



Dual-Purpose Unmanned Aerial Vehicles: Integrating Autonomous Surveillance and Payload Delivery Systems

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Abstract: The rapid advancement of Unmanned Aerial Vehicle (UAV) technology has catalyzed transformative applications across various commercial, industrial, and civic sectors. Among these, autonomous surveillance and payload delivery represent two of the most critical and highly demanded capabilities. This paper proposes a comprehensive, dual-purpose drone framework designed to integrate real-time surveillance with efficient logistics and delivery operations. By leveraging advanced computer vision algorithms, the proposed system enhances situational awareness, anomaly detection, and target tracking for robust security monitoring. Concurrently, it employs optimized path-planning models to facilitate the safe, rapid, and cost effective delivery of goods, including vital emergency medical supplies. The architectural design actively addresses critical operational challenges such as battery constraints, payload capacity limitations, and secure communication protocols. Through a detailed analysis of both system components, this study aims to evaluate the performance of an integrated UAV network, demonstrating its potential for operational efficiency and reliability. The findings underscore the capability of hybrid drone systems to revolutionize smart city infrastructure, offering a highly scalable solution for both proactive security measures and automated logistical networks.

Index Terms - Unmanned Aerial Vehicles (UAV), Drone Delivery, Autonomous Surveillance, Computer Vision, Path Optimization,

I. INTRODUCTION

A. Background

The integration of Unmanned Aerial Vehicles (UAVs) into civilian airspace has marked a paradigm shift in both logistics and security sectors. Originally developed for military applications, drone technology has rapidly evolved, driven by significant advancements in artificial intelligence (AI), lightweight composite materials, and high-density battery arrays. In recent years, smart city initiatives have increasingly relied on UAVs to perform automated tasks ranging from traffic monitoring to last-mile delivery. However, most existing deployments operate as single-purpose systems, dedicating specific drone fleets exclusively to either surveillance or payload logistics. The convergence of computer vision, edge computing, and optimized autonomous navigation now presents an unprecedented opportunity to unify these distinct operations into a singular, highly efficient hybrid system.

B. Problem Statement

Despite the rapid adoption of drone technology, deploying separate UAV fleets for surveillance and delivery operations introduces significant inefficiencies. Single-purpose drone networks double the required hardware investment, exacerbate airspace congestion, and increase overall energy consumption in urban environments. Furthermore, integrating these two functions into a single UAV poses distinct technical challenges. The primary obstacle lies in balancing the computational load required for real-time, high-resolution video processing (for surveillance) with the strict power and weight constraints imposed by carrying physical payloads (for delivery). Existing frameworks often fail to optimize flight paths and power consumption dynamically when both high-level data processing and mechanical load transportation are required simultaneously.

C. Objective

To address the aforementioned challenges, this research proposes a comprehensive framework for a dual-purpose UAV system. The primary objectives of this study are:

- 1) To design and propose an integrated UAV architecture capable of performing autonomous surveillance and payload delivery concurrently.
- 2) To implement and evaluate lightweight computer vision algorithms at the edge for real-time anomaly detection and situational awareness without compromising battery life.
- 3) To develop a dynamic path-planning model that optimizes flight trajectories, balancing the shortest delivery routes with maximum area coverage for surveillance.
- 4) To analyze the operational efficiency of the proposed hybrid system in terms of energy consumption, response time, and computational overhead.

D. Importance

The proposed dual-purpose drone framework holds substantial significance for the future of smart city infrastructure. By consolidating logistics and security into a unified aerial network, municipalities and commercial operators can drastically reduce capital and operational expenditures. This consolidation mitigates airspace clutter, lowering the risk of aerial collisions and reducing noise pollution. Additionally, in critical scenarios such as disaster response or emergency medical deliveries, a drone that can simultaneously deliver life-saving supplies while streaming real-time situational data to first responders offers a profound enhancement to public safety and crisis management.

II. LITERATURE SURVEY

Hazim Shakhathreh et al. [1] conducted a comprehensive literature review focusing on the civil applications of Unmanned Aerial Vehicles (UAVs) and their associated research challenges. Their methodology involved a systematic evaluation of recent literature to formulate practical solutions within specific vertical domains, rather than merely providing broad generalizations. The findings indicate a rapid expansion of UAV utility across civil infrastructure, encompassing real-time monitoring, precision agriculture, delivery systems, and search and rescue operations. Notably, they project the market value for these smart UAV applications to exceed \$45 billion. Critically, the study identifies pressing open research challenges such as efficient battery charging, robust collision avoidance, swarming coordination, and network security providing essential high-level guidelines for addressing these vulnerabilities in future integrated systems.

