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AIR TRAFFIC MANAGEMENT OF DRONES INTEGRATED INTO THE SMART CITIES

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Abstract

Recently, drones are developing very rapidly, including even small pilot-less air vehicles, air taxis. Therefore, the challenge is that drones can be integrated into the urban transportation system, which needs essential developed technical solutions, formulated regulatory frameworks, and design management systems to safely conduct operations, both in the air and the ground. This paper investigates the possible integration of air traffic management and total transport management systems. The purpose of the integration is to create an operational link between air navigation actors and traffic-managing systems. This approach represents a formal and collaborative commitment between all the actors in a total transport-managing system. The ultimate objective of this integration is punctuality at the destination while improving the system efficiency and predictability using enhanced collaboration between transport actors. The governing idea that the drone's motions will be managed by motion in lanes and motion of groups of drones. Therefore unique drone-following models are developed and tested; an airway network is designed, which combines the typical elements with safety and security requirements. The airspace structure and fixed routes are given in the global GPS reference system with supporting GIS mapping. The simulations and measurement in a semi-real environment demonstrate the applicability of developed methods.

Keywords: Air traffic management, drone-following model, transport managing system, cooperating vehicle, contrcact-based transport management.

1. Introduction

Nowadays, drones are being introduced into civilian operation, into urban traffic. Therefore, all the regulatory bodies (ICAO, EASA, FAA) stakeholder groups (IATA, EUROCONTROL) and large companies (like Airbus or Thales) are working on future unmanned aircraft system traffic management (UTM) [1], [2], [3].

Due to the use of drones has dramatically risen, so have the number of publicized incidents involving the unsafe operation of drones. There will be several events where drones are operated in a manner that causes people in their nearness to feel uncomfortable or that their privacy is being invaded. So the need to regulate drones to protect people and property and address privacy concerns are recognized by the state and local governments. The drone regulation under the laws of twelve countries and the European Union is investigated in [4], in which drones refer to unmanned aircraft systems (UAS), unmanned aerial vehicles (UAVs), or remotely piloted aircraft (RPA).

According to the Federal Aviation Administration (FAA), operating drones are classes of activities or specific operations that are usually prohibited for commercial drone applications [5]. However, airspace and equipment approval can be achieved depending on who you are and how you want to fly. This procedure is more straightforward and more flexible for operating commercial drones. Besides, a "phased-in approach" has been carried out to integrate drones with a national airspace system. Moreover, drones can be used for specific applications in restricted areas, for example, atmospheric research. According to Business Insider [6], the demand for commercial drones is expected to reach $3B by 2024. They cite several leaders in this market: senseFly (Switzerland), Aeryon (Canada), CybAero (Sweden), DJI (China), Gryphon (Korea).

In European countries, while the Joint Aviation Authorities (JAS) is responsible for operations and licensing, the European Aviation Safety Agency (EASA) is responsible for regulating airworthiness and maintenance issues [7]. Authors in [8] presented a case of studies regarding the legal use of drones, which has its perspective in the Slovak Republic. Generally, the increase in the use of drones will generate a new competitive environment for operating companies and cooperative enterprises. However, the recent legislation regarding drones' applications does not satisfy this challenge because of the flexible legal use of drones, such as monitoring employees and delivering documents.

Besides, the National Aeronautics and Space Administration (NASA) has been working with academia and the FAA to create a novel Air Traffic Management (ATM) system for low altitude airspace management, particularly for Unmanned Aircraft Systems (UAS). At that time, Amazon, Google, General Electric, Europe's SESAR, and numerous other entities have announced their programs in this area. These developments indicate a consensus that the existing ATM system may not adequately support new UAS and drones. The actual concept of operations and the ultimate National Airspace System (NAS) integration plans are remained unclear, even significant investment in these systems, and displayed prototype capabilities. This is because of the lack of explicit identification, where current ATM capabilities are inadequate and must be augmented by these new systems.

Four potential challenges regarding the anticipated number, density, altitude, and diverse characteristics of these new operations and operators that may constrain the scale-up of ATM services, were presented in the scientific report [9]. Six implications that insufficient ATM capacity may have on the process of UAS and drones were discussed, including delays, fees, safety issues, and rejection of access to saturated airspace. A limited set of high-capacity Takeoff and Landing Areas (TOLAs) is developing to support the initial implementation of services along specific routes and corridors. A significant development challenge exists if the service becomes available to a broad geographic area with high capacity. The lack of TOLA infrastructure has been shown to amplify aircraft staging, airspace congestion, and route capacity challenges.

The investigations [10], [11], [12], [13] into the development of UTM for the urban operation of drones and analysis of the possible solutions have resulted in the identification of several significant problems:

- difficulties in using passive surveillance systems (due to the low flight altitudes and large buildings),
- the complexity of conflict/obstacle detection and resolution (due to high traffic intensity and a lot of built obstacles such as houses), and
- need for a cost-effective solution (low-cost UTM, due to the very low operational cost of drones).

The solutions for these problems require full integration of ATM/UTM into the total (urban) transport-management systems and the development of unique methods for managing a large number of vehicles in formation flight. This includes the management of dynamically variable groups of drones [14], [15], [16], swarm optimization [17], [18], and drone-following models for individual vehicles [19] moving with similar trajectories; being in the same "trajectory tunnels." Several studies presented new operational concepts and the integration of drones in smart city transportation systems [20], [21], [22], [23], [24], [25], [26], [18], [27].

Based on the literature reviews, this study is motivated by the development and management of UAV operations for civil use, especially for larger drones operated at low altitudes.

This paper aims to investigate the possible integration of drones in the smart city transportation system. The purpose of the integration is to create an operational link between air navigation actors and traffic-managing systems. This approach represents a formal and collaborative commitment between all the actors in a total transport-managing system. Generally, the role and the tasks and responsibilities of each of the actors must be based on well-defined, agreed, and shared objectives. These objectives represent the commitment of each actor to deliver a particular aircraft inside temporal and spatial intervals. These commitments are agreed upon by all involved actors for specific transfer of responsibility areas. Then, each actor will be fully accountable for its achievements. The ultimate objective of this integration is punctuality at the destination while improving the system efficiency and predictability using enhanced collaboration between transport actors.

2. Integrating air traffic management system with a total transport-managing system

A total transportation management system uses a vast distributed network of sensors to monitor and recognize the different cooperating and non-cooperating vehicles, extreme traffic situations (Fig. 1). The sensors are mechanical, optical, electromagnetic, biological sensors. Extensive wireless communication transfers the sensed data to the system center (working as a command point). The intelligent system generates the controls for avoiding extreme and dangerous situations and managing the more practical, greener traffic, and supporting the contracting vehicles and priority traffic.There is no principal difference in cases when the vehicles are moving autonomously or driver-controlled. A driver screen may show the position of the other vehicles, obstacles around the vehicle.

