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Design and Implementation of Quadcopter Avionic System

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Abstract In recent years, quadcopters have become valuable tools for solving complex human challenges across sectors such as security, agriculture, and land surveying. By serving as an alternative to human involvement in hazardous or labor-intensive tasks, quadcopters offer substantial versatility and efficiency. Specifically designed for Vertical Takeoff and Landing (VTOL). Quadcopters employ a four-motor configuration that provides agile and stable flight control. This flight control is achieved through fine-tuned adjustments of pitch, yaw, roll, and throttle, with each motor operating at variable speeds to execute precise maneuvers. A sophisticated combination of avionics and control systems, including the flight controller, Inertial Measurement Unit (IMU), Electronic Speed Controller (ESC), Global Positioning System (GPS), compass module, and power distribution board, ensures seamless operation and accurate response to flight commands. This study provides a detailed examination of the fabrication, configuration, and programming processes involved in constructing a quadcopter capable of autonomous flight.
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Keywords: Avionics, Drone, GPS, Quadcopter, Unmanned arial vehicle

I. Introduction

Advances in propulsion systems and battery technology have allowed quadcopters to operate at impressive altitudes and for extended durations. A quadcopter equipped with a 5000mAh lithium polymer (LiPo) battery, A2212/6T 1000KV brushless motors, and 10x4.5-inch propellers can achieve an altitude of up to 200 meters and a flight time ranging from 15 to 17 minutes. This configuration is optimal for generating the thrust required for various field applications while maintaining stability and efficiency [1, 2].

This study provides a comprehensive examination of the fabrication, configuration, and programming processes required to develop a quadcopter suited for operational tasks. The fabrication process involves selecting lightweight and durable materials to achieve a total weight of 0.0992kg while accommodating a payload capacity of up to 5kg. The configuration stage includes calibrating the gain-response parameters for pitch, yaw, roll, and throttle to optimize performance across diverse operating conditions. Programming involves implementing algorithms within the flight controller to enhance control accuracy, minimize drift, and respond effectively to real-time environmental feedback. This enables the quadcopter to handle complex maneuvers while conserving battery power and stabilizing flight under variable loads and conditions.

This study will also demonstrate how quadcopters can be customized for specialized applications by refining their mechanical design, flight algorithms, and propulsion systems. The insights gained from this research contribute to the broader understanding of Unmanned Aerial Vehicle (UAV) applications, highlighting their potential for reliable and adaptable service in diverse industrial contexts, including automated inspection, crop monitoring, and emergency response [3, 4]. The design and development of quadcopter avionics and communication systems

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have gained significant traction in the field of robotics engineering, reflecting the demand for advanced autonomous solutions across diverse industries. Quadcopters (or UAVs) are versatile platforms that is capable of performing complex tasks autonomously or semi-autonomously; thereby making them invaluable tools for addressing contemporary challenges in security, agriculture, and land surveying.

Lately, the issue of security has motivated extensive research into UAV technology, with quadcopters emerging as a viable option for surveillance, border patrol, and disaster response. Their ability to operate remotely and autonomously allows them to perform real-time surveillance over large areas, providing a valuable asset for monitoring potentially dangerous environments. In agriculture, quadcopters have proven effective for crop health assessment, precision agriculture, and soil analysis, helping farmers optimize resources and enhance crop yield. Land surveying applications benefit from quadcopters' high-precision mapping capabilities, allowing for efficient data collection over challenging terrain without endangering human surveyors [6].

Central to the operation of these quadcopters is the use of flight mission planning through the MAVLink protocol, a communication system that transmits commands between the ground control station and the UAV. The MAVLink protocol enables the quadcopter to receive and execute flight instructions, with the ground control station managing flight paths via a series of waypoints. These waypoints, defined in mission planning software, allow the quadcopter to autonomously navigate predetermined routes, ensuring that the mission objectives are met accurately and efficiently. The mission planning process thus allows the quadcopter to perform tasks with minimal human intervention, making it ideal for repetitive or high-risk operations [4, 5].

A critical component of the quadcopter's avionics system is the Pixhawk flight controller, which is an advanced control module that accommodates the main flight circuitry and processes incoming commands. The Pixhawk serves as the core of the UAV's flight management system, handling inputs from various sensors and translating them into control signals that adjust motor speeds, stabilize flight, and enable maneuverability. This controller, coupled with an IMU and other sensors, enhances the quadcopter's stability and responsiveness, providing real-time feedback for precise adjustments to pitch, yaw, roll, and throttle [7].

