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Developing transport management system for integrating drones into a smart city environment

A dissertation submitted by:

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Introduction

Nowadays, society and policymakers have been continuously working on smart city developments, while the economy found it a well-explanted future business [1]. Depending on the researchers', developers' point of view, smart cities have 5–8 significant components: smart infrastructure, transportation, environment, services, governance, people, living, and economy [2], [3]. From these, smart mobility, smart transportation is one of the most important for society and the economy.

Smart mobility, intelligent transportation includes (i) smart infrastructure (roads, rails, tracks, waterways, bridges, tunnels, stations), (ii) smart people, smart economy, (iii) smart vehicles, (iv) smart info-communication and control system (from traffic lights, up to operation centres), (v) optimization principles, and (vi) smart policy-making and legislation [4], like traffic rules, can solve several transportation problems, such as traffic jams, accidents, pollution, fuel cost, or high insurance costs. According to the investigation of the IDEA-E project [5], [6], [7], smart transportation is a slightly large system, including all the transport modes, all infrastructure covering roads, rail tracks, tunnels of underground transportation, bridges, or multi-modal transport hubs.

By the analysis of the stakeholders' interests, the users' expectations, and the application of the terms (i) connected vehicles (introduced by smart city, smart transportation operators), (ii) non-cooperative and cooperative targets (introduced by the developers of the primary, radar surveillance), (iii) contract-based service (implemented by air traffic management), the transportation system can be set up as a single system classified in hierarchically structured layers.

The smart or intelligent transportation system (ITS), focuses on economic and social interest, reducing congestion [8], [9], [10], the reduced travel times [11], [12], dynamic road [13], [14], the fuel consumption, pollution, as well as improving traffic safety [15]. Several smart transportation system applications rely on the Internet of Things (IoT), including smart roads [16], intelligent parking systems [17], real-world connected vehicle data [18]. Numerous studies deal with the environmental impact of smart cities, smart transportation, including life-cycle analyses [19], [20], and the stochastic shortest path problem [21], while just a limited amount of papers discuss the possible environmental reduction by optimizing total transportation. Instead of that, some parts of transportation and optimization are investigated, like the impact of using electric vehicles [22].

Besides, science and technology are ready to develop and produce an extensive series of low-cost small remotely controlled or autonomous air vehicles as drones (generally unmanned aerial vehicles/systems – UAV, UAS, including even small pilot-less air vehicles, air taxis). The market of 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 [23], [24]. The existing air traffic management system (ATM) cannot control the predicted amount of drones operated at low altitude in the urban area between large buildings and complex environment (with, e.g., reflection), due to, e.g. (i) the limitations in the system capacity, (ii) the required workforce, (iii) the expected cost, (iv) the required duration of the system development [25], [26]. Hence, integrating drones in smart city transportation is an essential task, which 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 safely conduct operations, both in the air and the ground. 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 [27], [28], [29]. Concerning the management system, the operation of a drone must follow the International Civil Aviation Organization (ICAO) [30]. Several scientific reports focused on the management of drones in smart cities [31], [32], [33], [34]. However, given the anticipated large amounts of drones and widely varying performance characteristics, it is far beyond the capabilities of conventional Air Traffic Management (ATM) systems to deliver services for drones in a cost-effective manner. Traditional ATM framework is mainly established for human-crewed aircraft, while 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 collision, tracking trajectories, path planning, communication, and control.

The main objective of this thesis is to develop an intelligent total transportation management system for integrating drones into the smart city environment. This objective is divided into five sub-objectives, including (i) to develop the concept of an intelligent total transportation management system for future smart cities; (ii) to analyze and develop an air traffic management and flight control for managing drones or a group of drones (iii) to develop drone-following models to manage many drones in traffic flow; (iv) to improve a method for managing drones based on the Internet of Thing (IoT) and the Internet of Drones (IoD) technologies; (v) to investigate the landing process of UAVs.

Research hypotheses

My objective is to develop the requirements or vision requirements for integrating drone motion into the smart city transport management system. After preliminary analysis, investigation of available materials, and my previous and recent practices, I have developed the following hypothesis.

Hypothesis 1: Available technologies enable the management of transportation in smart cities totally, including special methods according to different classes of vehicles.

Hypothesis 2: Drone flights can be integrated into smart city transport if unique trajectories and corridors will be defined using sensor fusion, real-time GIS support, centralized dynamic sectorization, and special sensors integrated for managing the following trajectories, fixed trajectories, or predefined corridors.

Hypothesis 3: Drone-following models represented the one-by-one following drone process must be applied in managing drone operations in traffic flow in a smart city environment for increasing safety.

Hypothesis 4: The Internet of Things and new technologies enable the development and implement unique drone management systems for active traffic flow control.

Hypothesis 5: The fixed-wing UAV may be followed the desired landing trajectory for reducing the requirement of landing areas and applicable to emergencies.

Significant Results

- *An intelligent total transportation management system.*

The developing traffic-managing system uses a vast distributed network of sensors for surveillance and recognition of the different cooperating and non-cooperating vehicles, extreme traffic situations (Fig. 1). The system has three layers: physical, info-communication, and control generation. The physical part including all the vehicles, the available infrastructure, the sensor network, and traffic controls integrated into the infrastructure. The infrastructure takes part in the system entirely. That means, for example, a series of signal lights are built into the line dividing the lanes. The communication is based on the wireless system, partly on using the Internet. The control layer is a hierarchically organized software set. It is used to recognize and classify vehicles, traffic situation awareness, conflict detection, and resolution, including the sense and avoidance of obstacles, other vehicles, people, etc. Such a system is working as a single system, while it deals with four different classes of tasks, including handing the non-cooperative vehicles, traffic management based on the cooperative vehicle information, contract-based traffic management, and priority transportation management.

