Design of an Autonomous Surveillance Quadcopter

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***Abstract*— This research paper presents the design, development, and implementation of an autonomous surveillance quadcopter as a team project. The quadcopter was developed with the primary objective of conducting aerial surveillance in a controlled environment with minimal human intervention. The platform utilizes a lightweight carbon fiber frame, BLDC motors with 50mm propellers, and a 1200mAh Li-polymer battery. Through rigorous testing and optimization, the quadcopter achieved a flight time of 10 minutes with a communication range of 100 meters. The system demonstrated excellent stability during test flights with no issues observed. Making it an affordable and accessible solution for surveillance applications. This paper discusses the design methodology, hardware specifications, testing protocols, and future scope of the project.**

Keywords*— *quadcopter, UAV, autonomous surveillance, BLDC motors, flight dynamics, aerial monitoring

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs), particularly quadcopters, have emerged as revolutionary technology in the field of aeronautics and automation. A quadcopter is a vertical takeoff and landing (VTOL) aircraft that uses four propellers driven by electric motors to achieve flight [1]. Unlike traditional fixed-wing aircraft, quadcopters offer superior maneuverability, easier control, and the ability to hover in place, making them ideal for various applications including surveillance, aerial photography, search and rescue operations, and environmental monitoring [2]. A quadcopter is a flying machine that can take off and land vertically. It uses four motors and propellers arranged in a cross (X) shape. Unlike helicopters, quadcopters do not use complex mechanisms like variable pitch blades. Instead, they control motion by changing the speed of motors.

Quadcopters are widely used in:

- Surveillance
- Photography
- Agriculture
- Delivery systems

This project aims to build a simple and affordable quadcopter suitable for student-level understanding and applications.

II. LITERATURE REVIEW

A. Quadcopter Design Fundamentals

A quadcopter operates on the principle of differential thrust distribution across four rotors arranged in an X or plus configuration [4]. Each rotor generates lift through the rotation of propellers, and the aircraft achieves maneuverability by varying the rotational speed of individual motors. This design philosophy provides inherent redundancy and improved stability compared to traditional helicopter designs.

The fundamental forces acting on a quadcopter include thrust (vertical force), drag (air resistance), and weight (gravitational force). For stable hovering, the total thrust generated by all four motors must equal the total weight of the aircraft. Flight control is achieved through attitude adjustment (pitch, roll, and yaw) by modulating motor speeds [5].

B. BLDC Motors in Quadcopter Applications

Brushless Direct Current (BLDC) motors have become the standard choice for quadcopter propulsion systems due to their high efficiency, low maintenance requirements, and excellent power-to-weight ratio [6]. BLDC motors offer several advantages over brushed DC motors, including reduced electromagnetic interference, longer operational lifespan, and better thermal management.

In quadcopter design, motor selection is critical and depends on several factors including desired payload capacity, desired flight time, and battery specifications. The motor selection process involves calculating the required thrust per motor, which is typically 25% of the total weight of the quadcopter for stable hovering [4]. For a surveillance quadcopter designed to operate efficiently, the motor characteristics must be carefully matched with propeller size and battery capacity.

C. Li-polymer Battery Technology

Li-polymer batteries have revolutionized portable power storage due to their high energy density, lightweight design, and flexible form factors. These batteries are commonly used in UAVs because they provide substantial power output relative to their weight [7]. A 1200mAh Li-polymer battery can provide consistent voltage output and sufficient current for small to medium-sized quadcopters.

The relationship between battery capacity, current draw, and flight time is crucial for mission planning. Flight time is directly affected by the total weight of the quadcopter and the efficiency of the propulsion system. Battery management and proper voltage regulation are essential to prevent over-discharge, which can damage the battery and reduce its lifespan [7].

D. *Autonomous Surveillance Applications*

Autonomous surveillance platforms utilizing quadcopters have gained significant traction in various sectors including agriculture, infrastructure inspection, law enforcement, and disaster management [3]. The ability to conduct aerial surveillance without constant pilot control reduces operational costs and improves mission consistency. Modern surveillance quadcopters can be equipped with various sensors including cameras, accelerometers, and communication modules for real-time data transmission [8].

III. PROJECT METHODOLOGY AND HARDWARE DESIGN

A. *Design Approach*

The design process followed a systematic engineering approach involving component selection, structural analysis, assembly, and comprehensive testing. The team prioritized three key design criteria: structural integrity, weight optimization, and cost-effectiveness. Carbon fiber was selected as the primary material for the frame due to its exceptional strength-to-weight ratio and resistance to environmental conditions.

