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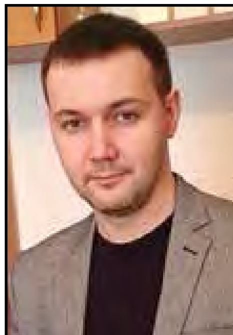
Enhanced Security of Unmanned Aerial Vehicles Operations at Transport Infrastructure Facilities



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ABSTRACT

Unmanned aerial vehicles (UAV), also known as drones, are gaining more and more practical application in modern society, particularly as the tools of implementation of the concepts of «smart city», «smart health care», «smart industries», Internet of Things, 3D mapping, digital transport. But currently it is impossible to use of UAV at certain objects, comprising objects of transport infrastructure (OTI), primarily, airports, because of existing restrictions due to security threats arising during the UAV flight.

The authors of the present work have set a goal to offer a solution that allows to start operating UAV at transport infrastructure facilities that are currently prohibited for UAV flights.

To achieve the objective of the work, using analysis and synthesis, comparison and generalization, factors and conditions for safe use of UAV at OTI have been formulated, a method for increasing security of UAV flight has been developed, followed by the suggestion on the UAV route control system.

The proposed system makes it possible to safely use UAVs at OTI by restraining their flight area strictly to the designated corridor, which eliminates a threat of a collision of UAV with other vehicles operated at OTI, dangerous elements of OTI, as well as with people at the object.

The system does not need electric power feeding, which makes it possible to implement the system without creating an auxiliary power supply infrastructure.

The practical application of the proposed system and, as a consequence, implementation of a greater number of opportunities for the use of UAV, are capable to generate fundamentally new technological processes and structures at transport facilities, which is one of the directions for creating the next generation transport infrastructure based on IoT and artificial intelligence.

Keywords: *unmanned aerial vehicle, UAV, object of transport infrastructure, security enhancement.*

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Background. Unmanned aerial vehicles (UAV), also known as drones, are gaining more and more practical application in modern society, including in implementing such applications as «smart city», «smart health care», «smart industries» [1–5]. In addition, «drones and the Internet of Things (IoT) are working together to help develop security, 3D mapping, transportation, and more» [6]. But, currently «proliferation of opportunities provided by technologies and methods associated with unmanned aerial vehicles is constrained by the existing restrictions on the use of UAV at certain objects» [7], including certain objects of transport infrastructure (OTI), primarily, airports.

Currently, the use of unmanned aerial vehicles at certain transport facilities, primarily at airports, is legally prohibited in many countries of the world [7], including Russia, because of security threats that arise during the flight of UAV. Such threats include accidents and emergencies (ES) [8], which may arise in case of a collision of UAV with vehicles operated at OTI, dangerous goods located at the facility or dangerous technical elements of the transport infrastructure facility. Dangerous technical elements comprise technical installations and systems that use flammable and chemically hazardous substances, power supply systems, traffic control systems, etc.

The risk of collision of UAV with other vehicles or elements of the technical equipment can be regarded as low [7; 9; 15], however, the consequences of such an accident, according to studies [10–14], can be quite serious, especially if we take into account «that weight of professional drones now reaches tens of kilograms, while some models of drones run on liquid fuel» [15]. The fuel tank of AB5 Jet Quad turbojet drone [16], developed by Fusion Flight (USA), holds 19 liters of diesel fuel. AB5 Jet Quad is capable of carrying cargo weighing 18 kg, the drone itself weighs 23 kg, as a result, the total weight of a fueled AB5 Jet Quad drone carrying cargo will reach 60 kg.

In the near future, it is planned to start mass production of a new generation of civilian cargo drones with a carrying capacity of hundreds of kilograms. An example of such aircraft is the «helicopter» type CAV cargo UAV, developed by Boeing [17], capable of carrying cargo weighing up to 227 kilograms. «CAV is 6,1 meters long, 5,3 meters wide and 1,5 meters high, and weighs 498,9 kilograms» [17].