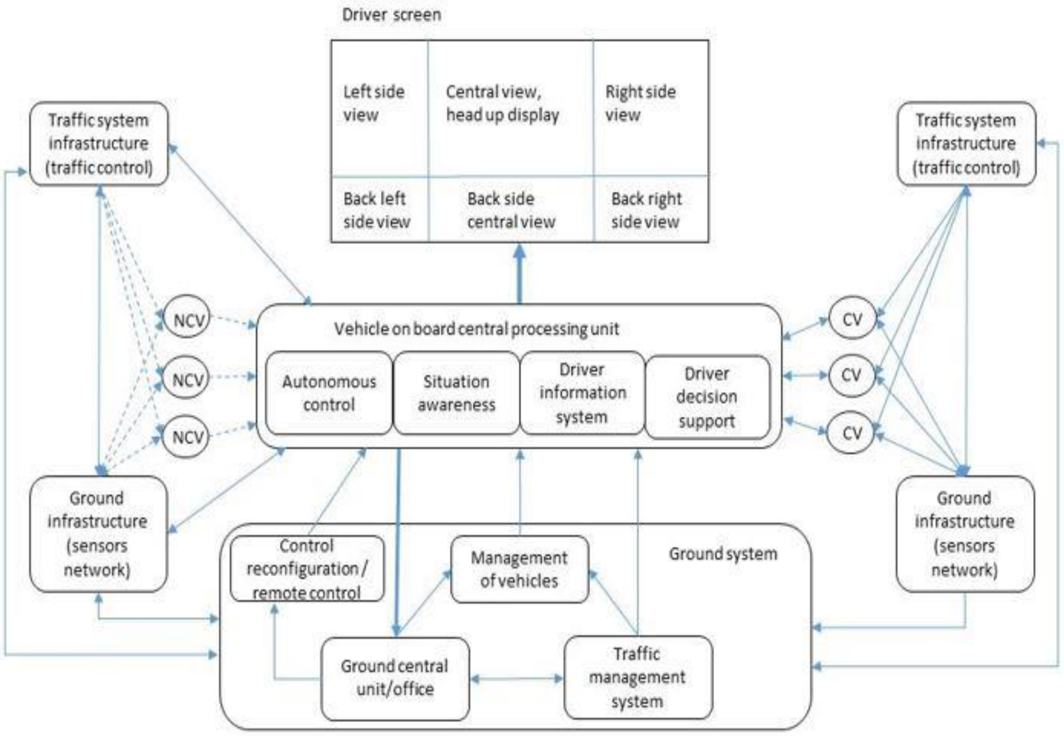


Figure 1 - The traffic management system architecture (NCV-non-cooperating vehicle, CV-cooperating vehicle).

The total transportation management system is combined from three layers, including physical, info-communication, and control generation. The physical part consists of all the vehicles, the available infrastructure, the sensor network, and traffic controls integrated into the infrastructure. The communication is based on the wireless system, partly on using the Internet. The control layer is a hierarchically organized software set used to recognize and classify vehicles, traffic situation awareness, conflict detection, and resolution, including the sense and avoidance of the obstacles, other vehicles, and people.

Such a system deals with four different tasks, including non-cooperating vehicles, cooperating vehicles, contract-based, and priority traffic management.

2.1 Managing the non-cooperating vehicles

The available and measured information about the traffic infrastructure, traffic intensity, complexity, and vehicles, regardless of they are cooperative or non-cooperative vehicles, are used as the primary input (data of primary surveillance).

The non-cooperative vehicles are identified and classified depending on their size, mass, predicted performances (acceleration, turning radius), and predictable goal of trips. The optical, infrared, ultrasonic, radar sensors built into the infrastructure, lampposts, traffic lights, nearby buildings are the elements of the first surveillance, which provide the inputs. The system applies this information quickly to forecast the traffic intensity and complexity, and information provided by the cooperating vehicles. The goal is to evaluate where, which direction will increase the traffic, where the traffic jam might appear. With managing such traffic situations, traffic jams, the developing system will support even the drivers of non-cooperative vehicles. For example, the four lanes road might be dynamically controlled: two lanes supporting the traffic into the more intensive traffic direction and one, only, for the other direction, while one lane will dedicate to the contract-based and priority traffic.

2.2 Managing the cooperating vehicles

In air traffic management, the aircraft have transponders that reply to each interrogation signal by transmitting a response containing encoded data identifying the given aircraft. Such a method is secondary surveillance. In a smart city, net-centric transport managing system, the cooperating vehicles continually provide information about the type of vehicle, motion condition (velocity, changing in velocity, direction), and actual (GPS) position.

There are three levels of cooperation, describing as follows:

- In the first level of cooperation, called primary cooperation. The cooperating vehicles provide information on the vehicles, motion conditions, and actual position using info-communication networks. These vehicles also provide this information to the nearby vehicles and harmonize their motions.
- The second level of cooperation, called secondary surveillance, is characterized by sending information about the goal and target of trips to the traffic-managing center that may directly support these vehicles.
- In the third level of cooperation, the cooperating vehicles send data to the traffic managing center about the nearby vehicles, infrastructure, traffic situations.

The inputs from primary and secondary surveillance allow the introduction of total traffic management. Of course, traffic management may support the cooperating vehicles directly.

2.3 Contract-based traffic management

The contract-based traffic management (CTM) introduces a new service opening new market segments for people who would like to reduce their travel time. That possible services may start from the dedicated parking areas at P+R systems, through the special small buses transport from parking place to the city business centers, drop off car system. When the driver stops the car anywhere in the city and the traffic-managing system will park it at the nearest parking place. Later the system will transfer the car to the driver-defined place. The system may use remote control, or the car may have the required information from the transport-managing system and may pay autonomously. The top-level of contract-based traffic may include a “semi priority” system. In such cases, the drivers will have information from the transport-managing centers about the recommended shortest ways and possible shorting the traveling time, and at the same time, they will see unique commanding signals on the road (appearing for the short time and the given vehicles).

Contract-based vehicles pay for having a little bit of priority, not the highest priority, such as taxis, then they can get information from the service provider who will change the control traffic light better for them than others. Contract-based vehicles like cooperative vehicles provide information about the vehicles, motion conditions, and actual position using info-communication networks to the nearby vehicles and harmonize their motions. However, the cooperative vehicles do not pay for service, and they only sent the information. The contract-based vehicles pay for service by signing the contract.

2.4 Priority transport management

The total transport management system uses all the available information about the transport infrastructure, vehicles, traffic complexity, appeared in traffic situations, and may simulate the transport and determine the future optimal, more efficient transportation. Therefore, it may manage the priority transport, too. Generally, the transport-managing system uses passive methods to monitor the non-cooperative transport, semi-active methods (for partly controlling) the cooperating transport, an active method for supporting the contract-based transportation, and a proactive approach for managing priority transport. The priority transport (police, fire machines, ambulances, traveling the protected persons) might be supported by opening them the free lanes, freeways by the total transport management system.

