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Aspects of Equipping Transport Facilities with Systems for Controlling Routes of Unmanned Aerial Vehicles

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ABSTRACT

Currently, the problem of ensuring safety of flights of unmanned aerial vehicles (UAVs) over the territory of transport infrastructure facilities (TIF), primarily airports, remains topical.

In one of the previous works, the author together with the co-author proposed a method for increasing safety of movement of unmanned aerial vehicles and the system for controlling the routes of unmanned aerial vehicles (hereinafter – route control system, RCS) that implements it, which makes it possible to improve safety and security of UAV traffic at transport infrastructure facilities by limiting UAV traffic area strictly to a dedicated air corridor (DAC). The development of this system creates the prerequisites for removing the existing restrictions on the use of unmanned aerial vehicles at transport infrastructure facilities.

For practical implementation of the proposed system, it is relevant to develop a method of placing RCS at transport infrastructure facilities. This condition can be justified by the fact that RCS, as a rule, will be located under conditions of dense infrastructural development, including dangerous technical elements of technical equipment, a collision of a UAV with which can lead to an emergency situation (ES); besides, the movement of air/ground vehicles will be carried out in the immediate vicinity of RCS along transport routes/corridors, and employees, passengers and visitors of TIF will move along the pedestrian paths.

The objective of this study – to develop a methodology for placing systems controlling routes of unmanned aerial vehicles at transport infrastructure facilities.

The study conducted with well-known scientific methods, including the basic routing problem posed by Dantzig and Ramser, modelling, analysis, and synthesis, made it possible to develop a method for placing RCS for unmanned aerial vehicles at transport infrastructure facilities. The practical application of the proposed methodology makes it possible to build routes for movement of UAV at TIF, to form a network of dedicated air corridors for UAV at TIF operated in relationship with the system, determine the optimal location of the RCS elements at TIF.

Keywords: unmanned aerial vehicle, UAV, transport infrastructure facility, route control system, placement technique.

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Background.

Unmanned aerial vehicles (UAVs) constitute a basic element of the next generation transport infrastructure, which will be based on the Internet of Things (IoT) and artificial intelligence. But now, the use of UAVs in the transport sector, including modern logistics centres at large aviation hubs, is restrained by legislative prohibitions [1]. «Such bans on UAVs' flights over the territory of transport facilities are adopted in most countries of the world» [1], including Russia [1–3]. Such restrictions are aimed primarily at ensuring safety and security of transport infrastructure facilities and vehicles operated at them, as well as personnel, visitors, and passengers [1; 2].

At present, the efforts of many researchers, both in Russia and abroad, are aimed at solving problems of ensuring the safety of UAVs' flights. There are two main areas of research. The first is legal regulation in the field of the use of UAVs [1; 4–6], the second is development of organizational and technical solutions aimed at solving security problems in the area under consideration [7–20].

So, the author in [21] proposed together with the co-author a development aimed at controlling the routes of UAV during their flights over the territory of transport infrastructure facilities (TIF, or objects of transport infrastructure: OTI), creating the preconditions for removing the existing restrictions on the use of unmanned aerial vehicles at TIF, including airports.

It should be noted that for practical application of the above development, which is route control system (RCS), the issue of the method of placing such systems at transport infrastructure facilities is quite relevant. This precondition can be justified by the fact that route control systems, as a rule, will be located under the conditions of dense infrastructure development, including hazardous technical elements of technical equipment, a collision of a UAV with which can lead to an emergency [22]. Air/ground vehicles will move along transport routes/corridors in the immediate vicinity of RCS, while employees, passengers, and visitors of TIF will move along the pedestrian paths.

The *objective* of this study is to develop a methodology for placing systems controlling the routes of unmanned aerial vehicles at transport infrastructure facilities, which, in the author's opinion, is a necessary condition for ensuring safety and security during the operation of UAVs at TIF.

