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Research Article

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Development of an Unmanned Aerial Vehicle

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Abstract Unmanned aerial vehicles (UAVs) are quadcopters that can be used for many purposes. Precision agriculture, dropping logistics, defence, surveillance, and dropping logistics are just a few of the areas that use UAV technology. The goal of the study is to develop, and test a quadcopter drone that has better balance and stability and can carry out a range of duties in the field. This study provides an excellent solution for unmanned aerial vehicles (UAVs) with their size and prospective uses by presenting the mechanical structure and describing the various sections of a quadcopter. The quadcopter configuration is more stable than the other configurations, and unlike the other configurations, it may hover near its target. The UAV's maximum flying duration is estimated to be 15.6 minutes. The 960 kV brushless out-runner motors that were deployed are operational units. The total mass lifted by each motor was determined to be 0.3007 kg.

Keywords Unmanned aerial vehicles (uavs), Quadcopters, Precision agriculture, surveillance, Stability.

1. Introduction

Drones are commonly referred to as unmanned aerial vehicles (UAVs). Unmanned aerial vehicles (UAVs), also referred to as drones, are aircraft that are not equipped with a human pilot, crew, or passengers. A drone is essentially a flying robot that uses GPS technology. With software-controlled flight plans in its embedded electronics, the drone can be operated remotely or on its own. UAVs were first created in the 20th century to perform military tasks that were too "dull, dirty, or dangerous" for humans [1]. By the 21st century, most militaries had adopted UAVs as indispensable tools. Control technologies have been used in numerous non-military applications as costs have decreased and they have improved [2]. They consist of drone racing, aerial photography, area coverage, [3] precision agriculture, monitoring forest fires, rivers, and the environment; [4] policing and surveillance; infrastructure inspections; smuggling; product deliveries; and entertainment.

Unmanned aerial systems (UAS) comprise UAVs as well as a ground-based controller and a communications system for the UAV [4]. Another name for an unmanned aerial vehicle system (UAVS) is a remotely piloted aircraft system (RPAS), or remotely piloted aerial vehicle (RPAV). Numerous synonymous words are employed. As substitutes for "unmanned," "unoccupied" and "uninhabited" are occasionally employed [6]. Disaster scenarios can make use of Unmanned Aircraft Vehicles (UAV), which are equipped with remote sensing instruments. The unmanned aerial vehicle's capacity for disaster management can be expanded upon upon obtaining photogrammetric data accompanied by relevant image information [7]. Using drones is most common in the military. On the other hand, it is also utilised for traffic monitoring, search and rescue, surveillance, and weather monitoring. Drones have gained interest recently due to a variety of commercial applications. Although the industry for non-military surveillance is still relatively young, it is growing quickly. It is being utilised more and more in firefighting and police activities, among other things. This effort, which is a component of this significant development, will be helpful for a variety of non-military surveillance applications in addition to the military.

Moreover, re-identification techniques enable autonomous UAV identification across various cameras with varying perspectives and hardware configurations [8]. Major international airports now have commercial systems installed, like the Aaronia AARTOS [9]. There are a wide range of applications for digital image processing in the current world, such as traffic, highways, surveillance, etc. Autonomous drones use a variety of cutting-edge technology, including cloud computing, computer vision, artificial intelligence, machine learning, deep learning, and thermal sensors, in addition to software to accomplish their missions autonomously and without human assistance. The ability to respond faster to emergency situations and be more aware when spotting people and items in various areas is the work's biggest benefit. This can help a lot with things like crime rate and location tracking, rescue and surveillance missions, and more.

2. Materials and Methods

2.1 Material selection

The UAV is made up of the following functional blocks;

a. Quadcopter Frame unit
b. Motor Unit
c. Electronic Speed Controller (ESC) Unit
d. Propeller Unit
e. Flight Controller Unit
f. Transmitter and Receiver Control Unit
g. Global Positioning System (GPS) Unit
h. Battery Unit

Figure 1 depicts the installation of electronic components and flying tests.