3. Airway network for autonomous drones in smart city traffic management

The airway network structure is based on an extensive study being available in the literature [28]. An airway network is a better traffic flow distribution that might reduce congestion and provide more flexibility to flight schedules and routes. Therefore, traffic flows are managed better and traffic congestion is reduced. Such a airway network used four different sectors, including geographic, vertical separation (between the large buildings), vertical motion (climb/descent), and restricted areas.

3.1 Typical elements of airway network

The proposed airway network used typical elements that are simple elements of trajectories, lanes in which the aircraft might fly in one stationer flight mode as a straight flight, changing the lane, descent, or climb, coordinated turn (Fig. 2-5).

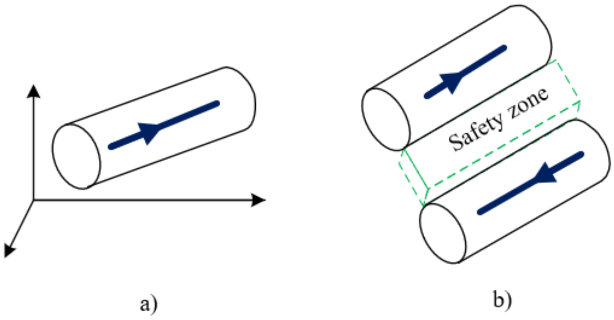


Figure 2 - Single lane: a) one direction, b) two directions

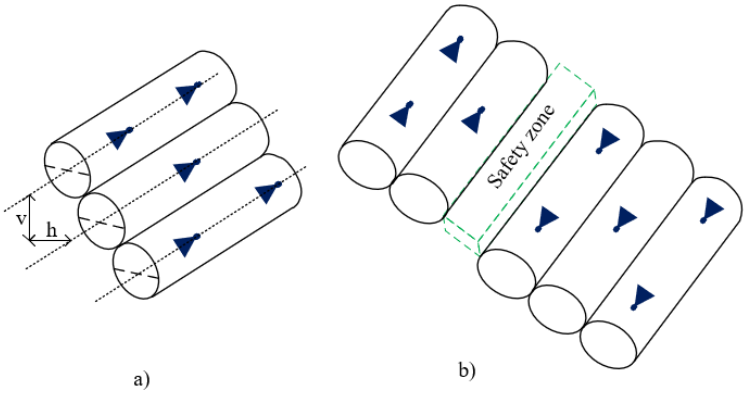


Figure 3 - Multi-lanes: a) one direction, b) two directions

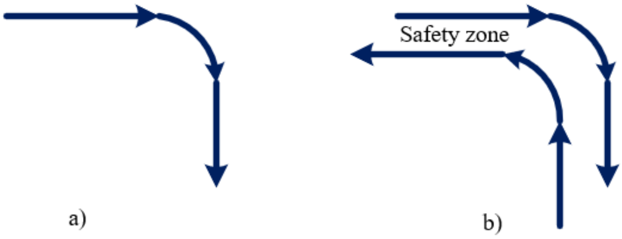
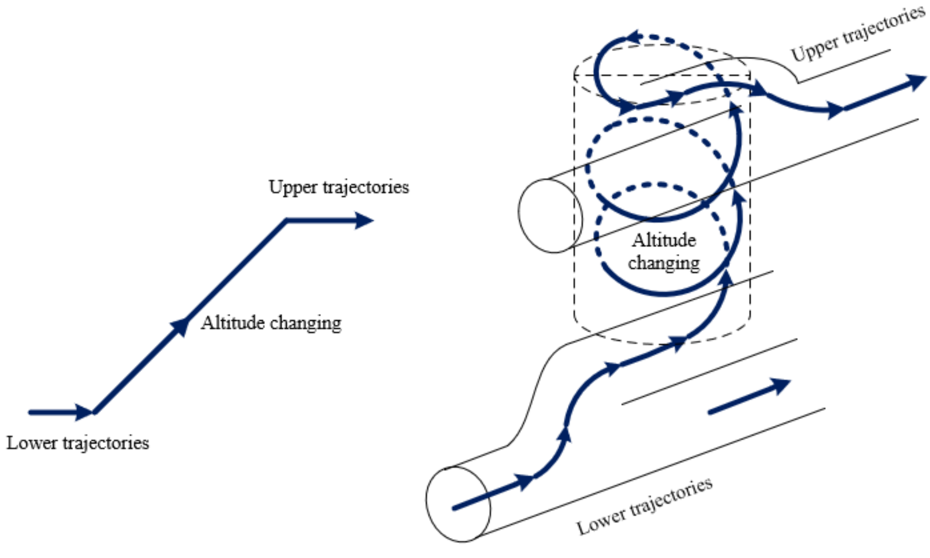


Figure 4 - Turning: a) in one way at the same altitude, b) in two ways at the same height



a) b)

Figure 5 - Changing altitude in the same direction

There are two different crossing options: (i) the straight-line crossing with no heading modification after the crossing (changing lane) (Fig. 6a) and (ii) the crossing with heading modification, including possibly a vertical motion due to the modified heading (Fig. 6b).

a) b)

Figure 6 - Crossing: a) changing lane, b) changing heading (in top view)

However, changing the direction (or heading) is not as straightforward. To minimize the number of potential conflicts, lanes of different headings are at different altitudes. Thus, heading modifications lead to the following six simple maneuvers, as shown in Figure 7.

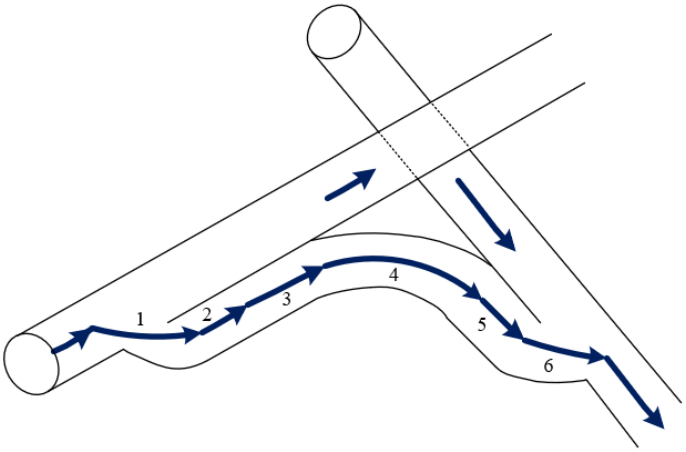


Figure 7 - Changing heading at different altitude: 1- changing to a new lane, 2- flying in the new lane, 3- increasing / decreasing the altitude, 4- turning on the same altitude, 5- flying at the new lane in the desired heading, 6- merging in the lane at the same altitude and at the desired new heading.