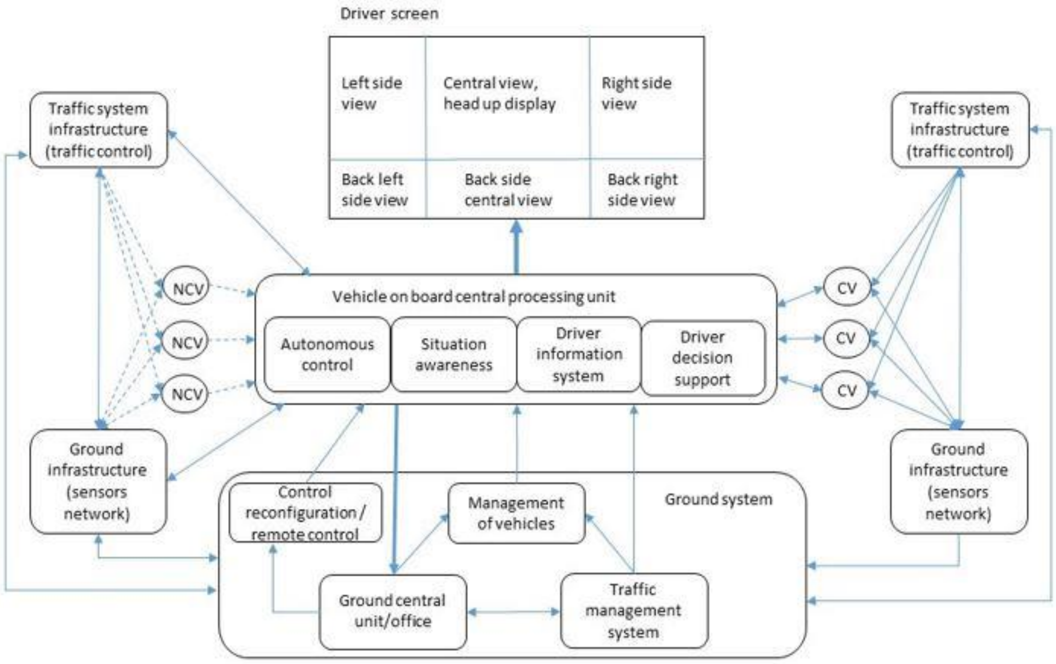
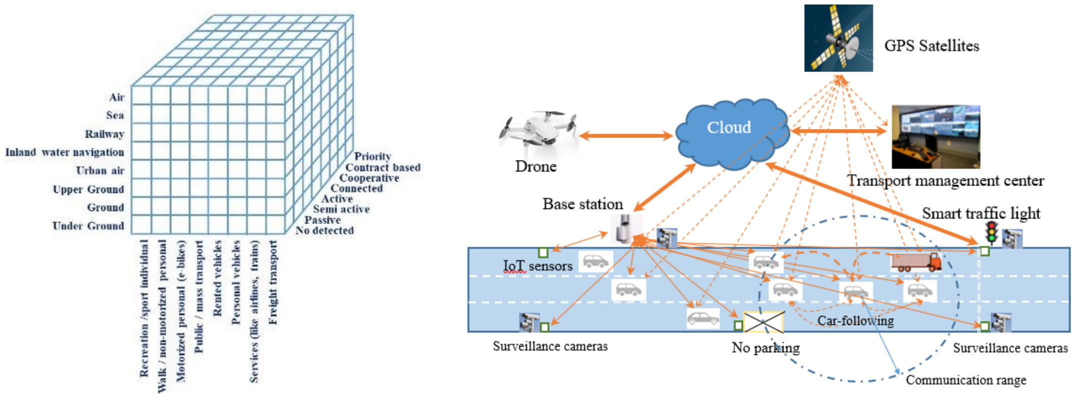


Figure 1. The traffic-managing system architecture (NCV - non-cooperative vehicle, CV - cooperative vehicle)

This system has been developed to connect central management and vehicles, which generates the controls for avoiding extreme and dangerous situations and managing the more valuable, greener traffic, and supporting the contracting vehicles and priority traffic. The controls are realized through the traffic controls (control lights, control signalization, and actuators integrated into the infrastructure). There is no principal difference in cases when the vehicles are moving autonomously or driver-controlled. Figure 1 shows the possible monitor for this development in the monitoring situation. For example, a driver screen may show the position of the other vehicles, obstacles around the vehicle.

- *Classification of the transportation segments partly used a hierarchical concept.*

The classification of the transportation segments uses a hierarchical concept (see Fig. 2). However, vehicles can be grouped depending on their participation in the transportation system (Fig. 2a), namely on the level of their cooperation with the operation centre (Fig. 2b). Each cube can be separated investigation of elements. For example, I have introduced new concepts, including non-detected, cooperative, and contract-based vehicles. The *non-detected vehicles* are objects that are not appearing on the surveillance screen. The *cooperative vehicles* provide information about 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 *contract-based vehicles* pay for having a little bit of priority, not a full priority, such as taxis, then they can get information from the service provider who will change the control traffic light better for them than other vehicles. Contract-based vehicles are like cooperative vehicles. However, the cooperative vehicles do not pay for service, and they only sent the information, while contract-based vehicles pay for service by signing the contract.



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

Figure 2. Hierarchical classification of the vehicles and primary information transmissions (**a**) cube of hierarchical structure, (**b**) system interconnections.

The recommended concept is total transport and total management system. It means that all motions of people and goods (including walking, sport, travels, freight transport) are realized by any vehicles (from electric scooters up to the supersonic business jets) as elements of the single transportation system are monitored and controlled by a particular hierarchical concept.

- *An optimization method solves the traffic optimization problem.*

By adapting the total impact concept [20], [6], the objective function can be defined in several different forms depending on the management's objectives. One of the most critical primary objectives is the minimization of the energy used by transportation. Total energy consumption, E_t, used by total urban transport system related an hour or day (or season) can be defined as

$$E_t = f(x) = \frac{1}{\tau}\sum_{i=1}^{N}\int_{t_{s_i \geq 0}}^{t_{f_i \leq \tau}} w_{v_i} e_{vc_i}\left(\boldsymbol{r}_{v_i}, \boldsymbol{p}_{v_i}, \boldsymbol{p}_{vd_i}, \boldsymbol{o}_{v_i}, \boldsymbol{x}_{v_i}, \boldsymbol{z}_{v_i}, \dots, \boldsymbol{\xi}_{v_i}, t\right) dt,$$
$$\boldsymbol{x}^T = \left[\boldsymbol{r}_{v_i}, \boldsymbol{p}_{v_i}, \boldsymbol{p}_{vd_i}, \boldsymbol{o}_{v_i}, \boldsymbol{x}_{v_i}, \boldsymbol{z}_{v_i}, \dots\right] \in X \quad (1)$$