Moreover, the quadcopter's flight mechanism leverages its four brushless motors, which allow it to hover, ascend, and perform complex aerial maneuvers by modulating motor speeds in response to control signals. This ability to control flight dynamics, combined with the quadcopter's lightweight design and efficient power distribution system, makes it suitable for tasks requiring high levels of precision and endurance. As UAV technology continues to advance, there is an increasing focus on integrating artificial intelligence and machine learning algorithms into the control systems, enabling quadcopters to make real-time decisions and adjust their flight paths in response to changing environmental conditions [8]. By integrating advanced avionics and leveraging robust communication protocols, the quadcopter's performance, stability, and versatility in practical applications is enhanced; hence, contributing to ongoing research in UAV technologies and their expanding role in automation and remote operations [9].

This paper explores the integration of sophisticated avionics, control systems, and communication protocols within quadcopters, aiming to enhance their capabilities and expand their applications in these critical areas.

II. Materials and Methods

Mission Planning is managed through open-source software designed to streamline autonomous flight paths for UAVs. This Ground Control Station (GCS) application, compatible with Microsoft Windows, allows for mission programming and command storage. The flight controller executes commands sequentially, with the capability to add or modify waypoints in real time. The waypoint options include functions like insert/delete WP, Loiter WP, RTL (Return to Launch), and Land; with each designed to control specific mission requirements. The flight data recorded in the launch phase indicated a steady elevation to 20 meters in altitude, progressing to a peak altitude of 150 meters while recording corresponding distances and flight modes. Once maximum altitude was reached, the altitude hold mode was activated, allowing for stable hovering before beginning descent.

A. Frame Selection

In choosing the appropriate frame for a quadcopter, several essential factors must be evaluated. These include matching the motor, propeller, and battery specifications to optimize the quadcopter's performance. Additionally, considerations such as the total weight, including the payload capacity, significantly impact flight duration, stability, and maneuverability. Table 1 gives general characteristics for designing the frame of a quadcopter.

For this work, a 450mm carbon fiber frame was selected due to its lightweight and durable characteristics, which reduces the strain on the motors while providing structural integrity. This frame size is designed to be compatible with propellers ranging from 9 to 11 inches in diameter, motors with specifications around 2212-2216, and an optimal power range of 800-1000 kV with a 3300mAh 4S battery or higher. This combination ensures that the quadcopter achieves sufficient lift and stability for smooth operation.

B. Brushless DC Motor and Propeller

The brushless DC motor acts as the primary driver of the quadcopter, enabling it to achieve thrust, pitch, roll, and yaw controls. The selected motor, rated at 2212–1000KV, operates in conjunction with an ESC to manage the speed and direction of the quadcopter's movement. Each motor can generate up to 1 kg of thrust at

Table 1: Frame Design Characteristics for Quadcopter

Frame size (mm)	Prop size (mm)	Motor size	Motor (KV)	LiPo battery
120 or smaller	76.2	1104 - 1105	4000+	80-800mAh 1s/2s
150-160	76.2-101.6	1306 - 1407	3000+	600-900mAh 2s/3s
180	101.6	1806 - 2204	2600+	1000-1300mAh 3s/4s
210	127	2204 - 2206	2300-2700	1000-1300mAh 3s/4s
250mm	152.4	2204 - 2208	2000-2300	1300-1800mAh 3s/4s
330-350	177.8, 203.2	2208 - 2212	1500-1600	2200-3200mAh 3s/4s
450-500	228.6, 254, 279.4	2212 - 2216	800-1000	3300mAh 4s or +

1000KV when used with a 1045-inch propeller. Propellers are designed to rotate in opposing directions, with two in a clockwise direction and two counterclockwise as shown in Figure 1, in order to maintain balanced flight and stabilize the quadcopter against rotational torque.

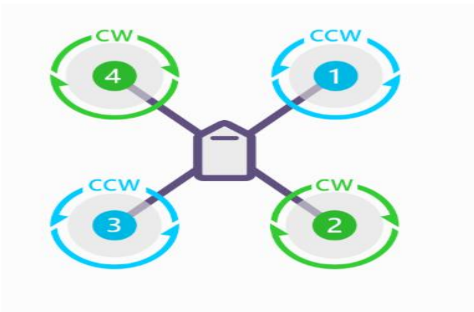


Figure 1: Layout Arrangement of Quadcopter Propellers

To achieve upward thrust, the four motors must operate at a uniform speed, causing the quadcopter to lift vertically. Adjusting the speed of the front and rear motors enables pitch control, while altering the relative speed between left and right pairs of motors facilitates roll control. Yaw control is achieved by varying the rotational directions of motor pairs, enabling precise direction adjustments in mid-flight. Diagrams of the DC motors and propellers are displayed in Figure 3.