3.2 Safety and security aspects

The authors had investigated and evaluated several recent regulations and related works focusing on drones' safety and security aspects [2], [3], [7], [11], [29], [30], [31], [32], [33], [34], [35], [36]. The following rules are suggested to define the airway network:

- Safe distance: Defining speed limits to 30 m/s for the corridors, 20 m/s for drones flying in fixed trajectories, at a minimum of 20 m from any infrastructures (buildings), and 10 m/s for drones moving 20 m closer (but 5 m away) from the infrastructure.
- Safe speed: The drone's recommended longitudinal separation in a fixed trajectory depends on the speed, difference in speeds, and the level of cooperation between the given drones. Preliminary longitudinal separation ”time” should be a minimum of one second plus an additional second by each 10 m/s of flight speed sec, for the non-cooperative vehicles that should be increased when the follower (i+1) drone has a greater speed, Δv (m/s) being compared to the leading (i-th) drone for Δv /3 in sec. In the case of cooperative drones, the longitudinal separation time can be decreased by 30 – 40 % (depending on the actual intensity of air turbulence), and for the case of formation flight, another 30 %.
- Safe zone: The lateral separation (horizontal and vertical direction) is defined by Figures representing the recommended typical elements of airways. As a general rule, the horizontal and vertical distance between the drones’ center of gravity heading in the same direction should be equal to 5 – 8 times their maximum dimensions. If drones fly in the opposite direction, a particular safe distance equal to an empty lane should be applied.
- The airways and the total network should be composed of the elements described above, and the drones might only change lanes in the horizontal or vertical direction.
- The defined trajectory as a channel for the given drone is fixed and cannot cross any other trajectory.

The suggested rules are applied to eliminate or mitigate causal factors or unsafe situations. These safety requirements for drone operations must be assigned to the aviation authority and the manufacturer. However, a complete analysis of the authority and manufacturer levels needs to be studied as future works.

3.3 Safe airspace, airway network design

The air traffic management center applied sectorization to develop and implement the traffic management system, including geographic, vertical, and ground obstacles. Because the sectorization is dynamic and active, it can be changed dynamically depending on the available and measured data.

Trajectories are designed and developed applying multi-disciplinary and multi-objective optimization to minimize the total impact of drones with a minimum total cost that is the sum of all the effects or costs of all drones. Total cost is determined by considering all the costs, including the operation, production, development, and operation of all the required infrastructures or the external cost affected by accidents.

The airway network is operated in urban areas, where accurate positioning and traffic management require special supporting regulation and a built environment. The regulation might be developed by the partial implementation of the road traffic rules and unique markers being integrated into the city infrastructure.

3.4 Security aspects

This study deals with the civil and commercial application of drones in urban areas - smart cities. The management might be ranged from autonomous vehicles in corridors and small air vehicles following trajectories. The big drones (up to 1600 kg take-off mass) are operated in the fixed corridors that are far enough from the built environment. Whereas, the smaller drones are followed the fixed trajectory, which may cause fewer damages and problems.

Therefore, four significant security problems should be solved:

- Cybersecurity: it is a general problem of highly automated and autonomous vehicles, objects having large and centralized info-communication and management systems,
- Using drones as weapons for unlawful actions,
- Flight into restricted areas,
- Attack on drones using arms, guns, weapons.

These security aspects might be solved by implementing the available and emerging security methods and developing a closed system for the drones’ traffic management. The latter means that all operators, service providers, and drones should be integrated into one system, applied the following methods and solutions:

- Primary surveillance: using fixed optical and microwave systems, sensors, receivers integrated into the urban environment, and using fixed surveillance radars and mobile drones for further detections,
- Secondary surveillance: developing and implementing mini transponders might cooperate with the surveillance system within a low distance, up to 600 m. The system elements should be integrated into the urban area along the fixed trajectories, channels, corridors.
- Secure communication system: the drone's security identification being able to detect possible anomalies in the communication or potential cyber-attacks using continuously changing coding system.
- Onboard security controller - first level: a unique device avoids entering restricted areas.
- Onboard security controller - second level: the security problems, attacks, and the emergency landing area are detected.
- Defense and protection system: as part of the total drone traffic management system, it automatically detects the possible violation of the defense zone.

4. Drone following process

Generally, drones follow a reference trajectory to do their task. The reference trajectories are usually planned as straight lines, curves, or a combination of both. A precise, robust, and effective trajectory-following guidance law is required to achieve an excellent autonomous flight. Various guidance laws were developed for trajectory following, including waypoint following [37], vector-field-based trajectory-following guidance laws [38], adaptive optimal trajectory-following guidance law using the linear quadratic regulator technique [39], nonlinear guidance law [40] virtual-target-based approaches [41], or PID controller techniques [42]. The authors in the study [43] presented new trajectory-following guidance for a UAV to track a virtual target moving along the reference trajectory based on a line-of-sight (LOS) angle constraint. This approach addressed significant initial heading angle errors with satisfactory performance. A coordinated path following for fixed-wing UAVs with speed constraints in the 2D plane was investigated [44]. In this study, a hybrid control law based on an invariant set to solve the coordinated path following problem of a group of fixed-wing UAVs. However, when the UAVs are outside the coordination set, collision avoidance is not guaranteed because they execute the single-agent level control law.

Several investigations deal with flight planning, including the uncertainties in the environment, precise aggressive maneuvers, or low altitude flights [45], [46], [47]. The trajectory tracking or path following, especially in quadrotors, could be supported with backstepping trajectory control [48], barometric altitude measurement for fault diagnosis using feedforward neural networks [49], multi-loop PID controller [50], infrared (IR) camera, and IR beacon [51], feedback linearization control-oriented algorithms, non-linear guidance law, or carrot-chasing geometric algorithms [52].

In a simplified case, the trajectory following methods might be based on a discrete time-variant state-space representation of the drone motion:

$$\mathbf{x}[k+1] = \mathbf{A}(\mathbf{x}[k], \mathbf{z}[k], T)\mathbf{x}[k] + \mathbf{B}(\mathbf{x}[k], \mathbf{z}[k], T)\mathbf{u}[k], \tag{1}$$

$$\mathbf{y}[k] = \mathbf{C}(\mathbf{x}[k], \mathbf{z}[k], T)\mathbf{x}[k] + \mathbf{D}(\mathbf{x}[k], \mathbf{z}[k], T)\mathbf{u}[k], \tag{2}$$

where **x, y, u, z** are the state, output, input (control), and environmental vectors, **A, B, C, D** are the state (or system), control, output and feedthrough (or feedforward) matrices, and k is the time variable.

The drone’s trajectory, position in the 3D space - in the coordinate system being connected to the drone management center – could be determined from the state characteristics, and more precisely, from the velocity components. Similarly, the measured actual trajectory characteristics can be transferred into the changes in state vector elements. Therefore, in the following, equation (1) will be used only.

The trajectory following model is based on a unique inversion-model-based control. It is not a simple feedforward control, as the predicted trajectory is based on approximation and interpolation of the controlled drone.

