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INFORMATION SERVICES OF USERS OF RUTM UNMANNED TRAFFIC CONTROL SYSTEM

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ABSTRACT

The priority task of the development of unmanned aviation is to create conditions for flight safety, which is impossible without the use of unmanned aerial vehicle (UAV) flight control system. One of such systems is the Russian unmanned aircraft system traffic management (RUTM), an important part of which is the flight service support system. Based on the analysis of typical actions of users of RUTM system, the article formulates the requirements for their user interfaces and provides a list of necessary services. The issues of organizing the operation of these services based on the database of aeronautical information (AI) intended for storage, processing and provision of up-to-date information to users of the system are also considered. The size of such a base largely depends on the choice of a system of spatial coordinates, with the help of which objects on the map are associated with real objects on the ground. The analysis of existing coordinate systems showed that for the database under consideration, the best option is to store AI in World Geodetic System (WGS) WGS 84 geographic coordinate system. At the same time, the provision to the end user is carried out after recalculating it into the appropriate projection, depending on the requirements for the nature of the distortions. When displaying AI on 3D map, it is proposed to use a cube or an octahedron as a base polyhedron, and a projection of a sphere onto an octahedron as a projection, which makes it possible to halve the redundancy of the initial AI. The novelty of the work is in the fact that in the course of the study, the requirements for user services of the Unmanned Traffic Management (UTM) system were formulated in detail, based on typical user actions, and the size of AI database necessary to ensure the safety of UAV and manned aircraft flights was determined. The formulated requirements can be a useful addition to the regulations adopted by the leading countries, which provide high-level requirements for the necessary user interfaces of UTM system.

Keywords: *Unmanned aerial vehicle (UAV); Russian unmanned aircraft system traffic management (RUTM); airspace; aeronautical information (AI); external pilot (EP); air traffic flow management (ATFM); World Geodetic System (WGS) WGS 84*

1. INTRODUCTION

The widespread use of UAV in commercial and civil areas leads to a situation where there is not enough space in the airspace for manned aircraft. This situation often arises in the central part of Russia, where UAV have found wide use in the commercial sphere. This situation poses risks to flight safety. According to various estimates of marketing agencies, the volume of the world market in 2020 is estimated at 14–24 billion dollars, and growth is expected in 2030 to 53–70 billion dollars. These circumstances require the speedy development and implementation of a control system for UAV in the general airspace.

One of the main tasks at the present stage of development of unmanned aviation is the integration of UAV into the existing airspace. The purpose of such integration is to create conditions for organizing the safety of UAV and civil aircraft on the basis of a single information space using modern information technologies [1-4]. A certain contribution to the solution of this problem was made by the work on the creation of UAV control systems: American unmanned ATFM, Chinese unmanned aircraft system aviation operation management system (UOMS), European U-Space and Russian Jupiter [5-10]. Despite all the positive aspects of these unmanned aircraft control systems, they have limited functionality, since they involve the coordination of UAV flights in urban areas or in areas where there are no manned aircraft (airplanes and helicopters).

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The Russian program for the integration of UAV into the national airspace on the basis of joint air navigation and information services for unmanned and manned aircraft is deprived of this shortcoming [11]. Within the framework of this program, it is planned to create information services to ensure automatic flight safety for unmanned and manned aircraft in a single airspace. One of the developed control systems that meets this program is RUTM [12-14]. The purpose of this article is to formulate requirements for the composition of services and user interfaces of RUTM system, as well as requirements for the functionality and dimensions of the database of AI, necessary for the functioning of these services.

2. THEORETICAL BASIS

To ensure the safety of UAV flights, it is necessary to have a service support system for flights. Section 2.1 deals with the organization of user interfaces of RUTM system, and section 2.2 deals with the organization of AI database that ensures their functioning.

2.1. User interfaces of RUTM system

To identify the necessary services, which are described in section 3.1, we consider typical user actions that each of them performs to solve their tasks. The main users of RUTM system include:

- airspace constructor;
- RUTM system operator;
- EP (or remote pilot), which controls UAV, performs takeoff and landing and controls the performance of the flight task;
- provider;
- external users (insurance companies, executive authorities, etc.).