Methodology for placing UAVs' RCS at transport infrastructure facilities

The unmanned aerial vehicle route control system has the following application restrictions:

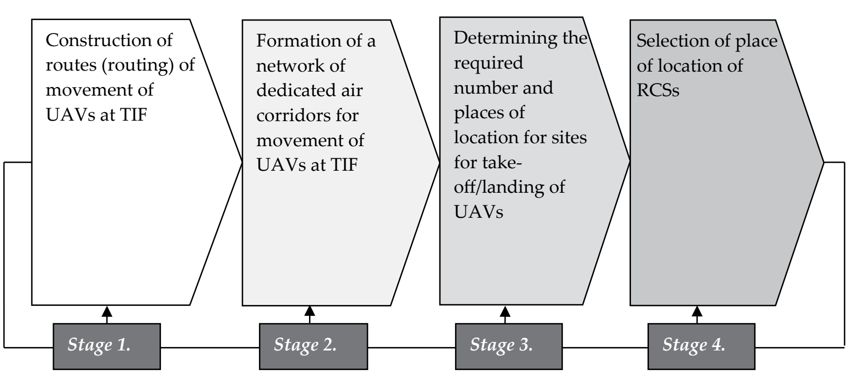
• The system is applicable in applications providing for movement of UAVs along a certain route.

• The system is applicable at ground transport infrastructure facilities.

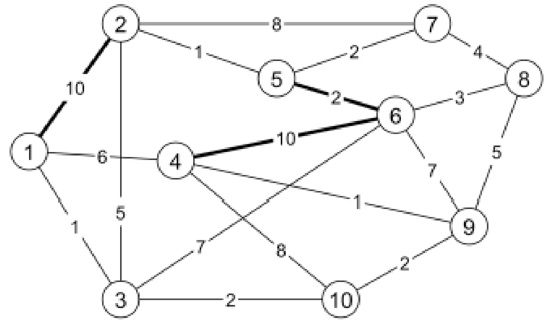
• The system is designed to work with UAV of vertical take-off and landing, of «helicopter» type.

The basic principles that must be followed when placing route control systems at transport infrastructure facilities are that UAV, while moving, should not be able to encounter the infrastructure elements of TIF, other vehicles, and people. Counter flows of moving UAVs must be separated along at least two non-contiguous dedicated air corridors.

The main requirement for location of the elements of the route control system for



Pic. 1. Algorithm for placing RCS at TIF [compiled by the author].



Pic. 2. Transport network, where N = {3, 9}, R = {{1, 2}, {6, 5}, {4, 6}}, V(R) = {1, 2, 4, 5, 6}; (1, 2, 5, 6, 4, 9, 10, 3, 1) is optimal circular route [24].

unmanned aerial vehicles is the presence in the selected area of an uninterrupted GSM signal (or of another applied communication signal) that provides operator to UAV communications.

The algorithm for placing the RCSs at TIF can be divided into four stages shown in Pic. 1.

To implement the phases of RCS placement (Pic. 1), a digital map (model) of TIF is required, which will reflect: buildings and structures, ground and overhead communications, paths (corridors) of vehicle movement, pedestrian paths, and other structural elements of TIF. Dangerous elements of the elements of transport infrastructure, a collision of a UAV with which can lead to an emergency, should be highlighted on the map (model) of TIF.

Stage 1: construction of routes (routing) of movement of UAV at TIF

At this stage, the goals of using UAV are formulated, based on which initial, intermediate, and final points of the routes[1], their number and coordinates are identified and determined.

The starting and ending points of the route can be designated as *base* points of the route.

UAV route can be *single-point* route when take-off and landing point is located in the same place. Variants are possible when UAV route combines two points, such a route can be designated as a *two-point* route, and a route with numerous take-off/landing points will be *multi-point* route.

Take-off/landing points are plotted on the digital map (model) of TIF, the designation of base and intermediate points should be different. These points are used to route the movement of UAV at TIF.

The basic principle of laying routes for UAV at TIF is the *minimum route length*, the application of this principle allows the most efficient use of the limited battery charge of UAV.

