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Development of an Intelligent Drone Management System for Integration into Smart City Transportation Networks

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Abstract: Drones have experienced rapid technological advancements, leading to the proliferation of small, low-cost, remotely controlled, and autonomous aerial vehicles with diverse applications, from package delivery to personal transportation. However, integrating these drones into the existing air traffic management (ATM) system poses significant challenges. The current ATM infrastructure, designed primarily for traditionally manned aircraft, requires enhanced capacity, workforce, and cost-effectiveness to coordinate the large number of drones expected to operate at low altitudes in complex urban environments. Therefore, this study aims to develop an intelligent, highly automated drone management system for integration into smart city transportation networks. The key objectives include the following: (i) developing a conceptual framework for an intelligent total transportation management system tailored for future smart cities, focusing on incorporating drone operations; (ii) designing an advanced air traffic management and flight control system capable of managing individual drones and drone swarms in complex urban environments; (iii) improving drone management methods by leveraging drone-following models and emerging technologies such as the Internet of Things (IoT) and the Internet of Drones (IoD); and (iv) investigating the landing processes and protocols for unmanned aerial vehicles (UAVs) to enable safe and efficient operations.

Keywords: UTM; ATM; intelligent transportation system; UAV; smart city

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1. Introduction

Drones, generally known as unmanned aerial vehicles (UAVs), are remotely piloted aircraft with vital roles in protection and commercial sectors. Drones can direct themselves automatically without any human control. A drone can equip various Internet of Things (IoT) devices, including sensors and payloads, to perform specific tasks such as delivering packages, patrolling areas, monitoring infrastructure, searching, and securing. In these platforms, drones were used as teleoperated vehicles through the Internet or radio-link based on low-level cooperation directly associated with the primary drone flights. However, controlling and managing drones through the Internet or radio-link poses new challenges, which means that many drone applications, particularly in airspace, raise the need for drone traffic management or, in general, unmanned aircraft vehicle traffic management (UTM). The investigations into UTM development for the drones' urban operation and analysis of the possible solutions have identified several significant problems, such as difficulties using passive surveillance systems and the complexity of conflict/obstacle detection and resolution. Therefore, this study proposes integrating drones into the urban total transport management systems and developing unique methods for managing many drones or a group of drones. Such approaches include working dynamically with variable groups of drones, swarm optimization, and drone-following models for individual vehicles moving with similar trajectories.

Firstly, an intelligent total transport management system (ITTMS) has been developed for transport management in smart cities. The ITTMS aims to optimize the whole transport system and improve mobility. It can operate as a single system that increases user comfort, reduces traffic jams, and increases security by providing users with real-time data regarding rerouting traffic and traffic reports and adjusting speed limits based on this information.

Secondly, this study investigates the possible integration of drones into the smart city transportation system. Drones may follow fixed trajectories or predefined corridors. Several methods, such as sensor fusion, real-time GIS support, centralized dynamic sectorization, active management, fixed trajectory flowing models, and predefined flight modes like coordinated turns, active conflict/obstacle detection and resolution, drone-following models, and formation flights, should support the drone's operation in smart cities.

Thirdly, this study presents unique methods for managing many drones in smart cities, including drone-following models. The drone-following models are based on the drones' initial idea of a leading drone in the traffic flow. Based on the simulation results, there is no accident and no unrealistic deceleration, and the velocity of the following drone is changed according to the drone's speed ahead.

Last but not least, this study investigates the landing process of UAVs. The landing's approach is one of the critical stages of the entire flight to bring the UAV to land safely at the desired location. UAVs' landing stages consist of three stages: the directive stage, the lower altitude stage, and the deceleration stage. The landing areas are determined by solving the differential motion system of the aircraft, on which the desired landing orbit is calculated. The simulation results show the shapes of the trajectories in different initial conditions.

Overall, the critical research questions driving this investigation are the following:

(1) How can a conceptual framework for an intelligent total transportation management system be effectively designed to incorporate drone operations in future smart cities?
(2) What are the essential components and capabilities required for an advanced air traffic management and flight control system to safely and efficiently manage individual drones and drone swarms in complex urban environments?
(3) How can drone management methods be improved by leveraging drone-following models and emerging technologies such as the Internet of Things (IoT) and the Internet of Drones (IoD)?
(4) What landing processes and protocols are necessary for unmanned aerial vehicles (UAVs) to enable safe and efficient drone operations in intelligent city transportation networks?

2. Literature Reviews

Organizations and policymakers continuously work on smart city growth, while the economy has discovered it to be a well-explored future business [1]. Depending on the researchers' and developers' points of view, smart cities have 5–8 significant components: intelligent infrastructure, economy, living, services, people, governance, environment, and transportation [2]. Intelligent mobility and transport are the most critical for society and the economy.

Intelligent mobility and transport contain the following:

(i) Intelligent infrastructure (roads, rails, tracks, waterways, bridges, tunnels, stations);
(ii) Intelligent economy, intelligent people;
(iii) Intelligent cars;
(iv) Intelligent info-communication and control system (from traffic lights to operation centers);
(v) Optimization principles;
(vi) Intelligent policy-making and legislation [3], like traffic rules.

According to this project's investigation [4], smart transportation is a slightly extensive system that includes all transport modes and all infrastructure, covering roads, rail tracks, tunnels of underground transportation, bridges, or multi-modal transportation intersections.

The smart transportation system focuses on economic and social interests, reducing congestion [5], travel times [6], dynamic roads [7], fuel consumption, and pollution, as well as improving traffic safety [8]. Several smart transport approach applications trust the Internet of Things (IoT), including intelligent roadways [9], smart parking methods [10], and real-world connected car data [11]. Several research studies focused on environmental influence, such as life-cycle analyses [12], and the stochastic fastest path issue [13]. At the same time, only a few papers discuss the possible environmental decrease by optimizing the whole transport system. Instead, small parts of transport and optimization are researched, such as the influence of utilizing electric cars [14].

In addition, science and technology are ready to develop and produce an extensive series of low-cost, small, remotely controlled, or autonomous air vehicles, such as drones (generally unmanned aerial vehicles/systems—UAVs and UASs—including small pilotless air vehicles and air taxis). The market for their civil application, generated by the economy and social needs, is rapidly growing. On the other hand, a severe problem blocks the rapid introduction of drones in city operations and smart city transportation [15]. The existing air traffic management system (ATM) cannot control the predicted amount of drones operated at low altitudes in urban areas between large buildings and complex environments (with, e.g., reflection) due to, e.g., (i) the limitations in the system capacity, (ii) the required workforce, (iii) the expected cost, or (iv) the required duration of the system development [16]. Hence, integrating drones into smart city transportation is an essential task that requires innovative, highly automated, autonomous solutions.

To enable drones to be operated regularly as an integral part of the urban air transportation system, it is essential to develop technical solutions, formulate regulatory frameworks, and design management systems to conduct operations in the air and on the ground safely. Regarding technologies and models, researchers have focused on altitude control and trajectory tracking control problems. Several scientific reports have presented the altitude control problem in the literature [17]. Concerning the management system, the operation of a drone must follow the International Civil Aviation Organization (ICAO) [18]. Several scientific reports focus on managing drones in smart cities [19]. However, given the anticipated large amounts of drones and their widely varying performance characteristics, it is far beyond the capabilities of conventional Air Traffic Management (ATM) systems to deliver services for drones cost-effectively. The traditional ATM framework is mainly established for human-crewed aircraft. At the same time, the absence of a pilot on board will pose a unique set of management issues not seen in human-crewed aircraft operations, such as avoidance of collision, tracking trajectories, path planning, communication, and control.

In addition, research has explored innovative approaches to optimizing last-mile delivery using drones and traditional vehicles. Lu et al. proposed a drone–rider joint delivery mode with multi-distribution center collaboration, utilizing a two-stage heuristic algorithm to minimize costs and maximize customer satisfaction [20]. The authors demonstrate that this approach can significantly reduce delivery time and costs compared to traditional methods. Building on this, Liu et al. focused on joint UAV–traditional vehicle delivery in mountainous cities, where integrating drones and ground vehicles can be particularly beneficial [21]. Their study shows that the combined use of drones and vehicles can reduce total delivery distance, improving efficiency and reducing environmental impact. Salama and Srinivas presented a more holistic approach, jointly developing mathematical models for optimizing customer clustering and drone-based routing [22]. Their work considers both restricted and unrestricted focal points for drone launches, allowing for greater flexibility in deployment strategies and further enhancing the potential benefits of drone-assisted delivery. Wang et al. introduced a multi-mode system that combines the use of vans, trucks, and drones, where trucks transport drones to designated stations for parcel delivery [23]. This integrated approach aims to leverage the strengths of each mode of transportation, potentially leading to improved overall delivery performance. Across these studies, a consistent theme emerges: integrating drones with traditional delivery vehicles can significantly reduce costs, improve efficiency, and enhance customer satisfaction in various urban and geographical contexts. As the technology and regulatory environments continue to evolve, the potential for drone-assisted last-mile delivery to transform the logistics industry remains a promising area of research and innovation.

Further, several studies explore innovative approaches to optimizing delivery systems, addressing critical efficiency, safety, and customer satisfaction challenges. C. Tang et al. proposed new distribution modes that utilize two-stage multi-objective optimization algorithms to simultaneously improve rider safety and platform efficiency [24]. Their findings suggest that delivery platforms can achieve notable improvements in overall system-wide outcomes by carefully balancing the competing objectives of rider well-being and operational performance. Comparative analyses by Hong Jiang and Xinhui Ren indicate that drone delivery can outperform traditional rider-based delivery under specific conditions, such as longer delivery distances and shorter pickup times [25]. The authors posit that drones' unique capabilities can provide tangible advantages in delivery scenarios. Looking at the broader integration of delivery modes, Jianxun Li et al. explored ground vehicle and UAV collaborative delivery models, demonstrating their potential to reduce costs and improve timeliness in emergency logistic distribution [26]. By combining the strengths of ground-based and aerial delivery systems, this approach can enhance the resilience and responsiveness of supply chains during critical events. Addressing the challenge of long-distance drone delivery, J. Shao et al. proposed a novel service system incorporating battery exchange stations and maintenance checkpoints [27]. This integrated system aims to facilitate the widespread adoption of drone-based delivery over extended ranges, overcoming key operational constraints by utilizing an improved ant colony optimization algorithm with A* for efficient path planning. These advancements in delivery system optimization, mode integration, and technological innovations represent a concerted effort to enhance the performance of delivery systems, addressing various challenges in the evolving landscape of on-demand and emergency logistics. As the field continues to evolve, these research insights can inform the development of more efficient, safe, and customer-centric delivery solutions.