We consider the typical actions of users and the interfaces they need at various stages of organizing UAV flight.

2.1.1. User actions and their interfaces out of flight

Outside of flight, the airspace designer can enter and edit a map of the terrain and obstacles, zones of permanent and temporary restrictions. This requires an interface for the introduction, editing of AI, maps of terrain and obstacles.

EP registers itself and all its UAV, for which it needs a separate registration interface.

2.1.2. User actions and their interfaces before flight

Prior to the flight of EP, it is necessary to complete preliminary training, consisting of the following tasks:

- study the area of planned work: analyze information about the terrain, check the presence of power lines, view up-to-date information on restrictions and prohibited areas of flight;
- choose a platform for take-off and landing, taking into account the possibility of access to them;
- get acquainted with the preliminary weather forecast for the day of flights;
- perform calculation of aeronautical flight elements (safe flight altitude, calculation of distance, flight time, etc.);
- make a flight plan;
- coordinate the use of airspace with the zonal center;
- prepare cartographic material for the flight.

Thus, EP requires the following interfaces to perform preconditioning:

1. Interface with display of:

- terrain;
- power lines in the flight area;
- up-to-date information on flight restrictions and restricted areas and other AI;
- maps of the area for the selection of take-off and landing sites, taking into account the possibility of access to them.

2. Interface for getting acquainted with the actual and forecast information about the weather on the day of flights;
3. Interface for performing calculations of air navigation elements of the flight;
4. Interface for drawing up a flight plan;
5. Interface for interaction with the main center of the unified ATFM to coordinate the possibility of using the airspace.

Prior to the flight, the provider must:

- prepare a daily plan of air traffic;

- inform the airports of departure/arrival about changes in routes;
- during the day, control the arrival of the airborne personnel to the flight area to perform pre-flight preparation, inform about the conditions for the flight;
- perform other procedures in accordance with the rules of air navigation services for airspace users.

Thus, the provider needs the following interfaces to prepare the dispatcher for duty:

1. Interface for preparing daily air traffic plan;
2. Interface for interaction with other dispatchers;
3. Interface for interaction with EP:

- to control the arrival of EP in the area of the flight;
- to inform about flight conditions.

2.1.3. User actions and their interfaces during flight

During the flight of EP, we must:

1. Conduct pre-flight preparation:

- check the compliance of the weather in the flight area with the operational characteristics of UAV;
- compose a flight task and upload it to the ground control station;
- deploy a ground control station and prepare the take-off site;
- check the technical condition of UAV;
- obtain permission to use the airspace in the zonal center of air traffic management two hours before departure;

2. Keep in touch with the dispatcher of the zonal center.

3. Take off UAV and monitor the air situation during the flight.

4. Inspect the area according to the images of UAV FPV camera.

5. Monitor UAV and flight parameters.

Thus, EP needs the following interfaces:

1. Interface described above with the display of the terrain, power lines, air navigation flight zones and terrain maps.
2. Interface described above to see the actual weather information.
3. Interface described above for compiling a flight plan for:

- loading into the ground control station.

4. Interface described above for interaction with the main center of the unified air traffic management system for:

- obtaining permission to use the airspace;
- exchange of information about the air situation during the flight.

5. Interface for monitoring UAV and flight parameters.

During the flight, the provider must:

1. Ensure the release and reception of UAV.
2. When UAV is taking off, assess the air situation, paying special attention to the location of departing, flying and landing aircraft and meteorological situation and make sure that there are no obstacles on the runway.
3. During the flight, assess the air situation, report the accumulation and flights of birds, as well as dangerous weather events.
4. Control the flight of UAV, in case of deviations from the flight route, inform EP.
5. When landing UAV, ensure that there are no other air and mobile technical means in the landing area.
6. Other procedures in accordance with the rules of air navigation services for airspace users.