Based on this principle, it is advisable to use the solution of basic routing problem (VRP – Vehicle Routing Problem) posed, e.g., by Dantzig and Ramser [23], as well as of the problems such as Chinese postman problem [24–26], to route UAV movement to TIF. When choosing a route, the optimal route will be the one that has the minimum length, «such a route is called an «Euler route», and the graph containing it is called an «Euler graph» [24]. Moreover, «it is required to find in the graph $H = (V, U)$, a cycle that includes all vertices from N and all edges from R and has the minimum sum of weights of edges included in it. Obviously, if this cycle is simple, then it is the optimal circular route» [24] (Pic. 2).

The principle of the *minimum route length* does not apply, provided that the route is set with the purpose (purposes) of using UAV, for example, when it moves along the perimeter of TIF for the purpose of monitoring security of the facility. In this case, the route is laid based on the purposes of using UAV, in the case under consideration it is designed along the perimeter of TIF.

The formed network of UAV routes is entered into the digital map (model) of TIF.

Stage 2: formation of a network of dedicated air corridors for movement of UAV

The formation of a network of dedicated air corridors is carried out based on the routes formed in the digital map of TIF. The air

[1] Points of the routes:
• initial points of the routes – place of UAVs' take-off;
• intermediate points of the routes – place of intermediate landing/take-off of UAVs;
• final points of the routes – place of UAVs' landing.

corridor is allocated in accordance with the planned route, while its trajectory is adjusted considering the buildings and structures located on the path of the air corridor, the paths/corridors of other vehicles, communications, pedestrian paths, and other influencing factors. A factor influencing the adjustment of DAC trajectory is the need to consider the technological conditions for mounting the support-brackets on which the monorail is installed.

The updating of the trajectory of the dedicated air corridor relative to the laid route is carried out based on the principle of a *minimum increase in the length of the corridor*, based on the limited charge of UAV batteries.

The start point of DAC will be the take-off point of UAV at the beginning of the route, the end of DAC will be the point of landing of UAV at the end of the route.

The DAC axis will be the trajectory of the ground mobile platform.

The circumference of DAC (C_{AP}) can be calculated using the formula:

$C_{AP} = (C_L + 1/2M_S + D_U) \cdot 2$,

where C_L is length of the holding cable;

M_S is length of the movable platform;

D_U is UAV length.

Stage 3: determination of the required number and location of sites intended for take-off/landing of UAV (hereinafter referred to as landing sites (LS))

Landing sites are located both at the base and intermediate points of UAV route, and additional LS can also be provided for the purposes of technological operations with UAV, such as changing batteries, on-board equipment, and similar operations, in other places of UAV route. Several LS can be provided at each base or intermediate point of the route.

The size and shape of the landing site are determined considering dimensions of UAV used, the contents and composition of the planned technological operations with UAV, as well as the characteristics of the adjacent territory.

Branches from the monorail are provided to LS locations, if necessary, which allows given UAVs not to block movement of other UAVs along the monorail, and allows landing sites to be placed not only next to the main monorail, but also at the required distance, which expands the possibilities when choosing the most convenient locations for platforms and other elements of the system.

The total number of landing sites is not limited and depends on RCS operating conditions.

Stage 4: choice of the location of the control centre (CC) for UAV RCS

The control centre for UAV RCS includes operators who remotely control movement of UAVs, and hardware and software complexes that allow operators to remotely control UAVs. In addition, other additional equipment and employees may be provided as part of the system CC to increase reliability and productivity of RCSs.

The main requirement for location of CC is the presence of an uninterrupted GSM signal (or of other applied signal) providing communication between the operator and UAVs.

CC can be both single and distributed, consisting of several geographically distributed workplaces of operators controlling UAV traffic. The optimal is formation of a single CC from where the operators direct contact each other, it can be organized like air traffic control centre.

The optimal location for the system control centre is the one from which operators can observe movement of UAVs not only using hardware, but also visually.