With the above literature review, it can be noted that drone management is a significant issue not only in the transportation system but also in the air traffic system in smart cities. Firstly, the transport system is a complex system, which becomes an essential task that can be widely observed, analyzed, and managed by employing an expansive distribution network of detectors and actuators merged into a system transmitting via the Internet. Secondly, aerial transportation will continue to increase and face new challenges, such as increased capacity, efficiency, and safety. Thus, the hottest topic in integrating UTM with a total transport-managing system is the management of drones in urban areas. The primary identified problems are passive surveillance, possible high traffic intensity, and conflict detection and resolution, including conflicts with built obstacles. The solutions for these problems require the full integration of UTM into the urban transport-management system and the development of unique methods for managing many vehicles in formation flight.

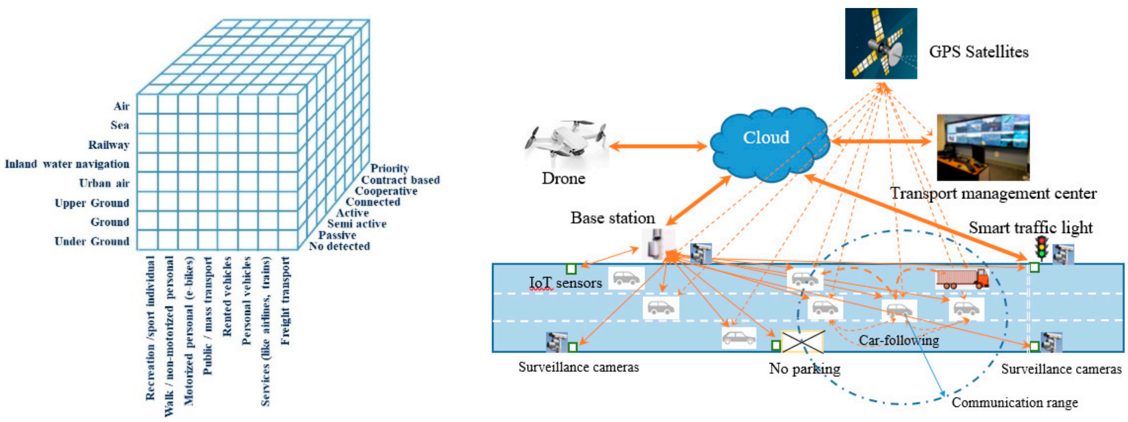
3. Proposed Solutions

3.1. Developing a Transportation Management System

Urban transportation systems enable safe, efficient, and sustainable transport within city boundaries. These systems are integral to the broader transportation infrastructure, serving as critical subsystems that interface with and support the wider regional and global transportation networks. In this context, an urban transportation system encompasses the various modes, services, and technologies that enable mobility within a city or metropolitan area. Such a system includes the physical infrastructure, like roads, railways, and airports, and the operational and management frameworks that coordinate the flow of traffic, passengers, and freight. The effective integration of the urban transportation subsystem with larger-scale transportation systems is essential for ensuring seamless connectivity and accessibility. For example, highways traversing or adjoining a city, rail stations located within urban centers, and airports serving as multimodal hubs all contribute to the interconnectedness of the overall transportation ecosystem. By optimizing the design, operation, and integration of urban transportation subsystems, cities can enhance their environmental sustainability and economic productivity, as well as the quality of life of their residents. This holistic approach to urban mobility is a crucial element in developing smart and livable cities that cater to the evolving transportation needs of modern society.

This study takes a holistic approach to urban transportation, treating it as an integrated system rather than a collection of disparate modes and services [28]. The aim is to develop a comprehensive transportation management framework encompassing the systematic description, hierarchical organization, and holistic optimization of all mobility-related elements. In this context, the concept of a "single system" refers to the seamless integration of various passenger and freight transport modes, including pedestrians, bicycles, trains, watercrafts, aircraft, and emergency vehicles. These different transportation options are interconnected components within a unified management structure, supported by an underlying transportation infrastructure, services, logistics, and control mechanisms. The terms "smart" and "intelligent" are often used interchangeably in this context, though they may imply slightly different approaches. While a "smart" transportation system may focus on solving mobility and logistic challenges using available technologies and theories, an "intelligent" system may explore more innovative solutions tailored to the specific circumstances and characteristics of the urban environment. By adopting this comprehensive, system-level perspective, this study aims to develop transportation management solutions that optimize urban mobility's overall efficiency, sustainability, and responsiveness, contributing to the realization of brilliant and livable cities.

The intelligent total transportation management system (ITTMS) takes a comprehensive approach to managing all modes of transportation within a city's ecosystem. It monitors and coordinates the movements of people and goods, whether traveling by foot, bicycle, private vehicle, public transit, or any other means—from electric scooters to high-speed business jets. The ITTMS employs a specialized hierarchical framework to oversee and optimize the performance of this integrated transportation network as a cohesive whole (Figure 1). By adopting this holistic perspective, the ITTMS can ensure the efficient, safe, and sustainable flow of all forms of mobility throughout the urban environment.



(**a**) (**b**)

Figure 1. Hierarchical classification of the vehicles (**a**) and system interconnections (**b**) in the ITTMS [29].

The intelligent total transportation management system (ITTMS) leverages a specialized data-processing and decision-support subsystem to achieve its objectives (Figure 2). This subsystem integrates the latest advancements in artificial intelligence and ubiquitous computing to enable a skillful and distributed control architecture. By combining centralized optimization with locally embedded, partially optimized systems, the ITTMS can operate an efficient, sustainable, and environmentally friendly transportation network that meets the community's and economy's diverse needs. Crucially, this intelligent transportation management approach also ensures high safety and security for all users.

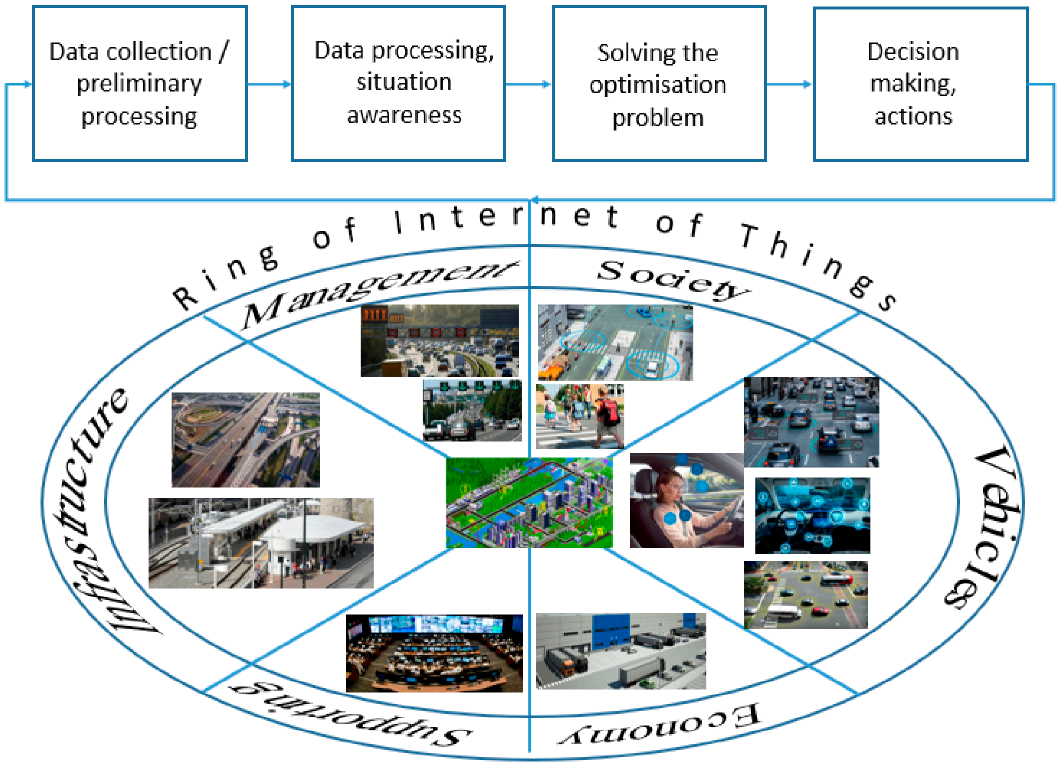


Figure 2. Representation of management using the intelligent total transportation system [29].

The intelligent total transportation management system (ITTMS) developed in this study aims to bridge the gap between the solutions proposed for individual system components (such as junction control, smart parking, and multimodal transport optimization) and the overarching management of the entire transportation network. The ITTMS introduces a comprehensive vision and conceptual framework for managing the total transportation system within a smart city context.

Specifically,

(i) The ITTMS describes the urban total transportation system, accounting for its various subsystems and their interconnections.
(ii) The ITTMS adopts a hierarchical approach to managing the total transportation system, enabling coordinated decision-making across different operational levels.
(iii) The ITTMS defines the general optimization objectives and constraints governing the transportation management framework, considering factors like efficiency, sustainability, and user experience.
(iv) The ITTMS introduces a classification of sensor technologies and outlines their integration within vehicles and transportation infrastructure to enable real-time monitoring and data collection.
(v) The ITTMS highlights the role of data processing, big data analytics, and artificial intelligence techniques in powering intelligent transportation system management.
(vi) The ITTMS develops advanced models for safe and optimized transportation management, leveraging insights from various transportation research domains.
(vii) The ITTMS describes the potential pathways for the highly automated realization of the total transportation management system, including integrating autonomous and connected vehicle technologies.
(viii) The ITTMS compares its performance and capabilities to existing transportation management systems.

The ITTMS lays the foundation for a comprehensive, intelligent, and integrated approach to managing urban transportation systems. Addressing these key aspects aligns with the vision of smart and sustainable cities.

3.2. Autonomous Flight Trajectory Control System for Drones

The primary goal of this proposed solution is to establish a framework for the definition and autonomous execution of desired routes and trajectories for drone operations. The underlying airspace structure and fixed routes are defined within a global GPS-referenced coordinate system, which also serves as the basis for Geographic Information System (GIS) mapping and visualization. In the context of drone operations, the actual motion of these aircraft is typically monitored and recorded as a flight path. The concept of predefined "trajectory tubes" is introduced, within which different types of drones can safely operate under real-world disturbances and environmental conditions. Trajectory-following control algorithms are employed to keep the drones within these predefined trajectory tubes during their flights. The envisioned drone operation scenario involves the aircraft following predefined trajectories or corridors. Each drone is assigned its unique trajectory, which may involve lane changes, heading adjustments, altitude variations, or speed modifications as needed. Notably, the system is designed to ensure that drones never directly intersect or collide with one another, even when flying in opposite directions on their respective trajectories. The proposed solution aims to enable the safe, efficient, and autonomous operation of unmanned aerial systems within the designated airspace by establishing this structured and coordinated approach to drone trajectory management. The global GPS-based reference system and GIS integration provide the necessary spatial awareness and mapping capabilities to support the comprehensive planning and execution of drone missions.

