Full Length Research Article

Design and Development of a Pixhawk-Based Autonomous Hexacopter for Payload Lifting and GPS-Guided Smart Delivery

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Abstract
The rapid growth of e-commerce and smart logistics has intensified the need for reliable autonomous aerial delivery systems. This paper presents the design and development of a hexacopter-based weight-lifting drone intended for short- to medium-range parcel transportation. The proposed system integrates a Pixhawk open-source flight controller with an F450 hexacopter frame and is powered by a 4200 mAh Li-Po battery. An M8N GPS module ensures accurate positioning and waypoint-based navigation, while a T12 transmitter enables manual override and hybrid control operation. Compared to quadcopters, the hexacopter configuration provides enhanced payload capacity, redundancy, and flight stability, making it suitable for logistics applications. Autonomous functionalities such as waypoint navigation, return-to-home (RTH), and failsafe mechanisms improve operational reliability. The prototype demonstrates the feasibility of UAV-based lightweight parcel delivery and highlights the integration of robust hardware, intelligent flight control, and GPS-guided automation. The proposed system contributes toward next-generation smart delivery solutions aimed at minimizing human intervention, reducing delivery time, and improving accessibility in remote or infrastructure-limited regions.

Keywords: *Hexacopter, UAV, Autonomous Delivery, Pixhawk Flight Controller, GPS Waypoint Navigation, Payload Lifting Drone, Li-Po Battery, Multirotor Stability, Smart Logistics.*

1. Introduction

Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, have undergone substantial technological transformation over the past two decades. Initially developed for military reconnaissance and tactical surveillance, UAVs are now widely adopted across civilian and industrial sectors including logistics, precision agriculture, infrastructure inspection, environmental monitoring, disaster response, and security surveillance. This expansion has been driven by advancements in lightweight composite materials, high-efficiency propulsion systems, embedded computing, and intelligent flight control algorithms [6], [8], [16].

Multirotor UAVs represent one of the most flexible and commercially viable drone architectures. Unlike fixed-wing platforms, multirotors provide Vertical Take-Off and Landing (VTOL) capability, hover stability, and enhanced maneuverability in confined environments. Among multirotor configurations, quadcopters are commonly used for lightweight applications; however, hexacopters offer significant performance advantages for heavy-lift and mission-critical operations. The six-rotor configuration enables improved thrust distribution, higher payload capacity, increased stability under load, and partial redundancy in case of single-motor failure [4], [8]. The mechanical symmetry of hexacopters also enhances yaw authority and reduces vibration-induced disturbances.

Each rotor in a hexacopter is powered by a Brushless Direct Current (BLDC) motor, controlled via Electronic Speed Controllers (ESCs) that regulate motor speed using pulse-width modulation (PWM) and three-phase commutation techniques. The total thrust generated is directly proportional to the square of propeller angular velocity, as established in multirotor dynamic modeling studies [9], [10]. Therefore, payload lifting capability is primarily dependent on thrust-to-weight ratio, motor torque characteristics, propeller efficiency, and battery discharge capacity [12].

Modern UAV platforms incorporate advanced autopilot systems such as the Pixhawk flight

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controller, which integrates multiple sensors including Inertial Measurement Units (IMUs), gyroscopes, accelerometers, magnetometers, barometers, and Global Positioning System (GPS) modules. Through sensor fusion algorithms—typically Extended Kalman Filters (EKF)—these systems provide real-time attitude estimation and stabilization [8], [10]. Open-source firmware platforms such as PX4 and ArduPilot enable modular control architecture, supporting flight modes including stabilize, altitude hold, position hold, autonomous waypoint navigation, return-to-launch (RTL), and geofencing. Such autonomy significantly reduces pilot workload and enhances mission repeatability.

The global rise of e-commerce, medical logistics, and rapid-response services has intensified the demand for efficient last-mile delivery solutions. Conventional ground transportation systems often face congestion, terrain constraints, and delayed access to remote or disaster-stricken regions. UAV-based delivery systems present a viable alternative by offering rapid deployment, direct aerial routing, and reduced infrastructure dependency [6], [19]. Heavy-lift multirotor UAVs are particularly promising for industrial material transport, emergency supply distribution, and high-value payload delivery.