Thus, the provider needs the following interfaces to serve the airspace:

1. Interface to ensure the release and reception of UAV for:

- clarification of the technical condition of the aerodrome of departure and destination, if the departure is from an airport;
- assessment of the air situation for the presence of restrictions or a ban on the flight of UAV, for the presence of other air assets, as well as mobile technical equipment, for the presence of obstacles on the airstrip;

- assessment of meteorological and ornithological conditions.

2. Interface for assessing the air situation during the flight:

- for the presence of accumulation and flights of birds;
- for the presence of dangerous weather phenomena;

3. Interface for controlling the flight of UAV (for example, in case of deviations from the flight route, inform EP).

2.1.4. User actions and their interfaces after the flight

After the flight of EP, we must:

- inform the dispatcher about a successful landing;
- conduct a post-flight inspection of UAV.

In accordance with this EP, after the flight, the above-described interface for interacting with an air traffic controller in order to inform the controller of a successful landing.

After the flight, the provider must:

- receive a report on the completion of the flight;
- record the landing time and UAV callsign in the log.

The provider needs the following interfaces:

- above-described interface for communicating with EP to receive a message about the end of the flight;
- interface for keeping a log of UAV flights.

External users of RUTM system can analyze flight data and upload analytical reports on specific UAV flights. External users can be, for example, insurance companies in the investigation of aviation accidents. They require a separate interface to access flight data with the ability to upload analytical reports on flight accidents.

2.2. AI database functionality and dimension requirements

As follows from the above description of the main services of RUTM system users, their organization requires the full amount of AI necessary to build and control UAV route. To accumulate, store, process and provide all users with up-to-date information, AI database is required, which should provide:

- generation and display of two-dimensional and three-dimensional images based AI;
- managing the display parameters of the territory model on the graphical client;
- display control using devices for user interaction with the system;
- receiving, processing and displaying incoming data from external systems.

An important aspect of AI database is its size, by which we mean the area of the territory described by its contents with a given accuracy. The minimum size of AI database should cover RUTM service area plus 25-40 km as a buffer zone.

The maximum size of the database should provide for modeling a large state or region. For the case when the simulated territory is expressed by the surface of the entire planet, the amount of information of all types, even in average quality, will be very significant. Large amounts of information necessitate the use of:

- effective data projections, which are discussed in sections 3.2 and 4.2;
- organization of non-trivial structures of information storage;
- effective methods of data compression and special file formats, for example, ARINC, WXXM, GeoTIFF, etc. [15,16].

3. METHODOLOGY

3.1. Services of RUTM system

Taking into account the description of the user interfaces of RUTM system given in section 2.1, the following services can be distinguished that cover the needs of the main users according to their typical actions:

1. Registration and accounting service is required for UAV registration and pilot;
2. Service for flight route planning and its authorization in the system allows plotting a route, analyzing possible risks and obtain permission to fly. For the implementation of

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this service, it is necessary to have the flight performance of UAV, aeronautical and meteorological data;

3. Air traffic monitoring service provides air traffic participants with traffic information based on airborne and ground-based surveillance system data. The service allows adjusting the density of air traffic;
4. Service for maintaining safe intervals and avoiding collisions during the flight predicts the dynamics of UAV flight, identifies the risks of collision with other objects and notifies the pilot of a possible incident. This service uses UAV flight performance, AI and surveillance data;
5. Service for the prevention of collisions with the ground and the management of zones of temporary restrictions and prohibitions. The service issues alerts and recommendations about a possible collision. This service requires aeronautical and altitude in-formation;
6. Service for dynamic control of UAV flight trajectories for flying over emerging obstacles or dangerous weather events in real time;
7. Service for decoding data from on-board instruments and their analysis for the investigation of aviation accidents.

3.2. Map projections for displaying objects on the Earth's surface

The size of AI database largely depends on the choice of the spatial coordinate system, with the help of which objects on the map are associated with real objects on the ground. The location of objects on the Earth's surface is determined using geographic coordinate systems. Geographic coordinate systems use spherical (three-dimensional) angular geographic coordinates (latitude and longitude), such as WGS 84 [17].