where τ is the time, frame of reference, i = 1, 2, …. N number of vehicles, **w, e, r, p, o, x, z, ξ**, and t are the weighting coefficient, energy consumption, real pathway, parameters, operational characteristics, vehicle motion characteristics/performance, environmental characteristics, noise vector and time, while the indexes $t_{s_i \geq 0}, t_{f_i \leq \tau}$ mean motion starting and finishing times (forgiven i-th vehicle), v- given vehicle (v_i depicts the i-th vehicle), vc, vd are related to the vehicle instantaneous consumption and a human vehicle driver. Here, $\mathbf{r}_{v_i}$ vector characterizes the real pathway (slopes, curves of the road, track) along which the given i-th vehicle moves during $[t_{s_i \geq 0}, t_{f_i \leq \tau}]$ time period. Vectors $\mathbf{p}_{v_i}, \mathbf{p}_{vd_i}$ are completed from the vehicle (types, sizes, empty mass, engine, engine performance) and drivers characteristics (dynamics, reaction time). The operational characteristics $\mathbf{o}_{v_i}$contains all the available real data, the real condition of the given i-th vehicle as load factor, age, used size of tires, pressure in tires. The real motion of the i-th vehicle is characterized by a vector, $\mathbf{x}_{v_i}$. The environment as air temperature, raining, fog, are defined by the vector $\mathbf{z}_{v_i}$ according to the i-th given vehicle. Finally, the noise vector contains the random noise as traffic jam, accident, road reconstruction) related to the given i-th vehicle and its pathway.

Equation (1) seems solvable; nevertheless, it deals with many vehicles reaching even some millions in large megacities. Instead of the nonlinear objective Function (1), a simplified linear function might be applied:

$$E_t = f(x) = \frac{1}{\tau}\sum_{i=1}^{N} w_{v_i} e_{v_{i_{sf}}} \quad (2)$$

where $e_{v_{i_{sf}}}$ minimum energy used by i-th vehicle during its moving from start to the final position.

In Equation (2), the weighting coefficients, w_{v_i}, take into account the real operational conditions as load factors (as how many passengers are in the car). It is clear that the minimum energy used elements, $e_{v_{i_{j,l;p,r}}}$, to complete a special minimum energy used matrix, E_{min,v_i}, for each i-th vehicle.

- *An autonomous drone management system, in which drones follow the predefined trajectories/corridors.*

This system is based on the airway network, safety rules, and supporting methods such as sensor fusion tools, desired trajectory following management, following process, formation flight with obstacle avoidance. The general concept and system layout are shown in Fig. 3.

The airway network structure is based on an extensive study being available in the literature [35]. An airway network is a better traffic flow distribution that might reduce congestion and provide more flexibility to flight schedules and routes. Four different sectors are recommended to be used, such as geographical sector, sectors in vertical separation (between the large buildings), sectors for vertical motion (climb/descent), and sectors for restricted areas.

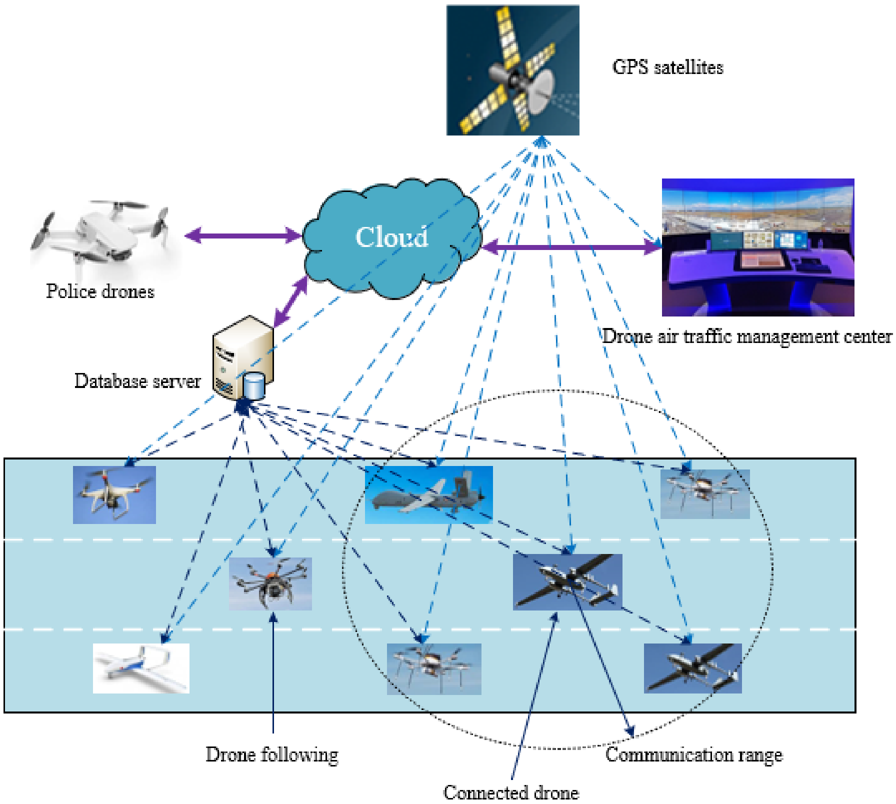


Figure 3. General concept and system layout of the proposed autonomous drone management system.

Elements of the airway-network 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.

To define the airways, the authors investigated and evaluated several recent regulations and related works focusing on drones' safety and security aspects. The following assumptions were made as a means to define the airway network under study and the research scope:

- 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.

- 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.
- 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 change lanes in the horizontal or vertical direction only.
- The defined trajectory as a channel for the given drone is fixed and cannot cross any other trajectory.

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

- *Drone-following models in smart cities*

Generally, UAVs follow a reference trajectory to do their task. The reference trajectories are usually planned as straight lines, curves, or a combination of both. To achieve an excellent autonomous flight, a precise, robust, and effective trajectory-following guidance law is required [36], [37], [38], [39]. However, 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 process in the traffic flows.

The first drone-following model is based on the principle that it keeps a safe distance according to relative velocity (SD). Such a model describes situations that the drone's velocity depends on the traffic situation, namely on the distance to the drone ahead and its velocity. This approach has led to the linear models assuming that its controller controls the followed drone's acceleration to keep zero relative velocity to the drone ahead.

