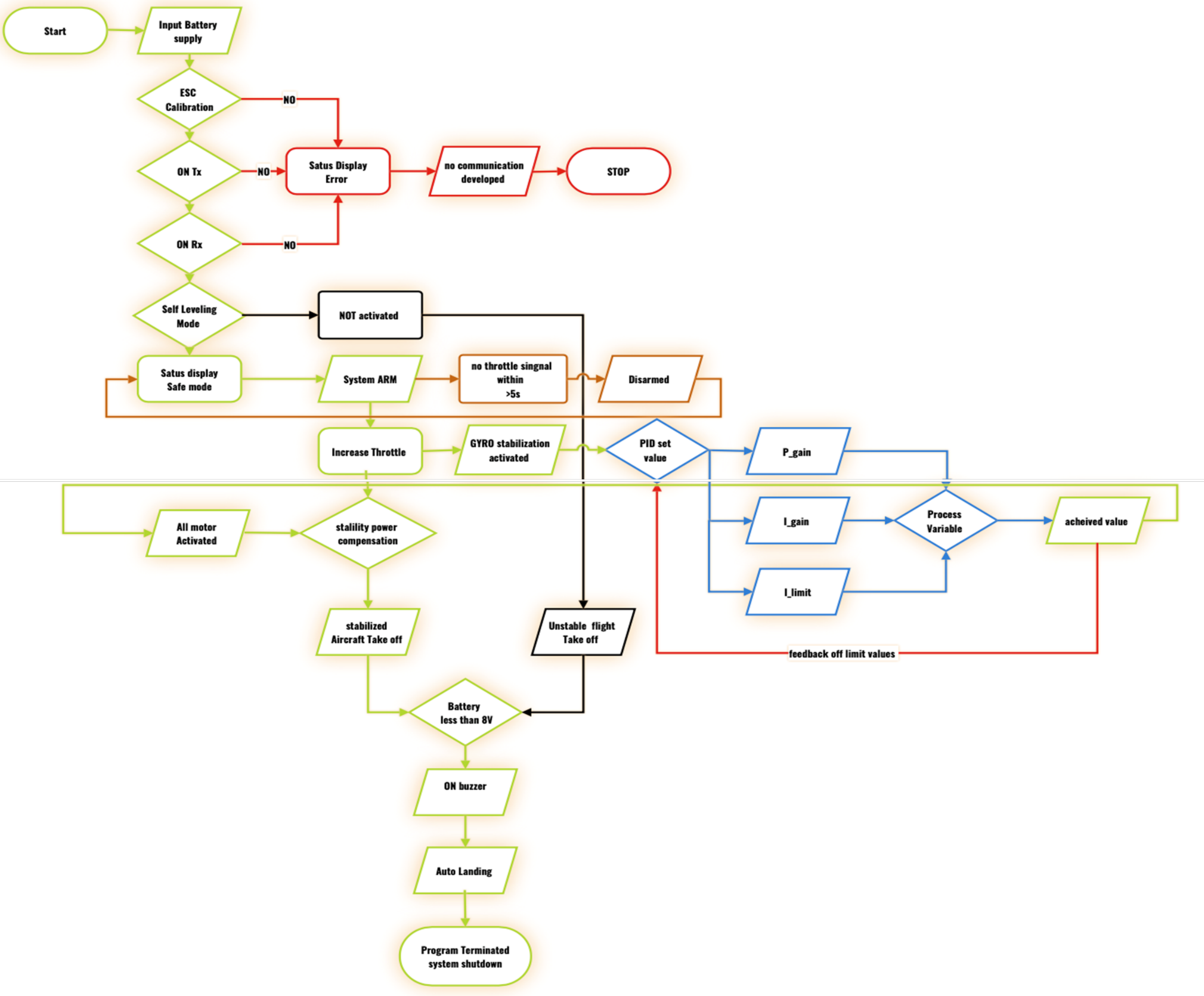

Figure 3: Flow Chart of overall drone

4 3D-Designs of quadcopter frame

We have encountered several failures in our design. However, after careful consideration, we developed a robust frame for the drone. The detail designs are given below in figure 4, 5 and 6.