The coordinate system of a map projection is a rectangular system associated with a geographic system by a set of special formulas. Map projections never give an absolutely accurate representation of a spherical surface. In most cases, when choosing the type of projection, one of the main ones is the requirement for a possible reduction in distortion, and two cases are more common:

- weaken or even completely eliminate area distortion on the map;
- if possible, uniformly attenuate the distortions of all three main types, i.e. distortion of lengths, areas and angles.

Depending on the nature of the distortions, the following main types of cartographic projections are distinguished:

1. Conformal projections: projections that allow transferring angles on maps without distortion and maintain a constant scale in all directions at each point, although the scale is different in different places on the map. The angle on the ground is always equal to the angle on the map; a line that is straight on the ground is a straight line on the map.
2. Equal-area projections are projections that do not distort areas and maintain a single scale of areas throughout the map, due to which the areas of the figures on the map are proportional to the areas of the corresponding figures in reality.
3. Equidistant projections: projections in which there are no length distortions, and distances remain unchanged in certain directions.

The initial information of RUTM system is supposed to be stored in the form received from suppliers, that is, in various coordinate systems and projections. At the same time, the concept of building AI database provides for the transformation of all types of coordinate systems and projections into a single system of geographical coordinates WGS 84 and further storage and processing in this system. Presentation to the end user is carried out after recalculation in the selected projection, depending on the requirements for the nature of the distortion. Such an operation is not difficult and can be carried out using various conversion services from one coordinate system to another [18-20].

4. RESULTS

4.1. User interfaces of RUTM system

Table 1 summarizes the interfaces of the main users of RUTM system, which provide EP of UAV with all the information necessary for flight safety.

4.2. Selecting a projection to display on 2D map

The choice of projection for display on a two-dimensional map is not difficult, since the vast majority of mapping services currently use a simplified modification of the Mercator projection [21]. The Mercator projection, which is the de facto standard in modern 2D computer mapping, has simple transformation formulas and satisfactory distortion characteristics.

4.3. Choosing a projection for 3D visualization

In the case of depicting the figure of the Earth in 3D graphics, it is possible to model the ellipsoid directly in three dimensions, but modern computer technology is much better suited to work with "flat" elements that form a three-dimensional object. Therefore, the figure of the Earth can be represented in 3D graphics by a polyhedron close to an ellipsoid, the degree of tessellation (breaking the original polyhedron into smaller convex polyhedra) (tessellation) of which depends on the current level of detail.

When choosing a base polyhedron and the type of projection of geodetic coordinates onto its flat faces, the following requirements should be taken into account, if possible:

- globality of the projection, i.e. ability to set the projection for any point in the world as a function of a point on the surface of the sphere (x, y) = f(v);
- mutual uniqueness of the transformation, i.e. the existence of an inverse function v = f-1(x, y);
- absence of singular points, for example, points of poles;
- relative simplicity of mathematical formulas for direct and inverse projection transformation;
- as a little distortion as possible.

4.3.1. Choosing a base polyhedron

For the purposes of visualization, the differences between the earth's ellipsoid and the sphere are insignificant, so we will further consider the sphere. If we consider regular polyhedra as a basic one, at first only a cube meets the requirement of “squareness”, since the dodecahedron has pentagonal faces, and the octahedron, tetrahedron and icosahedron are triangular. However, by applying a shear transformation, we can transform the 4 pairs of faces of the octahedron into 4 squares, each of which will be the root node of the quadtree.

Thus, it is advisable to choose a cube (6 projection zones) or an octahedron (4 projection zones) as the base polyhedron.

4.3.2. Projection selection

The standard choice of the projection of a sphere on the face of a cube is an approach based on the Cube mapping method [22]. However, this option gives significant distortions in the scale of the points of the center of the face in relation to the vertices of the cube.

Significantly smaller distortions are produced by the projection of a sphere onto an octahedron, which is described by very simple formulas for direct and inverse transformations between projection coordinates and geodesic coordinates. This projection has good characteristics in terms of equal area, transmission without distortion of angles and scales, and is also easy to convert from geographic coordinates. In addition, this projection minimizes the redundancy of the original AI and saves up to 50% of the data volume compared to the original projection.