4. Methodologies

To address potential technical gaps, the proposed methodologies are described in the following subsections.

4.1. Following Process

As drones increase, the potential for severe accidents in the sky becomes more evident, even in relatively simple scenarios. Investigating drone traffic safety and developing intelligent transportation systems require drone-following models that accurately describe the one-by-one following processes within drone traffic flows.

These drone-following models are based on the premise that each drone can be flown in a manner that follows its leader, with the function of safe distance or relative velocity between the drones serving as the underlying principle. For example, if three drones fly simultaneously on the same route, two of them can fly by following the lead drone.

In the context of drone following, the drone's velocity is dependent on the traffic situation, namely the distance to the drone ahead and its velocity. This approach has led to the development of linear models, where the assumption is that the drone's controller adjusts its acceleration to maintain a zero relative velocity with the drone in front. By incorporating these drone-following models, researchers and developers can better understand and simulate the dynamics of drone traffic, ultimately contributing to the design of more robust and secure drone transportation systems.

The safe distance (SD) model is given as follows:

$$\ddot{X}_n(t+T) = \lambda \frac{\left[\dot{X}_n(t)\right]^p}{\left[X_{n-1}(t) - X_n(t)\right]^q} \left[\dot{X}_{n-1}(t) - \dot{X}_n(t)\right] \tag{1}$$

where $X_n(t+T)$: the acceleration of the n-th drone after a reaction;
$X_{n-1}(t) - X_n(t)$: the relative distance between the (n – 1)-th drone and the n-th drone;
$\dot{X}_{n-1}(t) - \dot{X}_n(t)$: the relative velocity of the (n – 1)-th to the n-th drone in time t;
T: the delay time of the controller; λ: a weight coefficient related to the controllers;

p, q: parameters related to the velocity and distance of the drone ahead.

The SD model appears well suited for describing the motion of drones flying along a desired flight path. However, air turbulence and wind flow, separate from the infrastructure, can introduce stochastic disturbances to drone motion. To account for the characteristics of advanced drone controllers, the controller's relative distance and actual reaction time were incorporated into the control feedback loop. This approach led to the development of an improved model known as the Markov model.

The Markov model is based on approximating the stochastic process governing the drone's velocity decision-making. One key advantage of the Markov model over the SD model is that the inputs to the controller are different velocities and deviations in the relative distance between drones, which can be described as follows:

$$\ddot{X}_n[\mathrm{k}+1] = c_v\left(\dot{X}_{n-1}[k] - \dot{X}_n[k]\right) + c_x\left[(X_{n-1}[\mathrm{k}] - X_n[k]) - \Delta X_{pdn}\right] + \varepsilon[k] \tag{2}$$

where c_v and c_x: coefficients depending on the time, given the drone and controllers;

$\Delta X_{pdn} = \dot{X}(t)$: the predefined safety distance between the drones;
k: the number of steps in a chain ($t = k \cdot \Delta t$);
$\varepsilon[k]$: the random value disturbing the process.

By utilizing the Markov model, researchers and drone control system designers can better capture the stochastic nature of drone motion in the presence of environmental disturbances, leading to more accurate simulations and the development of more robust control strategies.

4.2. Obstacle Avoidance Method

As the use of drones continues to expand, the issue of drone collision safety with buildings, helicopters, and the surrounding environment has become an urgent concern for civil and defense agencies. A collision avoidance system is essential for drone flights, particularly for autonomous drones operating in dense airspaces shared with other aircraft, to ensure the security of the airspace.

Conflict detection and collision avoidance are valuable tools for highly automated and autonomous vehicles. Several simulation systems were developed in laboratories to test and design algorithms.

One of the critical components of these systems is the obstacle model, which is typically represented as a cylinder with a center point C_{Bl} and a radius r_{Bl}, as shown in Figure 3. The surfaces of these cylinders can be utilized to construct restrictions for obstacle avoidance. The safe distance $d_{s,l}$ from the obstacle l is computed from the cylinder's center to its surface at flying height.

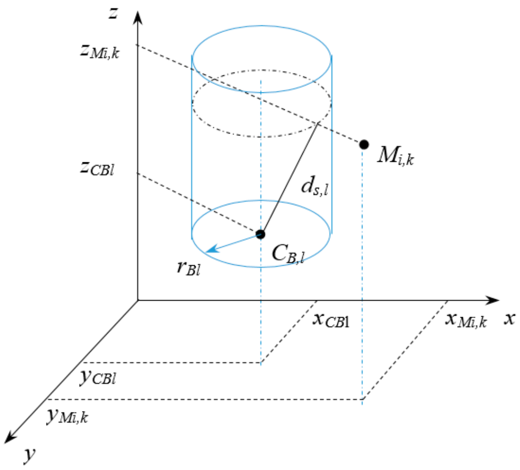


Figure 3. Obstacle representation and safe distance calculation.

By incorporating this obstacle model, collision avoidance systems can effectively detect potential conflicts and generate appropriate maneuvers to ensure the safe navigation of drones and autonomous vehicles in complex environments.

4.3. Desired Landing Orbit for UAVs

The UAV landing areas include the following three zones (Figure 4):

- ➢ Deceleration zone: This is the smallest circle on the horizontal plane, containing the projection of the UAV's orbit, which flies straight with decreasing speed during the landing's approach. Then, the deceleration zone's shape is a circle with a center 0 and radius R_1;
- ➢ Descending zone: This is the smallest circle on the horizontal plane, containing the projection of the UAV's orbit, which flies in the process of altitude reduction. This area is a circle with a center 0 and radius R_2;
- ➢ Directive zone: This is the smallest circle on the horizontal plane, containing projections of two circles with a radius R_{min}. These two circles are tangent to each other in the opposite direction of the wind.

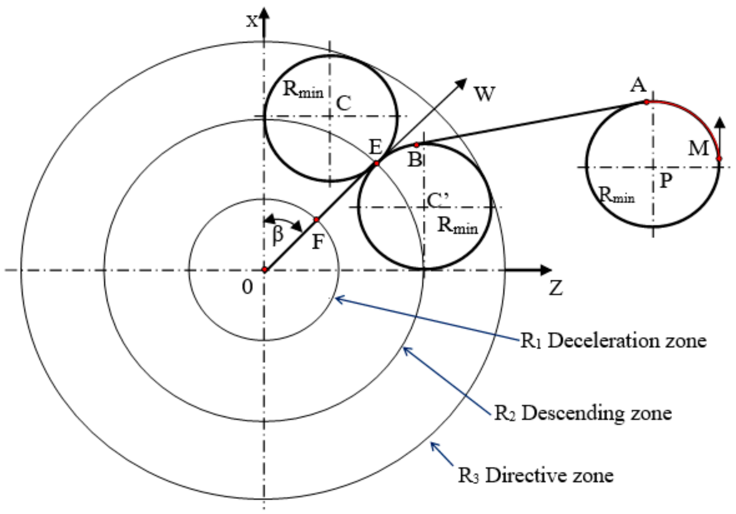


Figure 4. The proposed UAV landing zones.

The R_{min} is the smallest rounding radius of the UAV. Thus, the directive zone is the circle with center 0 and the radius R_3.

UAVs' landing processes consist of three stages: the directive stage, the descending stage, and the deceleration stage. These stages are determined when the UAV is in each landing zone. The landing zones are determined by knowing the radius of each region. The most common method is to investigate UAVs' kinetic dynamics by solving the differential motion system. Therefore, UAV dynamics are used to calculate the deceleration zone, and then the remaining landing areas are identified by analytical methods.

As the UAV can turn left or right to connect with the R_{min} circle on the left or the right (following the direction of the wind), the UAV from a position with any vector speed can fly to the standard location for landing in four different orbits. After calculating four orbits, we compare them to choose the shortest one, which is determined by the desired landing orbit.

4.3.1. Situation 1: Turning Left to Reach the Left Circle (The Orbit Is MABEO; See Figure 5)

Table 1 shows the formulas used for calculating the distance of the landing orbit.

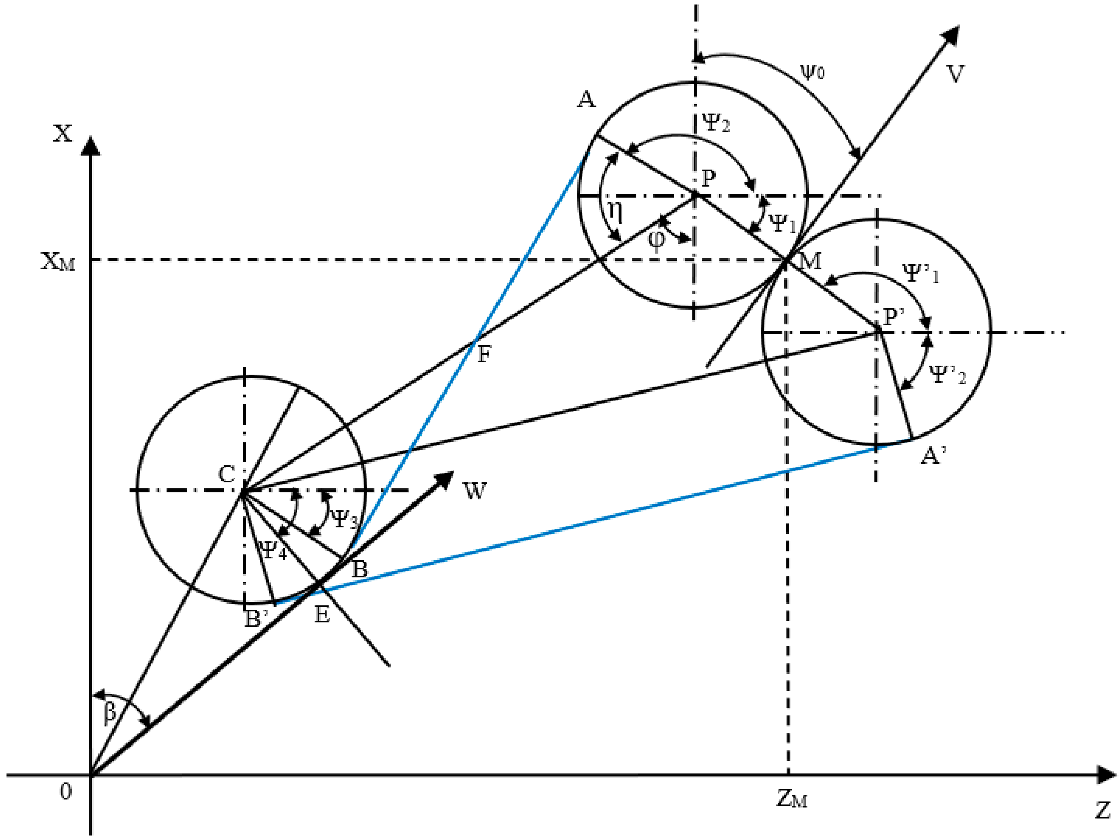


Figure 5. Landing approach connected to the left circle.

