Drone-Based Delivery in Logistics: Interdisciplinary Challenges

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Abstract—As urban logistics continue to evolve, there is a growing need for innovative delivery solutions that can meet rising demand while addressing sustainability and cost-effectiveness. To tackle these challenges, eco-friendly transportation methods must be adopted to minimize environmental impact, enhance safety and optimize costs. Drone delivery has emerged as a transformative approach that offers speed, adaptability and reduced emissions compared to conventional logistics. However, its large-scale deployment presents technical and operational challenges that require an interdisciplinary approach. This paper examines these challenges through the integration of control engineering and computer science, identifying how their synergies can enhance efficiency and scalability in drone logistics by developing complementary solutions that address various logistical challenges.

Keywords–Drone Delivery, Logistics, Automation, Artificial Intelligence, Optimization

I. INTRODUCTION

Unmanned aerial vehicles (UAVs), commonly known as drones, have made significant advances in recent years and are playing a key role in the digital transformation of multiple sectors. Their growing use is driven by advantages, such as speed, cost savings and lower environmental impact. While drones are used in security [1], surveillance [2] and agriculture [3], one of their most promising applications is in logistics, especially last-mile delivery [4].

Traditional delivery methods often face significant challenges, including traffic congestion, high fuel costs and carbon emissions. Drones offer an alternative that is both faster and more adaptable, capable of reaching areas where conventional transport is inefficient or impractical [5]. For instance, companies such as *Zipline* [6] have successfully deployed drones to deliver blood and medical supplies in African countries, such as Rwanda and Ghana. These deliveries, which once took hours by road, now arrive in minutes, often saving lives. By avoiding traffic and poor road conditions, these drones ensure that critical medical supplies reach hospitals without delay.

Industry leaders such as *Amazon* are actively developing drone delivery systems to transport small packages more efficiently. Their goal is to accelerate deliveries while reducing the dependence on traditional transportation methods, reducing costs and minimizing environmental impact [7].

The logistics sector has started integrating drones to enhance delivery efficiency, particularly in urban area. However, drone-based delivery systems come with unique challenges that require addressing multiple aspects, such as:

i) The choice of appropriate delivery models based on product type, payload capacity and delivery range.

ii) The interaction between drones and other transportation modes, including terrestrial robots, electric and thermic vehicles, and human-operated systems.

iii) The optimization of delivery routes and fleet coordination to minimize operational costs and maximize efficiency.

iv) The regulatory and safety concerns, including compliance with airspace regulations and public acceptance of drone-based delivery services.

Drones are being integrated into logistics operations, working alongside traditional transportation methods to enhance efficiency. Furthermore, The diagram in Figure 1 presents a classification of drone applications in logistics. It outlines four key domains where drones are making a significant impact, from improving delivery times to optimizing supply chain processes and enhancing security measures:

- Last-mile delivery: includes essential applications such as medical supply transport and food delivery, which highlight the advantages of drones in rapid and emergency logistics.

- Warehouse operations: cover tasks, such as inventory scanning and internal transportation, where drones improve efficiency in storage facilities.

- Supply chain optimization: leverages drones for route optimization and real-time tracking that enable businesses to enhance delivery accuracy and reduce delays.

-Infrastructure and security applications: include surveillance and facility inspection that provide monitoring and maintenance capabilities for logistics hubs.

This paper examines these aspects by analyzing various delivery scenarios from both a computer science and a control engineering perspective. The goal is to bridge the gap between these two disciplines and identify common ground for addressing key challenges.
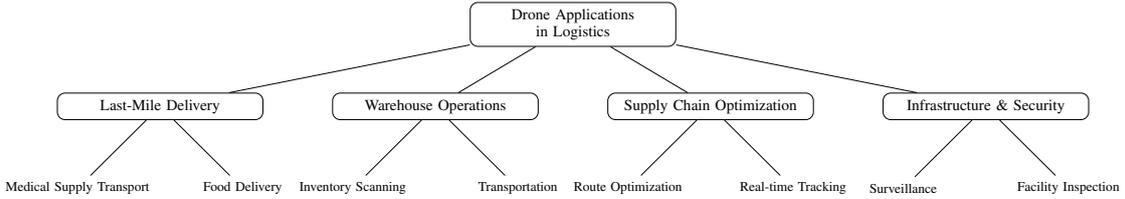
Fig. 1: Classification of drone applications in Logistics, including last-mile delivery, warehouse operations, supply chain optimization, and infrastructure security (e.g., warehouse surveillance).