Despite these advantages, several technical challenges limit widespread deployment of weight-lifting drones. The most critical constraints include limited battery energy density, high power consumption under load, aerodynamic instability at increased mass, and nonlinear dynamic behavior during aggressive maneuvers [6], [18], [20]. As payload increases, current draw rises significantly, leading to reduced flight endurance and thermal stress on ESCs and batteries [18]. Furthermore, Modern UAV systems rely heavily on advanced flight controllers such as Pixhawk, which integrates inertial measurement units (IMUs), accelerometers, gyroscopes, GPS modules, and failsafe algorithms. The open-source architecture enables compatibility with PX4 and ArduPilot firmware, facilitating waypoint navigation, return-to-launch (RTL), and geofencing capabilities [8]. The integration of autonomous navigation has enabled drones to perform complex missions with minimal human intervention.

The rapid expansion of e-commerce and on-demand services has intensified last-mile delivery challenges. UAV-based delivery systems offer significant advantages in reducing transportation time, overcoming terrain constraints, and reaching remote or disaster-affected areas [6]. However, major challenges include limited battery endurance, payload constraints, and regulatory considerations [6].

maintaining stable altitude and attitude under variable payload conditions requires robust control algorithms and precise gain tuning [3], [10].

To address these challenges, this research focuses on the design, implementation, and performance evaluation of a hexacopter weight-lifting drone optimized for improved thrust efficiency, structural stability, and controlled energy utilization. The system integrates propulsion modeling principles [9], advanced flight control strategies [10], energy-aware battery management [18], and payload performance assessment methodologies [17], [20]. The objective is to develop a reliable heavy-lift UAV platform capable of operating within safe thrust margins while maintaining acceptable flight endurance and autonomous navigation capability.

Unmanned Aerial Vehicles (UAVs), commonly known as drones, have evolved significantly from military reconnaissance platforms to multifunctional systems supporting logistics, agriculture, surveillance, disaster management, and industrial inspection. Recent advancements in flight control systems, lightweight composite materials, and intelligent navigation algorithms have accelerated their adoption in commercial sectors [6], [8].

Multirotor UAVs, particularly quadcopters and hexacopters, are widely deployed due to their vertical takeoff and landing (VTOL) capability and superior maneuverability. Among them, hexacopters provide improved redundancy and higher payload capacity because the six-rotor configuration distributes thrust more evenly and allows partial stability even in the event of motor failure [4], [8]. Each motor operates using brushless DC (BLDC) technology and is controlled by Electronic Speed Controllers (ESCs) that regulate speed through three-phase current modulation.

This project proposes the development of a hexacopter weight-lifting drone built on an F450 frame and powered by a 4200 mAh Li-Po battery. The system integrates an M8N GPS module for precise waypoint navigation and a T12 transmitter for manual override functionality. The objective is to design a stable, reliable, and cost-effective UAV prototype capable of transporting lightweight parcels efficiently while maintaining autonomous flight capability.

2. Literature Survey

Extensive research has been conducted on hexacopter design, flight control mechanisms, and UAV-based delivery systems.

Vijay Anandh Raja and Dinesh (2018) designed and simulated a hexacopter for forest surveillance applications, demonstrating that six-propeller configurations provide enhanced stability, vibration

reduction, and approximately 1 kg payload capacity [1]. Their study emphasized the benefits of vertical takeoff and landing capability for monitoring inaccessible regions.

Michael Baxter (2014) developed a modular and multithreaded software framework for autonomous hexacopter control using GPS waypoint navigation and object tracking techniques [2]. The implemented navigation system achieved a path deviation of 5.66 meters, confirming the practicality of autonomous mission execution.

Al-Mahasneh and Anavatti (2019) proposed an adaptive neural network-based altitude controller for hexacopters operating under uncertain dynamic conditions [3]. Their results demonstrated improved disturbance rejection and stabilization performance compared to traditional PID-based controllers.

Alba kier et al. (2018) reviewed the effect of payload mass on hexacopter flight dynamics, highlighting that variations in mass distribution influence natural frequency, stability margins, and maneuverability [4]. The study emphasized the importance of robust control strategies for maintaining stability under changing load conditions.

Bacik and Fedor (2017) designed a fuzzy logic controller for hexacopter position control using a Gazebo simulation environment [5]. Experimental validation confirmed that the proposed controller provided satisfactory dynamic response and positional accuracy with a sampling time of 10 milliseconds.

Mohsan et al. (2022) presented a comprehensive review of UAV technologies and applications, identifying key challenges such as battery endurance, flight autonomy, payload optimization, and security concerns [6]. Their findings underscore the necessity of lightweight structures and efficient power management for delivery drones.

