Method of movement control of unmanned vehicles according to specified trajectory of movement and safety considetations

Sposób sterowania ruchem pojazdów bezzałogowych zgodnie z określoną trajektorią ruchu i względami bezpieczeństwa

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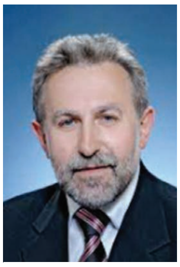

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Streszczenie: Artykuł ma na celu poznanie możliwej trajektorii bezzałogowych statków powietrznych w aglomeracjach zabudowanych. Wskazuje na problemy związane z bezpieczeństwem, wyborem korytarzy lotu oraz opisem sposobu sterowania ruchem bezzałogowego statku powietrznego według określonej trajektorii jego ruchu. W artykule przedstawiono propozycję projektową bloku pamięci trajektorii referencyjnych UAV oraz metody rozwiązywania kwestii bezpieczeństwa i niezawodności w aglomeracjach.

Słowa kluczowe: *Bezzałogowy system lotniczy; Aglomeracje zabudowane; Bezpieczeństwo; Operator pilota; Trasa lotu; Metoda kontroli; Ustalona trajektoria*

Abstract: The article is aimed to the possible trajectory of unmanned aerial vehicles in built-up agglomerations. It points out problems relating to safety, selection of flight corridors and description of the method of movement control of unmanned aerial vehicle according to specified trajectory of its movement. Design proposal of UAV reference trajectory memory block and methods of solving safety and reliability in agglomerations are presented in the article.

Keywords: *Aviation unmanned system; Built-up agglomerations; Safety; Pilot operator; Flight route; Control method; Established trajectory*

Introduction

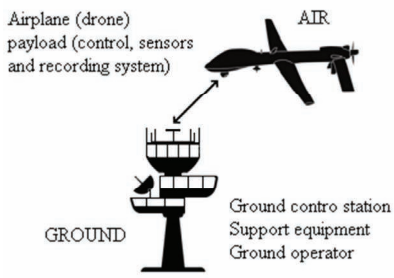
Unmanned Aircraft Systems (UAS) are an integral part of the global aviation system. It must be considered as part of local or global air transport environment with rules, regulations and disciplines.

UAS systems generally have the same components as manned aircraft systems, but the control of the on-board elements has been replaced by an electronic intelligence and control subsystem.

UAS consist of six basic components: the pilotless aircraft (UAV), its payload, the data communication link, the ground control station, ground support equipment and ground operators (Fig.**1**) [1].

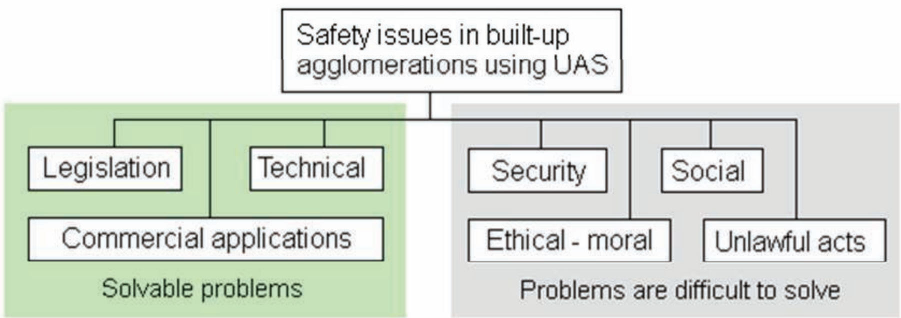
The term "drone" is an uncrewed aircraft or ship guided by remote control or on-board computers.

Usually refers to any pilotless aircraft. Sometimes referred to as "Unmanned Aerial Vehicles" (UAVs). The problem connected with the movement of Unmanned Aerial Vehicles (UAV) as a part of UAS in built-up agglomerations arose during their use for entertainment as models, when a greater extent of their movement occurred by the discovery of remote control with a range over longer distances (1km or more). Starting from the philosophy that safety is paramount in aviation, a number of problems need to be solved. Similar problems were solved when aviation began to be used for commercial purposes (transport of goods and also even passengers) in small and large scale. Similarly, a number of problems must be solved when using UAVs.