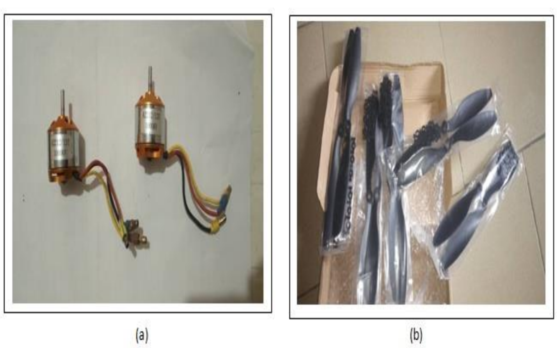


Figure 2: Samples of DC Motors and Propellers

C. Electronic Speed Controller

Electronic speed controllers (ESCs) are critical for regulating and modulating the speed of the quadcopter's motors. Each ESC is rated for a maximum current of 30A, optimized for motors running at 1000KV and a battery capacity of 500mAh. ESCs must meet or exceed the power requirements of the motors to prevent burnout and ensure stable performance. Additionally, calibration of the ESCs is essential to synchronize them with the controller for responsive throttle control. ESCs receive pulse-width modulation signals from the transmitter, allowing the operator to control the quadcopter's speed and maneuvering with precision.

D. Lithium-Polymer Battery

The lithium-polymer (LiPo) battery serves as the primary power source for the quadcopter. Each cell of a LiPo battery has a nominal voltage of 3.7V, and they are configured to operate within a range of 3.0V to 4.2V per cell. Overcharging beyond 4.2V can cause the battery to overheat, leading to potential fire hazards, while discharging below 3.0V risks permanent battery damage. The "S" rating on a battery refers to the number of cells connected in series. Therefore, a 4S battery has four cells with a total voltage of 14.8V (see Figure 3).

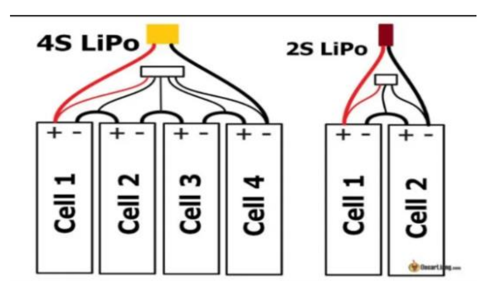


Figure 3: S-Type LiPo Battery Connection

A 6S battery would therefore provide 22.2V, supporting higher power requirements for larger quadcopters. Battery capacity is measured in milliampere-hours (mAh), and denotes how much current the battery can supply over time. A 3000mAh battery discharges at 3A for one hour, and larger capacities allow for longer flight times. The "C" rating specifies the maximum discharge rate without damaging the battery. The maximum current draw, therefore, is calculated by multiplying the battery capacity by its C-rating.

E. Flight Controller

The flight controller, considered the central processing and control unit of the quadcopter. it is an open-source system that manages flight stability and control. It integrates an IMU and accelerometers to monitor and adjust for orientation and speed. Additionally, the GPS compass module provides navigation data to maintain accurate positioning. The Pixhawk flight controller allows for various flight modes, including Acro mode, Stabilize mode, Loiter, Altitude hold, Return to Launch (RTL), and Land. Each mode enables the quadcopter to respond to specific commands, such as maintaining altitude, autonomous navigation, or precise hovering. The IMU combines accelerometers and gyroscopes to measure motion, enabling the flight controller to adjust for tilt and direction, while the GPS module utilizes satellite navigation to provide positional data, essential for autonomous flight modes. The controller's firmware coordinates the functionality of all hardware components, ensuring smooth and controlled flight.

F. Radio Transmitter and Receiver

The transmitter and receiver enable remote communication between the operator and the quadcopter. The transmitter sends pulse-width modulation (PWM) commands to the receiver, which then relays them to the flight controller. Typically, a 10-channel radio with telemetry capability is used to allow multiple controls, such as throttle, yaw, pitch, and roll, essential for maneuvering the quadcopter.

Automatic Frequency Hopping Digital System (AFHDS) utilizes spread-spectrum technique to achieve reliable signal transmission. Frequency and control features are provided to enable the transmitters operate at 2.4 GHz and it includes various switches for different flight functions.