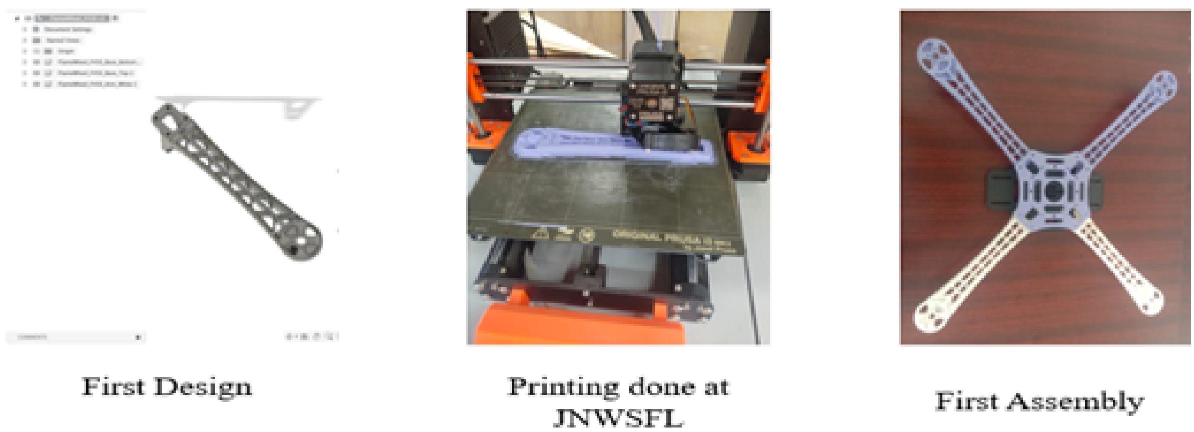

Figure 4: 1st Drone Arm designs

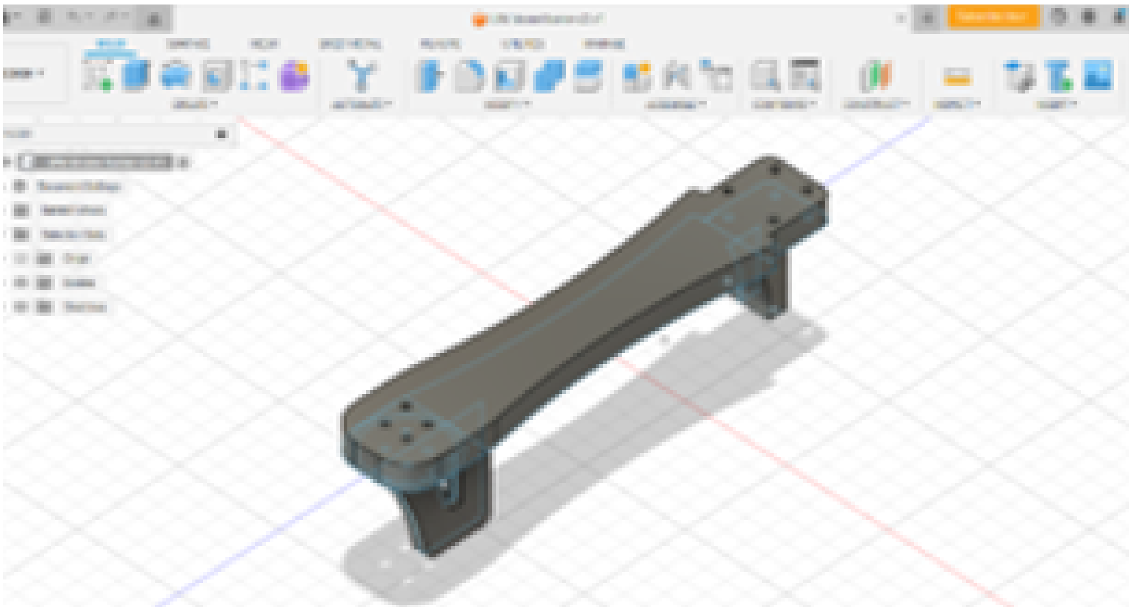

Figure 5: 2nd Drone Arm designs

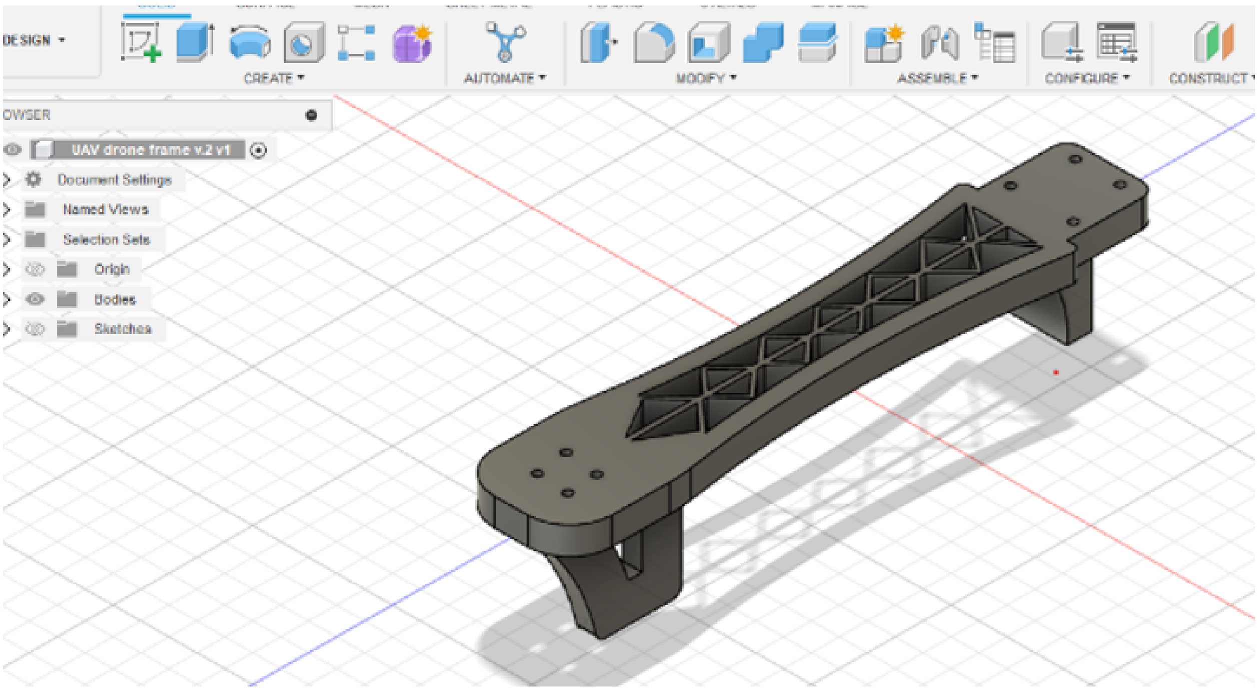

Figure 6: 3nd Drone Arm designs

We have encountered several failures in our design. However, after careful consideration, we developed a robust frame for the drone. The detail designs are given below in figure 4, 5 and 6.

First design was a failure due it being brittle and the weak point was near the motor mounting side (thinner in thickness).

The second design could solve the first issue, however, was heavy because of the force acting against it. In the third design, we added some cavity/holes to overcome the force because of gravity.

Basic tools used: Extrude, Offset, Fillet, 3-Point Curve.

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5 Results and Discussion

5.1 Thrust Calculation

Figure 7: Weight measurement of the drone

- Weight of the drone (mass, m) = 0.900 kg
- Acceleration due to gravity (g) = 9.8 m/sš
- Number of motors = 4

5.2 Calculations

1. Calculate the Force due to Gravity (Weight):

$$\begin{aligned}\text{Force} &= \text{mass} \times \text{gravity} \\ &= 0.900\,\text{kg} \times 9.8\,\text{m/s}^2 \\ &= 8.82\,\text{N}\end{aligned}$$