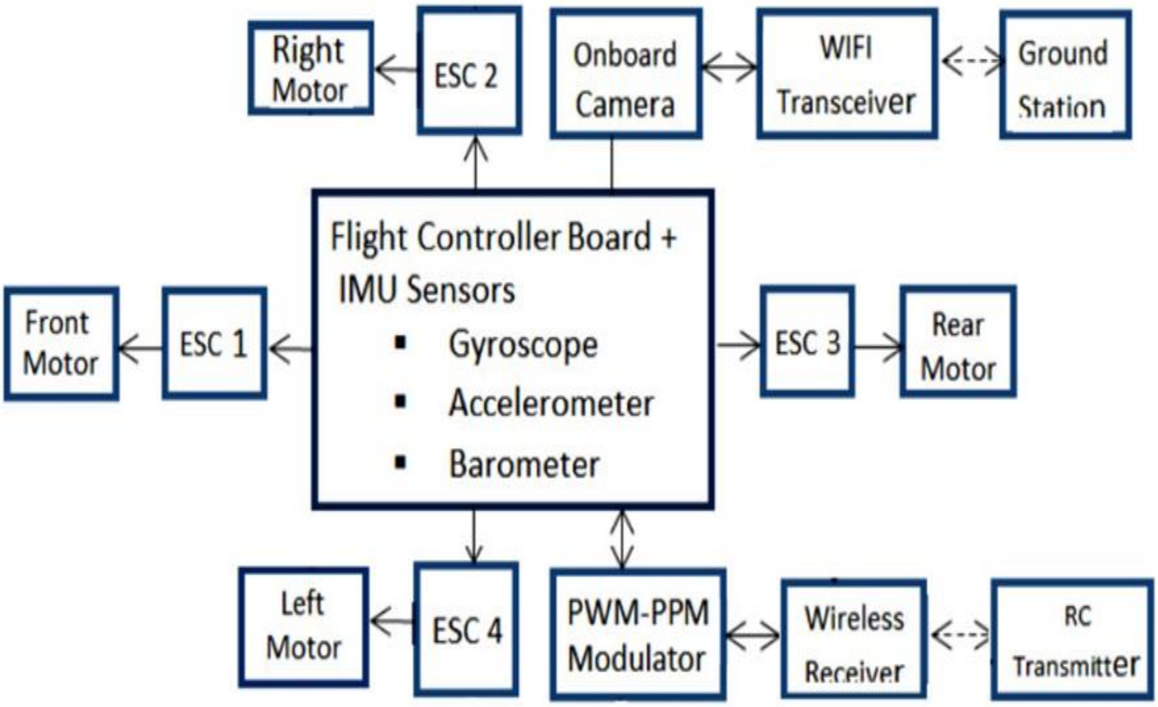

Figure. 1: Basic block diagram of UAV

2.1.1 Function of blocks

i. Quadcopter Frame: It includes arms to hold motors and a chassis to hold the flight controller, battery, and other accessories on board.

ii. Motors: This helps the quadcopter perform a “lift-up” action. It also produces the rotational forces for the propellers.

iii. Electronic Speed Controller (ESC): Since the motors used in quadcopters usually require a 3-phase supply, this cannot be supplied directly, hence the need for ESCs, which convert the signals from the controller and send them to the motors in order to control their speed.
iv. Electronic Speed Controller (ESC): Since the motors used in quadcopters usually require a 3-phase supply, this cannot be supplied directly, hence the need for ESCs, which convert the signals from the controller and send them to the motors in order to control their speed.
v. Propellers: One of the most important parts of the drone are the propellers. These spinning blades are the wings of the quadcopter. This is the very part that creates the airflow that lifts your equipment into the air.
vi. Flight Controller: Its function is to direct and synchronise the revolution per minute (rpm) of each motor in response to input. A command from the pilot or from the flight computer to the quadcopter to move forward sends a signal to the flight controller, which determines how to manipulate the motors accordingly.
vii. Remote-Controlled Transmitter and Receiver: A radio transmitter and receiver is an electronic device that controls the quadcopter remotely.
viii. GPS module: This provides the coordinates for the quadcopter, which enables the drone to navigate from its current location to a new position.
ix. Battery: The quadcopter battery is the power source that drives all the systems on your drone and allows it to perform flight operations.

2.2 Design considerations

The functional blocks served as the basis for the UAV's design. The components that make up a quadcopter are crucial to the structure's stability. The payload greatly influences which BLDC, ESC, and battery are chosen. The brushless DC motor ratings determine the ESC ratings. High Kv (rpm/volts) ratings, high thrust, low weight, and high efficiency are factors that influence the choice of BLDC. The propeller blade specifications and the necessary payload determine the motor ratings. Select high-rated motors, which call for a higher current rating ESC, if the payload is heavy. The propeller's diameter and pitch determine how much thrust is generated. A completely new set of BLDC motors, ESCs, and batteries would be needed if the motors were to be changed in order to increase the payload as described by [8].