B. *Hardware Specifications*

The autonomous surveillance quadcopter incorporates the following hardware components:

Table 1: Hardware Specifications of the Surveillance Quadcopter

Component	***Specification***
Frame Material	Carbon Fiber
Frame Dimensions	120mm × 120mm
Motor Type	BLDC Motor (3-Volt)
Propeller Size	50mm
Number of Motors	4 (Quadcopter Configuration)
Battery Type	Li-polymer
Battery Capacity	1200mAh
Sensor Suite	Accelerometer
Communication Range	100 meters
Flight Time	10 minutes (Average)

C. *Structural Design and Material Selection*

The frame structure was designed using carbon fiber tubes arranged in an X-configuration, which provides excellent stability and weight distribution. Carbon fiber offers multiple advantages for this application:

- High Strength-to-Weight Ratio: Carbon fiber provides superior structural strength with minimal weight addition
- Vibration Damping: The material naturally absorbs vibrations, improving flight stability and reducing sensor noise
- Environmental Resistance: Carbon fiber is resistant to humidity and temperature variations common in operational environments
- Durability: The material can withstand multiple impacts and thermal stresses during extended operational periods

The 120mm × 120mm frame dimensions were selected as an optimal balance between structural stability and maneuverability. This size accommodates four BLDC motors, battery pack, control electronics, and sensor payload without exceeding practical weight limitations.

D. *Propulsion System Design*

The propulsion system consists of four identical BLDC motors, each rated for 3-Volt operation, paired with 50mm propellers. This configuration was selected based on thrust requirements calculated from the total mass of the quadcopter. The 50mm propeller size provides optimal aerodynamic efficiency for this motor class and voltage range [6].

Each motor generates thrust through the rotation of its propeller in either clockwise or counter-clockwise direction. In a standard X-configuration quadcopter, two motors rotate clockwise while two rotate counter-clockwise to eliminate net torque and maintain stable flight. The differential speed control of individual motors enables attitude adjustment and autonomous navigation [4].

E. *Power Management System*

The 1200mAh Li-polymer battery serves as the primary power source for the entire system. The battery voltage is regulated through a dedicated power distribution board that ensures stable voltage delivery to the BLDC motor controllers and sensor electronics. The battery management system includes:

- Voltage regulation and distribution
- Over-current protection circuits
- Battery status monitoring
- Safe discharge protocols to prevent battery damage

The 10-minute flight time achieved by the system represents a balance between battery capacity, total system weight, and motor efficiency. Weight management through carbon fiber construction was instrumental in achieving this flight duration with the given battery capacity.

F. *Sensor Integration*

The quadcopter is equipped with an accelerometer sensor for measuring acceleration forces during flight. The accelerometer provides critical feedback for:

- Real-time stability monitoring
- Attitude determination and correction
- Vibration analysis during flight operations

Data logging for post-flight analysis

IV. TESTING AND RESULTS

A. *Flight Testing Protocol*

a) Comprehensive flight testing was conducted in a controlled environment to validate the design and verify performance specifications. The testing protocol included:

b) Pre-flight Checks: Structural integrity inspection, motor functionality verification, battery voltage confirmation

c) Static Thrust Tests: Measurement of individual motor thrust outputs under controlled conditions

d) Tethered Flight Tests: Initial flights with safety tethering to verify motor synchronization and basic control response *e)* Autonomous Flight Tests: Untethered flights over controlled areas with safety boundaries

f) Stability Assessment: Monitoring flight stability during horizontal movement and altitude changes

B. Performance Results

The quadcopter successfully achieved all primary design objectives:

- Successfully completed multiple autonomous flights without stability issues
- Achieved sustained hovering capability for extended periods
- Demonstrated responsive attitude control (pitch, roll, yaw adjustments)
- Maintained communication range of 100 meters as specified

C. Stability Analysis

The accelerometer data collected during flight operations indicated no stability issues. The system demonstrated:

- Rapid vibration dampening after disturbances
- Smooth response to control inputs without oscillations
- Consistent altitude maintenance during autonomous missions
- Predictable behavior during altitude changes and directional movements

D. Weight Management Success

Through careful component selection and optimization of structural design, the team successfully achieved a total system weight suitable for the BLDC motors and 1200mAh battery. This weight optimization was a critical factor in achieving the 10-minute flight time and stable flight characteristics.

E. Force Analysis

The resultant forces are transferred to rod by the propeller then rod to clamp and then clamp to the top and bottom plates. For static strength testing, the forces applied on the Rod are given as the thrust, centrifugal force and the moment created by the propeller.

$$F_c = mR\omega^2$$

(6)

Here F_c= Centrifugal Force (N)
m=Mass of propeller (Kg)
R =Radius of the propellers (m)
N=Speed of the propeller (rpm)

$$\omega = \frac{2\pi N}{60}$$

ω=Angular speed (rad/sec)

$$Moment = F_c * \begin{pmatrix} Perpendicular\ Distance \\ Bet^n\ Propcenter\ and\ Road\ Surface \end{pmatrix}$$

(7)

Then, we know twisted portion of the propeller is generally termed as pitch. The propeller is specified on the basis of its pitch and diameter. Diameter of propeller (D) is calculated by using equation of power (in Watt),

$$Power = K_p \times D^4$$

Here, KP= Propeller constant (for APC Controller)