The SD model is given as follows:

$$\ddot{X}_n(t+T) = \lambda \frac{[\dot{X}_n(t)]^p}{[X_{n-1}(t) - X_n(t)]^q} \left[\dot{X}_{n-1}(t) - \dot{X}_n(t)\right] \quad (3)$$

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.

The SD model is one of the first developed and maybe most used to describe one microscopic simulation model applied in traffic system modeling and control. However, drone motion can be described by a stochastic process due to the drone's dynamic motion is non-linear. Therefore, the second developed model is the Markov model based on approximating the stochastic process of velocity decision by Markov chain process.

$$\ddot{X}[k+1] = c_v\left(\dot{X}_{n-1}[k] - \dot{X}_n[k]\right) + c_x\left[\left(X_{n-1}[k] - X_n[k]\right) - \Delta X_{pdn}\right] + \varepsilon[k] \qquad (4)$$

Where, c_v and c_x are coefficients that can depend on the time, given drone and controllers; $\Delta X_{pdn} = [\dot{X}(t)]$ is the predefined safe distance between the drones; k is the number of steps in a chain ($t = k\Delta t$); $\varepsilon(k)$ is the random value disturbing the process.

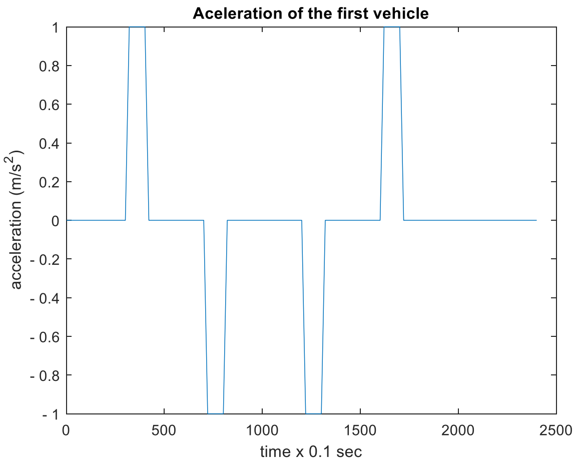


Figure 4. Acceleration of the first drone

The numerical simulation experiments on the SD and the Markov models show no accident and no unrealistic deceleration (see Fig. 4 and 5). It can be seen in Fig. 5 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. The velocity of the followed drone is changed according to the speed of the drone ahead. However, the followed drone can react quickly compared to the leading drone's reaction because of the difference in its acceleration.

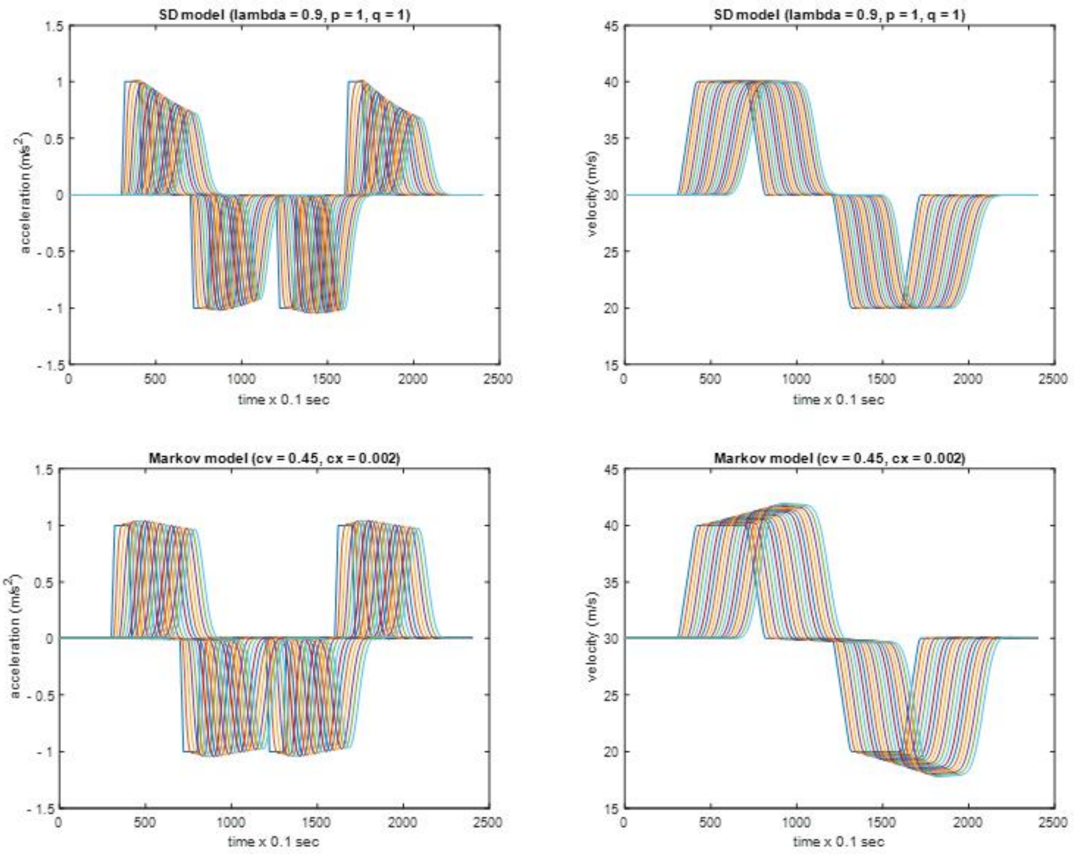


Figure 5. The comparison of the SD and Markov models

- *Cloud-based drone managing system*

The Cloud-based drone managing system (CbDMS) motivated by IoT and the Internet of Drones (IoD) technologies have shown exemplary performance in dealing with complicated and active traffic flows. This platform has three main layers: (i) *physical layer*, including connected drones and fundamental infrastructure; (ii) *cloud layer*, including storage, computation, and interfaces, is based on the wireless system, using the Internet, and (iii) *control layer* is a hierarchically organized software set used to control and manage drones in the traffic flows (Fig. 6).