Table 1. Formulas used for calculating the distance of the landing orbit.

The Circle of Left Turning	The Circle of Left Connecting	Angles
$X_P = X_M + R_{min}.sin\psi_0$	$X_B = X_C - R_{min}.sin(\eta + \varphi - \frac{\pi}{2})$	$\varphi = arctg\frac{Z_P - Z_C}{X_P - X_C}$
$Z_P = Z_M - R_{min}.cos\psi_0$	$Z_B = Z_C + R_{min}.cos(\eta + \varphi - \frac{\pi}{2})$	$\eta = arccos\frac{R_{min}}{FP}$
$FP = \frac{1}{2}\sqrt{(Z_P - Z_C)^2 + (X_P - X_C)^2}$		$\psi_1 = arctg\frac{X_P - X_M}{Z_M - Z_P}$
$X_A = X_P + R_{min}.sin(\eta + \varphi - \frac{\pi}{2})$		$\psi_2 = arctg\frac{X_A - X_P}{Z_A - Z_P}$
$Z_A = Z_P - R_{min}.cos(\eta + \varphi - \frac{\pi}{2})$		$\psi_3 = arctg\frac{X_C - X_B}{Z_B - Z_C}$
		$\psi_4 = arctg\frac{X_C - X_E}{Z_E - Z_C}$

Based on these formulas in Table 1, the distance of the landing orbit, in this case, can be calculated as follows.

$$L_1 = R_{min}(\psi_1 + \psi_2 + \psi_4 - \psi_3) + \sqrt{(Z_A - Z_B)^2 + (X_A - X_B)^2} \tag{3}$$

4.3.2. Situation 2: Turning Right to Reach the Left Circle (The Orbit Is MA'B'EO; Figure 5)

With similar calculations, in this case, the landing distance is

$$L_2 = R_{min}(\psi_1 + \psi_2 + \psi_3 - \psi_4) + \sqrt{(Z_{A\prime} - Z_{B\prime})^2 + (X_{A\prime} - X_{B\prime})^2} \tag{4}$$

4.3.3. Situation 3: Turning Left to Reach the Right Circle (The Orbit Is MABEO; Figure 6)

The formulas used for calculating the distance of the landing orbit, in this case, are shown in Table 2.

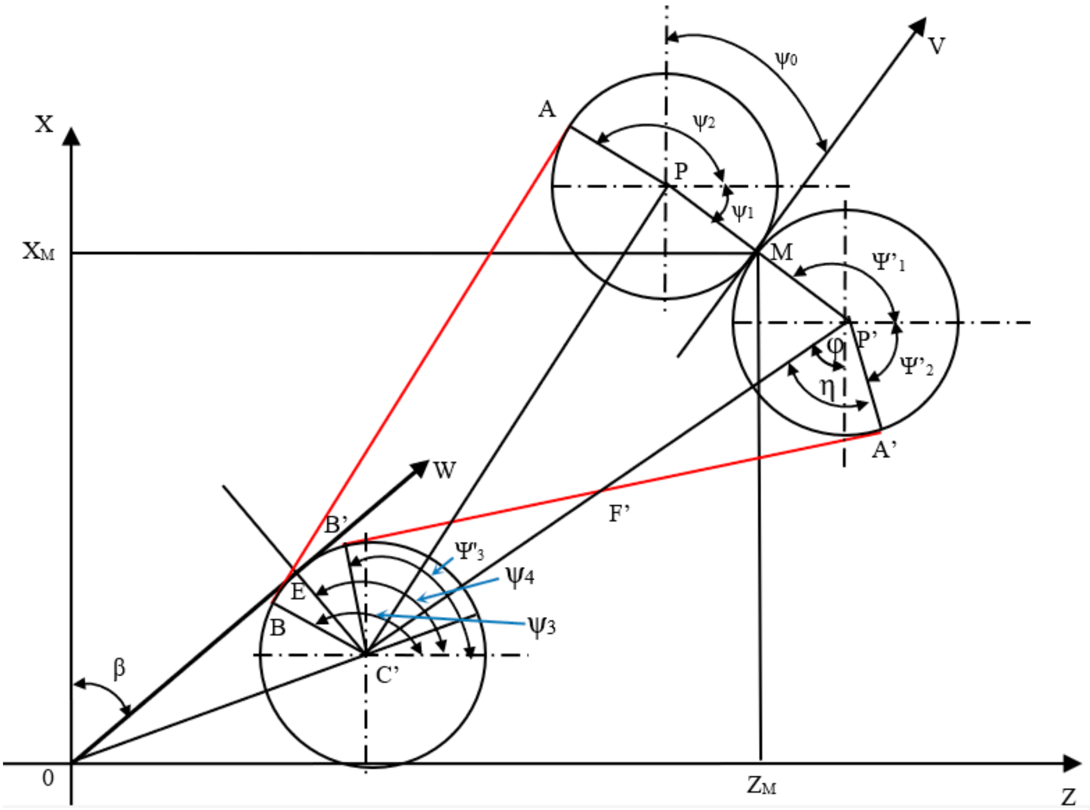


Figure 6. Landing approach connected to the right circle.

Table 2. Formulas used for calculating the distance of the landing orbit.

The Circle of Left Turning	The Circle of Right Connecting	Angles
$X_P = X_M + R_{min}.sin\psi_0$	$X_B = X_{C\prime} + R_{min}.sin\varphi$	$\varphi = arctg\frac{Z_P - Z_{C\prime}}{X_P - X_{C\prime}}$
$Z_P = Z_M - R_{min}.cos\psi_0$	$Z_B = Z_{C\prime} - R_{min}.cos\varphi$	$\psi_1 = arctg\frac{X_P - X_M}{Z_M - Z_P}$
$X_A = X_P + R_{min}.sin\varphi$		$\psi_2 = arctg\frac{X_A - X_P}{Z_A - Z_P}$
$Z_A = Z_P - R_{min}.cos\varphi$		$\psi_3 = arctg\frac{X_B - X_{C\prime}}{Z_B - Z_{C\prime}}$
		$\psi_4 = arctg\frac{X_E - X_{C\prime}}{Z_E - Z_{C\prime}}$

Based on these formulas in Table 2, the distance of the landing orbit, in this case, can be calculated as follows.

$$L_3 = R_{min}(\psi_1 + \psi_2 + \psi_4 - \psi_3) + \sqrt{(Z_A - Z_B)^2 + (X_A - X_B)^2} \quad (5)$$

4.3.4. Situation 4: Turning Right to Reach the Left Circle (The Orbit Is MA′B′EO; Figure 6)

$$L_4 = R_{min}(\psi_1 + \psi_2 + \psi_4 - \psi_3) + \sqrt{(Z_{A\prime} - Z_{B\prime})^2 + (X_{A\prime} - X_{B\prime})^2} \quad (6)$$

Choose the situation with the shortest flight distance:

$$L_{min} = \min (L_1, L_2, L_3, L_4) \quad (7)$$

5. Results and Discussion

5.1. Intelligent Total Transportation Management System

The urban transportation system is a crucial subsystem within the broader transportation infrastructure. It is responsible for facilitating the safe, environmentally sustainable, efficient, and reliable movement of people and goods within city limits. This urban system is closely interconnected with more extensive transportation networks, such as highways, railways, and airports, that enable the flow of people and cargo into and out of the city.

The improvement in information technology has led to the emergence of the intelligent total transportation management (ITTM) concept as a potential solution for managing urban transportation. This approach leverages the power of IoT (Internet of Things) technologies to enable smarter and more integrated transportation systems.

The core objective of the ITTM concept is to provide enhanced and more efficient transportation services to urban areas, thereby improving residents' safety, security, and overall quality of life. The ITTM system can help reduce congestion, increase user comfort, and conserve energy by offering real-time traffic data, rerouting options, and adaptive speed controls. Additionally, intelligent parking solutions can eliminate the need for drivers to search for vacant spots, further streamlining urban mobility.

The ITTM system operates as a holistic, integrated platform that manages all modes of transportation, from pedestrians to luxury vehicles, as well as various logistics and infrastructure elements. This comprehensive approach relies on a hierarchical structure and optimization algorithms to coordinate the movement of people and goods within the urban environment.

At the core of the ITTM system is a vast, distributed network of sensors that continuously monitor and recognize different types of vehicles, both cooperative and non-cooperative, in various traffic situations. The system is composed of three main layers: the physical layer (including vehicles, infrastructure, and sensor networks), the communication layer (based on wireless and internet-based technologies), and the control layer (a hierarchical software system responsible for vehicle recognition, situation awareness, conflict detection, and conflict resolution) (Figure 7).