The rest of this work is structured into three main sections. Section II presents drone delivery models and scenarios by describing different approaches and their applicability in logistics. Section III addresses key challenges from engineering perspectives for drone delivery. Section IV summarizes the findings and outlines future research directions in drone-based logistics.

II. DRONE DELIVERY MODELS AND SCENARIOS

Drone-based delivery can be categorized into different models based on their operational characteristics and collaboration with other logistics resources. The key delivery models include:

A. Full drone-based delivery systems

In this model, drones operate independently, picking up packages from a distribution center and delivering them directly to customers without human intervention as shown in Figure 2a. Autonomous drones rely on GPS navigation, obstacle avoidance algorithms, and real-time environmental awareness to execute deliveries safely and efficiently [8]. Apart from drone delivery, there are several scenarios that utilize this model of autonomous drone. In the full replacement scenario, drones handle all deliveries without relying on conventional vehicles. For example, they transport packages to hard-to-reach places (such as mountains, islands, or deserts) or deliver blood and medicine to areas lacking adequate infrastructure. Drones can also be used to assess damage, locate stranded individuals, and deliver emergency supplies in case of wildfires. Similarly, after floods, when roads are blocked, they can be deployed to transport essential goods such as medicine, food, and drinking water to affected communities. Additionally, drones have been successfully used in post-disaster situations to quickly survey damage, identify survivors, and assist rescue teams when ground access is restricted.

B. Partial replacement in delivery systems

In partial replacement delivery systems, drones assist conventional logistics rather than completely replacing them. They enhance efficiency by handling specific delivery segments, such as last-mile delivery or urgent shipments. There are two main scenarios: Hybrid delivery models, where drones work alongside traditional vehicles and cobot delivery coordination, where drones collaborate with ground robots to optimize last-mile logistics.

1) hybrid delivery drone-vehicle system: as illustrated in Figure 2b, drones work alongside trucks to improve delivery efficiency, e.g. vehicles transport goods over long distances, while drones are used for difficult-to-access areas, traffic congestion or emergency situations.

Drones can temporarily replace traditional transportation methods in several situations where conventional vehicles are unavailable. For example, in the case of a breakdown of fuel-powered vehicles, drones can step in to ensure deliveries continue without disruption. Similarly, for electric vehicles that require recharging and cannot immediately complete their routes, drones can take over urgent deliveries while the vehicle is out of service. Additionally, in urban environments where traffic congestion can significantly delay deliveries, drones provide an alternative by bypassing roadblocks and reaching destinations faster.

2) Drone-ground robot collaboration: recent advancements in robotics have enabled the integration of drones with autonomous ground robots. In this model, a drone transports a package to a designated drop-off point where a ground robot completes the final delivery to the doorstep of the recipient, as shown in Figure 2c. A second scenario is demonstrated in Figure 2d, reverses the roles: drones transport packages over most of the route, while ground robots handle the final delivery. In this model, drones carry packages quickly over long distances and drop them at designated hubs. Ground robots then pick up the packages and navigate complex urban environments or rough terrain to ensure precise doorstep delivery. This hybrid model reduces drone landing constraints, minimizes energy consumption for ground robots and enhances delivery speed and flexibility. It is particularly useful in dense cities or locations with strict airspace regulations.