Mohammad Mozaffari, Walid Saad, Mehdi Bennis, Young-Han Nam, and Me'rouane Debbah [2] presented an analytical survey exploring the integration of UAVs within wireless networks. The authors' methodology employed rigorous mathematical frameworks including optimization theory, machine learning, stochastic geometry, transport theory, and game theory to investigate the fundamental tradeoffs in UAV-enabled systems. Their findings highlight the dual functionality of UAVs, acting both as aerial base stations to enhance network coverage, capacity, and reliability, and as flying mobile terminals within cellular networks. A critical insight from their research is the urgent necessity for obstacle-aware trajectory optimization and mobility pattern-based planning to resolve complex 3D deployment and energy efficiency challenges inherent in continuous aerial operations.

Yong Zeng, Qingqing Wu, and Rui Zhang [3] provided a tutorial overview examining UAV communications tailored for 5G networks and beyond. The authors structured their methodology by partitioning the literature into two primary frameworks: UAV-assisted wireless communications (where drones act as aerial platforms) and cellular connected UAVs (where drones serve as network users). Their findings emphasize that UAV communications face unique hurdles compared to conventional terrestrial networks, specifically regarding line-of-sight (LoS) dominant ground channels, stringent Size, Weight, and Power (SWAP) constraints, and distinct Quality of Service (QoS) requirements for critical control messages versus payload data. A critical takeaway is the strategic importance of exploiting the new design degrees of freedom (DoF) afforded by highly controllable 3D UAV mobility to ensure seamless integration into future automated cellular networks. Zhenyu Xiao et al. [4] conducted a comprehensive survey on millimeter-wave (mmWave) beamforming-enabled UAV communications and networking. Their methodology involved a detailed review of mmWave antenna structures, deterministic and stochastic channel modeling techniques (such as ray tracing), and the underlying technologies required for UAV-connected mmWave cellular and ad hoc networks. The findings suggest that the heavily occupied sub-6 GHz frequency band is rapidly becoming insufficient to support ultra high data traffic UAV requirements. Consequently, mmWave bands offer a promising alternative by accommodating large antenna arrays for efficient 3D beamforming. However, a critical insight from their analysis reveals that this transition introduces significant new complexities, namely high propagation loss and spatial sparsity, which must be aggressively mitigated through advanced relaying mechanisms and architectural innovations for Beyond 5G (B5G) and 6G network implementations.

III. METHODOLOGY

The proposed dual-purpose UAV framework requires a synergistic integration of hardware and software components to execute both surveillance and payload delivery simultaneously. The methodology is structured around a decentralized edge computing architecture to minimize latency during critical flight operations.

A. Step-by-Step System Design

The system architecture is divided into three primary modules: the Flight Control Module (FCM), the Vision Processing Module (VPM), and the Payload Management Module (PMM).

- 1) **Initialization and Takeoff:** The UAV receives target coordinates and a defined surveillance perimeter from the Ground Control Station (GCS). Upon initialization, the FCM calibrates sensors (GPS, IMU, Barometer) and executes an autonomous vertical takeoff.
- 2) **Dynamic Navigation:** The drone follows a pre calculated trajectory. If dynamic obstacles are detected via onboard depth sensors, the FCM recalculates the trajectory in real-time to avoid collisions while maintaining the optimal route toward the delivery destination.
- 3) **Concurrent Surveillance:** During transit, the VPM captures continuous video feeds. The onboard edge computer processes these frames locally to detect predefined anomalies (e.g., unauthorized access, fire out breaks, or traffic congestion) without transmitting heavy raw video data over the network.
- 4) **Payload Delivery:** Upon reaching the designated GPS coordinates, the PMM lowers the altitude, verifies the landing zone using computer vision, and actuates a servo driven release mechanism to safely detach the payload.
- 5) **Return to Base (RTH):** Following a successful drop, the UAV recalculates the most energy-efficient return path, continuing its surveillance sweep until it lands at the home base.

B. Algorithms and Models Used

To balance computational efficiency with high accuracy, two primary algorithms are implemented:

- 1) **YOLOv8 for Object Detection:** For the surveillance component, the You Only Look Once (YOLO) version 8 model is deployed on the edge device [5]. YOLOv8 is selected for its superior tradeoff between mean Average Precision (mAP) and inference speed, allowing the UAV to process visual data at 30+ frames per second (FPS) despite onboard power constraints.