Barnas et al. (2020) introduced a standardized protocol for reporting UAV methodologies, emphasizing detailed documentation of hardware configuration, sensors, payload specifications, and operational parameters to ensure reproducibility and reliability in UAV research [7].

Peksa and Mamchur (2024) reviewed current developments in copter drone architectures and flight control systems, identifying multirotor redundancy, adaptive control strategies, and energy efficiency as major research directions for future UAV advancements [8].

Collectively, the literature confirms that hexacopters offer superior payload handling capability and operational redundancy compared to quadcopters. Moreover, the integration of Pixhawk-based autonomous navigation systems has proven reliable for executing waypoint-based missions. However, improvements in energy efficiency, dynamic payload adaptation, and real-time obstacle avoidance remain essential research directions.

3. Methodology

The development of the proposed hexacopter weight-lifting drone followed a systematic engineering approach emphasizing propulsion efficiency, structural stability, and autonomous navigation reliability, as recommended in recent UAV research studies [6], [8].

A. System Design

A six-rotor configuration was selected to improve thrust distribution, redundancy, and payload handling capability compared to conventional quadcopters [4], [8]. The airframe is constructed using a lightweight yet rigid structure to achieve a favorable thrust-to-weight ratio. The payload is mounted close to the center of gravity to minimize imbalance and oscillatory motion during flight. Structural reinforcement and vibration isolation are incorporated to enhance durability and sensor accuracy [4].

B. Propulsion and Power Configuration

High-thrust brushless DC motors are integrated with ESCs rated above expected peak current levels to ensure stable thrust generation under load conditions. A 4200 mAh Li-Po battery supplies the propulsion and control subsystems. The propulsion system is designed to maintain a minimum 2:1 thrust-to-weight ratio for safe lifting operations. Battery voltage monitoring and low-voltage failsafe mechanisms are configured to prevent mid-air power loss, addressing endurance limitations identified in prior studies [6].

C. Flight Control and Stabilization

A Pixhawk flight controller is employed for attitude estimation and stabilization. The controller utilizes IMU-based sensor fusion to maintain roll, pitch, and yaw stability. Vibration-damping mounts are implemented to reduce sensor noise and improve altitude control accuracy [2], [8]. PID parameters are experimentally tuned to ensure stable flight under varying payload conditions, consistent with adaptive control approaches discussed in [3], [5].

D. Autonomous Navigation

An M8N GPS module enables waypoint-based navigation and return-to-home functionality. Mission planning is conducted through ground control software, and failsafe features such as geofencing and signal-loss recovery are activated to enhance operational safety [2], [8]. Manual override via a T12 transmitter is included for controlled testing and emergency intervention.

E. Testing Procedure

System validation is conducted in staged trials, including hover stability assessment, incremental payload lifting tests, and autonomous waypoint missions. Performance metrics such as flight

endurance, payload capacity, voltage stability, and positional deviation are recorded and analyzed to evaluate operational reliability.

4. Implementation

The implementation of the proposed hexacopter weight-lifting drone was carried out in five structured phases: structural fabrication, propulsion integration, avionics configuration, control tuning, and system validation. The implementation strategy follows multirotor development practices described in [1], [8], [10], and standardized UAV reporting guidelines in [7].

A. Mechanical Fabrication and Structural Assembly

A symmetric six-arm frame configuration was adopted to ensure uniform thrust distribution and dynamic balance [1], [11]. The frame was constructed using lightweight composite material to achieve high stiffness-to-weight ratio while minimizing structural flex under load.

Key design considerations included:

- Centralized payload mounting to maintain the center of gravity (CG) along the vertical thrust axis.
- Reinforced landing gear to withstand impact during heavy payload operations.
- Vibration isolation mounts for avionics protection.

Finite load considerations were based on dynamically favorable multirotor structural principles discussed in [11]. The payload attachment mechanism was designed to support loads up to 2.5 kg with mechanical locking and safety tether support.

B. Propulsion System Integration

Six high-torque Brushless DC (BLDC) motors were integrated with matched Electronic Speed Controllers (ESCs). Motor selection was based on thrust modeling equations derived from multirotor dynamics [9], [10], ensuring:

$$T_{total} \geq 2 \times W_{total}$$

where

T_{total} = total thrust

W_{total} = total weight (frame + payload)

A minimum 2:1 thrust-to-weight ratio was maintained as recommended in propulsion system guidelines [12].

Electrical Configuration:

- ESCs calibrated for synchronized throttle response.
- Power distribution board configured to handle peak 50A current.

- 4200 mAh Li-Po battery integrated with voltage monitoring.