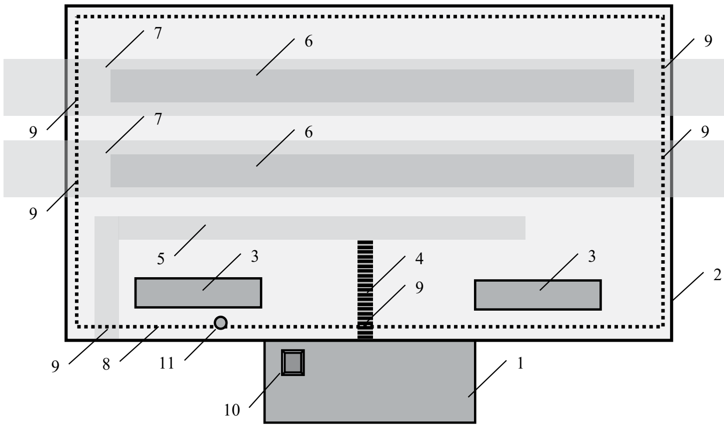
Additional factors considered when choosing the location of CC are as follow:

• *availability of access roads*. The availability of such routes will allow operators and technical personnel of the system to quickly go to the distributed points of RCS to perform various technological operations, including repair;

• *availability in the immediate vicinity of a take-off/landing site for UAV operated together with RCS*. The presence of such a site will allow the operators and technical personnel of the system to carry out the necessary technological operations with UAVs directly next to the control centre;

• *availability of a backup line (source) of power supply*. The presence of a reserve source of power supply makes it possible to increase reliability of RCS operation;

• *presence of security at the entrances to the building (room) in which CC is supposed to be located*. The presence of security allows to



Pic. 3. Layout of UAV route control system at the transport infrastructure facility (airport) [author's design].

increase security of RCS control centre against unauthorized interference and influences;

• *availability of access control systems (ACS) at the entrances to the premises in which CC is supposed to be located.* Availability of ACS will increase security of RCS control centre against unauthorized interference and impact.

Ultimately, according to the data obtained at all four stages, the location of RCS at TIF may be determined. The location of RCS elements is reflected in the digital map (model) of the transport infrastructure facility. The resulting layout of RCS at TIF allows formulating the terms of reference for creation of a control system for UAV routes at the considered object of transport infrastructure.

The author has tested the developed methodology using a universal airport model (Pic. 3), which contains the following elements: terminal building *1*, airfield perimeter *2*, technical buildings *3*, pedestrian paths *4*, paths for ground vehicles *5*, runways *6*, air corridors for aircraft traffic *7*.

Based on the proposed model of the airport, RCS placement was focused on the purpose of UAV application, which in this example is set as monitoring safety along the perimeter of the aerodrome *2*. Based on the goals of application, the route for movement of unmanned aerial vehicles was built, based on which DAC8 was assigned for movement of the UAV, in this example, along the perimeter. On the obtained RCS layout scheme (Pic. 3), the places of intersection of DAC9 with air corridors *7* and ground corridors/paths for vehicle movement *5*, as well as pedestrian paths *4*, were determined, control system *10*, which allows monitoring movement of UAV not only with hardware tools, but also visually, as well as the base point of the route *11* containing LS were designated.

At the intersection of DAC with the air corridors *7*, DAC is provided to pass under the air corridors *7*. At the intersection of DAC with the ground corridors/paths for movement of the vehicle *5* and pedestrian paths *4*, DAC is provided for passage over the corridors/paths *5* and *4*.

Conclusions. In this study, a methodology has been developed for placement of systems controlling the routes of unmanned aerial vehicles at transport infrastructure facilities. The methodology examines practical aspects of equipping transport facilities with systems for controlling UAV routes. The introduction of systems to control flight routes of unmanned aerial vehicles is a prerequisite for ensuring safety and security, and creates necessary conditions for removing the existing restrictions on the use of unmanned aerial vehicles at transport infrastructure facilities.

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