2.3 Design of the quadcopter frame unit

The quadcopter system operates on the theory of high-pressure air lifting phenomena. The goal of every new design is to be more flexible and stable. A UAV's ability to fly steadily is largely dependent on its design, and because of the system's reduced stability, designing the control system becomes more difficult. The resulting moments and forces about the centre of gravity (C. G.) determine the UAV's motion. The Newton-Euler model provides a good quantitative relationship between forces and torque about the body's centre of gravity (Hartley *et al.*, 2023). For example, if a UAV needs to hover at a particular height, the moments about the centre of gravity need to be zero. The forces and moments applied at the centre of gravity depend on the structure and design. The design of a quadcopter has both mechanical engineering and computer engineering aspects.
The quadcopter design is based on the embedded system platform. It consists of microcontrollers that control the overall performance of the quadcopter, such as the flying mechanism and live streaming of videos. After the microcontroller, the ESC is used to control the propeller speed, depending on the signal from the computer. The power supply for the quadcopter is provided by the battery. These requirements make sure that the quadcopter maintains stable flight while moving or hovering. Generally, the X-type frame is used in the quadcopter because it is thin, strong enough to withstand deformation due to loads, and light in weight. Usually the frames are indicated as motor-to-motor distance or the diameter of the circle of frame area. Generally, the diameter of the circle of frame area for a mini-aerial vehicle ranges between 1/4m and 1m. For the mini aerial vehicle, a 1/2-metre area is chosen as per the application.

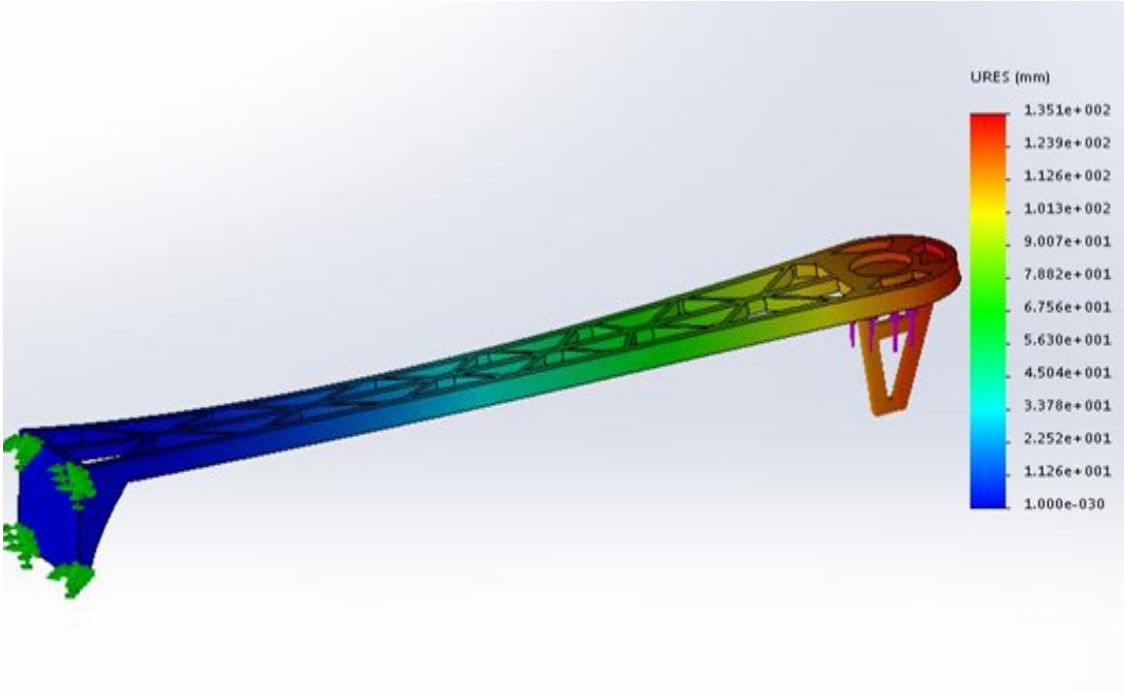

Figure 2: Static displacement

Source: (Hartley *et al.*, 2023).

The load on each arm is 2.5 N, as indicated in Fig. 2, where the average stress of an arm is 1.7 N/mm^2. This is sufficient for a total load of about 10.0 N. It shows how an arm can move in a static position. With 2.5 N of load on each arm, the displacement result is only marginally above the satisfactory level. For the purposes of the study, the frame will, nevertheless, prove to be sufficiently reliable because the overall estimation of static stresses using the Force Equilibrium Motion (FEM) indicates that it will have sufficient strength for the load.