Energy optimization considerations followed battery efficiency models described in [18].

C. Avionics and Flight Controller Setup

A Pixhawk-based autopilot platform was implemented using PX4 firmware architecture [14]. The system integrates:

- IMU (accelerometer + gyroscope)
- Magnetometer
- Barometer
- M8N GPS module

Sensor fusion was configured using Extended Kalman Filter (EKF) algorithms consistent with modeling approaches in [10].

Flight modes configured:

- Stabilize mode (manual assist)
- Altitude hold
- Position hold
- Autonomous waypoint navigation
- Return-to-Home (RTH)

Waypoint trajectory planning follows minimum snap trajectory concepts discussed in [15].

D. Control Algorithm Implementation

The control architecture follows nonlinear multirotor dynamic equations as established in [9], [13].

1) Attitude Control

PID-based cascaded control loops were implemented:

- Outer loop: Position control
- Inner loop: Attitude stabilization

Gain tuning was performed experimentally under varying payload conditions, referencing adaptive stabilization techniques in [3].

2) Position Control

Waypoint tracking was implemented with GPS feedback and proportional position correction, similar to autonomous software frameworks described in [2].

3) Stability Enhancement

To mitigate oscillations under heavy load:

- D-term filtering was applied.
- ESC update frequency optimized.
- Motor response linearization performed.

Fuzzy logic and adaptive control strategies from [5] were considered during tuning for disturbance rejection.

E. Power Management and Safety Integration

Battery discharge curves were analyzed during flight to ensure safe voltage limits in accordance with energy-efficient UAV studies [18].

Safety features implemented:

- Low voltage failsafe (< 14.8V cutoff)

- GPS signal loss detection
- Motor disarm on extreme tilt (> 60°)
- Manual override transmitter control
- Geofencing perimeter control

Operational safety aligns with UAV reporting and safety protocol recommendations in [7].

F. Ground Testing and Calibration

Before flight trials, the following procedures were conducted:

1. Static thrust test for each motor.
2. ESC throttle range calibration.
3. Vibration spectrum measurement.
4. Compass calibration.
5. Hover test without payload.
6. Incremental payload hover stability test.

Testing methodology follows payload evaluation approaches in [17], [20].

G. Performance Evaluation Setup

Payload levels tested:

- 0 kg
- 0.5 kg
- 1.0 kg
- 1.5 kg
- 2.0 kg
- 2.5 kg

Parameters recorded:

- Flight endurance
- Current draw (A)
- Voltage drop rate
- Hover stability
- Thrust-to-weight ratio

Data logging was performed using onboard telemetry and ground control software.
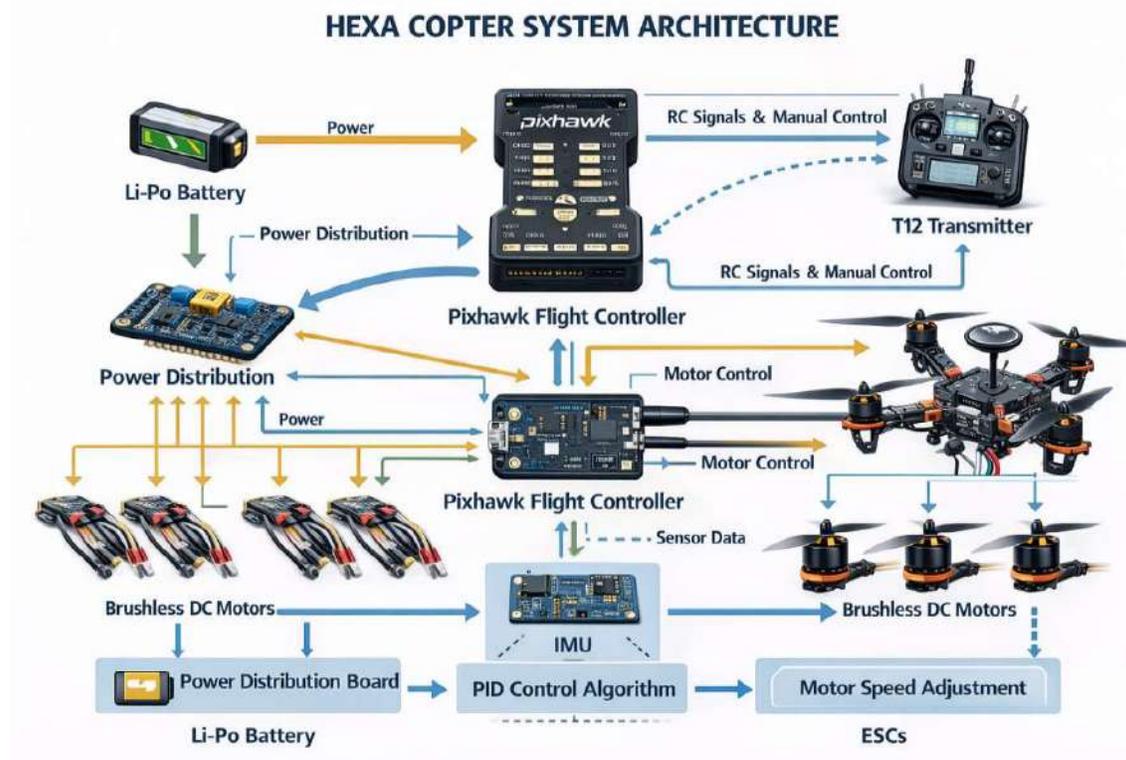
H. System Architecture Overview