G. Radio Telemetry Module

The radio telemetry module, operating at 915 MHz with a 500mW power rating, facilitates air-to-ground communication between the quadcopter and the GCS. The module employs the MAVLink protocol for data and command transmission, with time-division multiplexing (TDM) for efficient signal allocation. MAVLink is widely used in UAVs to facilitate real-time data exchange and remote execution of flight commands, which is especially beneficial for autonomous missions. Figure 4 shows the autonomous ground control flight system for the quadcopter.

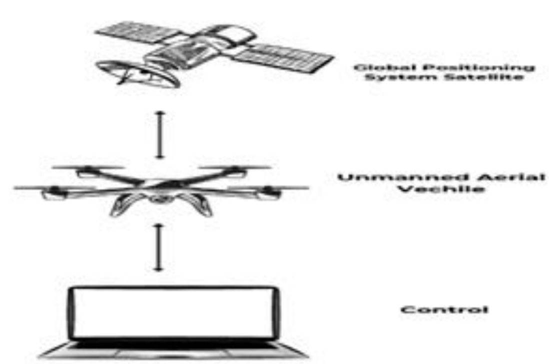
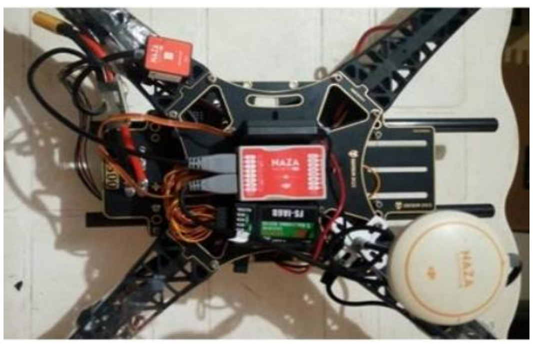


Figure 4: Autonomous Ground Control Flight System

III. Results and Discussion

Figures 5(a) and (b) shows the quadcopter frames before and after the various electronic components such as speed controller, flight controller, radio transmitter and receiver, telemetry module and battery were installed.

(a)



(b)

Figure 5: (a) Quadcopter Frame, and (b) Quadcopter with Controllers, Transmitters and Batteries

In Figure 6, the satellite image for the Department of Electronic and Computer Engineering and other surrounding buildings is displayed. It shows the flight plan with several waypoints, using the mission planner software as the ground control station. The way point H, shows that the unmanned aerial vehicle is launched and after arming the drone it hovers in several waypoint at a certain altitude before returning back to the take-off point. The waypoint was set in form of command setting each desired altitude from one way point to another before it can be set to return to the launch station.

Figure 6: Recorded Waypoint Chart of the Quadcopter during Test Flight

Figure 7 shows the plot of altitude in meters against rage of distance, from which the quadcopter is launched from 0 meters altitude to 50 meters and each distance indicates each waypoint. The maximum altitude attained is 150 meters; a constant altitude is set within way points. When the flight mission is completed, the altitude of the quadcopter is decreased until it gradually gets back to zero altitude. That is, returning back to the launch station.

Figure 8 depicts the flight test being conducted in an open field. The flight is completely autonomous using the mission planner software as the ground control station.

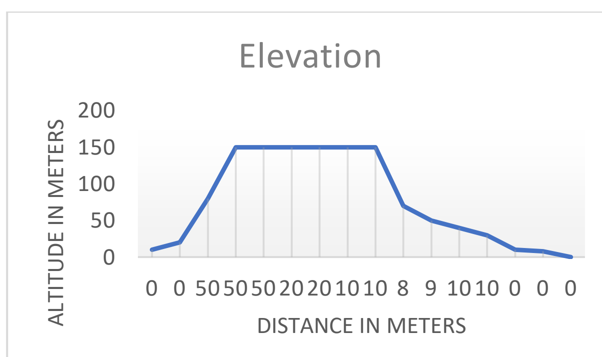


Figure 7: Measured Altitude versus Distance of the Quadcopter at Test Flight

Figure 8: Picture of the Quadcopter

IV. Conclusion

Quadcopter technology offers transformative possibilities in modern applications such as agriculture, land surveying, and military surveillance. The integration of advanced avionics, communication systems, and autonomous navigation capabilities enables quadcopters to execute complex missions with precision and efficiency. The use of a telemetry module for real-time data and command transfer enhances flexibility in mission planning, allowing operators to adjust flight paths dynamically or carry out pre-programmed commands seamlessly. With continued development, quadcopters can further enhance operational efficiency across diverse fields, showcasing their potential for innovative solutions in remote monitoring and data gathering applications.

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