2.4 Design of the motor unit

DC brushless motors were selected. Quadcopters that are the right size for the project typically have BLDC motors. These motors are suitable for mounting on the frame and are simple to operate. An armature that is fixed is centred around a permanent magnet that powers each motor. When compared to brushed DC motors, BLDC motors have a few benefits. Increased efficiency, longer lifetime, less noise, increased torque per weight, and improved reliability are a few benefits. According to [10], the UAV flight stack software allows ground control and mission planning, as well as data collection from the sensors and motor control to maintain UAV stability. Increased efficiency, longer lifetime, less noise, increased torque per weight, and improved reliability are a few benefits. According to [10], the UAV flight stack software allows ground control and mission planning, as well as data collection from the sensors and motor control to maintain UAV stability. Selected DC brushless motors are shown in Figure 3. Tosky 960kv brushless outrunner motors that are ready to run were used for this project. Their power output of 150 watts is ideal, and their medium kv rate of 960 rpm/volts is suitable, as it offers both high torque and the necessary rotational speed.

Figure 3: Ready to sky 960kv Motors [6;7;8]

2.4.1 DC motor performance

A brushless DC motor functions almost exactly like a brushed DC motor does. The primary distinction is that the commutator of a brushed DC motor is housed inside the motor, whereas the commutator of a BLDC is integrated into the speed controller. The relationship between the voltage and the RPM is known as the Kv rating.

Regarding the motor selected for this project: Kv = 960 [rpm / $volts$]. The following is the determination of the torque constant T_3 through measurement of the electro-mechanical relationship:

$$M_p = E_p E_{ff} \quad (1)$$

$$EI = 2\left(\frac{2\pi}{60}\right)T \quad (2)$$

Where;

M_p = Mechanical power

E_p = Electrical power

E_{ff} = Efficiency

E = motor voltage rms [V]

I = motor current [A]

N = angular velocity of the motor [rpm]

T = motor torque [Nm]

$$\frac{E}{N} = \frac{1}{Kv} \quad (3)$$

$$\frac{T}{I} = K_t \quad (4)$$

Thus, the constant relationship between K_t and K_v is obtained.

Therefore, K_t = 0.01794 kv (5)

The torque (T) was calculated as follows:

T = I * Kt (7)

The revolution per minute- r.p.m (N) speed was calculated as follows:

N = Kv * input volt (8)

Depending on the application, BLDC motors are typically referred to in KVs, such as 850 KV to 1800 KV. A 1000 KV BLDC motor will spin at 1000 rpm with 1 volt applied, and 12 volts wold cause the motor to spin at 12000 rpm.

2.5 Electronic speed controller ESC unit

Brushless motors are operated by means of an electronic speed controller (ESC). A standard RC signal is used by the ESC to operate at 100 Hz, producing a high pulse lasting 1-2 milliseconds. The ESC's internal regulator regulates the motor's speed. A TURNIGY Plush 30-amp speed controller was selected as the ESC for the project. This kind of ESC is appropriate because the motor can handle up to 32 A of current load. An ESC provides the proper amount of electrical power to run a brushless motor. The flight controller generates the pulse signal, which is subsequently sent to the ESC. By adjusting the PWM signal, the motor can rotate at its ideal speed [15;16].

ESC rating = (1. 2 to 1. 5) * max. Ampere rating of motor

Therefore; 1.5 * 20A = 30amps

2.6. The propeller unit

Two criteria were used to select the appropriate kind of propeller: the motors' power output and the battery's capacity. Calculations indicate that an 8045 SF propeller—which is made of lightweight, durable plastic, has an 8-inch length and a 4.5-inch pitch—would be the best option. According to the pitch, the propeller travels six inches in a transverse direction for every rotation. The selected propellers are strong enough to lift a quadcopter that is fully loaded, and because of their low cost, a few extras can be included in the project budget as described by [8;9]. The propellers are among the most fragile and heavily used parts of the quadcopter, so these extras are a crucial addition. Furthermore, there is no need to balance the propellers before the quadcopter takes off because the project's propellers are sufficiently well-balanced and vibration-free. The propellers' aerodynamic characteristics are crucial and apply to the planning and building of any aircraft. While the quadcopter is in flight, it is subject to three primary forces [2;3]. Torsion, centrifugal force, and thrust are these. The force that causes the quadcopter to move vertically as a direct result of the propellers' rotation is called thrust. Propeller rotation also produces centrifugal force, which causes the blades to spin away from and away from the centre. The centrifugal force required for the propellers to operate in the current study can be ignored because it has very little impact on the quadcopter. The resulting air forces cause the torsion, or twisting force, which is a feature of the blade design and tends to twist the blades towards a lower blade angle.