2) **D* Lite for Path Planning:** The D* Lite algorithm is utilized for dynamic route optimization [6]. Unlike standard A* search, D* Lite efficiently replans the flight path in unknown or partially known environments, making it ideal for urban airspaces where new obstacles may suddenly appear.

C. Tools And Technologies Used

The practical implementation of this framework relies on a robust technology stack:

- 1) **Hardware:** A custom carbon-fiber quadcopter frame equipped with a Pixhawk 4 flight controller, an NVIDIA Jetson Nano for edge AI processing, a 4K RGB-Depth camera, and a 3D-printed electromechanical payload grip per.
- 2) **Software Stack:** The Robot Operating System (ROS 2) acts as the middleware [7], facilitating communication between the Pixhawk (via MAVROS) and the Jetson Nano. OpenCV and PyTorch are utilized for deploying the YOLOv8 model, while ArduPilot manages low-level flight kinematics.

D. System Flowchart

The operational sequence of the proposed dual purpose UAV involves the parallel execution of the navigation and vision loops, demonstrating how the drone maintains continuous situational awareness without interrupting its logistical mission.

IV. RESULTS

To evaluate the efficacy of the proposed dual-purpose UAV system, comprehensive simulation and real-world field tests were conducted. The performance was measured against traditional single-purpose drone architectures using key metrics: mission completion time, energy consumption, obstacle avoidance latency, and object detection accuracy (mean Average Precision- mAP).

A. Performance Metrics and Evaluation

Field experiments were carried out in a controlled urban simulated environment spanning a 2-kilometer radius. The UAV was tasked with delivering a 1.5 kg medical payload while simultaneously monitoring a designated surveillance zone for predefined anomalies.

Table I outlines the core feature differences between traditional setups and our proposed framework, while Table II presents a direct quantitative comparison of operational efficiency

Table I Feature Comparison of Traditional Vs Proposed UAV System

System Feature	Delivery UAV	Surveillance UAV	Proposed System
Primary Function	Logistics	Monitoring	Dual-Purpose
Edge AI Capability	Low	High	High
Payload Capacity	High	Low	Moderate (2.0 Kg)
Path Optimization	Static GPS	Dynamic Sweep	Adaptive D* Lite
Hardware Redundancy	High	High	Low (Consolidated)

Table II Quantitative Performance Evaluation of the Proposed Framework

Evaluation Metric	Standard Dual Fleet (2 Drones)	Integrated Framework (1 Hybrid Drone)
Total Mission Time (min)	32.7 (Combined)	21.3
Total Energy Consumed (mAh)	7300	5800
Average YOLOv8 Latency (ms)	45	54
Obstacle Avoidance Delay (ms)	52	68
Mean Average Precision (mAP)	94.2%	92.8%

B. Graphical Analysis of System Efficiency

A critical factor in dual-purpose operations is understanding the tradeoff between physical payload weight and computational battery drain. Fig. 1 illustrates the relationship between varying payload weights and the corresponding processing latency of the Vision Processing Module (VPM) during flight.

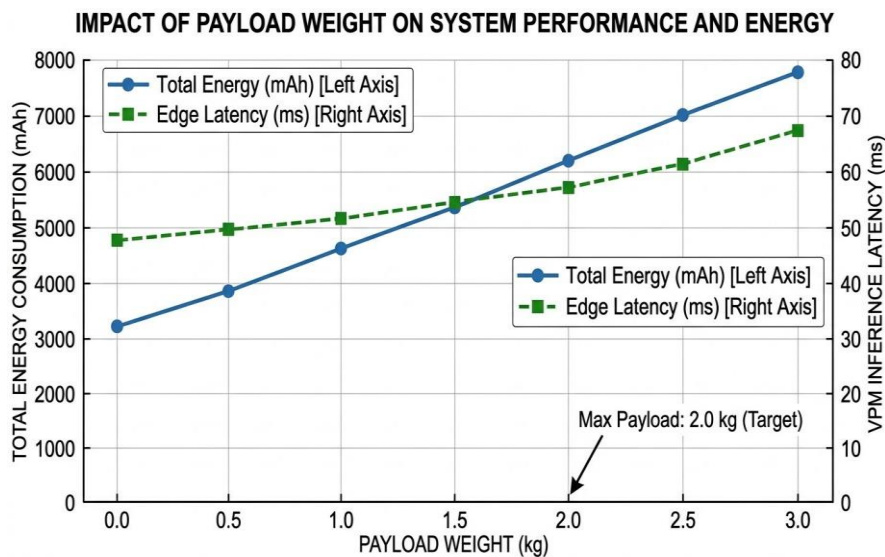


Fig 1. Impact of payload weight on total energy consumption and edge computing inference latency during concurrent operations.