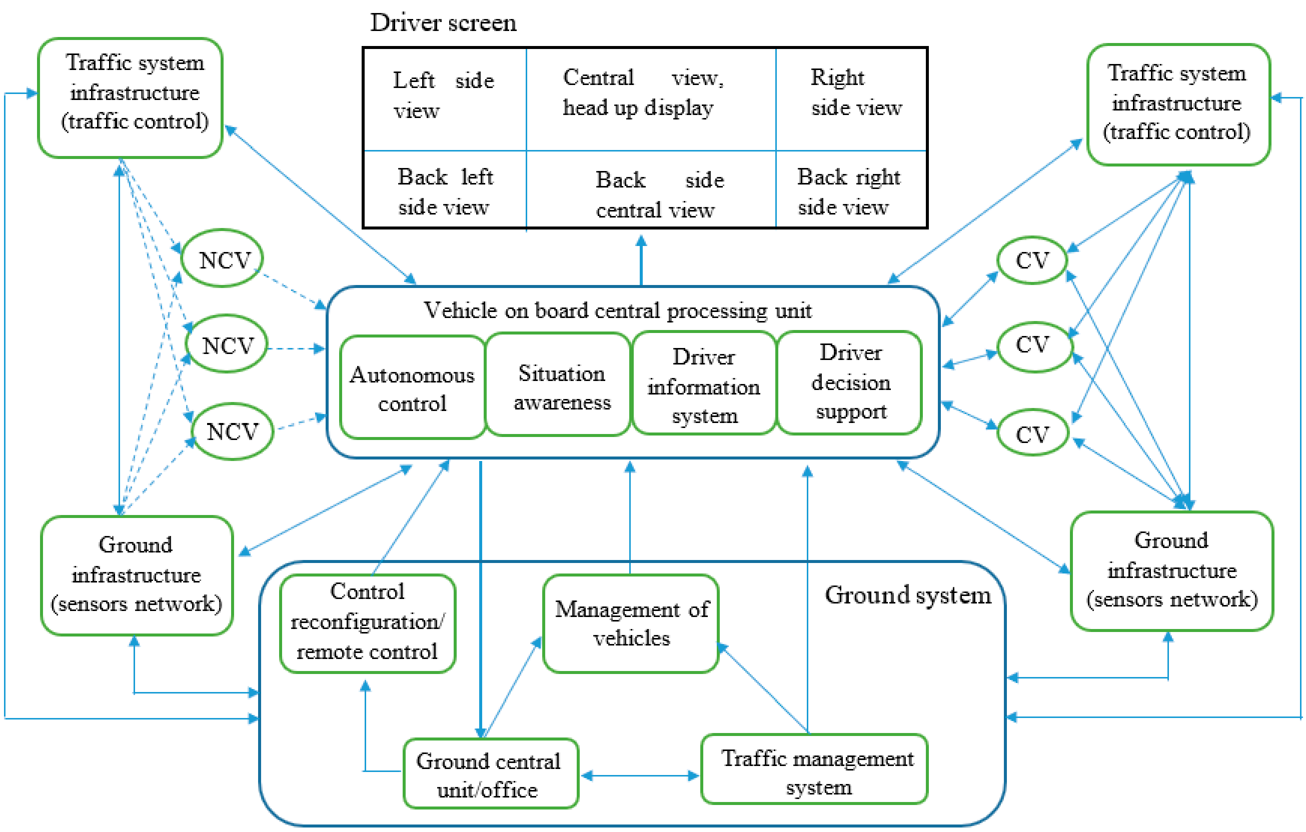


Figure 7. The traffic-managing system architecture (NCV—non-cooperative vehicle, CV—cooperative vehicle).

The ITTM system operates as an integrated platform capable of handling various transportation tasks, including managing non-cooperative vehicles, facilitating traffic management based on cooperative vehicle information, implementing contract-based traffic management, and prioritizing specific transportation needs.

Non-cooperative vehicles refer to those that are not visible on the system's surveillance screens. In contrast, cooperative vehicles provide real-time information about their movements, conditions, and locations through information communication networks. These cooperative vehicles also share data with nearby vehicles to harmonize their motions.

Contract-based vehicles, such as taxis, are similar to cooperative vehicles, but they pay for a slight priority in the transportation system. Unlike the non-paying cooperative vehicles, these contract-based vehicles receive prioritized information and traffic control adjustments from the service provider, which only provides data, without receiving any special treatment.

The ITTM system is designed to connect the central management system with the vehicles, generating controls to avoid extreme and dangerous situations, prioritize greener and more valuable traffic, and support contracted and priority vehicles. These controls are implemented through the transportation infrastructure's traffic signals, signalization, and other actuators.

The ITTM system's operation is the same whether the vehicles are autonomous or driver-controlled. As illustrated in Figure 7, the system's monitoring capabilities can display the positions of other vehicles and obstacles around the driver's vehicle.

Implementing an effective ITTM system requires careful consideration of various design aspects to ensure its suitability for the city and urban area. By leveraging artificial intelligence and optimization algorithms, the ITTM system can effectively alleviate current urban transportation management challenges and promote coordinated development across different traffic management departments within the city. Continued research and development utilizing internet-based technologies are essential for building a more systematic and comprehensive intelligent traffic control and management system.

5.2. An Autonomous Drone Management System

The "autonomous drone management system" is presented in the following diagram (Figure 8), including the following components:

- ➢ Airway network: Represents the airspace infrastructure and routes that the drones navigate.
- ➢ Safety and security rules: Depicts the set of regulations and protocols governing the safe operation of drones.
- ➢ Supporting methods: This includes various tools and techniques that enable the autonomous management of drones, such as sensor fusion, desired trajectory following, formation flight, and obstacle avoidance.

The diagram is designed to be visually appealing and easy to understand. The following subsections present the details of each component.

5.2.1. Airway Network

The airway network structure is based on extensive research and studies available in the literature [30]. It is a more efficient approach to traffic flow distribution, as it can help reduce congestion and provide greater flexibility in flight scheduling and routing.

Four distinct types of sectors are recommended for the airway network: geographical sectors, vertical separation sectors (between large buildings), vertical motion sectors (for climb and descent), and sectors for restricted areas.

The elements of the airway network are the essential components of aircraft trajectories, including lanes in which the aircraft can fly in a single stationary flight mode, such as straight flight, lane changes, descent, climb, and coordinated turns [31].

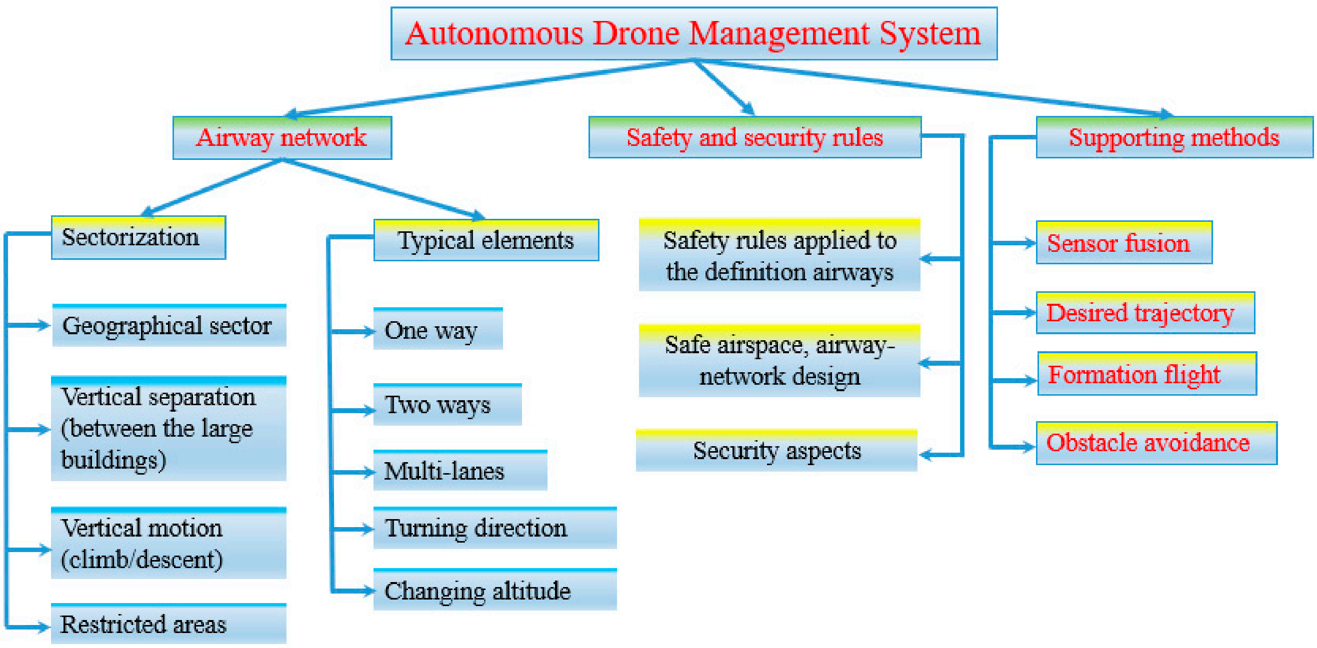


Figure 8. The diagram of the autonomous drone management system.

By implementing this airway network structure, air traffic management systems can optimize traffic flow distribution, reduce congestion, and provide more flexibility in aircraft routing and scheduling, ultimately enhancing the overall efficiency and safety of the airspace.

5.2.2. Safety Rules Applied to the Definition Airways

The authors have investigated and evaluated recent regulations and related works to define the airway network for drone operations. They have made the following assumptions to establish the airway network and research scope:

- Speed limits:

For corridors, 30 m/s.
For drones flying in fixed trajectories at least 20 m from any infrastructure, 20 m/s.
For drones flying within 20 m (but 5 m away) from infrastructure, 10 m/s.

The differentiation of speed limits based on proximity to infrastructure is prudent. Drones operating closer to buildings, power lines, and other obstacles require lower speeds to enhance safety and maneuverability.

The 30 m/s speed limit for corridors allows for the efficient transportation of goods and services, while the lower speeds of 20 m/s and 10 m/s for drones near infrastructure ensure they can navigate the cluttered urban airspace safely.

These tiered speed limits reflect the need to balance operational efficiency and safety, which is crucial for the large-scale deployment of drones in cities.

- Longitudinal separation:

Minimum of 1 s plus an additional second for every 10 m/s flight speed for non-cooperative drones. The minimum 1 s separation plus an additional second per 10 m/s of speed for non-cooperative drones is a reasonable approach that provides a safety buffer to account for potential latency, communication issues, or unexpected maneuvers.

Decreased by 30–40% for cooperative drones. The 30–40% reduction in separation for cooperative drones, which can communicate and coordinate their movements, is logical, as it allows for the more efficient use of the airspace.

Further, the number decreased by 30% for formation flights. The further 30% reduction for formation flights recognizes the increased predictability and cohesion of drones flying in a coordinated group.

- Lateral separation:

The horizontal and vertical distance between the drone's center of gravity should be 5–8 times their maximum dimensions. This ensures adequate clearance to account for a potential drift or instability in the drones' positions.

A safe distance (an empty lane) should be applied for drones flying in opposite directions, which is a sensible safety measure to prevent collisions.

- Airway network composition:

Composed of the defined trajectory elements.

Drones can change lanes in the horizontal or vertical direction only.

The defined trajectory for a given drone is fixed and cannot cross any other trajectory.

Defining fixed trajectories that drones can only change in the horizontal or vertical direction is a structured approach to managing the drone traffic flow. Prohibiting drones from crossing each other's trajectories helps minimize conflicts and streamline airspace management.

5.2.3. Safe Airspace, Airway Network Design

The authors propose a sectorization approach as the primary drone traffic management method. The drone traffic management center develops and implements this sectorization approach. The size and dimensions of the 3D sectors are determined based on various factors, such as geographical aspects, ground obstacles, predicted market needs, demand for drone services, and expected traffic intensity. The sectors can have different vertical dimensions, with more sectors in the lower levels of urban areas to facilitate various operations.

The sectorization is designed to be dynamic and active, allowing for changes based on historical/predicted data and real-time measured situations. The trajectories and airway networks are developed through multi-disciplinary and multi-objective optimization to minimize the total impact and cost of drone operations. The concept of "total impact" includes immediate, short-term, and long-term effects and externalities caused by drone activities, such as the impact on the environment, health, and the economy. The "total cost" considers all the costs related to the operation, production, development, and infrastructure required for drone operations.

In urban areas, the airway network requires special supporting rules and integration with the built environment, which may involve partially implementing road traffic rules and incorporating unique markers into the city infrastructure. The airway network and sectorization are operated using passive, dynamic, and active methods. If safety and security problems are detected, special zones should be created for emergency landings.