2.7 The battery unit

The battery is another important part of the project since the duration that the quadcopter can stay in the air is solely dependent on the battery's power supply. Because the battery is the most heavily loaded component installed in the frame, weight is also an important consideration. For the project, a lithium polymer (LiPo) battery was chosen because of its favourable power-to-weight ratio and capacity to produce a sufficient amount of power [11]. A TCB three-cell LiPo battery provides power to the motor. The motors are powered by the battery, which produces 5200 mAh and 11.1 volts. It is continuously able to feed 182 amps. Three LiPo cells are connected in series with one another. 11.1 volts is produced by each cell, which is 3.7 volts. The rating of 35C for this specific battery indicates how much continuous current as follows:

$$5200\text{mAh} * 35\text{C} = \frac{5200}{1000} * 35 = 182\text{Ah} \quad (9)$$

The approximate flying time of the quadcopter was calculated using the 15A average current as follows:

$$\text{MCWM} = \text{nM} * \text{MCSM} \quad (10)$$

Where;

MCWM is maximum current withdrawn by motor;

nM is number of motors;

MCSM is max current of single motor

2.8 Drone fly time

Based on the brushless motor specifications, the quadcopter is estimated to use about 20 amps on average when flying with a full sensor load. This multirotor type UAV used a 3S LiPo battery with a stamped rating of 5200 mAh. Thus, the following estimate of this quadcopter's maximum flight time was calculated as follows:

Step 1: The rating of the battery is 5200 mAh.

Step 2: The amp-minute for the battery is 5200/1,000 * 60 = 312 amp-minutes.
Step 3: From the brushless motor rating, the motors are estimated to draw about 15 amps on average during flight.
Step 4: The expected duration (in hours) of a quadcopter flight is given as,
Duration = capacity of battery in Ah / max current drawn by motors
The estimated maximum flight time for the UAV is 312/20, or 15.6 minutes.

2.9 Force analysis

The propeller transfers the resulting forces to the rod, which is subsequently clamped to the top and bottom plates. The thrust, centrifugal force, and propeller moment are the forces applied to the rod during the static strength test as computed as shown:

$$F_c = mR^2 \tag{9}$$

Where;
Fc = Centrifugal Force (N)
M = Mass of propeller (Kg)
R = Radius of the propellers (m)
N = Speed of the propeller (rpm)
W = Angular speed = ($2\pi N$ /60) rad/sec [4;7]
The propeller is specified on the basis of its pitch and diameter. The diameter of the propeller (D) was calculated using the equation of power (in Watts) as follows:

$$Powe = K_p D^2 N^3 P \tag{10}$$

Where;
K_P = Propeller constant (1.11 for APC Controller)
P = Pitch of the propellers (m)
The thrust (Tr) was calculated from the expression in equation (11):
Thrust = (π * D^4 * p *v * dv)/ 4

$$T_r = \frac{\pi D^4 P V d_v}{4} \tag{11}$$

P = Density of air (kg/m^3)
v = Velocity of air (m/s)
dv = Velocity of the air accelerated by propeller
Then, the total mass lifted by the quadcopter is calculated as follows:
M = total mass lifted by the quadcopter (kg)
M = thrust/aacc due to gravity (9.81 m/s2)
The total weight to be carried is 1200 g.
Therefore:
T = 1.2kg * 9.81 (from equation 7)
= 11.778N
Thrust of each motor = 11.772N/4
= 2.943N per motor
Recall 1N = 0.1019716713kg
Therefore, the total mass lifted per motor is:
2.943 * 0.1019716713 = 0.3007kg per motor
The relationship governing the lift capabilities of a flight system as follows:

$$Lift_{(kg)} = \frac{(WD^4N^2)(\frac{P24}{Cf*29.9})}{2.2} \tag{12}$$

Where C_f is Lift coefficient

2.9.1 Method for assembly

1. Assemble the lower board. Note: To avoid breaking threads, use the proper force when installing the screws. When installing screws, use the proper amount of silicon or screw glue.