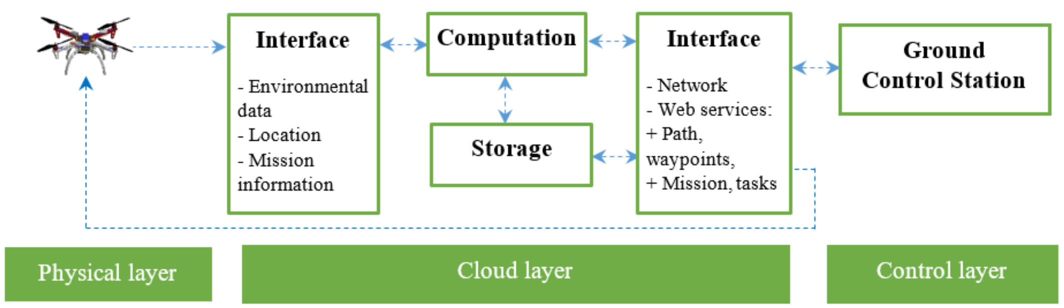


Figure 6. The Cloud-based drone managing system

The control layer specifies the required policy to the central controller in the cloud layer, and the controller passes those requirements to the drones in the physical layer. This operation will be done with the help of the interface components based on Internet protocols, such as wireless local area network (WLAN), wireless personal area network (WPLAN), low-power wide-area network (LPWAN), and cellular.

We carried out tests with a drone to validate the proposed approach and assess its achievement - the test situation of following a set of waypoints with a real drone in a particular area. The diagram of this testbed platform is illustrated in Fig. 7.

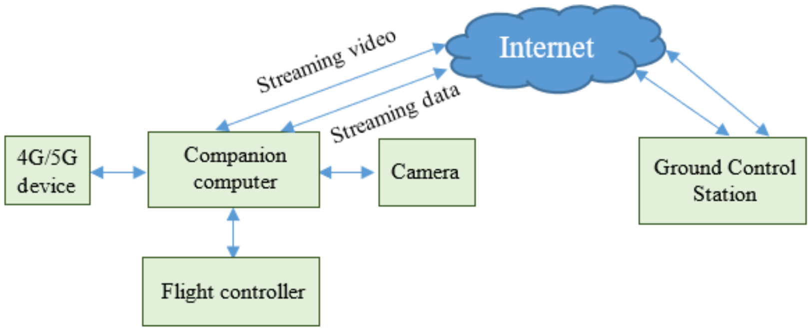


Figure 7. The diagram of the testbed platform

The experimental result is demonstrated in Fig. 8, and Figure 9 illustrates the difference between desired and actual altitude of drone. Initially, the drone was placed at a home position. When it received the command from the ground control station (GCS), it take-off and did a mission, visiting the created waypoints. It is seen that the desired trajectory and actual trajectory are correlated. The gap between the two trajectories represents GPS location because the drone receives the GPS location.

The CbDMS is an advanced approach for managing drones to meet critical features. With CbDMS, complicated missions can be taken with efficiency, improving safety and applicability. However, it is necessary to examine the limitations of the proposed method, such as controlling and managing real-time drones over the network is highly dependent on a guaranteed quality of assistance.

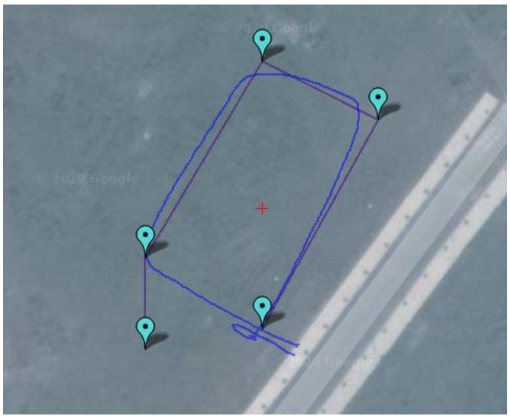


Figure 8. The difference between desired and real trajectories (pink line – desired trajectory, blue line - real trajectory)

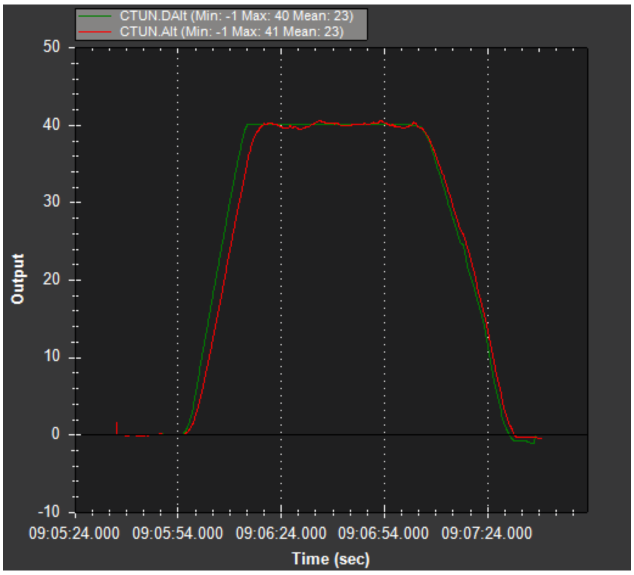


Figure 9. The difference between desired and actual altitude of drone, green line – desired altitude, red line – actual altitude

- *Managing drones as a formation to avoid obstacles in smart cities*

Formation motion means a group of vehicles moving together and following a leader vehicle. In such a case, the motion of the group of vehicles can be managed by only controlling the leader vehicle, as originally developed for advanced air traffic control. The formation flight modes are considered more than relevant for the coordination of drones, as conventional air traffic management techniques and tools are powerless in dealing with such a high number (and complexity) of movements. The model can be relatively easily adapted to the road or urban traffic systems.

The formation can be represented by a simple system of the linearized equations:

$$\dot{s_i} = Ps_i + Qu_i \quad (5)$$

$$\dot{s_0} = As_0 \quad (6)$$

where, $s_i \in R^n$ is the drone i*'s* state, namely it is a state vector and $u_i \in R^n$ is the drone i*'s* input, input vector, which can only use local information from its neighbour drones. Matrix $P = [p_{ij}] \in R^{nxn}$ is a diagonally dominant matrix or state transition matrix. The matrix Q is of full column rank. $s_0 \in R^n$ is the state of the leader drone.

With the assumption that the pair (P, Q) is stabilizable, the drone Formations (5) and (6) is said to be achieved if, for each drone $i \in \{1, \ldots, N\}$, there is a local state feedback u_i of $\{x_j: j \in N_i\}$ such that the closed-loop system satisfies $\lim_{t\to\infty} \|s_i(t) - s_0(t)\| = 0$ for any initial condition $s_i(0)$, $i = 0, 1, \ldots, N$.