5.2.4. Security Aspects

This project focuses on drones' civil and commercial applications in urban, "smart city" environments. The proposed urban drone traffic system and management would operate relatively large autonomous drones (up to 1600 kg) in corridors and smaller drones (mostly under 60 kg) following fixed trajectories or channels. The corridors are designed to be far enough from the built environment to allow for reaction in case drones unintentionally leave their fixed paths, and the smaller drones on fixed trajectories are expected to cause fewer damages and problems, limiting potential unlawful actions.

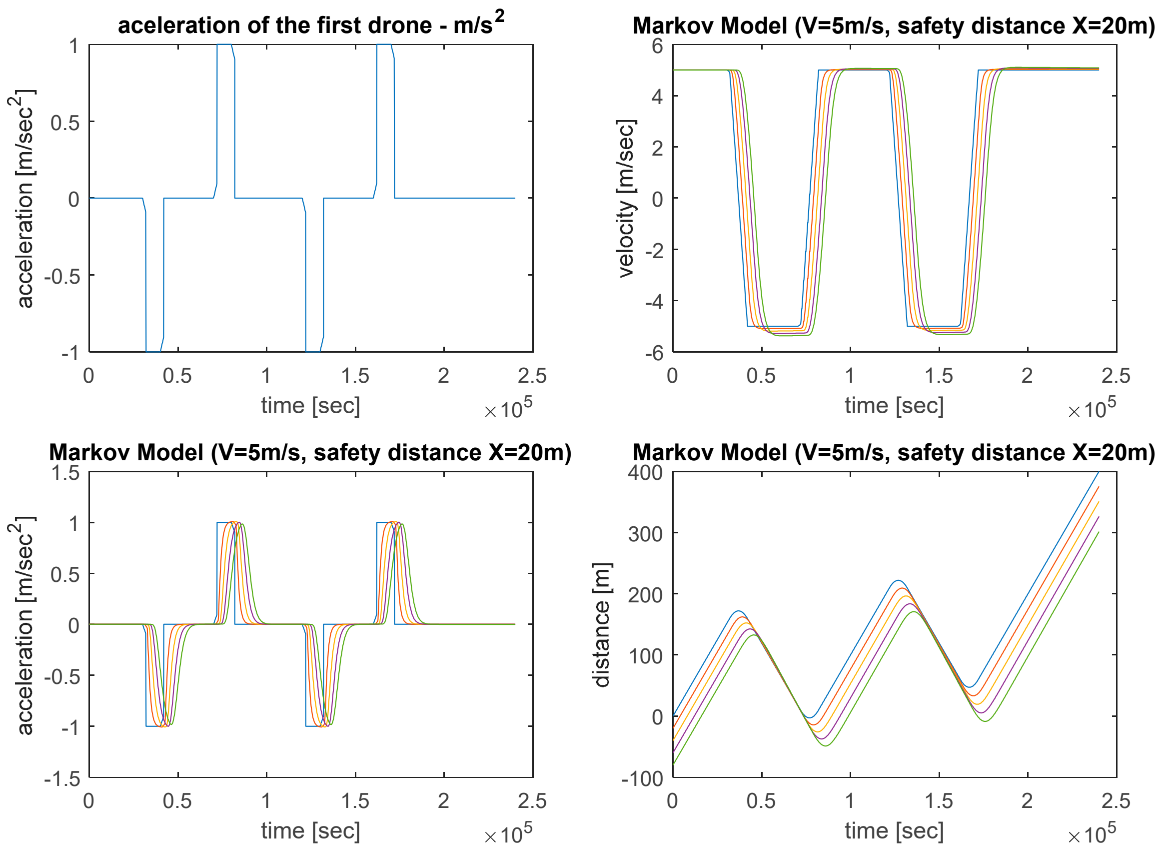
The authors identify four significant security challenges that need to be addressed in this urban drone ecosystem: cybersecurity, the potential use of drones as weapons for unlawful actions, unauthorized entry into restricted areas, and attacks on drones using weapons. To solve these problems, the authors recommend implementing a closed, integrated system for drone traffic management, which would include the following key elements:

- Primary (passive) surveillance using fixed optical, microwave, and radar systems integrated into the urban environment along fixed trajectories and corridors and mobile drone-based surveillance.
- Secondary (active) surveillance using mini transponders that can communicate with the surveillance system within a low distance (up to 600 m) along the fixed routes.
- A secure communication system with a continuously changing coding protocol and the ability to detect anomalies or cyber-attacks.
- Onboard security controllers, including a device to prevent entry into restricted areas, detect security problems, and initiate forced landings.
- A defense and protection system that can automatically detect and intercept or destroy drones that violate its designated defense zones.

5.3. Simulation Results of Drone-Following Models

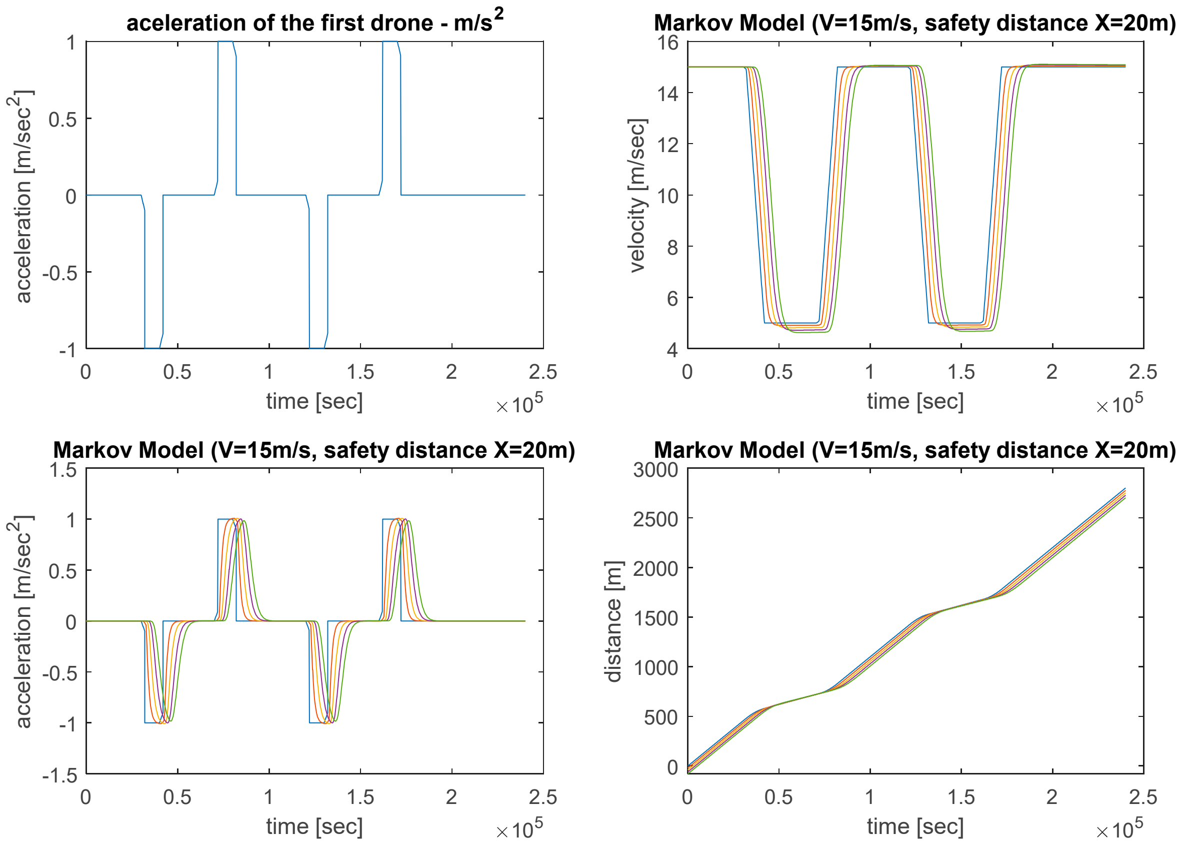
This subsection gives the main results obtained in the simulation experiments on the Markov model.

In our simulation, the number of drones is 5, the velocity of a drone is V = 5 m/s (Figure 9a), 15 m/s (Figure 9b), and 25 m/s (Figure 9c), and the safety distance ΔX = 20 m.

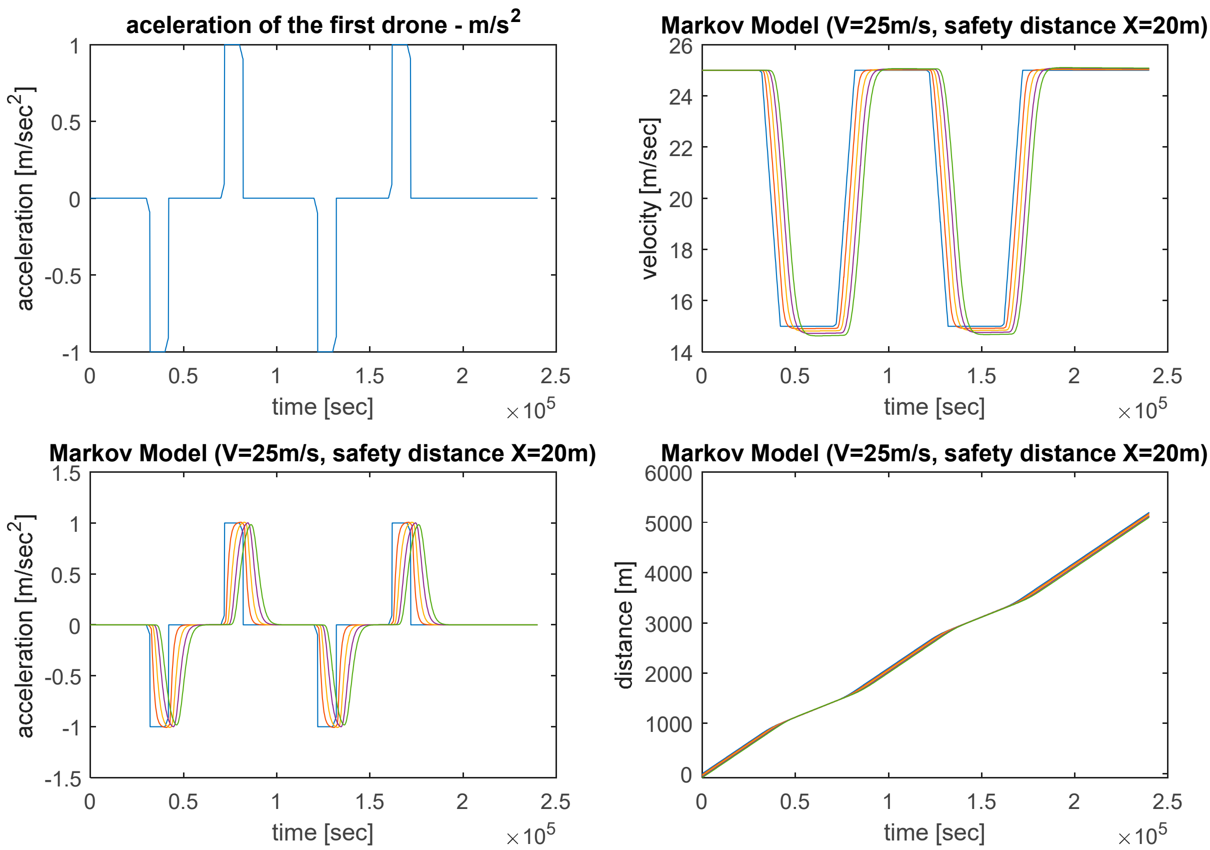


(**a**) Velocity of the leader drone is 5 m/s

Figure 9. *Cont.*



(**b**) Velocity of the leader drone is 15 m/s



(**c**) Velocity of the leader drone is 25 m/s

Figure 9. The simulation results with different velocities (Each drone represents a color line).