III. CHALLENGES IN ENGINEERING PERSPECTIVES FOR DRONE DELIVERY

Drone delivery presents several engineering challenges that span multiple disciplines, particularly in automation and control engineering as well as computer science. Addressing these challenges requires an interdisciplinary approach that integrates control algorithms, AI and optimization techniques to develop a scalable and efficient drone delivery network. Beyond these broad engineering concerns, several technical and operational constraints directly impact feasibility:
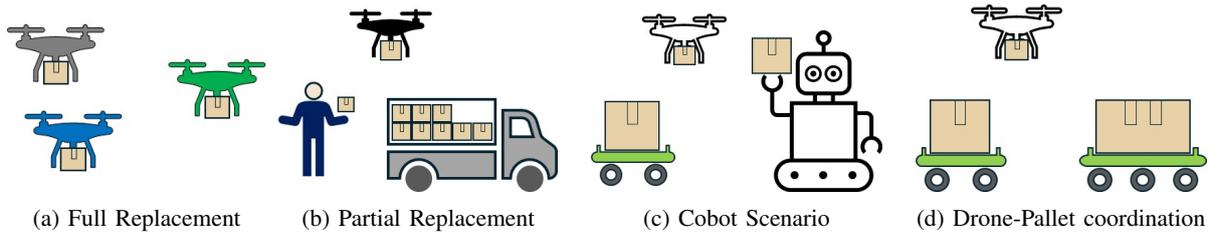
Fig. 2: Illustrative figures to represent possible hybrid drone delivery scenarios, including full replacement of traditional vehicles, partial integration with ground vehicles (e.g., electric or thermal trucks) and collaborative robotics (drones and terrestrial robots).

i) Energy Efficiency: one of the primary challenges in drone delivery is the *limited battery life*, which directly affects operational range and delivery efficiency. Most commercial drones have a flight time of 20 to 40 minutes, restricting them to short-distance deliveries. Addressing this issue requires advancements in battery technology, such as high-energy-density lithium batteries, hybrid power systems and wireless charging stations to enable mid-route recharging [9], [10], [11]. Additionally, optimizing energy consumption through efficient flight path planning and aerodynamically optimized drone designs can extend operational duration [12], [13].

ii) Payload Capacity: most delivery drones currently have a payload capacity of less than 5 kg, significantly limiting the types of packages they can transport. Increasing payload capacity requires structural design to maintain a balance between weight, power consumption and flight stability. Furthermore, efficiency challenges arise when transporting heavier payloads over longer distances, which calls for further advancements in drone design optimization [14], [15], [16], [17].

iii) Safety and Airspace Management: the safety and reliability of drone operations remain significant concerns, particularly in urban and high-density environments where drones must coexist with traditional transport systems and other aerial vehicles.

A. Perspectives from Control Engineering and Automation

Automation and control systems play a crucial role in drone delivery, particularly in ensuring the reliability, safety and efficiency of operations. Here are some key aspects of their role:

1) Autonomous navigation: Automated systems guide drones autonomously using navigation algorithms and onboard sensors like GPS, LiDAR, and cameras. Real-time mapping technologies help determine precise positioning, detect obstacles and adjust flight paths dynamically. As a result, drones operate independently while optimizing routes for better performance. These systems also ensure compliance with air traffic regulations, prevent entry into restricted zones and adapt to environmental changes. This enables safe

and structured drone operations within the airspace [18].

2) Fleet management: control systems play a key role in managing a fleet of drones by handling mission planning, payload allocation, flight condition monitoring and dynamic task assignment. They continuously monitor drone operations and can intervene in case of anomalies, optimize task distribution and improve resource utilization, which enhances overall performance in large-scale deployments [15], [16].

3) Safety and obstacle detection: drones must be equipped with automated systems to detect and avoid obstacles during flight, whether they are buildings, other aircraft or unexpected weather conditions. These systems rely on perception algorithms, real-time data processing and instant decision-making.

4) Real-time communication: a centralized control system enables continuous communication between drones and base stations, which ensures that all information regarding the status of drone (battery, position, performance) is updated and considered for mission management.

- Route optimization: automated systems can also optimize delivery routes by dynamically adjusting flight paths based on traffic conditions, weather patterns and delivery priorities. From a control engineering perspective, model predictive control (MPC) and trajectory optimization techniques enable drones to minimize energy consumption and ensure timely deliveries.

- Predictive maintenance: by continuously monitoring drone performance parameters such as battery health, motor efficiency and sensor functionality, control systems can anticipate maintenance needs and prevent unexpected failures. From a control engineering perspective, condition-based monitoring (CBM) and predictive analytics enhance system reliability by reducing unscheduled downtime and operational risks. Additionally, automated self-diagnosis mechanisms enable drones to report anomalies, adjust flight behavior or return to a maintenance hub autonomously.