We use the control law for drone i as follows:

$$u_i(x) = \sum_{j \in N_i} \left\| s_j - s_i - d_{ij} \right\|^2 \tag{7}$$

where, d_{ij} is the desired inter-distance related to the position vector. A drone j is the neighbour of drone i.

The collision and obstacle avoidance mechanism has been provided autonomously to ensure stability and robustness of the group of drones. Several methods have been used to obstacle avoidance, including artificial potential field [40], combination of the artificial potential fields and static fields [41], model predictive control [42], and combination of the artificial potential field method with rotational vectors [43]. Besides, there currently exist several studies and works on the conception of a UTM system to enable the safe integration of drones on low-altitude shared airspace. There are several methods for conflict detection and resolution (CDR) of a drone operation processing, including: Pre-flight CDR, In-flight CDR, and Sense and Avoid methods [44], [45].

The obstacle model is one of the critical parts of obstacle avoidance and conflict detection systems, described as the following. Assume that each obstacle is prescribed in a cylinder with the center C_{Bl} and radius r_{Bl}, as shown in Fig. 10. The surfaces of cylinders can then be used to form constraints for obstacle avoidance. Accurately, the safe distance $d_{s,l}$ from the obstacle l is calculated from the cylinder center to its surface at the flying height.

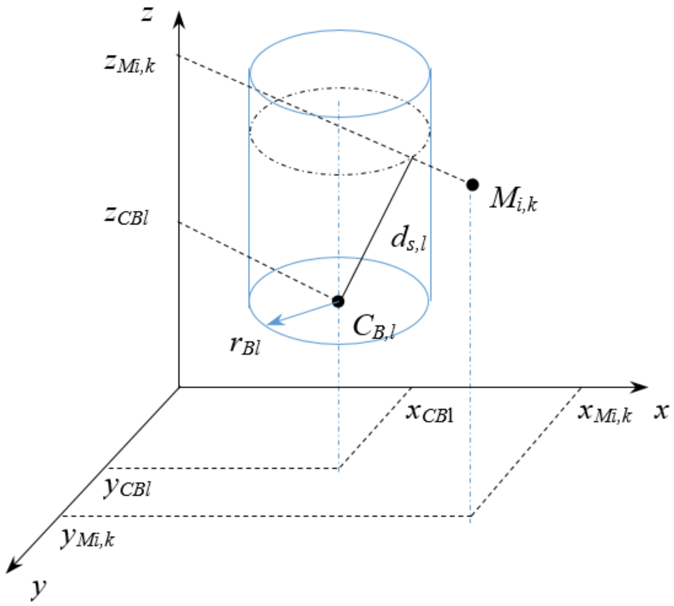


Figure 10. Obstacle representation and safe distance calculation

- *Investigating the landing process of UAVs*

The landing approach is one of the critical stages of the entire flight to bring the UAV to land safely at the desired location. Common landing approaches consist of the following stages: (i) heading against the direction of the wind, (ii) descending, (iii) slowing down. However, this process will be influenced by several factors such as wind disturbance, general aerodynamic force, the traction force of an engine, and the propeller's reaction moment.

Methodologies used to determine and calculate the landing areas are based on solving the aircraft's motion equations and analytical methods. Based on the landing areas, the desired landing orbit is estimated, within the UAV can land accurately at the desired position.

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 into each landing zones. Landing zones will be determined by knowing the radius of each region (see Fig. 11). The most common method is to investigate UAVs' kinetic dynamics by solving the differential motion system. Therefore, UAV dynamics will be used to calculate the deceleration zone, and then the remaining landing areas will be identified by analytical methods.

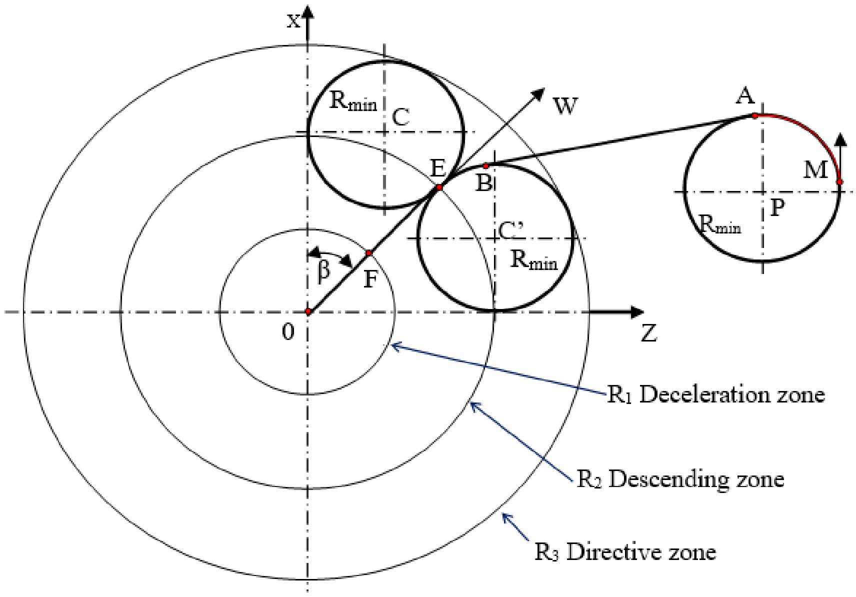


Figure 11. The proposed UAV landing zones

Based on the landing areas, the desired landing orbit is estimated, within the UAV can land accurately at the desired position. The simulation results for UAV landing in the given direction are shown in Fig. 12. and Fig. 13.

In this case, the desired landing orbit consists of two curves and two lines. At the height H = 500m, the UAV completes two turning with the desired roll angle $\gamma \leq 20^0$. Between these two times, a straight flight takes place with speed V = 40m/s. Then, the UAV flies in the right orbit in the given direction, starting to descend the altitude and finally straight flight at decreasing speed. The simulation result given is reasonable and necessary to implement controlling orders. The result shows that the landing direction is the direction from the current point of the UAV to the desired landing point, and this landing distance is the shortest one.