The reaction time, set at 0.7 s, was considered for all drones within the system. It was observed that the velocity changes experienced by each drone were relatively similar. However, the motion dynamics for subsequent drones resulted in a slower stabilization of their conditions compared to the first drone. This can be attributed to the delay in their reaction to the changing conditions of the leading drone.

The Markov model employed in this study considers the variations in relative distances between the drones. Consequently, the velocity of the following drone tends to exhibit more significant fluctuations than that of the preceding drone. These fluctuations directly affect the changes in relative distances between the drones, causing them to increase or decrease accordingly. This highlights the importance of considering the dynamics of relative distances when analyzing the behavior and interactions of multiple drones within the system.

5.4. Simulation of the UAV's Landing Process

The input data cover the key parameters necessary to model the UAV's flight dynamics, including its current position, direction, initial velocity, and wind conditions. This information would be essential for simulating or analyzing the UAV's flight trajectory and performance under the given environmental conditions.

There are some general insights on the potential reasons behind the selection of these input parameters:

- Wind speed and direction: Understanding the UAV's performance in the presence of wind is crucial for real-world applications, as wind can significantly impact flight dynamics;
- UAV position: Its 3D position data are necessary to model the UAV's spatial relationships and interactions with the environment;
- Flight direction: Knowing the initial flight direction is essential for calculating the UAV's trajectory and accounting for factors like wind effects;
- Initial velocity: The initial velocity is a crucial parameter that affects the UAV's flight dynamics, range, and energy consumption.

5.4.1. Case 1

Input data:

- Northern wind with a speed of 3 m/s; landing opposite to the wind direction
- The current position of the UAV in space:
- Coordinate (XYZ) = (2200, 500, 1200) [m]
- Flight direction (angle) = 30 [°]
- Initial velocity V0 = 40 [m/s]

The simulation results can be seen in Figures 10 and 11:

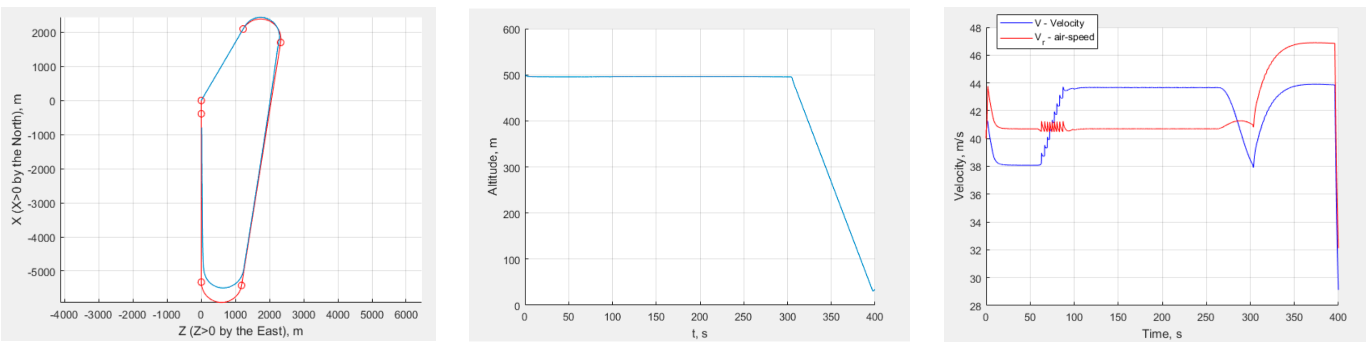


Figure 10. The process of landing approach of the UAV (on the **left** side; The blue line is the desired landing orbit and the red line is the simulation of the landing orbit), and the the altitude (**middle**) and velocity (on the **right** side) of the landing process opposite to the wind direction.

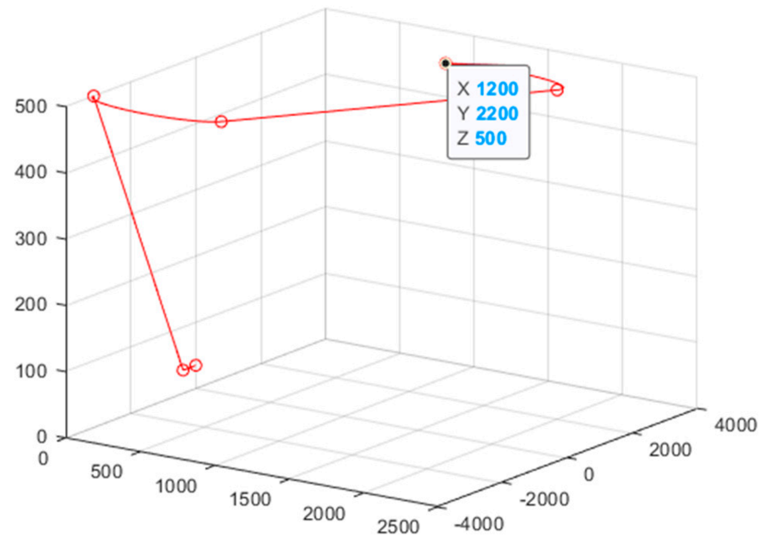


Figure 11. Investigation of the landing process in case 1 (unit: meter).

The simulation results demonstrate a robust and well-coordinated performance of the UAV's landing approach across various flight phases:

(i) Minimal initial orbit deviation:

- ➢ The simulation starts with zero initial orbit deviation, indicating that the UAV effectively handles the landing orbit without introducing significant errors;
- ➢ This result suggests that the model's initialization and pre-flight planning components are well-calibrated to minimize any residual deviations from the desired trajectory at the start of the mission.

(ii) Controlled errors during the first turning maneuver:

- ➢ Some control errors are introduced when the control channels activate during the first turning maneuver;
- ➢ However, the small magnitude of these error parameters ensures the orbital deviation remains relatively small, within the acceptable limits;
- ➢ This demonstrates the model's ability to maintain stability and control precision, even in transient disturbances during dynamic maneuvers.

(iii) Coordinated channel synchronization:

- ➢ The orbital parameters undergo minimal changes throughout the flight as the yaw and speed channels synchronize their actions;
- ➢ This coordinated, collaborative effort between the control channels helps maintain the orbital parameters' overall stability and consistency;
- ➢ The model's ability to achieve this level of channel synchronization is a key strength, as it ensures the UAV can reliably follow the desired trajectory without significant deviations.

(iv) Harmonious automation during second turning:

- ➢ The automation system operates harmoniously during the second turning maneuver, resulting in low orbit deviation and input speed;
- ➢ The velocity-controlling channel and the orbital roll-angle-controlling channel collaborate effectively, generating minimal errors;
- ➢ Consequently, the orbital deviation remains small, and the actual and desired orbits align closely, demonstrating the model's precision and adaptability in handling complex maneuvers.

(v) Cooperative channel action during descent:

- ➢ During the descent phase, the yaw and altitude channels work together cooperatively;

- ➢ This collaborative channel action keeps the orbital deviation small, ensuring the desired trajectory is closely followed throughout the landing's approach;
- ➢ The model's ability to coordinate multiple control channels during the descent phase is crucial for maintaining a stable and accurate flight path, particularly in the critical landing phase.

Overall, the simulation results showcase a robust performance during landing approach thanks to the ability to maintain minor orbital deviations and closely track the desired trajectory throughout the flight. The UAV's strength lies in its well-coordinated control channel synchronization, adaptive automation, and cooperative multi-channel collaboration, ensuring high precision and stability during even the most challenging flight maneuvers.

5.4.2. Case 2

Input data:

- No wind (w ≤ 1 m/s); land in the shortest distance.
- Current position of the UAV in space:
- Coordinate (X Y Z) = (2500, 500, 1400), [m]
- Flight direction (angle) = −30 [°]
- Initial velocity V0 = 40 [m/s]
- In this case, the wind direction was suggested as the direction from the coordinate "0" to the current position of the UAV in space when the UAV is ordered to land.
- The simulation results can be seen in Figures 12 and 13:

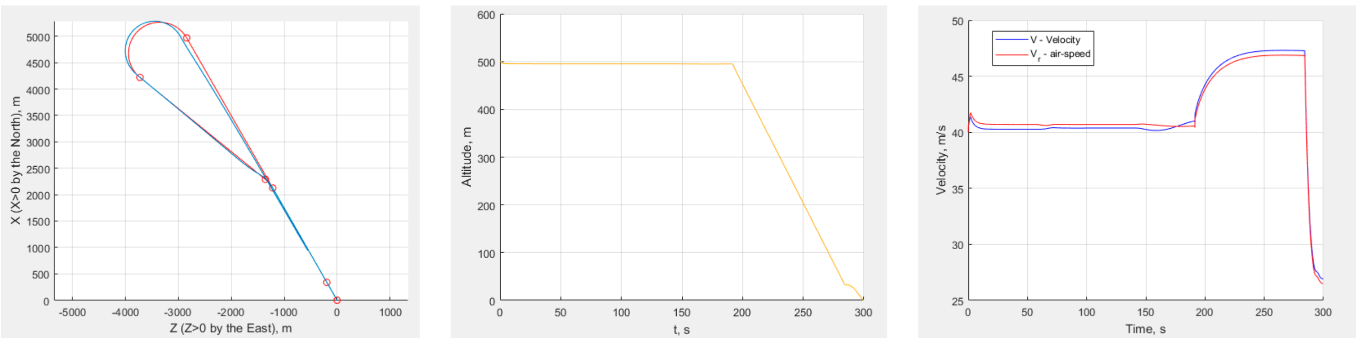


Figure 12. The process of landing approach of the UAV (on the **left** side; The blue line is the desired landing orbit and the red line is the simulation of the landing orbit), and the altitude (**middle**) and velocity (on the **right** side) of the landing process in the shortest distance.