In modern conditions, solving the problem of ensuring security issues linked to unmanned aerial vehicles is impossible without creating an appropriate methodological and technological apparatus. When forming the theory and methods enhancing security of UAV flights, it is necessary to apply an integrated approach, including a joint consideration of the results of scientific research and practical needs to ensure safety of both operated unmanned aerial vehicles and the security at transport infrastructure facilities where they are operated.

The *objective* of this study is to develop a method to enhance security of the flights of unmanned aerial vehicles and a technical solution for implementing it, jointly allowing to create necessary conditions for removing the existing restrictions on the use of UAV at OTI.

Results.

To achieve this goal, according to the authors, it is initially necessary to formulate the factors affecting the security of operation of unmanned aerial vehicles at transport infrastructure facilities, as well as a list of conditions for secure use of UAV at OTI.

Factors and conditions for safe use of UAV at OTI

The main factors affecting security of operation of unmanned aerial vehicles at transport infrastructure facilities can be divided into six groups.

1. Infrastructure factors:

• *proximity of traffic routes of other vehicles*. The air corridors allocated for movement of UAV should not intersect in the same plane with routes (corridors) of movement of other vehicles operated at OTI;

• *minimum amount of free space for maneuvering*. The space for UAV maneuvering at OTI is limited by the existing routes of movement of other vehicles, as well as by buildings, structures and communications located at OTI.

2. Technological factors:

• *the technological process of a number of equipment used at OTI operates radio channels*.

UAV is an aircraft, which is controlled remotely by radio channel. In this regard, it is necessary to take into account the risk of failure in control of UAV due to the influence of other radio signals;

• *a number of OTI use equipment that generates radio interference*. When planning routes for movement of UAV, it is necessary to take into account that on the route of movement of UAV there should not be areas with such a level of radio interference, at which malfunctions in control of the aircraft are possible.

3. Regulation and legal factors:

• *owner of an unmanned aerial vehicle is responsible for causing damage to third parties by UAV*. When choosing a UAV route, it is necessary to take into account possible risks of collision not only with vehicles or OTI elements, but also with people on the object;

• *owner of an unmanned aerial vehicle is obliged to carry out the registration actions established by law and obtain the necessary permits*. The schedules and modes of movement of UAV must be agreed by the regulatory authorities.

4. Risk factors of unauthorized intervention and impact:

• *there is a risk of remote interception of the control of an unmanned aerial vehicle*. At the moment, there is no tool for guaranteed protection of UAV control channel against unauthorized interference and impacts from an offender [18]. It is necessary to take into account the risk of interception of control of the aircraft, including for the purpose of using UAV to commit an act of unlawful interference at OTI [19].

• *civil UAV are not protected against external physical impact*. It should be borne in mind that UAV can easily be damaged, for example, by a small object thrown in its direction by an offender. When planning routes and infrastructure for movement of UAV, it is necessary to consider that UAV should be inaccessible for direct physical impact from an offender.

Generalization of factors affecting operation security of unmanned aerial vehicles at transport infrastructure facilities makes it possible to formulate three fundamental conditions for safe use of UAV at OTI:

1) Area of possible movement of UAV must be within the boundaries of the designated air corridor. This condition is due to the fact that currently there is no protection against the threat of uncontrolled changes in UAV flight trajectory. «A change in trajectory can occur both as a result of operator errors» [13], and deliberate unauthorized interference and impact on the part of an offender, including remote interception of UAV control. In addition, there is a threat of loss of control over UAV in case of technical malfunctions in it, after which UAV can also change its trajectory and collide with other vehicles operated at OTI, dangerous elements of OTI or people;

2) it is permissible to use only «helicopter» type UAV. The possibility of using only this type of UAV is due to the fact that UAV of other types, primarily «aircraft» ones, can move at high speed, and are not intended for maneuvering within limited built-up areas;

3) it is permissible to use only UAV with electric engines. The requirement on that type of thrust is due to the fact that accidents involving «liquid fuel» UAV have a risk of more severe consequences due to possible ignition of liquid fuel on board.