2. Mount the motors and ESCs. Verify that each motor rotates in the same direction as it does in the previously displayed figure. If not, you can change the direction of rotation of the incorrect motor by flipping any one of its two wire connections.
3. Set up your electronic system and flight control system. The assemblages are shown in Fig. 6, 7, 8
4. Installation the top board.
5. Tidy all cables with zip ties. Make sure all cables are not cut by the frame boards and propellers. Smooth out the board edge if necessary.
6. Installation the propellers.

The flight control system configuration process comes after the propellers. It is guaranteed that the propellers rotate in the same direction. Rotating the propeller in the lock direction tightens it. There was no thread lock applied. Table 1 and 2 function description and component specification.

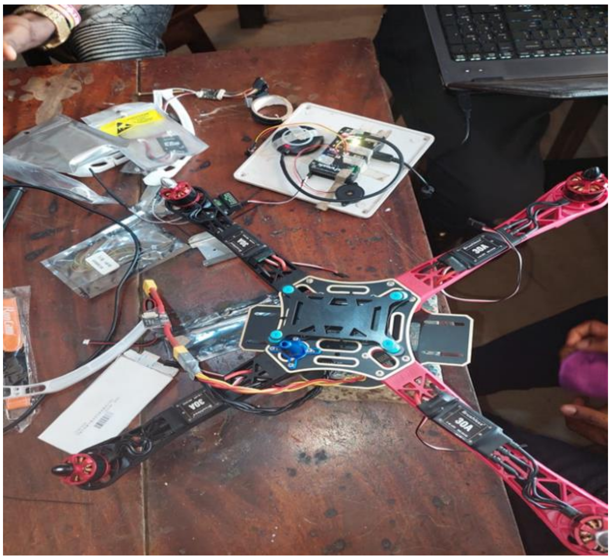

Figure 6: flight controller and stabiliser installation

Figure 7: Pixhawk installation and GPS mounting

Figure 8: Propellers installation Source: [2;4;6]

Table 1: ESC functional description

Normal	Description
1234	Ready
Abnormal	Description
BBBBBB…	No signal input, or throttle stick is not in the bottom position

Table 2: Component specifications

Frame	**Description**
Diagonal Wheelbase	450 mm
Frame Weight	282 g
Take-off Weight	800 g ~ 1600 g
ESC	
Max Allowable Voltage	17.4 V
Max Allowable Current (Persistent)	20 A
Max Allowable Peak Current (3 seconds)	30 A
PWM Input Signal Level	3.3 V / 5 V Compatible
Signal Frequency	30 Hz ~ 450 Hz
Battery	3S LiPo 5200mah
Weight (without cable)	12.5 g
Weigh (with cable)	27 g
Motor	
Stator size	23×12 mm
KV	960 rpm/V
Weight	57 g
Propeller	
Diameter / Thread Pitch	24×12.7 cm (9.4×5.0inch)
Weight (Single)	13 g

3. Results and Discussion

Sir Isaac Newton, an English scientist, published his now-famous three laws of motion in 1687 [5;6;7]. These laws explain the relationship between objects and forces that determine motion. According to Newton's third law of motion, there is an equal and opposite reaction to every action. The propellers of a quadcopter push air downward as they rotate. This illustrates the action according to Newton's third law. The existence of an equal and opposite reaction is necessary for Newton's law to hold true. The quadcopter is being pushed upward by this reaction. The quadcopter starts to move upward when this force surpasses the force of gravity dragging it downward.

3.1 Movement of a quadcopter

3.1.1 Vertical motion

Drones are propelled and controlled by rotors. Because they function essentially the same, you can think of a rotor as a fan. A spinning blade forces air downward. Naturally, all forces act in pairs, so when the rotor presses against the air, the air pushes back against the rotor. Lift is essentially about controlling the forces that are pulling upward and downward. The lift increases with the speed at which the rotors spin and vice versa as described by [8;9;10] Currently, a drone has three vertical flight modes: hover, climb, and descend. In order for the drone to hover, the net thrust produced by its four rotors must be greater than the force of gravity dragging it down. Simply increase the four rotors' thrust (speed) to create an upward force that is greater than the weight. Following that, it could somewhat reduce the thrust, but at this point, the drone is being affected by three forces: weight, thrust, and air drag. Thus, thrusters are required for more than just hovering. In order to descend, exact opposite is expected. To ensure that the net force is downward, rotor thrust is simply reduced.