2. Thrust calculation At 90% of throttle, we achieve the thrust of around 720g (7.20N) So, the total combine thrust of all four motors:

$$\begin{aligned}\text{Total thrust} &= 4 \times 7.20\,\text{N} \\ &= 28.80\,\text{N}\ (2880\,\text{g})\end{aligned}$$

3. Thrust to weight ratio Thrust to weight ratio:

$$\begin{aligned}\text{Thrust:Weight} &= \frac{\text{Total thrust}}{\text{Weight of drone}} \\ &= \frac{2880\,\text{g}}{900\,\text{g}} \\ &= 3.2 : 1\end{aligned}$$

Standard thrust to weight ratio is 2:1. So, with this ratio, we can lift up to 1440g
Total component weight:

$$\begin{aligned}\text{Component weight} &= 1440\,\text{g} - 900\,\text{g}\\ &= 540\,\text{g}\end{aligned}$$

5.3 Summary of Calculations

- The total thrust force of the drone is 8.28 N due to gravity.
- Using a 2:1 thrust-to-weight ratio. we can lift to 1440g of weight
- Each motor needs to provide 7.20 N (720 g) of thrust to meet our thrust-to-weight ratio, which is 3.2:1.

5.4 Conclusion

- **Total Thrust Required:** 28.80N
- **Thrust per Motor:** 7.20 N (720 g)

This calculation ensures that the drone will have sufficient thrust to not only lift off but also maintain stable flight and handle various in-flight maneuvers effectively.