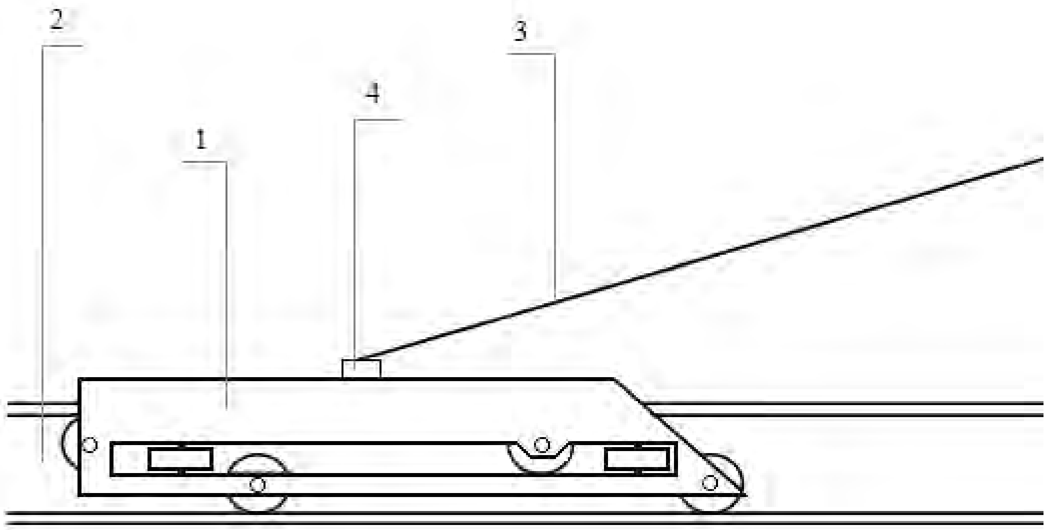
Ensuring security of operation of unmanned aerial vehicles at transport infrastructure facilities

The problem of safety of movement of unmanned aerial vehicles during operation at transport infrastructure facilities is directly related to stability of the boundaries of the designated (for UAV flights) air corridor (DAC), upon exiting which UAV may collide with other ground/air vehicles, elements of the technical equipment or people situated at OTI.

Stability of boundaries of the designated air corridor is a state in which UAV flight (from the take-off point to the landing point) is only possible within the boundaries of DAC.

Ensuring such stability is possible on the basis of creating conditions for blocking the object in question in the air corridor allocated for its movement, preventing thus emergencies associated with the object leaving the boundaries of the assigned air corridor. Technically, this task is reduced to preventing the possibility of UAV crossing DAC borders.

The problem formulated in such way, it seems expedient to provide constant communication between UAV and a non-free material point (NMT) located in the center of



Pic. 1. Route control system for unmanned aerial vehicles.

DAC circle and limited in movement by DAC axis.

In this case, the obtained connection should limit divergence of objects under consideration, at the distance exceeding a distance equal to the length of DAC radius minus UAV length and ½ of NMT length that will allow physical retention of the UAV within the DAC boundaries.

For practical implementation of the proposed method for increasing safety of UAV operation, a system of the control of the routes of unmanned aerial vehicles has been developed.

The route control system (RCS) for unmanned aerial vehicles allows for safe use of UAV at OTI by limiting UAV movement area strictly to a designated air corridor. When developing the system, the formulated conditions for safe use of UAV at OTI were considered.

RCS description

The principle of operation of the proposed system is that the unmanned aerial vehicle cannot go beyond the air corridor designated for its movement. This restriction is respected due to the fact that UAV is attached with a retaining cable to a ground mobile platform installed on a monorail laid along a given route of UAV. At the same time, UAV retains the ability to fly, but its flight area is limited by the length of the monorail and the length of the holding cable.

The detailed design of the developed system is shown in Pic. 1.

The system consists of the following main elements: ground mobile platform 1, mounted on a monorail 2; holding cable 3 is attached to attachment 4 installed on the ground mobile platform at one end, the cable is attached to the same attachment as above but on-board the UAV at the other end.