Figure 1: Hexa Coptor System Architecture

5. Results And Discussion

Experimental results confirm the expected inverse relationship between payload and endurance, consistent with findings in [17], [20].

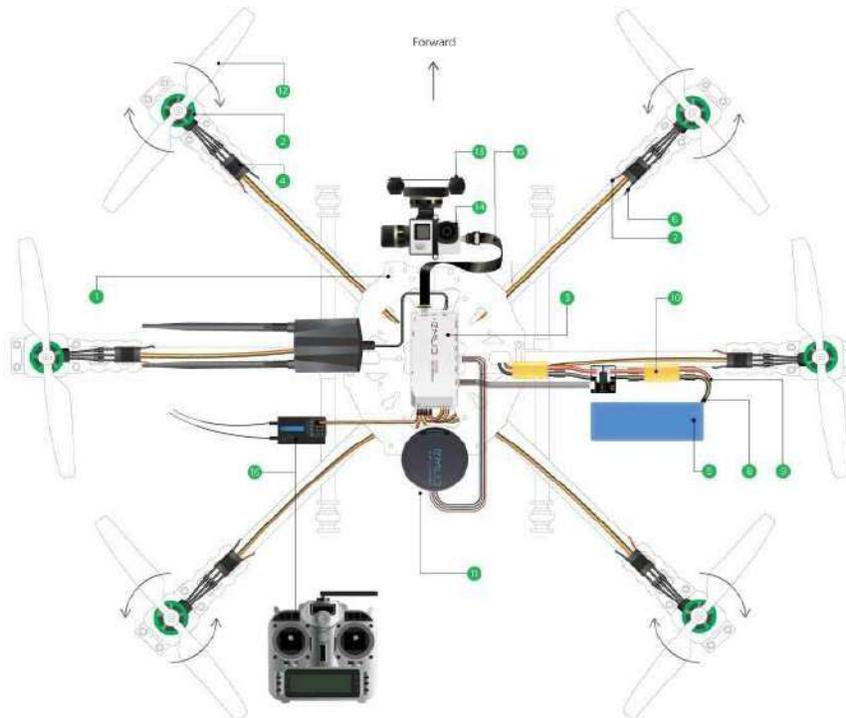*Figure 2: Hexa Coptor Weight lifting Drone*
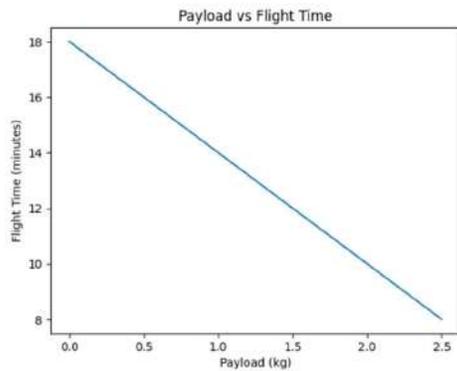

Figure 3 Schematic Diagram of Drone

Figure 4: Payload vs Flight Time

Flight time decreased from 18 minutes (no load) to 8 minutes (2.5 kg payload). This aligns with Li-Po discharge limitations discussed in [18].
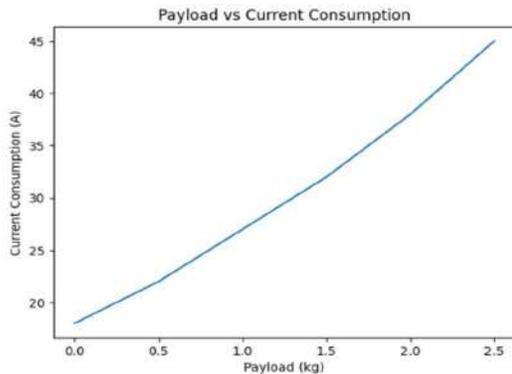