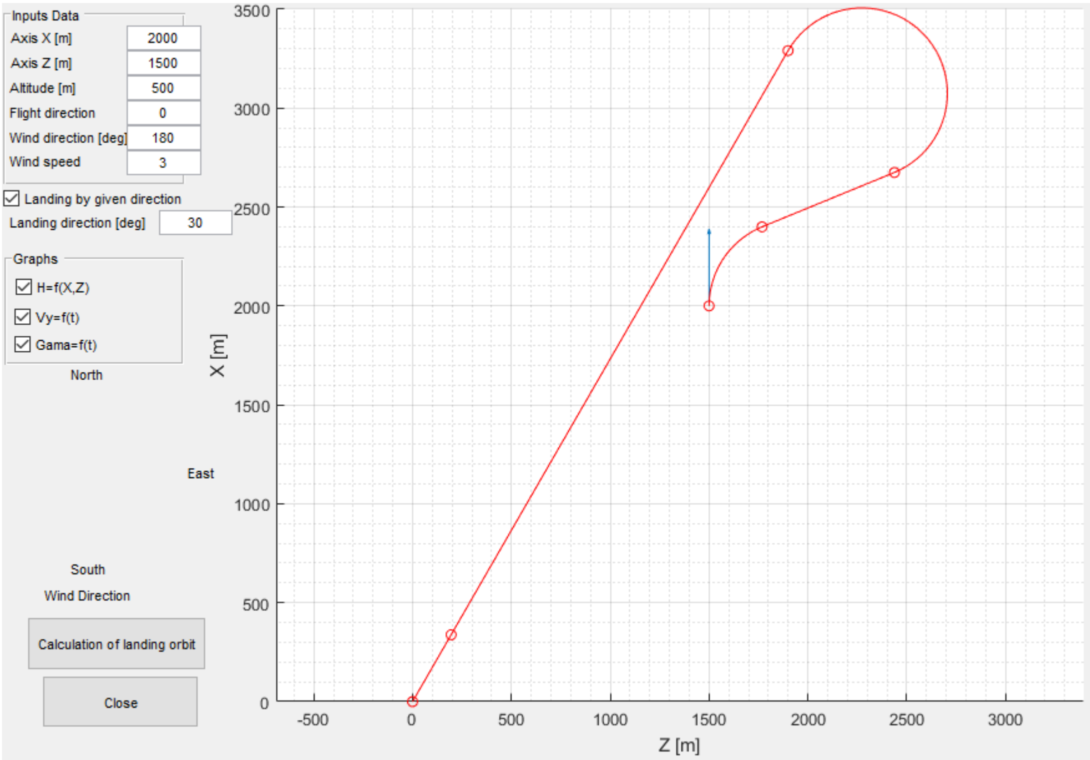


Figure 12. The desired trajectory for UAV landing in the given direction.

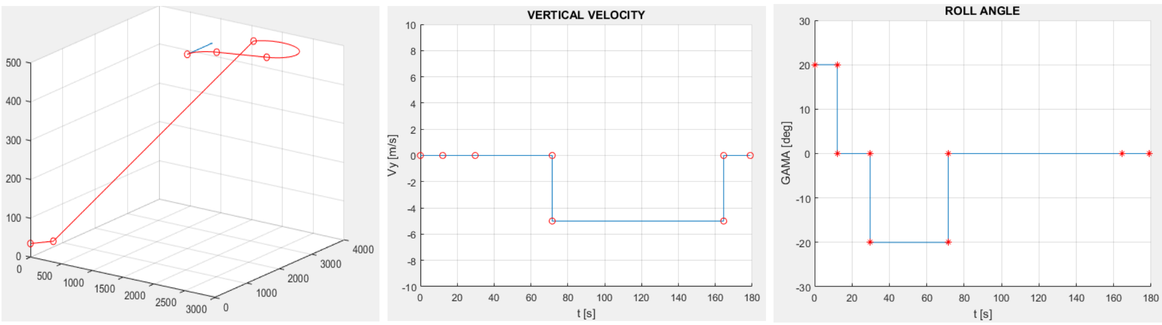


Figure 13. The altitude, vertical velocity, and roll angle when the UAV must land in the given direction.

Although this landing process is operated in standard conditions or with a required command from the ground control station, this approach can be applied in emergency landing situations. The emergency landing situations will occur when the UAV loses the command signals or thrust or weather conditions. Therefore, this application is beyond the thesis scope, and it is determined as a future study.

New scientific results

- *Thesis I: I have proposed an intelligent total transportation management system for future smart cities.*

  ✓ I have introduced a new classification of vehicles (as non-detected, passive, semi-active, active connected, cooperative, contract-based and priority, as well as the supporting partners) based on primary and secondary (passive and active) surveillance.

  ✓ I proposed a system that used the vast distributed network of sensors for surveillance and recognition of the classified vehicles, including three layers: physical, info-communication, and control.

  ✓ I have introduced a vision and a concept of managing the total transportation system (for all the classified vehicles) by defining the concept, the methodology, and the required sub-model developments for the future intelligent transportation related to smart cities. The system has a centralised command, controls the communication information centre of operation, manages sub-centres and distributed units, including autonomous vehicles.

  ✓ I have analyzed an optimization method to solve the traffic optimization problem that can be applied to optimize the vehicles' energy during their operation from the departure until the arrival point.

  Related publications: **J-2, B-3, B-4, B-5, B-7, C-8**

- *Thesis II: I have proposed an autonomous flight trajectory control system for drones in smart city traffic management.*

  ✓ I have proposed an airway network that might reduce congestion and provide more flexibility to flight schedules and routes.

  ✓ I have analyzed and developed the concepts and architecture of the autonomous drone management system.

  ✓ I have analyzed and improved the safety and security aspects of the autonomous drone management system.

  ✓ I have investigated and analyzed methods for an autonomous drone management system, including sensor fusion tools, desired trajectory following management, following process, and formation flight with obstacle avoidance.

  Related publications: **J-1, J-3, J-4, B-2, B-6, C-3, C-4, C-7, C-9, C-10, C-11**

- *Thesis III: I have developed a drone-following model to manage drones for air traffic flow in a smart city environment, namely for group flight of drones.*

- ✓ I have adapted the (probably) most used deterministic car-following model based on the principle that keeps a safe distance according to relative velocity.
- ✓ I have developed a new Markov drone-following model based on approximation of the stochastic drone process (disturbed by wind, air turbulence, and flow separated from infrastructure) as stochastic diffusion process of speed decision.
- ✓ I have verified this method by numerical simulation that demonstrates the safe distance between drones is maintained; namely, there is no accident in the traffic flow.
- ✓ This approach can be applied to dense traffic flow. In addition, the first model can be helpful in studies of local stability.