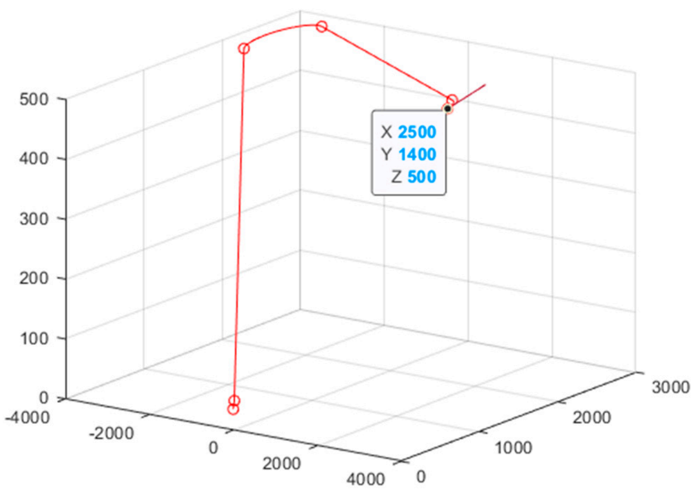


Figure 13. Investigation of the landing process in case 2 (unit: meter).

Based on the simulation results in this case, some comments and analyses are given as follows:

(i) Minimal wind impact on initial conditions:

- ➢ During the initial turning phase, the orbit deviation error starts at zero, indicating that the UAV's landing approach effectively handles the transition without any significant impact from external disturbances, such as wind;
- ➢ This result suggests the UAV's ability to accurately compensate for environmental factors and maintain a stable starting point for subsequent maneuvers.

(ii) Challenges of short-duration, high-range turning:

- ➢ The initial turning maneuver is short and requires a wide range of roll-angle adjustments (up to ± 20 degrees);
- ➢ These challenging conditions trigger the activation of the fuzzy gamma controlling channel, which is responsible for handling such extreme maneuvers.

(iii) Increased errors due to fuzzy gamma control:

- ➢ Unfortunately, while the activation of the fuzzy gamma controlling channel is necessary for a wide range of roll-angle adjustments, it leads to increased errors compared to the previous Case 1 (as shown in Figure 7);
- ➢ This result indicates that the fuzzy gamma control module, while capable of handling extreme maneuver requirements, may need to be more refined and optimized than the other control channels in the model.

(iv) Discrepancies between actual and desired orbits:

- ➢ The increased errors introduced by the fuzzy gamma control channel result in discrepancies between the actual and desired orbits during the initial turning phase;
- ➢ This result suggests that the model may need further refinement or optimization of the fuzzy gamma control algorithms to handle such challenging maneuvers without compromising the overall trajectory tracking performance;
- ➢ Enhancing the fuzzy gamma control module through parameter tuning, algorithm improvements, or the integration of more advanced control strategies could mitigate the increased errors and better align the actual and desired orbits during this critical phase of the flight.

The above analysis demonstrates that the UAV's landing approach can achieve a more consistent and precise performance across all flight phases, further strengthening its overall capabilities and robustness.

5.5. Discussion

One of the most pressing challenges for drone operations in urban environments is the complex and dynamic nature of the airspace. Urban areas are densely populated with tall buildings, communication towers, power lines, and various obstacles, resulting in cluttered and obstructed airspace. This complexity complicates safe navigation and collision avoidance, particularly when drones operate beyond the pilot's line of sight. Furthermore, urban airspace is often shared with a diverse array of aircraft, including those of commercial flights, private aviation, and emergency responders, as well as other drones, creating a significant logistical challenge in coordinating the movements of these various airborne entities within confined spaces.

Additionally, urban weather conditions can be highly variable and unpredictable, with factors such as wind gusts, turbulence, and abrupt changes in temperature and humidity impacting drone performance and safety. Therefore, this research focuses on solving the following fundamental problems.

5.5.1. Conceptual Framework for Drone Operations

The Conceptual Framework for Drone Operations revolves around the intelligent total transport management system (ITTMS), designed to integrate drones into smart city transportation networks seamlessly. The ITTMS operates on a hierarchical system that coordinates multiple transport modes, including drones, ground vehicles, and pedestrians, ensuring cohesive and efficient traffic management. By leveraging real-time data from sensors and the Internet of Things (IoT), the ITTMS continuously monitors and controls the movement of drones within urban airspace, allowing for adaptive routing and real-time adjustments that optimize traffic flow and enhance safety. This framework effectively unifies drone operations with other transportation modes, reducing congestion, improving efficiency, and ensuring safety within the broader urban mobility landscape. The structured and integrated approach provided by ITTMS enables the safe, autonomous, and efficient incorporation of drones into smart cities, aligning with the vision of sustainable, intelligent urban mobility systems.

5.5.2. Drone Air Traffic Management and Flight Control

In the context of Drone Air Traffic Management and Flight Control, the system incorporates several key components, such as the airway network, safety and security rules, and supporting methods, to effectively manage individual drones and drone swarms. The airway network provides designated corridors for drone operations, ensuring organized and conflict-free traffic flow. At the same time, the safety and security rules establish speed limits, separation protocols, and emergency procedures to prevent collisions and ensure compliance with regulatory standards. Supporting methods, like real-time trajectory monitoring, sensor fusion, and automated control algorithms, allow the system to optimize flight paths, adjust drone velocities, and safely navigate dynamic urban obstacles, such as high-rise buildings and other infrastructure. The inclusion of advanced safety features, like collision avoidance systems and secure communication protocols, ensures that drones operate autonomously and safely, even in high-density environments. By combining these components, the system guarantees efficient, safe, and autonomous drone operations, making it feasible to integrate drones into the complex airspace of modern urban environments, thus supporting the broader goals of smart city mobility.

5.5.3. Emerging Technologies for Drone Management

In Emerging Technologies for Drone Management, drone-following models play a pivotal role in managing drone traffic flow, especially in densely populated urban areas where efficient airspace utilization is critical. These models, inspired by vehicle-following principles, allow drones to maintain safe distances and speeds by adjusting their trajectories based on the movements of leading drones. Simulation results demonstrate how these models effectively reduce the likelihood of accidents and enhance overall system efficiency by ensuring smooth traffic flow and preventing abrupt deceleration or collisions. Integrating the Internet of Things (IoT) and the Internet of Drones (IoD) further amplifies these capabilities, enabling real-time communication between drones and control systems. This connectivity allows for greater flexibility, responsiveness, and scalability in drone management, making it possible to coordinate large numbers of drones safely and efficiently within urban airspaces. By leveraging these emerging technologies, the system is better equipped to handle complex traffic scenarios, ensuring safety and optimizing performance.

5.5.4. UAV Landing Processes and Protocols

The UAV Landing Processes and Protocols outlined in the paper emphasize three key stages, deceleration, descending, and directive, which work together to ensure precise and controlled landings for drones in urban environments. In the deceleration stage, the UAV reduces its speed while maintaining stability, followed by the descending stage, where the drone gradually lowers its altitude while staying within safe trajectory boundaries. The directive stage ensures the UAV approaches the landing zone at the optimal angle, considering environmental factors such as wind speed and direction. The paper's proposed landing procedures calculate optimal landing orbits, ensuring safety and efficiency, even in densely populated or complex urban landscapes. Simulations show how these methods allow for precise landings, mitigating risks associated with obstacles or unpredictable weather conditions. These protocols ensure that UAVs can safely navigate to their designated landing spots without deviation, reinforcing their viability in smart city environments. These landing protocols are crucial for integrating drones into urban transportation systems, as safe, reliable landings are essential for ensuring operational efficiency and public safety.

6. Conclusions

This study proposed a comprehensive intelligent total transport management system (ITTMS) designed for smart cities, which leverages IoT to integrate vehicles, drones, and infrastructure, along with the application of data-driven and automated management techniques. The primary objective of the system is to optimize urban mobility, including drone operations, within a unified transportation framework. However, the proposed solutions and methodologies require further investigation and refinement.

In response to the four critical research questions outlined in this paper:

(i) Conceptual Framework for Drone Operations: We have developed a conceptual framework within the ITTMS that incorporates drone operations into future smart city networks. The system integrates real-time data, sensors, and IoT technology to monitor and control drones in urban airspace, optimizing traffic flow and safety. The study demonstrates that such integration can enhance efficiency and support the seamless incorporation of drones into smart city infrastructure.

(ii) Advanced Air Traffic Management and Flight Control: The key components necessary for managing individual drones and drone swarms, such as the airway network, safety and security rules, and supporting methods, were discussed in detail. Combined with real-time monitoring and control, these components enable the system to manage flight paths, control velocities, and avoid obstacles in complex urban environments. Simulations validated that these components improve drone traffic efficiency and safety.

(iii) Improvement in Drone Management Methods: This study explored how emerging technologies such as the IoT and the Internet of Drones (IoD) enhance drone management by enabling real-time communication and coordination between drones and ground control systems. The drone-following models developed in this study demonstrated their ability to reduce collisions and optimize flight paths, thus improving the overall system's efficiency. The simulation results confirm that the system can handle large numbers of drones in urban airspace.

(iv) UAV Landing Processes and Protocols: This study proposed a detailed landing protocol for UAVs, addressing critical stages such as the deceleration, descent, and directive stages. The proposed landing procedures ensure safe and efficient drone landings in smart cities by calculating optimal landing orbits and accounting for environmental factors like wind. Simulation results showed the effectiveness of these protocols, demonstrating that they are vital for the safe integration of drones into urban transportation systems.

While the proposed solutions were verified through simulations, including drone-following models and UAV landing processes, additional research is needed to improve these systems. Future work can focus on the following:

- ➢ Developing methods for sensing non-cooperative vehicles and improving short-term transportation system dynamic predictions;
- ➢ Further exploration of drone management, particularly in high-density environments, and designing experimental studies to evaluate drone performance in space;
- ➢ Investigating emergency landing protocols to ensure the safe operation of UAVs during critical situations, such as signal loss or engine failure.

In summary, this study provides a foundational framework for integrating drones into smart city transportation systems while emphasizing the need for continued research to address the complexities of urban drone management and ensure safe, efficient operations.

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Conflicts of Interest: The authors declare no conflicts of interest.

Nomenclature

ATM	Air traffic management
CV	Cooperative vehicle
ICAO	Civil Aviation Organization
IoD	Internet of Drones
IoT	Internet of Things
ITTMS	Intelligent total transport management system
GIS	Geographic Information System
GPS	Global Positioning System
NCV	Non-cooperative vehicle
SD	Safe distance
UAS	Unmanned aerial system
UAV	Unmanned aerial vehicle
UTM	Unmanned aircraft vehicle traffic management

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