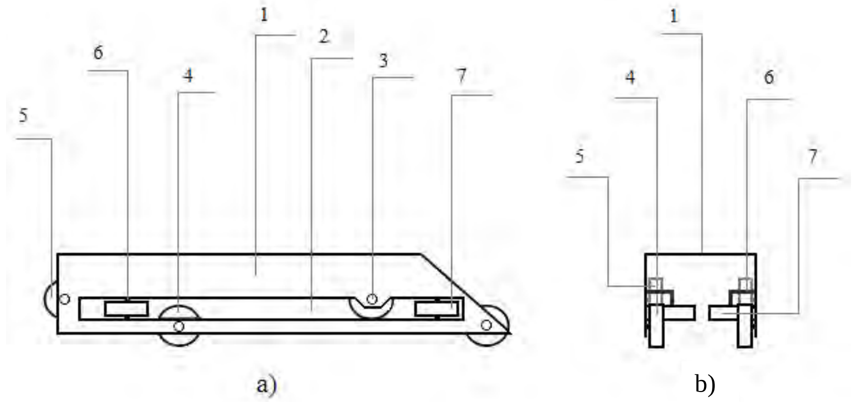
UAV is attached to the RCS with a retaining cable. The optimal is the use of a spring-loaded retaining cable, such a cable has minimal sag, which reduces threat of it catching on various surrounding objects during UAV flight.

The basic element of the system is a ground mobile platform (element 1 of Pic. 1), designed in such a way as to create a minimum braking effect during UAV flight. This is achieved due to biaxial arrangement of the platform wheels. In total, the platform has 12 wheels, which are based on roller bearings.

The detailed design of the movable platform is shown in Pic. 2.

The mobile platform consists of the following elements: body 1 with holes 2 on the sides; eight horizontally located axles 3, on which four lower wheels 4 and four upper wheels 5 are installed; four vertically arranged axles 6, on which four side wheels 7 are installed. The material of the body of the mobile platform is aluminum alloy AD31.

The mobile platform is installed on the monorail (element 2 of Pic. 1).



Pic. 2. Ground mobile platform: a) left view, b) front view.

The design of the mobile platform allows it to move along the monorail, both forward and backward.

The monorail is laid along the established route of UAV. The monorail is assembled from separate sections, the number of which is determined by design length of the monorail. The monorail is mounted on support-brackets, which are fixed in turn on suitable external objects, for example, on buildings or structures located along the route of the monorail, or on screw piles specially installed in the soil.

The detailed design of the monorail is shown in Pic. 3.

The section of the monorail 1 is fixed by the longitudinal upper fastener 2 and the longitudinal lower fastener 3 to the adjacent section of the monorail 4 and by the corner fastener 5 to the support-bracket 6. The material of the monorail is aluminum alloy AD31.

System operating conditions

A monorail system can simultaneously operate a single mobile platform or a group of platforms. Only single UAV can be attached to each mobile platform.

When operating a group of mobile platforms on a single monorail, their movement can be carried out only in one selected direction with a safe interval between them, this is necessary to prevent UAV collisions.

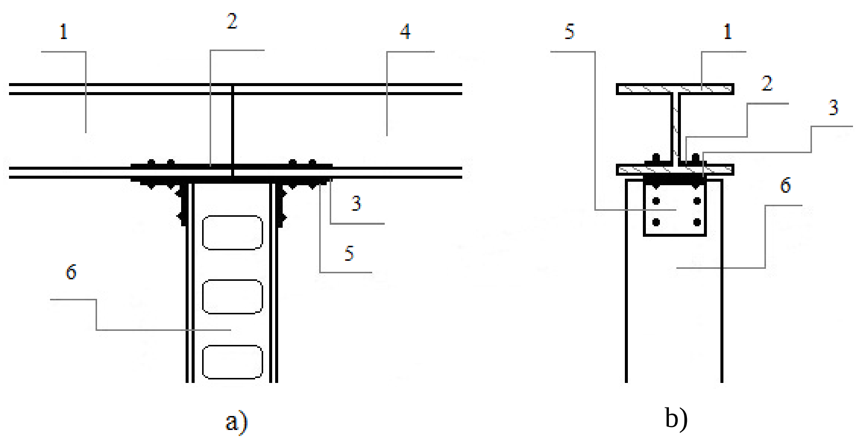
Safe interval (S_{int}) is determined according to the formula:

$$S_{int} = T_{res} + B_{dis} + L_{hc} \cdot 2, \qquad (1)$$

where T_{res} is distance traveled by UAV from the moment the operator detects an obstacle in the path of UAV movement and until the moment when the operator applies emergency braking;