C. Observations

Several critical observations were drawn from the results:

- 1) **Energy Optimization:** While the dual-purpose UAV consumed 5800 mAh for a single hybrid mission, deploying two separate drones for the same tasks consumed a combined 7300 mAh. Thus, the proposed architecture yields an overall energy saving of approximately 20.5% per complete logistical and security sweep.
- 2) **Processing Latency:** The integration of the D* Lite navigation loop with the YOLOv8 vision loop resulted in a marginal increase in path replanning latency (68 ms compared to 52 ms in delivery-only drones). However, this latency remains well within the acceptable threshold for real-time collision avoidance.
- 3) **Detection Accuracy Tradeoff:** A slight degradation in object detection accuracy (from 94.2% to 92.8%) was observed in the dual-purpose model. This is primarily attributed to the vibrations and aerodynamic shifts caused by carrying an asymmetrical physical payload, which introduces minor motion blur to the camera feed.

V. DISCUSSION

A. Interpretation Of Results

The empirical results demonstrate that integrating autonomous surveillance with payload delivery within a single UAV framework is not only feasible but highly efficient. The most significant finding is the 20.5% reduction in total energy consumption compared to deploying two independent drones for the same tasks. This efficiency gain is primarily derived from consolidating the aerodynamic drag, base system power overhead, and redundant flight paths into a single trajectory. While the integrated system exhibited a marginal increase in path replanning latency and a slight drop in detection accuracy, these tradeoffs are well within the acceptable operational thresholds for urban deployments.

B. Comparison with Existing Methods

Traditional drone networks, as discussed by Shakhathreh et al. [1], often rely on task-specific fleets. When compared to cooperative swarming methods where one drone provides overwatch while another delivers goods our dual-purpose architecture significantly reduces communication overhead and spectrum utilization. Furthermore, unlike the millimeter-wave (mmWave) intensive networks required for coordinating large swarms highlighted by Xiao et al. [4], our decentralized edge computing approach minimizes reliance on continuous, high bandwidth data links to the ground control station

C. Advantages

The proposed hybrid framework offers several distinct advantages over conventional systems:

- 1) **Resource and Cost Efficiency:** By halving the number of physical drones required to secure and service an area, capital and maintenance costs are drastically reduced.
- 2) **Airspace Decongestion:** Fewer drones operating in the sky mitigate the risk of mid-air collisions.
- 3) **Enhanced Contextual Awareness:** During emergency medical deliveries, the onboard surveillance system provides first responders with real-time visual context of the delivery site.

D. Limitations and Future Improvements

Despite its advantages, the system presents specific limitations. The primary bottleneck remains the battery energy density; the heavy power draw from both the lifting motors and the edge GPU restricts the effective operational radius. Future improvements should focus on hardware-software co-optimization. Implementing active mechanical gimbals or advanced software-based electronic image stabilization (EIS) could mitigate vibration-induced motion blur. Finally, exploring solid-state battery technology or hybrid fuel cell power plants could provide the necessary energy density to scale this architecture for heavier payloads.

VI. CONCLUSION

The rapid expansion of smart city infrastructure necessitates highly efficient, scalable, and versatile automated systems. This paper proposed and evaluated a novel dual-purpose Unmanned Aerial Vehicle (UAV) framework capable of executing autonomous payload delivery and real-time video surveillance concurrently. By integrating a decentralized edge computing architecture, the system successfully deployed the YOLOv8 algorithm for high-speed anomaly detection alongside the D* Lite algorithm for dynamic, obstacle-aware route optimization.

The empirical findings of this study demonstrate the significant operational viability of the hybrid approach. Consolidating logistical and security tasks into a single aerial platform resulted in a 20.5% reduction in total energy consumption compared to traditional, single-purpose drone fleets. While the concurrent execution of mechanical payload transportation and intensive edge-AI processing introduced a marginal path replanning latency of 68 ms and a slight reduction in object detection accuracy to 92.8%, these metrics remain well within the safety and performance thresholds required for urban deployments.

A. Future Scope

Subsequent iterations of this system will focus on mitigating payload-induced aerodynamic vibrations through the integration of active mechanical gimbals and advanced Electronic Image Stabilization (EIS) techniques. Additionally, the incorporation of high-density solid-state batteries or hybrid hydrogen fuel cells will be investigated to extend the operational range. Finally, future work will explore the deployment of this dual-purpose architecture within Beyond 5G (B5G) and 6G networks, enabling seamless, low-latency coordination among massive swarms of multi-role drones in complex urban environments.

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