***1**. Airborne unmanned system*

On the Fig.**2** is presented example of possible problem solution referring to safety in built-up agglomerations using UAVs. Problems can be generally divided into solvable and difficult to be solved. Solvable solutions include: legislative solution for the use of UAVs in built-up agglomerations, technical solution of UAVs and their commercial applications. Problems connected with UAVs can be specified into these areas: security issues, social issues,



***2**. Safety issues in built-up agglomerations using UA.*

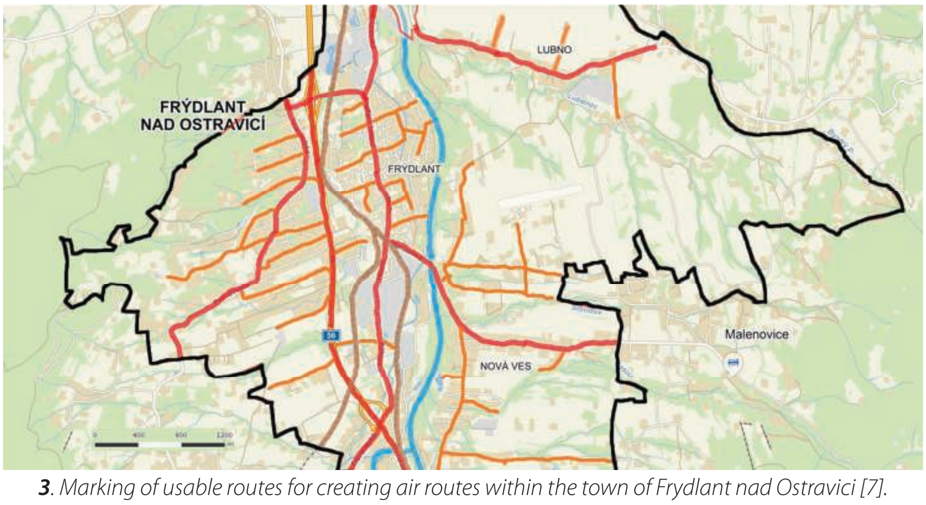
ethical and unlawful acts.

Based on the basic philosophy that the aviation security is a system combined of human and material resources to safeguard civil aviation against unlawful interference, human life and property, then the aim of the movement of aircraft unmanned aerial vehicles in the sky and mainly to altitudes up to 300 m is to find a suitable organizational and technical solution for this movement. A separate chapter is the legislative conditions, which are solved gradually with the acquisition of experience.

Analytical - synthetic methods with the use of already known experience in the movement of other means of transport are sought. There is described the problem of safety with mentioning solvable and difficult solvable problems. Furthermore, an example of selection of flight corridors and flight routes is implemented. Mainly the method of movement control of unmanned systems according to the determined trajectory of motion is proposed. From the very beginning of the use of transport by carriage, suitable navigable routes were used without modifications until today's motorways for cars, high-speed trains and ships with well-known tracks were reached. A separate problem is aviation, where the movement is in more dimensions than the above mentioned means of transport. All transports have their own rules for movement with special treatment and special control. Therefore, the movement of unmanned and manned aircraft must have a clear philosophy for their movement. This is particularly true for applications in partially or completely built-up agglomerations.

The movement of UAV is currently prohibited in most countries and in individual cases the movement is decided by the authorities.

The aim of the paper is also to point out the requirement of safety and reliability, to suggest possible variants for future unmanned aerial systems and to approach in which drones could fly in built-up agglomerations in the future while achieving sufficient safety of using unmanned systems. Another aim is to define and point out the basic factors affecting the reliability and security of UAV and describe their qualification and quantification values.



***3**. Marking of usable routes for creating air routes within the town of Frydlant nad Ostravici [7].*

The presented article could be a contribution to science in pointing out the problems of safety and reliability in the introduction of drones into built-up agglomerations.

The benefit for the practice is the proposal to direct the reliability of UAV and compliance with certain rules to ensure the safety of even such complex operations.