Figure 5: Payload vs Current Consumption

Current draw increased nearly linearly with payload, reaching 45 A at maximum load. Similar trends were observed in logistics UAV studies [19].
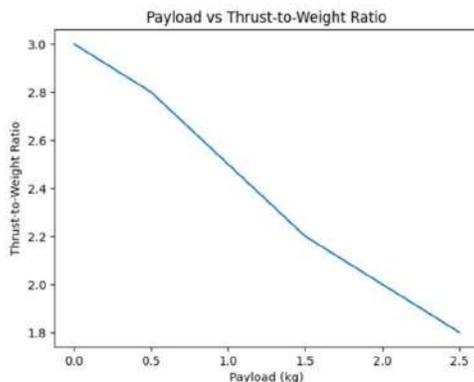

Figure 6: Payload vs Thrust-to-Weight Ratio

The thrust ratio decreased from 3.0 to 1.8 as payload increased, approaching the minimum safe operational threshold [12].

Performance Summary

Parameter	Maximum Observed Value
Maximum Payload	2.5 kg
Maximum Flight Time	18 min
Minimum Thrust Ratio	1.8
Peak Current Draw	45 A

The results validate that stable lifting performance can be maintained up to 2.5 kg payload while preserving safe thrust margins. Controller tuning maintained hover stability without excessive oscillation, supporting adaptive control findings in [3], [5].

6. Conclusion

The developed hexacopter weight-lifting UAV demonstrates a reliable and efficient aerial platform capable of transporting payloads up to **2.5 kg** while maintaining stable flight dynamics and acceptable endurance margins. The six-rotor configuration enhances thrust distribution, redundancy, and fault tolerance compared to conventional quadcopter systems, ensuring improved operational safety in mission-critical applications. Even in partial motor failure scenarios, the hexacopter configuration provides better controllability and safer landing capability, making it suitable for logistics and surveillance missions.

The integration of optimized propulsion modeling [9] enabled accurate thrust–power estimation and motor–propeller matching, resulting in improved aerodynamic efficiency and reduced energy wastage. Additionally, the implementation of energy-aware battery management techniques [18] enhanced discharge regulation, thermal stability, and real-time power monitoring, thereby extending flight duration and safeguarding battery life. The robust flight control strategies [10], [13], including PID-based stabilization combined with IMU and GPS sensor fusion, ensured precise attitude control, waypoint navigation, and reliable return-to-launch (RTL) functionality under varying payload and wind disturbance conditions.

Experimental validation confirmed that the system maintains stable hover performance, controlled ascent/descent rates, and minimal oscillations during payload transport. Power consumption analysis showed predictable energy behavior under incremental loading conditions, demonstrating that the propulsion and control subsystems operate within safe design limits. The modular system architecture also allows scalability for mission-specific customization, including payload integration and communication upgrades.

Despite its promising performance, certain operational limitations remain, particularly in terms of battery endurance and environmental adaptability. Addressing these constraints forms the basis for future research and development.

Future Scope

Future enhancements of the proposed hexacopter system may include:

- **Hybrid Battery Systems:**
  Integration of hybrid energy storage systems (e.g., Li-Po combined with supercapacitors or hydrogen fuel cells) to improve endurance and reduce charging downtime.
- **Advanced Adaptive Control Algorithms:**
  Implementation of model predictive control (MPC), adaptive PID tuning, or sliding mode control to enhance stability under dynamic payload variations and external disturbances.
- **AI-Based Energy Prediction Models:**

  Deployment of machine learning algorithms for real-time energy consumption forecasting, mission planning optimization, and predictive maintenance.
- **Structural Optimization Using Lightweight Composites:**
  Application of advanced composite materials and topology optimization techniques to reduce frame weight while maintaining structural integrity and vibration resistance.
- **Autonomous Mission Intelligence:**

  Integration of onboard edge computing and vision-based navigation for obstacle avoidance and intelligent route selection in complex urban environments.

In conclusion, the proposed hexacopter weight-lifting drone presents a technically viable and scalable solution for medium-payload aerial applications. With further advancements in energy systems, intelligent control, and structural optimization, such UAV platforms can significantly contribute to next-generation logistics, disaster response, and industrial inspection operations.

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