5.5 Theoretical calculation of Flight Time

Flight Time Calculation:

$$\text{Flight Time} = \left(\frac{\text{Battery Capacity (Ah)}}{\text{Hover Current (A)}}\right) \times 60 \quad \text{(in minutes)}$$

Drone Specifications:

$$\begin{aligned}\text{Weight of drone} &= 900\,\text{g}\\ \text{Propeller diameter} &= 10\,\text{inches} = 0.254\,\text{m}\\ \text{Motor KV rating} &= 14000\,\text{RPM/V}\end{aligned}$$

Battery Details:

$$\begin{aligned}\text{Cell voltage} &= 3.7\,\text{V}\\ \text{Number of cells} &= 3\\ \text{Total voltage} &= 3 \times 3.7\,\text{V} = 11.1\,\text{V}\end{aligned}$$

Maximum Motor Speed:

$$\begin{aligned}\text{RPM}_{\text{max}} &= \text{KV} \times \text{Total Voltage}\\ &= 14000 \times 11.1\\ &= 155400\,\text{RPM}\end{aligned}$$

Hover Current:

$$\begin{aligned}\text{Current per motor to lift 720g} &= 2.6\,\text{A}\\ \text{Total hover current (4 motors)} &= 2.6 \times 4 = 10.4\,\text{A}\end{aligned}$$

Battery Specifications:

$$\text{Battery capacity} = 2200\,\text{mAh} = 2.2\,\text{A}$$
$$\text{Minimum safe voltage per cell} = 2.96\,\text{V}$$
$$\text{Fully charged voltage per cell} = 3.7\,\text{V}$$
$$\text{Usable capacity (\%)} = \left(\frac{2.96}{3.7}\right) \times 100 = 80\%$$
$$\text{Effective battery capacity} = 2200 \times 0.80 = 1760\,\text{mAh}$$
$$\text{Effective battery capacity (A)} = \frac{1760}{1000} = 1.760\,\text{A}$$

Flight Time Estimate (Hovering):

$$\text{Flight Time} = \left(\frac{\text{Battery capacity (A)}}{\text{Hover current (A)}}\right) \times 60$$
$$= \left(\frac{1.760}{10.4}\right) \times 60$$
$$= 10.15\,\text{minutes}$$

Note: Flight time will be lower under full throttle or aggressive maneuvers.

5.6 Summary of Flight test

The flight test revealed several issues, including the weight of the drone, propeller imbalance, uncontrollability, improper PID tuning, motor vibrations, and instability with drifting. By addressing these issues through weight optimization, proper propeller and motor balancing, careful calibration, and precise PID tuning, the quadcopter's performance and stability were significantly improved. These adjustments ensured that the quadcopter could achieve stable flight and perform the desired maneuvers accurately. The successful resolution of these issues provides a solid foundation for future enhancements and advanced features.

Figure 8: Successful flight of drone

The PID constants for the roll, pitch, and yaw are defined based on the suggested starting values:

PID Constants for Roll and Pitch:

$$K_P^{\text{Roll/Pitch}} = 45.0$$
$$K_I^{\text{Roll/Pitch}} = 30.0$$
$$K_D^{\text{Roll/Pitch}} = 15.0$$

PID Constants for Yaw:

$$K_P^{\text{Yaw}} = 60.0$$
$$K_I^{\text{Yaw}} = 50.0$$
$$K_D^{\text{Yaw}} = 5.0$$

The calculate PID function is updated to use these values for control calculations. In the main loop, the PID control is applied to adjust motor speeds based on the PID outputs and throttle input, including the yaw control. Ensure the sensor calibration functions mpu6050 calibrate Gyro and mpu6050 calibrate are correctly defined in your MPU-6050 library and replace the placeholder read receiver inputs function with actual code to read PWM signals from your RC receiver. Perform thorough testing and tuning to achieve stable flight performance.

The PID values to be input into the PI editor of the KK 2.1.5 FCU for optimal control are as follows: for roll and pitch, set the P gain to 45.0, the I gain to 30.0, and the D gain to 15.0. For yaw, configure the P gain to 60.0, the I gain to 50.0 and the D gain to 5.0. These values should be precisely entered into the flight controllers PI editor to achieve the desired performance.

6 Conclusion

The development of the drone has resulted in the successful flight demonstrating the effectiveness of our design. Initially, we developed the drone using popular controller Arduino Uno R3. However, after several tests, flights we developed could not achieve the desired flight takeoff and landing. Then we tested the same design with a different controller, which is KK2.1.5 which resulted in desired output. There were various challenges in the journey of development, such as weight management, imbalance propeller, and its structure strength, uncontrollability, PID tuning, and motor vibrations. With our constant effort on optimizing, calibration and tuning, we could achieve stable quadcopter flight.

This project has greatly enhanced our theoretical knowledge by bridging the gap between classroom learning to apply practical skills, furthering our greater understanding of drones and its operations, construction using various design software and programming skills.

7 Acknowledgement

We would like to express our sincere gratitude and appreciation to all those who contributed to the successful completion of our project titled Design and Development of Quadcopter.

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