Example of selection of flight corridors and routes

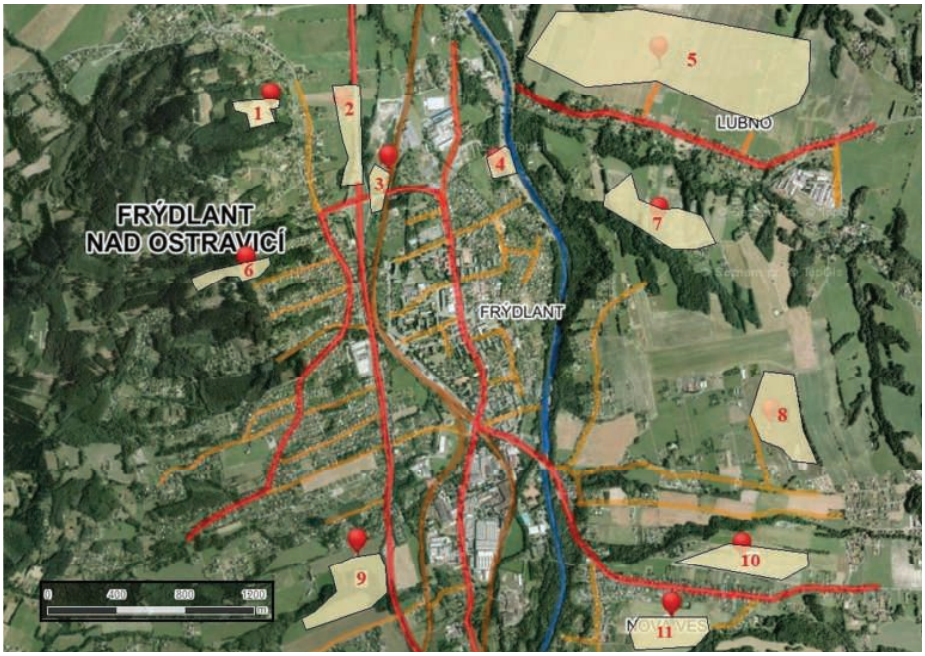
An example of the selection of flight corridors and flight routes with the description of usable routes for the creation of air routes is shown in the town of Frydlant nad Ostravici in the Moravian-Silesian Region, Czech Republic [4].

We are using accessible "https://www.google.com/maps/search/mapy.cz" with the possibility of marking networks of roads. This can be used as an example to illustrate the creation of flight corridors and flight routes. For the sake of simplicity, we are assuming that the flight corridors may not be directly above the road, but next to the road where there is sufficient space. The choice of flight corridors must be dealt with a thorough knowledge of the locations and safety.

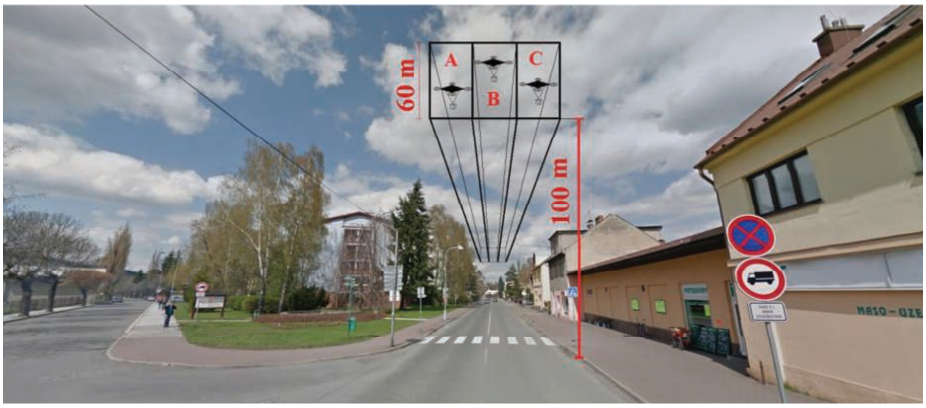
Fig. **3** shows the usable routes for the creation of air routes within the town of Frydlant nad Ostravici. The main and secondary aviation routes above the roads are shown in red and orange lines. Airways above railways are in brown lines and blue airway are above waterways. The black line defines the boundaries of Frydlant nad Ostravici.

The network of selected air routes is dense enough in the city center, and thinner around village Lubno and Nova Ves (Fig. **4**). Here, however, intersect air routes and sectors designed to operate unmanned systems. The service of these places can also be increased by flying over of lighter UAVs.

On the Fig. **5** shows an example of flight corridor visualization. The traffic directions are opposite in each of the



4. Marking of flight corridor within the town of Frydlant nad Ostravici together with an overview of the positions of the proposed corridors for the operation of UAV



5. Marking of flight corridor within the town of Frydlant nad Ostravici together with an overview of the positions of the proposed corridors for UA operation

secondary routes A, B and C. When turning from middle B route, UAV evade horizontally with UAV in A or C routes. These measures increase the safety of the proposal.

Method of movement control of unmanned systems according to specified trajectory of movement

The method of controlling the movement of unmanned vehicles according to a specified trajectory of movement is based on known predetermined and approved by Civil Aviation Authority trajectories of possible UAV movement in built-up agglomerations. Mentioned trajectory is made up of satellite navigation values and selecting the necessary trajectory to move from place A to place B in space, which is generated by the reference trajectory of Fig. **6**.