Let suppose the $\mathbf{u}_d$ as desired control keeps the drone on the trajectory, and the series of previously measured $\mathbf{x}[k], \mathbf{z}[k], \mathbf{y}[k]$ are available. The actual matrices **A, B, C, D** can be defined by the state and environmental vectors, $\mathbf{x}[k], \mathbf{z}[k]$, while the state and output vectors, $\mathbf{x}[k], \mathbf{y}[k]$ can be used to determine the prediction of the future state vector, $\mathbf{x}_p[k+1]$. The difference in the predicted and the desired trajectory characteristics can be used to determine the required changes in the desired input to return the drone to the predefined fixed trajectory. Applying this approach to equation (1), leads to the following:

$$\Delta\mathbf{x}[k+1] = \mathbf{x}_p[k+1] - \mathbf{x}_d[k+1] \tag{3}$$

and

$$\Delta\mathbf{u}[k] = (\Delta\mathbf{x}[k+1] - \mathbf{A}(\mathbf{x}[k], \mathbf{z}[k], T)\mathbf{x}[k])(\mathbf{B}(\mathbf{x}[k], \mathbf{z}[k], T)\mathbf{u}[k])^{-\mathbf{1}} \tag{4}$$

The application of the method is demonstrated in Fig. 8.

When the number of drones increases, severe accidents can appear in the sky, even in simple situations. The investigation of drone traffic safety and the intelligent transportation system's development requires drone-following models describing one-by-one following processes in the traffic flows. The drone-following models are based on the idea that each drone can be flown under its leader, expressed by the function of safety distance or relative velocity of two drones [19], [26].

The primary and probably most used car-following model was developed by Gazis et al. [36] based on keeping the safe distance according to the relative distance. This model is often called a safe distance or system dynamic (SD) model. The drone's velocity depends on the traffic situation in the drone following process, namely on the distance to the drone ahead and its velocity. This approach led to the linear models assuming that its controller controls the drone's acceleration to keep zero relative velocity to the drone ahead.

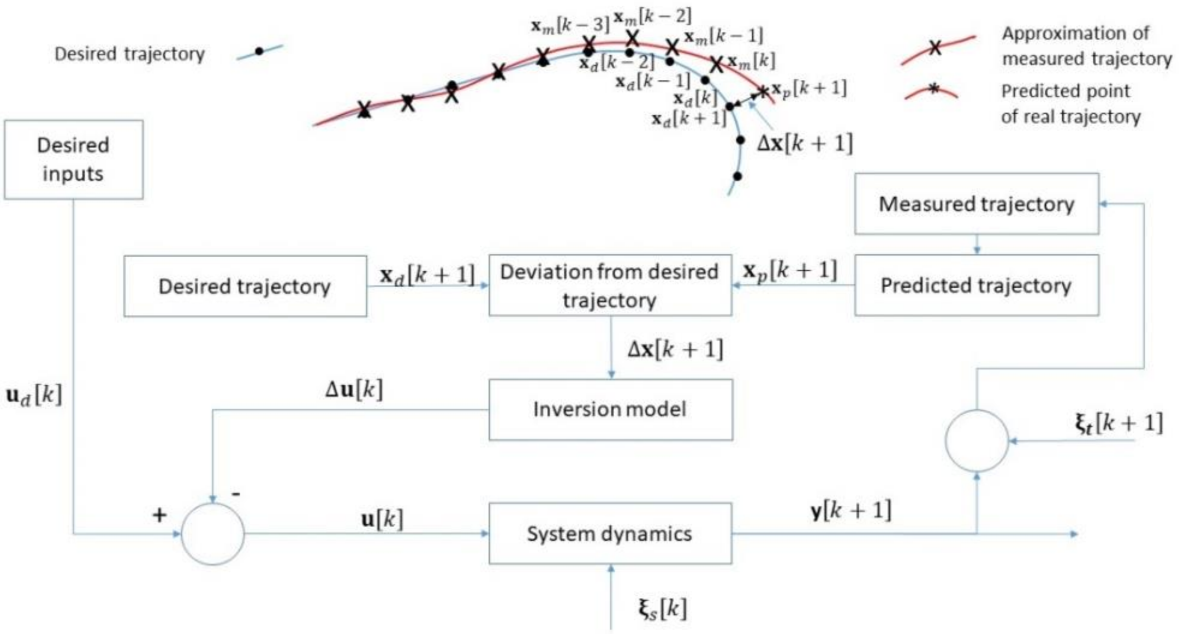


Figure 8 - The proposed trajectory following model

The SD model is given as follows:

$$\ddot{X}_n(t+T) = \lambda \frac{[\dot{X}_n(t)]^p}{[X_{n-1}(t) - X_n(t)]^q} [\dot{X}_{n-1}(t) - \dot{X}_n(t)] \tag{5}$$

Where, $X_n(t+T)$ – the acceleration of *n-th* drone after a reaction;

$X_{n-1}(t) - X_n(t)$ – relative distance between the *(n-1)-th* drone and the *n-th* drone;

$\dot{X}_{n-1}(t) - \dot{X}_n(t)$ - relative velocity of *(n-1)-th* to the *n-th* drones in time *t*;

T – delay time of a controller;

λ – a weight coefficient related to the controllers;

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

It seems this model is well applicable to the drones flying in the desired flight path. However, the air turbulences and wind flow separated from infrastructure cause rather stochastically disturbed motion of drones. With the characteristics of advanced controllers, the controller's relative distance and actual reaction time are added to the control close-loop. This approach leads to an improved model, called the Markov model.

The Markov model is based on the approximation of the stochastic process of velocity decision. One advantage over the SD model is that the inputs of the controller are different velocities and deviations in relative distance between the drones, which can be described such as follows:

$$\ddot{X}_n[\mathrm{k}+1] = c_v\left(\dot{X}_{n-1}[k] - \dot{X}_n[k]\right) + c_x\left[(X_{n-1}[\mathrm{k}] - X_n[k]) - \Delta X_{pdn}\right] + \varepsilon[k] \qquad (6)$$

Where, c_v and c_x – coefficients depending on the time, given drone and controllers;

$\Delta X_{pdn} = \dot{X}(t)$ – the predefined safety distance between the drones;

k – the number of steps in a chain ($\mathrm{t} = \mathrm{k}.\Delta\mathrm{t}$);

$\varepsilon[k]$ – the random value disturbing the process.

There are two significant differences between the SD and Markov models. Firstly, the SD model is linear, while the Markov model is non-linear. Secondly, the SD model is not taking into account the decision process. In contrast, the Markov model is developed to approximate the stochastic process of speed decision by the Markov chain process.

4. Evaluation and discussion

4.1 Drone-following process in the traffic flow

The simulation experiments of the drone-following models are illustrated in Figs. 9 and 10. These results verified that the developed Markov model might perform the longitudinal safety separation of drones as the SD model. In general form, the results partly validated the proposed method that is part of research aiming to integrate drones with the urban intelligent transport system. The drone-following method needs to verify through several immediate next steps, such as the safe distance being measured in the drone directly in front and two drones beside, designing and conducting an experimental study to collect quantitative information regarding drone performance in space.