Related publications: **J-1, J-4, B-2, C-2, C-5, C-12, C-13**

- *Thesis IV: I have proposed a new managing system for integrating drone motion into urban air traffic using the cloud-based approach.*

- ✓ I have created a framework based on cloud devices and services such as computation, storage, and web services.
- ✓ I have improved a communication approach that allows users to control and monitor drones as connected objects in a real-time environment, which provides the management and control of drone applications for delivery, surveillance, security, ambulance, and emergency response.
- ✓ I have validated this approach by an experimental study to evaluate the real-time performance of monitoring and controlling drones.
- ✓ This proposed system can be improved by increasing the frequency of updating GPS coordinates or adding filtering techniques (e.g., Kalman filters), using the special markers integrated into the infrastructure, developing the ”traffic rules”, allow increasing the accuracy of monitoring (surveillance) and reducing the noise.

Related publications: **J-1, B-1, B-2, C-2, C-3, C-5, C-12, C-13**

- *Thesis V: I have developed a methodology for determining and calculating the landing stages for UAVs.*

- ✓ I have improved the differential system equations of fixed-wing UAVs to determine the more accurate the landing areas with reducing environmental impacts.
- ✓ I have analyzed and developed an approach to calculate the desired orbit landing trajectory to reduce the landing areas' requirement.
- ✓ I have verified this approach by the simulation in a Matlab environment where the shortest landing orbit is calculated; this trajectory is a desired one, and I had a

validation test in the Army environment.

- ✓ The created methodology can be applied to the more complex task landing in city areas or emergency landing situations.

Related publications: **J-1, J-3, C-7, C-10, C-11**

Own publications

Journal papers

J-1. **Nguyen, D. D.**, Rohács, J., and Rohács, D. Autonomous Flight Trajectory Control System for Drones in Smart City Traffic Management. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 338. https://doi.org/10.3390/ijgi10050338, **IF 2.239**

J-2. **Nguyen, D. D.**, Rohács, J., Rohács, D., & Boros, A. (2020). Intelligent Total Transportation Management System for Future Smart Cities. *Applied Sciences*, *10*(24), 8933. DOI: https://doi.org/10.3390/app10248933, **IF 2.474**

J-3. **Dung, N. D.**, & Rohacs, J. (2019). Robust planning the landing process of unmanned aerial vehicles. *International Journal of Sustainable Aviation*, *5*(1), 1-18. DOI: https://doi.org/10.1504/IJSA.2019.099915

J-4. **Nguyen Dinh 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, 2019**.** DOI: https://doi.org/10.2478/ecce-2019-0010

Book chapters

B-1. **Nguyen Dinh Dung**. Cloud-Based Drone Management System in Smart Cities. In Krishnamurthi, R., Nayyar, A., Hassanien, A. (Ed.), *Development and Future of Internet of Drones (IoD): Insights, Trends and Road Ahead*. Studies in Systems, Decision and Control, vol 332, Springer, Cham, doi: 10.1007/978-3-030-63339-4_8

B-2. Nguyen Huu Phuoc Dai and **Nguyen Dinh Dung**. Drone application in smart cities: The general overview of security vulnerabilities and countermeasures for data communication. In Krishnamurthi, R., Nayyar, A., Hassanien, A. (Ed.), *Development and Future of Internet of Drones (IoD): Insights, Trends and Road Ahead*. Studies in Systems, Decision and Control, vol 332, Springer, Cham, doi: 10.1007/978-3-030-63339-4_7

B-3. **Nguyen Dinh Dung**, Utku Kale, and Rohács Dániel. Introduction of urban air transport into the total mobility system. In Rohács József (ed), *Total transport management in smart cities*. Budapest University of Technology and Economics, Budapest, Hungary, 2020. Chapter 7, pp. 175-198

B-4. **Nguyen Dinh Dung**, Rohács József, and Rohács Dániel. Sensing-monitoring supporting the total transport management. In Rohács József (ed), *Total transport management in smart cities*. Budapest University of Technology and Economics, Budapest, Hungary, 2020. Chapter 3, pp. 51-88

B-5. **Nguyen Dinh Dung**, Rohács József, and Rohács Dániel. Total transport management. In Rohács József (ed), *Total transport management in smart cities*. Budapest University of Technology and Economics, Budapest, Hungary, 2020. Chapter 2, pp. 37-50

B-6. Agnes Wanjiku Wangai, **Dinh Dung Nguyen**, Jozsef Rohacs, Daniel Rohacs. Studies into the future. In Rohács József (ed), *Total transport management in smart cities*. Budapest University of Technology and Economics, Budapest, Hungary, 2020. Chapter 4, 53p, pp. 123-175

B-7. **Dinh Dung Nguyen**, Jozsef Rohacs. Smart City Total Transport-Managing System. In Vo Nguyen-Son, Duong Trung Q. (Eds), Industrial Networks and Intelligent Systems. Springer International Publishing, 2019, pp. 74-85, paper: Chapter 7, 12p.

Conference papers

C-1. Sergey Kinzhikeyev, **Dinh Dung Nguyen**, Kale Utku, Wang Agnes, Jozsef Rohács, Daniel Rohács. Педагогическая компетентность для студентов инженерных специальностей - исследование, развитие и сове, In: Abzhapparov, AA. *MATERIALS of the International practical science conference "SHOQAN OQULARY – 24"*, Kokshetau, Kazakhstan, 2020, pp. 155-163, 9p.

C-2. **Nguyen DinhDung**. Identification of the parameters in mathematical model of a quadrotor. *International practical science conference "SHOQAN OQULARY-23"*, 2019, Vol.4, pp.99-110. ISBN: 978-601-261-434-3.

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C-5. **Dung, N. D.**, & Rohacs, J. (2018, November). The drone-following models in smart cities. In *2018 IEEE 59th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON)* (pp. 1-6). IEEE. DOI: 10.1109/RTUCON.2018.8659813

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C-7. **Nguyen Dinh Dung**, Jozsef Rohacs. Increasing the unmanned aerial vehicle landing accuracy for reducing environmental impact. *International Symposium on Sustainable Aviation 2018*, pp. 82-85. ISBN: 978-605-68640-2-5.

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