The easiest way would be to move along the shortest routes from 'A' on the defined flight path to 'B' and back, while ensuring the above conditions.

The unmanned motion control method according to the specified trajectory of motion, using satellite navigation, compares the reference flight path with the calculated shortest unmanned flight path. The data obtained from this comparison are intended for an automatic unmanned control system. The actual real position of the unmanned system is evaluated from satellite navigation, with the possibility of transmission to the ground control and control center.

For initial simplification, the starting area for the movement of the unmanned aircraft / aircraft is a small village with one main street, near a river and a railway line. UAV reference trajectories are stored in the UAV reference trajectory memory block (Fig.**7**) [8], and are provided to the Civil Aviation Authority (CAA) for approval for airspace G movement [1].

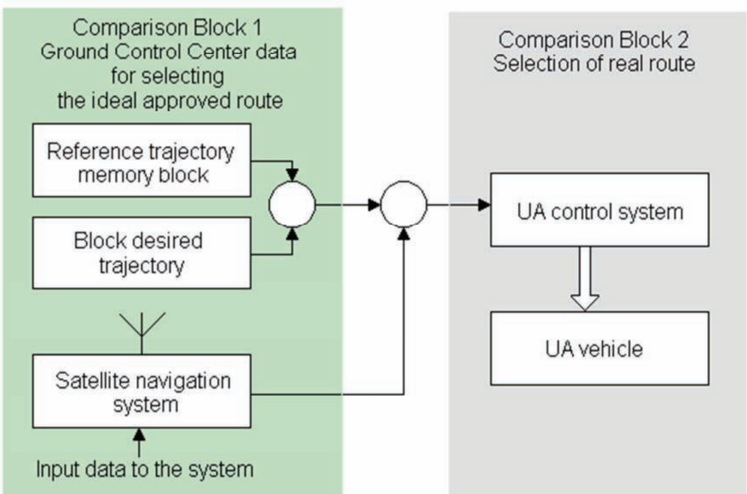
Based on the specific data required from the terrain, the route for the transfer of the UAV from "A" to "B" is entered and these data are entered into a block of required (desired) ideal and approved trajectories [2], [5].

In the ideal path selection comparison block, the reference trajectory from the reference trajectory block is compared with the desired trajectory. The resulting trajectory is trajectory needed for movement from point 'A' to point 'B' and will be the same as the route agreed by the Authority. This ideal route data is then routed to the real-time route comparison block.

This trajectory is selected on the basis of route length assessment - shortest, safe - selected - small movement of people, small buildings, low trees, etc. The trajectory obtained by the UAV operator is precisely determined by the CAA and is compared in flight with the current position from the satellite navigation block and again is compared with the data in the comparison block of the actual flight path of the flight path selection.

Following this approved trajectory, UAV with a predetermined regime move in a given situation and location (municipality). UAV along this route

6. UAV mission realization from the place of take-off and accomplishing the mission



7. Principle scheme of UAV's motion control system according to the determined trajectory of motion

travel from point "A" to point "B" and back. When moving around the village, the data from the real-path comparison block is sent to the UAV flight control system, which controls UAV movement. Data from the ground control center are also sent to the UAV system for possible position correction.

Similarly, the movement of UAV in a larger city with a greater number of streets, roads, parks, electric lines, water bodies, etc. can also be solved [6].

Safety and reliability of pilotless systems used in built-in agglomerations

Aviation safety is taken as a priority. The mass use of unmanned aerial vehicles in built-up areas (small municipalities, cities, large factories) is prohibited under current European and global legislation. This is authorized only upon special request by the National Aviation Authority. In some states, it is prohibited by law to fly in built-up areas, such as Japan. In the USA, the beginning of the use of UAV in built-up agglomerations is expected to start this year - 2021.

In the future, fast transport of goods to the customer is expected, which is the current and especially the trend in transport. New means are being sought to achieve this goal. One of them is the use of unmanned systems for fast import of goods to the customer. It turns out to be one of the means of first individual and then mass transport of goods.

These are mainly lighter packages for transport to the customer with a limited take-off weight and a limited maximum flight altitude.

Solutions to the safety and reliability of unmanned aerial vehicles have so far been little addressed. The problem is in the hands of designers and manufacturers of unmanned aerial vehicles. A separate chapter shows to be the human factor - pilot operator and UAV operators.