P=Pitch of the propellers (m) Thrust and Weight Analysis:The thrust (in Newton) can be given as:

$$Thrust = \frac{\pi \times D^4 \times}{}$$

Here,
D = Density of air (kg/m3)
v =Velocity of air (m/s)
V=Velocity of the air accelerated by propeller
Then, total mass lifted by the quadcopter is calculated as,
Here, M= Total mass lifted by the quadcopter (kg)

$$M = \frac{Thrust}{Acceleration\ due\ to\ gravity}$$

In design, our interest is to reduce weight (Wt.) by increasing the lifting ability of the flight system. Weight to Rpm Ratios:Unknown weight of quadcopter is given as,

$$W = \frac{Required\ rpm}{} \times \mathrm{R}$$

Here, W= Unknown weight of quadcopter (N)
Propeller Length to Weight Ratios:
Unknown propeller length is given as,

$$Y = \frac{Required\ Wt.}{} \times Refrence\ \mathrm{Pr}$$

Here, Y = Unknown propeller length (cm)
The relationship governing the lift capabilities of flight system is,

$$W \times D^4 \times N^2 \times$$

where Cf = Lift coefficient
Expected duration (in Hours) of quadcopter flight is given as, [10]

$$Duration = \frac{Capacity\ of\ b}{}$$

The above equation gives us information about pair of DC motors with speed and load carrying capacity of quadcopter.

V. APPLICATIONS AND FUTURE SCOPE

A. Current Surveillance Applications

The autonomous surveillance quadcopter is equipped for multiple practical applications:

Security Monitoring: The system can be deployed for real-time surveillance of restricted areas, perimeters, and critical infrastructure. The 100-meter communication range allows operators to maintain safe distance from monitored zones while conducting surveillance operations.

Environmental Monitoring: The quadcopter can be utilized for environmental assessment, wildlife monitoring, and aerial photography of natural landscapes. The lightweight design allows deployment in sensitive environments with minimal disturbance.

Infrastructure Inspection: The stable flight characteristics and camera integration capability make the quadcopter suitable for inspecting buildings, power lines, and other infrastructure from vantage points difficult for human inspectors to access.

B. Future Scope and Enhancement Possibilities

Autonomous Navigation Enhancement: Future iterations of this project could incorporate advanced autonomous navigation capabilities through GPS integration and artificial intelligence-based obstacle avoidance systems. This would reduce the requirement for continuous human pilot input [9].

Enhanced Payload Capacity: Through optimization of frame design and motor selection, the surveillance capabilities can be significantly expanded. Integration of high-resolution cameras, thermal imaging sensors, and advanced communication systems would enhance the platform's utility.

Mission-Specific Configuration: Future developments could include quick-swap payloads allowing rapid reconfiguration for different surveillance missions without redesigning the entire platform.

Advanced Control Systems: Implementation of sophisticated control algorithms utilizing machine learning for adaptive flight stability and autonomous mission planning would represent a significant advancement [8].

Spy Drone Capabilities: As a forward-looking development, the quadcopter platform could be enhanced for covert surveillance operations with features including:

- Ultra-quiet motor operation through advanced noise reduction techniques
- Low-light vision capabilities with thermal and infrared sensors
- Extended range through long-range communication protocols
- Stealth design modifications to minimize visual and acoustic detection
- Extended flight time through advanced battery technologies and energy management systems

Such enhancements would require additional research into stealth technologies, advanced sensor integration, and sophisticated control algorithms.

VI. CONCLUSION

The design and development of an autonomous surveillance quadcopter represents a successful integration of mechanical engineering principles with modern electronics and control systems. The project demonstrated that functional, stable, and cost-effective surveillance platforms can be developed by small teams using readily available components and materials.

Key achievements of this project include:

- Successful design and construction of a structurally sound, lightweight quadcopter using carbon fiber materials
- Integration of BLDC motors with 50mm propellers achieving stable flight characteristics
- Implementation of an efficient power management system providing 10-minute flight duration
- Achievement of 100-meter communication range suitable for surveillance applications
- Comprehensive testing demonstrating system stability and reliability
- Development of an affordable platform (₹4,000) making UAV technology accessible to educational institutions
- Creation of a platform with clear potential for future enhancements and applications

The autonomous surveillance quadcopter successfully fulfills its design objectives and serves as a testament to the practical application of aerospace engineering in educational contexts. The stable flight performance, extended range, and cost-effectiveness make it a valuable platform for surveillance applications, research, and further development.

Future work on this platform should focus on enhancing autonomous capabilities through advanced control systems and expanding surveillance capabilities through additional sensor integration. The successful completion of this project opens opportunities for pursuing more advanced UAV research and development, potentially leading to applications in critical infrastructure monitoring, disaster management, and advanced security systems.

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