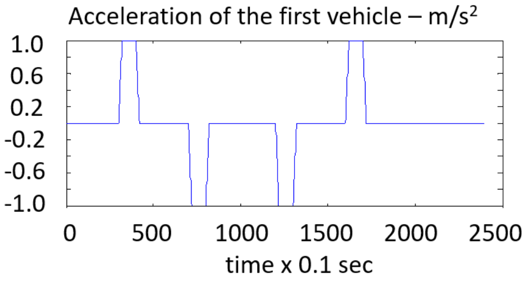


Figure 9 - Acceleration, deceleration of the first drone applied in verification tests

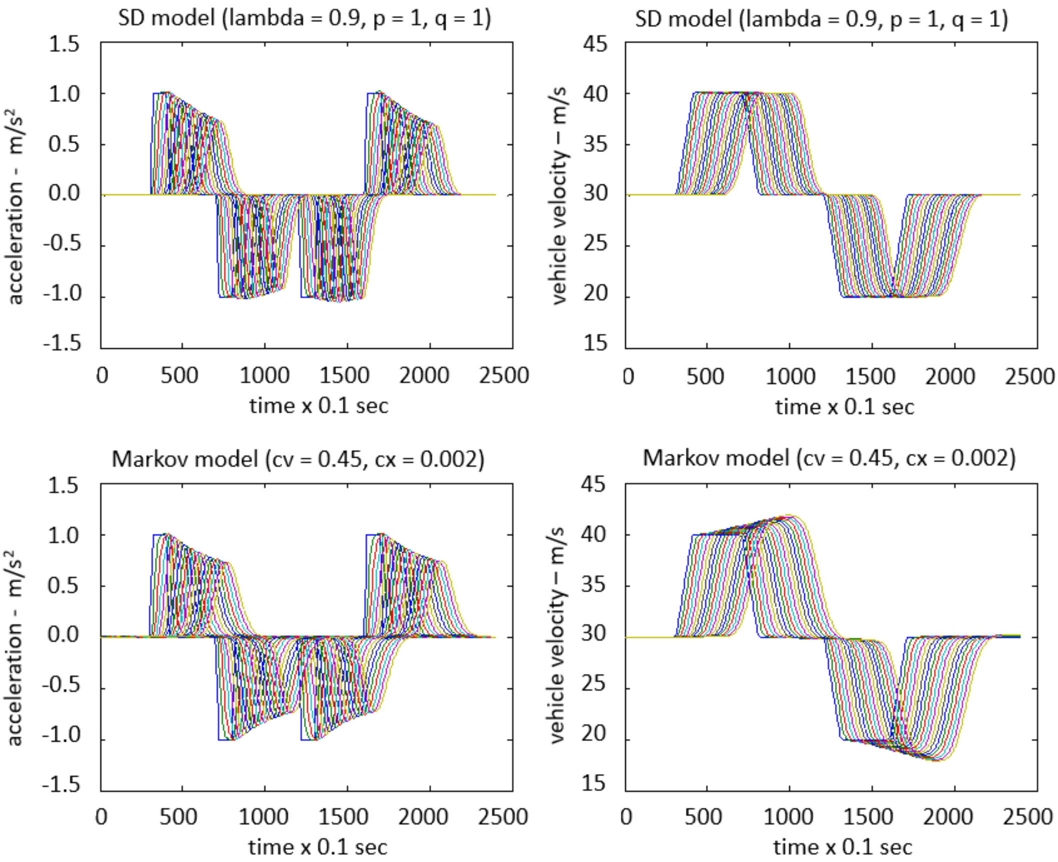


Figure 10 - Verification results for comparison of the SD and Markov drone following models

It can be seen in Fig. 10 that the changes in acceleration and velocities of the drones are nearly the same for each drone. The first line represents the acceleration or velocity of the first drone; the second line is the second drone’s acceleration or velocity, and so on. Therefore, there were no accidents.

As it seems, the developing Markov model might be more accurate in case of motion of drones in significant air turbulence and separated wind flow from the infrastructure. It can be used in areas where problems with GPS positioning might have appeared, especially comparing and working together with the GPS techniques or acoustic sensors.

5.2 Discussion

The authors have made significant efforts in designing an airway network for managing drones in traffic flow at smart cities. The proposed airway network has been systematically designed might improve traffic flow and help manage drones in urban air transportation. However, the challenge is that the complete design of an airway network considered several factors, including controlled and un-controlled airspaces, the UTM capacity, sectorization, or station connectivities.

Although simulation results of drone-following models have verified the proposed approach, several developments could be made as follows:

- Safe distance should be measured from two drones beside;
- The performance of the drone-following models should be evaluated in several situations, such as the increase or decrease of drones participating in the traffic flow.
- An experimental study regarding the drone performance in space, such as one drone cannot pass another, must be designed and conducted to collect quantitative information.

This study is part of the research that aims to develop a total transport management system for integrating drones into a smart city environment. Therefore, the future directions and challenges are suggested as follows:

- Air network organization and management have been the cornerstone for the safe integration of drones. Specifically, air network classification improved drones' integrated operation in controlled and uncontrolled airspaces.
- Drone trajectory management: concerning the future advanced operation of concepts, flexible and powerful drone trajectory management is recommended in the smart city environment

with guidance and control over the trajectories.

- There is still much room for developing communication, control algorithms, and path planning to support efficient, safe, and reliable drone operations in urban airspace.
- Standardization and regulation considerations.

6. Conclusion

This study proposed air traffic management of drones integrated into smart cities, aiming to create an operational link between air navigation actors and traffic managing systems. Firstly, a total transport-managing system based on cooperating, contract-based, and priority transport management has been introduced. Then, this study presented operational concepts for drone operations in urban areas, including airspace design, recommended construction of the airway network, and essential safety requirements. Finally, the verification of the proposed method has been satisfied by introducing some developed models, such as drone-following models.

By presenting this study, we hope to reduce much of the effort currently spent managing many drones with new autonomous system development projects, which will enable researchers, developers, and enthusiasts to significantly reduce time, effort, and funding. This paper also presented a comprehensive discussion on the results, limitations, and future research. However, it is required to further theoretical and practical investigation and applying an extensive series of different methods, techniques, solutions to understand better how the proposed system could be planned and implemented.

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References

[1] SESAR, "U-Space Blueprint," 2017. https://www.sesarju.eu/u-space-blueprint (accessed Jun. 20, 2021).

[2] SEAR, "European ATM Master Plan: Roadmap for the safe integration of drones into all classes of airspace," 2020. https://www.sesarju.eu/sites/default/files/documents/reports/European ATM Master Plan Drone roadmap.pdf (accessed Feb. 20, 2021).