B. Perspectives from Computer Science Engineering

Computer science is essential for addressing the challenges of drone delivery, particularly in optimization, AI and data science. Several key areas require
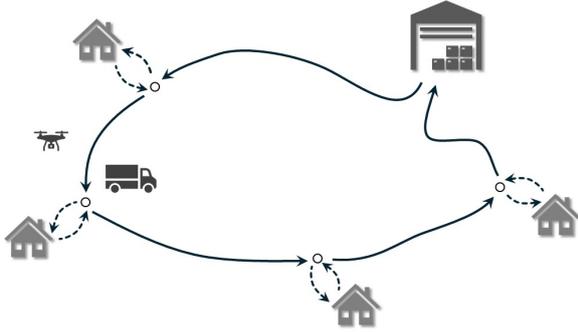
Fig. 3: Collaborative Vehicle Routing Problem with Drones (VRP-D) in Logistics

computational techniques to enhance efficiency and reliability.

1) Routing and Scheduling for Drone Delivery: optimizing drone delivery requires solving complex routing and scheduling problems, which are variants of the Vehicle Routing Problem (VRP) and its extensions. These problems involve determining the most efficient paths for both single and multiple drone fleets while considering multiple constraints. Key optimization challenges include:

- *Energy-constrained routing*: addressing battery limitations by optimizing flight paths to minimize energy consumption and enable mid-route recharging.

- *Time-window constraints*: ensuring deliveries meet strict time windows by integrating time-dependent travel costs into scheduling algorithms.

- *Dynamic and stochastic optimization:* handling real-time obstacles such as weather conditions and air traffic, while incorporating uncertainty in demand, drone availability and operational conditions.

- *Multi-objective optimization*: balancing multiple objectives such as minimizing delivery time [19], [20], maximizing fleet utilization and reducing operational costs, using approaches such as Pareto optimization [21].

For fleet coordination, various optimization models are applied:

- Vehicle Routing Problem with Drones (VRPD): optimizing the collaboration of drones with ground vehicles to improve delivery efficiency [22], as illustrated in Figure 3.
- Multi-Drone Coordination: involves optimizing the assignment and movement of multiple drones to ensure efficient parcel distribution while minimizing conflicts and delays [23].
- Dynamic Route Optimization: adaptive algorithms that reschedule routes in real-time based on operational constraints such as traffic, weather and battery levels [24].

2) Artificial Intelligence and Autonomous Decision-Making: machine learning models enable drones to make real-time decisions by processing vast amounts of sensor data to adapt dynamically to changing conditions. Deep learning techniques, particularly convo-

lutional neural networks and reinforcement learning, improve flight path optimization and real-time control. AI-driven computer vision enables precise navigation, object recognition and package drop accuracy by integrating sensor fusion.

3) Cybersecurity and Blockchain for Warehouse and Delivery Process Surveillance: to ensure the security and integrity of warehouse operations and delivery processes, cybersecurity methods and blockchain technology play a crucial role. Drones used for surveillance rely on secure communication protocols, encryption and blockchain-based tracking systems to protect sensitive data during the monitoring of goods in transit and storage. Blockchain ensures the immutability of transaction records, providing a tamper-proof audit trail for deliveries and inventory management. Additionally, encryption protocols safeguard drone communication, preventing unauthorized access or control. These methods enhance trust and transparency in the logistics process and ensure that sensitive data, such as delivery status and inventory information, remains secure throughout the entire supply chain.

Table I provides an overview of key studies on drone delivery in logistics. According to the table and the literature, most researchers use simulated data, likely due to flight safety constraints, the challenges of this relatively new field and the limited real-world applications. However, in our previous work (Belhor et al. [2]), we used real-world data to tackle the challenge of monitoring an area by geolocating an intruder drone. The proposed method can be adapted to the logistics field, where it can be applied to monitor warehouse activities. Additionally, we plan to implement optimization and AI techniques to enhance drone delivery routing and scheduling, in order to improve the overall efficiency of logistics operations.