3.1.2 Turning and rotating

What mechanism would allow a drone that is hovering and facing north to be rotated to face east by varying the power to its four rotors? It is essential to offer a solution based on Fig. 4. The green rotors in this arrangement rotate clockwise, while the red rotors rotate anticlockwise. The total angular momentum is zero because the two sets of rotors are rotating in opposing directions. The calculation of angular momentum involves multiplying the angular velocity by the moment of inertia, and it bears similarities to linear momentum. With the exception of rotation, the moment of inertia and mass are comparable. Therefore, the speed at which the rotors spin determines the angular momentum.

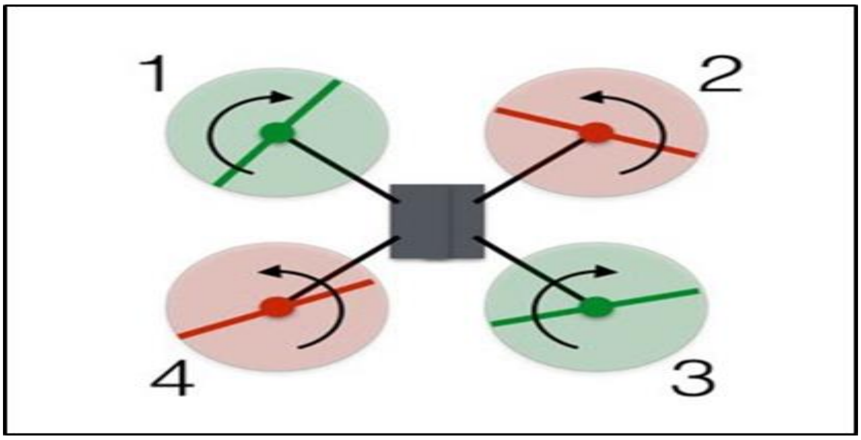

Figure 4: Diagram of the quadcopter

The total angular momentum in this scenario, which is zero, must remain constant if there is no torque applied to the system, which is the drone. Assume, for the sake of clarity, that the green clockwise rotors have a negative angular momentum and the red anticlockwise rotors have a positive one. The sum of the values of each rotor, which I omitted the units, is +2, +2, -2, -2. Assume that the drone should be turned to the right. Assume that (I) causes rotor (1) angular velocity to decrease such that, from -2 to -1, its angular momentum. The drone's total angular momentum would now be +1 if nothing else happened. Naturally, that is not possible. Thus, the drone rotates in a clockwise direction until its body has an angular momentum of -1. However, while rotor (1) spin was reduced, rotor (1) thrust was also reduced, which led to the drone rotating. The drone now descends because the net upward force is less than the gravitational force. Even worse, the drone tips downward towards rotor (1) due to an imbalance in the thrust forces as in agreement with studies of [12;13;13].

To fix the challenges, the following steps were taken:

By reducing the spin of rotors (1) and (3) and increasing the spin of rotors (2) and (4), the drone must rotate without causing any of the other issues. The drone body must rotate because the rotors' angular momentum still does not equal zero. However, the drone keeps hovering because the total force is still equal to the gravitational force. The drone is able to maintain its balance because the lower thrust rotors are positioned diagonally opposite one another as described by [14;15].

3.1.3 Forwards and sideways movement

Moving the drone forward or sideways is equivalent because it is symmetrical. This also applies to motion from side to side. A quadcopter drone can be thought of as a car with all of its sides acting as the front. This implies that describing how to go forward also describes how to go sideways or backward. A forward component of thrust from the rotors is required for the aircraft to fly forward. A side view of a drone travelling at a steady speed is displayed in Fig. 5.