[3] EASA, "Concept of Operations for Drones: A risk based approach to regulation of unmanned aircraft," *EASA*, 2015. https://www.easa.europa.eu/sites/default/files/dfu/204696_EASA_concept_drone_brochure_web.pdf (accessed Jul. 25, 2020).

[4] Nicolas Boring, "Regulation of Drones," 2016.

[5] E. Vattapparamban, İ. Güvenç, A. İ. Yurekli, K. Akkaya, and S. Uluağaç, "Drones for smart cities: Issues in cybersecurity, privacy, and public safety," in *2016 International Wireless Communications and Mobile Computing Conference (IWCMC)*, 2016, pp. 216–221. doi: 10.1109/IWCMC.2016.7577060.

[6] "THE DRONES REPORT: Market forecasts, regulatory barriers, top vendors, and leading commercial applications," 2016. https://www.businessinsider.com/uav-or-commercial-drone-market-forecast-2015-2 (accessed Jun. 20, 2021).

[7] "Safety Management Manual (SMM)," *International Civil Aviation Organization*, 2017. https://www.skybrary.aero/index.php/ICAO_Safety_Management_Manual_Doc_9859 (accessed Jul. 20, 2020).

[8] G. Fedorko, V. Žofčinová, and V. Molnár, "Legal Aspects Concerning Use of Drones in the Conditions of the Slovak Republic within the Sphere of Intra-logistics," *Periodica Polytechnica Transportation Engineering*, vol. 46, no. 4, pp. 179–184, 2018, doi: 10.3311/PPtr.12131.

[9] P. D. Vascik, H. Balakrishnan, and R. J. Hansman, "Assessment of Air Traffic Control for Urban Air Mobility and Unmanned Systems," *8th International Conference on Research in Air Transportation*, no. June, 2018.

[10] D. S. Gábor, T. R. Fekete, and D. Rohács, "The situation and future of European UTM," *RepTudKoz*, vol. 30, no. 2, pp. 189–204, 2018.

[11] Á. Szüllő, R. Seller, D. Rohács, and P. Renner, "Multilateration based UAV detection and localization," in *2017 18th International Radar Symposium (IRS)*, 2017, pp. 1–10. doi: 10.23919/IRS.2017.8008235.

[12] SESAR, "Full speed ahead for drone traffic integration: SESAR establishes U-space demonstrators across Europe,"

2018. https://www.sesarju.eu/index.php/news/uspacedemonstrators (accessed Jun. 20, 2021).

[13] R. Dániel; and D. S. Gábor, "PRESENTATION OF USIS SESAR UTM PROJECT."

[14] X. Wang, V. Yadav, and S. N. Balakrishnan, "Cooperative UAV Formation Flying With Obstacle/Collision Avoidance," *IEEE Transactions on Control Systems Technology*, vol. 15, no. 4, pp. 672–679, 2007, doi: 10.1109/TCST.2007.899191.

[15] J. Seo, Y. Kim, S. Kim, and A. Tsourdos, "Consensus-based reconfigurable controller design for unmanned aerial vehicle formation flight," *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, vol. 226, no. 7, pp. 817–829, 2011, doi: 10.1177/0954410011415157.

[16] B. Balázs and G. Vásárhelyi, "Coordinated Dense Aerial Traffic with Self-Driving Drones," in *2018 IEEE International Conference on Robotics and Automation (ICRA)*, 2018, pp. 6365–6372. doi: 10.1109/ICRA.2018.8461073.

[17] A. L. Alfeo, M. G. C. A. Cimino, N. De Francesco, A. Lazzeri, M. Lega, and G. Vaglini, "Swarm coordination of mini-UAVs for target search using imperfect sensors," *Intelligent Decision Technologies*, vol. 12, pp. 149–162, 2018, doi: 10.3233/IDT-170317.

[18] N. Dinh Dung, "A developed particles swarm optimisation algorithm for managing drones in smart cities," in *International Symposium on Sustainable Aviation 2019*, 2019, p. p.4.

[19] N. D. Dung and J. Rohacs, "The drone-following models in smart cities," in *2018 IEEE 59th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON)*, 2018, pp. 1–6. doi: 10.1109/RTUCON.2018.8659813.

[20] D. Rohacs and J. Rohacs, "Magnetic levitation assisted aircraft take-off and landing (feasibility study – GABRIEL concept)," *Progress in Aerospace Sciences*, vol. 85, pp. 33–50, 2016, doi: 10.1016/j.paerosci.2016.06.001.

[21] D. Rohacs, M. Voskuijl, and N. Siepenkötter, "Evaluation of landing characteristics achieved by simulations and flight tests on a small-scaled model related to magnetically levitated advanced take-off and landing operations," *29th Congress of the International Council of the Aeronautical Sciences, ICAS 2014*, pp. 1–10, 2014.

[22] I. Jankovics and U. Kale, "Developing the pilots' load measuring system," *Aircraft Engineering and Aerospace Technology*, vol. 91, no. 2, pp. 281–288, 2018, doi: 10.1108/AEAT-01-2018-0080.

[23] D. D. Nguyen, J. Rohács, D. Rohács, and A. Boros, "Intelligent Total Transportation Management System for Future Smart Cities," *Applied Sciences*, vol. 10, no. 24. 2020. doi: 10.3390/app10248933.

[24] D. D. Nguyen, J. Rohacs, and D. Rohacs, "Autonomous Flight Trajectory Control System for Drones in Smart City Traffic Management," *ISPRS International Journal of Geo-Information* , vol. 10, no. 5. 2021. doi: 10.3390/ijgi10050338.

[25] D.-D. Nguyen, "Cloud-Based Drone Management System in Smart Cities," in *Development and Future of Internet of Drones (IoD): Insights, Trends and Road Ahead*, R. Krishnamurthi, A. Nayyar, and A. E. Hassanien, Eds. Cham: Springer International Publishing, 2021, pp. 211–230. doi: 10.1007/978-3-030-63339-4_8.

[26] N. D. Dung, "Developing Models for Managing Drones in the Transportation System in Smart Cities," *Electrical, Control and Communication Engineering*, vol. 15, no. 2, pp. 71–78, 2020, doi: 10.2478/ecce-2019-0010.

[27] H. P. D. Nguyen and D. D. Nguyen, "Drone Application in Smart Cities: The General Overview of Security Vulnerabilities and Countermeasures for Data Communication," in *Development and Future of Internet of Drones (IoD): Insights, Trends and Road Ahead*, R. Krishnamurthi, A. Nayyar, and A. E. Hassanien, Eds. Cham: Springer International Publishing, 2021, pp. 185–210. doi: 10.1007/978-3-030-63339-4_7.

[28] L. Pathiyil, K. Low, B. H. Soon, and S. Mao, "Enabling Safe Operations of Unmanned Aircraft Systems in an Urban Environment : A Preliminary Study," in *The International Symposium on Enhanced Solutions for Aircraft and Vehicle Surveillance Applications (ESAVS 2016)*, 2016, p. p.10.