C. Multi-Disciplinary Synergy between Computer Science and Control Engineering

While Optimization approaches and AI techniques focus on enhancing decision-making and efficiency, control engineering ensures real-time stability and safe navigation. Table II provides a comparative overview of the key elements of control engineering and computer science in drone-based delivery systems. Automation focuses on real-time control, autonomous decision-making and operational efficiency. On the other hand, computer science enhances these capabilities through AI-driven algorithms, data processing and optimization techniques. Several interdisciplinary research topics emerge, such as *AI-Driven Control Systems* that integrate deep learning with adaptive control for intelligent drone flight, as demonstrated in [37]. Reinforcement Learning for Navigation, which leverages AI models to optimize real-time path planning and obstacle avoidance [38].*Swarm Intelligence and Multi-Agent Coordination* that combine decentralized AI decision-making with control-theoretic models for

TABLE I: Overview of recent research on drone-based delivery in logistics

Reference	Problem	Method	Constraints	Dataset
[25]	Trajectory planning with constraints	Data collection	Environmental, regulatory	Real data
[26]	Energy and cost reduction	Speed optimization	Limited range, energy consumption	Simulations
[27]	Hybrid truck-drone delivery	Tabu Search-Simulated Annealing algorithm	Truck-drone coordination	Real data
[28]	Optimization of drone-based humanitarian aid delivery under uncertainty	Stochastic optimization-based approach	Accessibility	Real data
[29]	Autonomous navigation	AI, computer vision	House identification	Simulations
[30]	Environmental impact	GIS-based spatial analysis, emission modeling	Energy requirements, delivery distance, number of recipients	Simulations
[31]	Hybrid truck-drone delivery	Hybrid modeling, simulation	Aerial traffic congestion	Simulations
[32]	Drone energy consumption	Comparative assessment of energy models	Variability in energy use under different conditions	Simulations
[33]	Vehicle routing problem with drones (A-VRPD)	AI, optimization	Drone autonomy	Simulations
[34]	One Center with Recharging	Mathematical model	Drone range limit, battery swapping time	Synthetic dataset
[35]	Drone delivery planning with real-time demand	Data-driven optimization using Markov Decision Process and supervised learning	Delivery time window and real-time request acceptance	Simulations
[36]	Optimizing drone delivery in smart cities	Heuristic-based contextual service composition	Traffic, weather, airspace	Real data

TABLE II: Key elements of Control Engineering and Computer Science in drone-based delivery

Aspect	Control Engineering	Computer Science
Navigation	Automated control systems (MFC, H_∞, MPC, IMC, PID, etc.)	Flight path algorithms, real-time data processing
Sensors & Perception	Autonomous sensing systems (LiDAR, cameras, etc.)	Image processing, object detection, machine learning
Flight Planning	Automated routing systems for drones	Routing and scheduling algorithms
Real-Time Decision Making	Drone reacts to inputs (obstacles, changes in environment)	AI models, machine learning for dynamic decisions
Communication	Automated communication systems	Data transmission protocols, cloud services, GPS tracking algorithms
Monitoring & Maintenance	Diagnosis via control-theoretic models	Software-based diagnostics, predictive maintenance using AI
Data Management	Control-oriented signal analysis and filtering	Data analytics, cloud storage, big data analytics
Optimization	Trajectory tracking algorithms	AI-driven optimization, predictive modeling for demand forecasting

synchronized drone operations, as shown in [39] and *Cyber-Physical Security in Drone Networks*, which ensures secure communication and resilience against cyber threats in autonomous logistics systems [40]. As a result of this interdisciplinary integration, drone-based automation is set to achieve greater efficiency, thereby paving the way for more reliable and intelligent logistics solutions.

IV. CONCLUSION

The integration of drones into logistics offers efficiency and sustainability but presents technical and operational challenges. Automation ensures autonomous navigation, fleet coordination and obstacle avoidance. Meanwhile, computer science contributes AI-driven optimization, machine learning for decision-making and data-driven analytics in order to improve route planning, predictive maintenance and cybersecurity in

drone logistics. Addressing these challenges requires interdisciplinary collaboration to develop scalable and adaptive solutions. In future work, we plan to propose an interdisciplinary approach for real-time drone delivery in logistics, through the development of an AI-driven control system for real-time route optimization.

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