Methods of solving safety and reliability

Three basic methods are used to implement the described method:

1. Analytical.
   - Analysis of individual elements of the unmanned aerial vehicle.
   - Analysis of the unmanned aerial vehicle as a whole.
   - Analysis of the selection of suitable premises (areas).
   - Analysis of pilot operator and UAV operator.
2. Analogous.
   Use of experience from conventional aviation from manned aircraft and the human factor in it.
3. Synthetic.
   - Assessment of individual elements of the unmanned aerial vehicle
   - A proposal to increase the reliability and safety of the unmanned aerial vehicle and its systems

Compliance with the above requirements must be demonstrated in accordance with aviation regulations by a safety analysis and, where absolutely necessary, by appropriate ground, flight or simulation tests. The safety analysis is therefore considered to be the priority and main method of demonstrating compliance, and this analysis is required to include:

- an overview of all possible modes of failure, including modes of malfunction and possible modes of damage from external causes and sources,
- estimation (calculation) of the probability of occurrence of failures of elements and combinations of failures, including, hidden failures,
- analysis of the resulting consequence of failures on the system, on the airplane and on the crew and passengers at all stages of the flight and foreseeable operating conditions,
- clear list of warning and caution signals and instructions for the crew, required corrective measures and means for early identification of the fault.

The analysis of each unmanned aerial vehicle can lead to one of the following conclusions:

- the aeronautical unmanned system meets all safety requirements - then the analysis can be presented as evidence of compliance with the relevant requirements,
- the aeronautical unmanned system does not meet the requirements - then, based on the results of the analysis, appropriate design modifications are proposed to eliminate the identified deficiencies (after the implementation of changes, the entire analysis procedure must be repeated).

Qualitative analysis

Qualitative analysis can be carried out using a known method - FMEA of individual system elements, which the manufacturer of each unmanned system can implement in its design and manufacture.

Quantitative analysis

Quantitative analysis is usually required for those systems where the possibility of serious and catastrophic failure conditions has been identified during the functional hazard assessment.

The aim of the analysis is then to determine the probability with which the occurrence of the relevant fault condition can be expected.

Conclusion

Urban areas represent the greatest potential for unintended harm to public safety and security due to more concentrated population and variations in built form. Several possibilities and considerations will be suggested to anticipate challenges to adoption of a future complex working urban management system for drones. Certain varieties of drones are self-aware of their surroundings, monitoring for sudden changes in order to avoid collisions. However, the majority of drones are programmed to fly at a certain set of altitudes along a flight path and will be unaware of obstacles.

At present, UAV movement is prohibited in most countries and in individual cases the UAV movement is decided by the authorities. This is hampered by a number of problems (technical, legislative) that need to be addressed [9].

Until the solution, the common even commercial use of UAV in built-up agglomerations will not be possible. Safety always comes first. The article describes safety aspects of the use of UAV in built-up agglomerations with reference to solvable and difficult to solve problems as an introduction to the problem for the selection of flight corridors and flight routes.

Allowing widespread use of drones in dense urban areas, in the "green zones" could prove highly valuable as a means of delivering items over the top of traffic congested roads, for example. In such green spaces the expectation is to reduce the likelihood of losing the drone or disrupting others in the event of an accident. Additionally, the privacy invasion costs the drones might impose on landowners in these places might be acceptable so long as there were rules requiring delivery drones to constantly continue moving until they reached their destination so they didn't hover outside high-rise windows.

The main part of the article is a description of a new method of motion control of unmanned systems according to the established trajectory of motion, mainly for use in built-up agglomerations.

The presented article could be a little benefit to science in the proposed method of controlling the motion of unmanned systems according to a specified trajectory.

The benefit for practice is the possibility of practical application of UAS and then UAV control by the method of motion control of unmanned systems according to the specified trajectory. This will enable precise control of UAS and UAV, along a precisely defined space along a precisely defined and approved trajectory (approved by the CAA) movement in a fragmented and built-up area. Under current conditions, the movement of UAV is prohibited or approved only under strictly defined conditions, the use of UAV is not observed. The method used can increase security, even with greater use of UAV.

Today's conditions (technical, legislative) do not yet allow the mass use of unmanned aerial vehicles in built-up areas. However, it is necessary to clarify and mainly solve the problems that may arise in connection with the safety of their use and thus the reliability of the use of UAV in built-up agglomerations. It is a matter of several years when all the conditions for the safe movement of first isolated and then mass flights are met, especially in densely built-up inhabited areas. The article describes how the individual parts of aeronautical unmanned systems contribute to safety and reliability in their use, especially in built-up agglomerations, and describes the conditions for movement and the conditions for their control. ◀

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