[29] "Annex 19 - Safety Management," 2013. https://www.icao.int/safety/SafetyManagement/Documents/Annex 19 - ICAO presentation - self instruction 24September2013.pdf (accessed Feb. 20, 2021).

[30] "Unmanned Aircraft Systems (UAS)-Cir 328," *ICAO*, 2011. https://www.icao.int/Meetings/UAS/Documents/Circular 328_en.pdf (accessed Jul. 20, 2020).

[31] R. Luppicini and A. So, "A technoethical review of commercial drone use in the context of governance, ethics, and privacy," *Technology in Society*, vol. 46, pp. 109–119, 2016, doi: https://doi.org/10.1016/j.techsoc.2016.03.003.

[32] A. Plioutsias, N. Karanikas, and M. M. Chatzimihailidou, "Hazard Analysis and Safety Requirements for Small Drone Operations: To What Extent Do Popular Drones Embed Safety?," *Risk Analysis*, vol. 38, no. 3, pp. 562–584, 2018, doi: 10.1111/risa.12867.

[33] M. Huttunen, "Drone Operations in the Specific Category: A Unique Approach to Aviation Safety," *The Aviation & Space Journal*, vol. 18, no. 2, pp. 2–21, 2019.

[34] R. Altawy and A. M. Youssef, "Security, Privacy, and Safety Aspects of Civilian Drones: A Survey," *ACM Trans. Cyber-Phys. Syst.*, vol. 1, no. 2, Nov. 2016, doi: 10.1145/3001836.

[35] J.-P. Yaacoub, H. Noura, O. Salman, and A. Chehab, "Security analysis of drones systems: Attacks, limitations, and recommendations," *Internet of Things*, vol. 11, p. 100218, 2020, doi: 10.1016/j.iot.2020.100218.

[36] C. Lin, D. He, N. Kumar, K. R. Choo, A. Vinel, and X. Huang, “Security and Privacy for the Internet of Drones: Challenges and Solutions,” *IEEE Communications Magazine*, vol. 56, no. 1, pp. 64–69, 2018, doi: 10.1109/MCOM.2017.1700390.

[37] Z. Liang, Q. Li, and Z. Ren, “Waypoint constrained guidance for entry vehicles,” *Aerospace Science and Technology*, vol. 52, pp. 52–61, 2016, doi: 10.1016/j.ast.2016.02.023.

[38] A. A. Pothen and A. Ratnoo, “Curvature-Constrained Lyapunov Vector Field for Standoff Target Tracking,” *Journal of Guidance, Control, and Dynamics*, vol. 40, no. 10, pp. 2729–2736, 2017, doi: 10.2514/1.G002281.

[39] A. Ratnoo, P. B. Sujit, and M. Kothari, “Adaptive Optimal Path Following for High Wind Flights,” *IFAC Proceedings Volumes*, vol. 44, no. 1, pp. 12985–12990, 2011, doi: 10.3182/20110828-6-IT-1002.03720.

[40] J. Deyst, J. How, and S. Park, “Lyapunov Stability of a Nonlinear Guidance Law for UAVs,” in *AIAA Atmospheric Flight Mechanics Conference and Exhibit*, American Institute of Aeronautics and Astronautics, 2005. doi: 10.2514/6.2005-6230.

[41] J. M. Zhang, Q. Li, N. Cheng, and B. Liang, “Path-following control for fixed-wing unmanned aerial vehicles based on a virtual target,” *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, vol. 228, no. 1, pp. 66–76, 2012, doi: 10.1177/0954410012467716.

[42] S. Zouaoui, E. Mohamed, and B. Kouider, “Easy Tracking of UAV Using PID Controller,” *Periodica Polytechnica Transportation Engineering*, vol. 47, no. 3, pp. 171–177, 2019, doi: 10.3311/PPtr.10838.

[43] Q. Chen, X. Wang, J. Yang, and Z. Wang, “Trajectory-following guidance based on a virtual target and an angle constraint,” *Aerospace Science and Technology*, vol. 87, pp. 448–458, 2019, doi: 10.1016/j.ast.2019.02.034.

[44] H. Chen, Y. Cong, X. Wang, X. Xu, and L. Shen, “Coordinated Path-Following Control of Fixed-Wing Unmanned Aerial Vehicles,” *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, pp. 1–15, 2021, doi: 10.1109/TSMC.2021.3049681.

[45] M. Jun and R. D’Andrea, “Path Planning for Unmanned Aerial Vehicles in Uncertain and Adversarial Environments,” in *Cooperative Control: Models, Applications and Algorithms*, S. Butenko, R. Murphey, and P. M. Pardalos, Eds. Boston, MA: Springer US, 2003, pp. 95–110. doi: 10.1007/978-1-4757-3758-5_6.

[46] D. Mellinger, N. Michael, and V. Kumar, “Trajectory generation and control for precise aggressive maneuvers with quadrotors,” *The International Journal of Robotics Research*, vol. 31, no. 5, pp. 664–674, 2012, doi: 10.1177/0278364911434236.

[47] R. Szabolcsi, “Flight Path Planning for Small UAV Low Altitude Flights,” *Land Forces Academy Review*, vol. 25, no. 2, pp. 159–167, 2020, doi: 10.2478/raft-2020-0019.

[48] N. Xuan-Mung and S. K. Hong, “Robust Backstepping Trajectory Tracking Control of a Quadrotor with Input Saturation via Extended State Observer,” *Applied Sciences* , vol. 9, no. 23. 2019. doi: 10.3390/app9235184.

[49] N. Xuan-Mung and S. Hong, “Barometric Altitude Measurement Fault Diagnosis for the Improvement of Quadcopter Altitude Control,” in *19th International Conference on Control, Automation and Systems (ICCAS)*, 2019, pp. 1359–1364. doi: 10.23919/ICCAS47443.2019.8971729.

[50] N. Xuan-Mung and S.-K. Hong, “Improved Altitude Control Algorithm for Quadcopter Unmanned Aerial Vehicles,” *Applied Sciences* , vol. 9, no. 10. 2019. doi: 10.3390/app9102122.

[51] N. Xuan-Mung, S. K. Hong, N. P. Nguyen, L. N. N. T. Ha, and T.-L. Le, “Autonomous Quadcopter Precision Landing Onto a Heaving Platform: New Method and Experiment,” *IEEE Access*, vol. 8, pp. 167192–167202, 2020, doi: 10.1109/ACCESS.2020.3022881.

[52] B. Rubí, R. Pérez, and B. Morcego, “A Survey of Path Following Control Strategies for UAVs Focused on Quadrotors,” *Journal of Intelligent and Robotic Systems: Theory and Applications*, vol. 98, no. 2, pp. 241–265, 2020, doi: 10.1007/s10846-019-01085-z.