B_{dis} is stopping distance traveled by UAV during emergency braking;

L_{hc} is the length of the retaining cable.



Pic. 3. Monorail complete with support-bracket: a) left view, b) front view.

Table 1

Developments involving the use of tethered UAV

Developer	Maximum flight altitude of the drone	Continuous flight time of the drone
Equinox Systems [20]	150 m	30 days
TDS [21]	120 m	Unlimited
Aria Insights [22]	120 m	Unlimited
Elistair [23]	80 m	10 hours

Formula 1 allows us to calculate a safe interval for a given UAV speed, for this, their values are substituted into T_{res} and B_{di} indicators as the considered speed.

Application restrictions

The RCS is operated for applications involving movement of UAV along a certain route.

The UAV RCS is applicable at ground-based transport infrastructure facilities.

The RCS is designed to operate «helicopter» UAV according to the vertical take-off and landing scheme.

Experimental testing of the system

A full-scale experiment was carried out by means of a 15-minute flight of a UAV attached by a holding cable to a mobile platform mounted on a monorail. Flight speed and altitude, location of UAV relative to the monorail, as well as cable tension force were periodically changed by the operator. As a result of the experiment, it was found that the route control system for unmanned aerial vehicles ensures limitation of UAV movement area within the boundaries of the designated air corridor, while UAV attachment to the system does not significantly affect controllability and speed of UAV.

Directions of further research

The research is developed by the authors in two directions.

The first direction provides for development of the technology allowing the operator to control the UAV using communication by cable instead of radio channel. Monorail and then retaining cable attaching UAV to the mobile platform will serve as cable line for transmitting data. This method of UAV control will permit to protect the channel of UAV control against failures caused by radio interference, and will provide protection against remote interception of the UAV control by an offender, that will reduce vulnerability of the system to unauthorized interference and impact.

The second direction provides for development of the technology pf remote electric feeding of the UAV within the RCS. The monorail and then the retaining cable will serve as electric power supply line. This method of power supply will permit UAV to work in practically continuous mode and will also increase its load lifting capacity by installing more powerful electric engines. Remote power supply of the UAVs will permit to create long systems of route and zone flights of UAVs in cities and regions with a possibility of their further integration. Introduction of the systems of such type will permit to develop in the future global logistics networks, where freight UAV will serve as delivery vehicles.

Comparison with solutions already known in the world

At the moment, a number of developments are known in the world that provide for the use of tethered UAVs (Table 1).

The fundamental difference between the solutions described in Table 1 from the proposed system is that in them UAV is attached by a cable to a ground stationary base (station), after takeoff and reaching a given altitude, is in a static state and is used as a platform for placing equipment, for example, designed to transmit a 3G/4G/5G signals to ensure cellular coverage in emergency areas, until damaged cell towers are restored. The route flight of UAV in the described solutions is not possible. An additional difference between the considered solutions from the proposed system is that they are intended for remote power supply of UAV. There is no information about whether these solutions are capable of retaining UAV in a given flight sector, and this does not allow considering these solutions as a means of ensuring safety of UAV traffic.

Conclusions. The present research has resulted in development of a method for improving safety of unmanned aerial vehicles and unmanned aerial vehicle route control system that implements it. The implementation of the system solves the problem of ensuring safety of movement of unmanned aerial vehicles during operation at transport infrastructure facilities, which in turn makes it possible to remove the existing restrictions on the use of UAV at OTI, in terms of unmanned aerial vehicles used in conjunction with the proposed system.

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