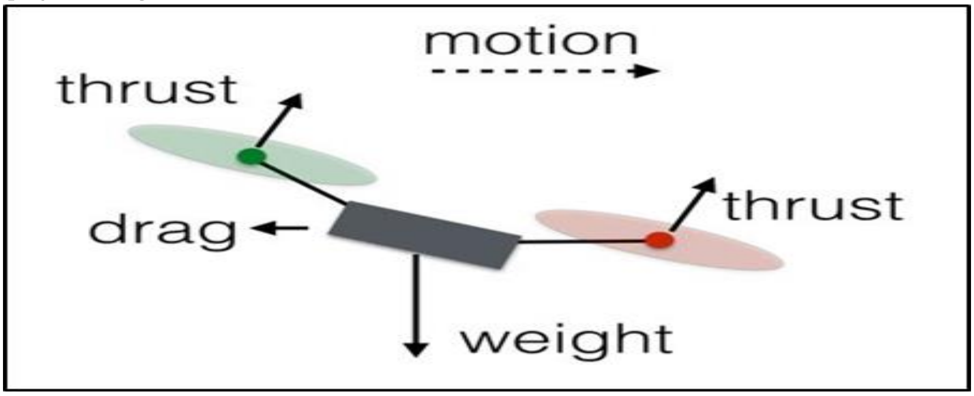

Figure 5: Quadcopter dynamics

3.2 Unit tests

By adjusting and piloting the quadcopter using PID (proportional-integral-derivative), the fundamental flight control of the Pixhawk was evaluated. In order to use the tracking algorithms, several sensors are required. To guarantee peak performance, the flight controller's barometer and compass are unit-tested.

3.3 Flight tests

Quadcopter testing was conducted using both tethered pre-flight and untethered post-flight testing techniques. A checklist was utilised during the pre-flight testing to make sure the quadcopter was in good working order prior to the post-flight testing. Prior to takeoff, quadcopters must undergo testing and calibration procedures. After this is finished, the quadcopter's Euler angles will be continuously controlled by the main control loop as related to the study of [16]. Figure 9 shows the control loop.

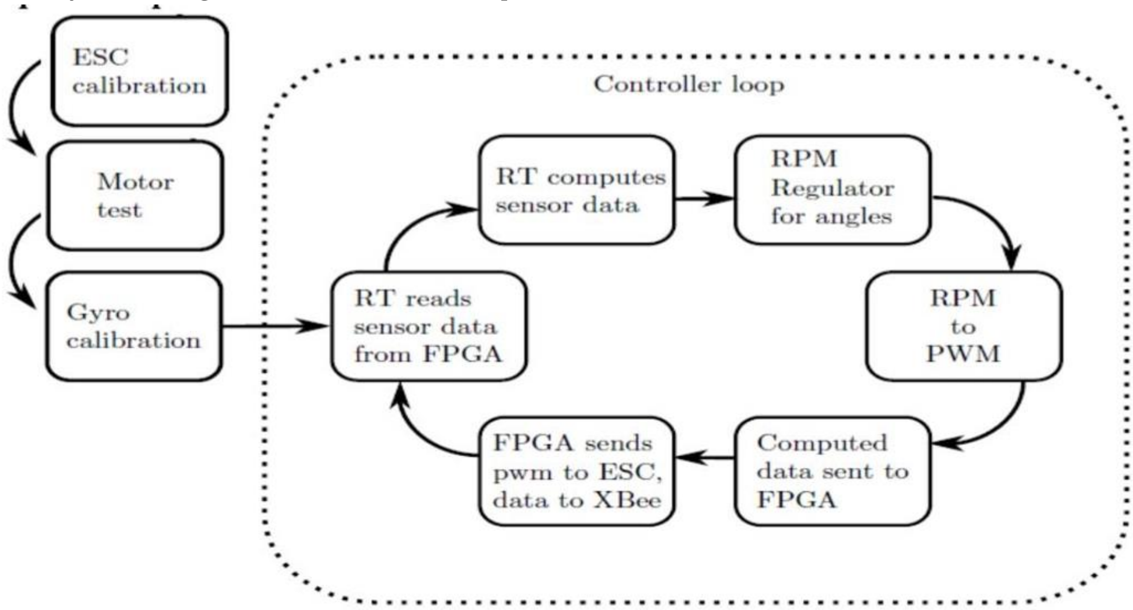

Figure 9: Control loop

Future aspects indicate a significant advancement in quadcopter technology. The Bell Boeing Quad TiltRotor, AeroQuad and ArduCopter, Parrot AR. Drone, Nixie, Zano (drone), Lily Camera Drone, and other projects have been the focus of recent efforts by companies such as Boeing, Airbus, DJ Innovations, Parrot, Walkera, Blade, and Heli-Max.

4. Conclusion

The mission of Surveillance, Search, and Rescue (SSR) is, without a doubt, essential, crucial, and the first line of defence in dealing with disasters. Preserving life and property from damage is of utmost importance. UAVs, or unmanned aerial vehicles, are one type of equipment that can be used in this context. They can fly at great altitudes and, when equipped with the appropriate features, they can record live video and take pictures of the areas they are investigating and transmit the information to equipment on the ground station. This gives the relevant authorities the immediate first-hand information they need to take immediate action. The copters are made to transmit wireless signals to the ground station, which enables them to deliver information when and where it's needed.

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