Therefore, the best option for 3D visualization of the Earth's figure is the projection of the sphere onto the octahedron, and all initial data must be converted to this projection.

5. DISCUSSION

The authors agree that this article does not reflect all aspects of building a database related to optimizing its dimension, in particular, the strategy of increasing RUTM service area to the scale of a region/state/planet is not considered:

- increasing the radius of the initial deployment zone with the formation of a single high-resolution model of the territory (scaling mode);
- supporting for multiple locations of small areas in a single database, united by a lower resolution/quality surface model (inset mode).

However, these issues require a more detailed consideration of approaches to increasing the detail of the Earth's figure in 3D graphics and are the subject of a separate article.

5.1. Main differences from previous work in this area

The novelty of the author's work is in the detailed requirements for user services in UTM system and determining the size of AI base necessary to ensure the safety of UAV and manned aircraft. The stated requirements can complement the regulations adopted by the leading countries that provide high-level requirements for the necessary user interfaces in UTM system. Compared to other articles in this field, the article has a more specific focus on user services and interface in RUTM system, and also offers an optimal choice for the spatial coordinate system and visualization of AI on a 3D map.

6. CONCLUSIONS

The scientific contribution of the work is in a detailed analysis and formulation of requirements for user services in the Russian traffic control system for UAV based on typical user actions. In addition, the authors determined the necessary volume of AI database required to ensure the safe flight of UAV and manned aircraft. The paper also proposes an optimal coordinate system for storing AI in RUTM database and suggests using a cube or octahedron as a base polyhedron for displaying AI on a three-dimensional map.

This work contributes to the development of UAV industry and provides valuable insights for government regulators and researchers working in the field of unmanned traffic control. Detailed analysis and formulation of requirements for user services in RUTM system can serve as a guide for the development of similar systems in other countries. In addition, the proposed methods for storing and displaying AI can improve the safety and efficiency of unmanned and manned flights.

The article complements the existing literature on UTM by providing specific recommendations for developing user interfaces and services for RUTM system that can be used as a basis for similar systems in other countries. The article also discusses the optimal spatial coordinate system for storing and presenting AI, which is an important point in the development of UTM systems.

In general, this work makes a valuable contribution to the development of UAV industry and the improvement of unmanned traffic control systems.

Thus, based on the analysis carried out, the following conclusions can be drawn:

- to ensure the safety of UAV flights, various information services are needed, the minimum list of them is given in the Table 1;
- information support for the operation of these services is provided using AI database;
- the best option for building this database is to store and process AI in a single system of geographical coordinates WGS 84;
- information is provided to end users by recalculating information in WGS 84 into the selected projection, taking into account the requirements for the nature of distortions;
- as a projection for displaying on 2D map, it is advisable to use the Mercator projection, which is de facto the standard one;
- when displayed on 3D map, to minimize the dimension of AI database, it is advisable to use a cube (6 projection zones) or an octahedron (4 projection zones) as a base polyhedron, and a projection of a sphere onto an octahedron as a projection.

One of the critical aspects of the discussion in the author's article is the lack of a comparative analysis with other existing UAV motion control systems. Providing such an analysis would help readers understand the unique features and benefits of RUTM system and its comparison with similar systems around the world.

In addition, it would be useful to discuss potential problems and limitations in implementing the proposed requirements for the user interface of RUTM system and AI database. For example, the costs and resources required to develop and maintain the necessary infrastructure can be significant. Consideration of these issues would provide a better understanding of the feasibility and practicality of RUTM system.

In general, the article provides valuable insight into user services and the organization of AI in RUTM system to ensure the safety of UAV. However, adding a comparative analysis of similar systems and a discussion of potential implementation issues would improve the overall quality of the article.

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Table 1. User interfaces of RUTM system

User interface	Interface purpose	Additional information
Airspace constructor interface	For introduction, editing AI, terrain maps and obstacles	
Remote pilot interface	For registration of EP and UAV	
	For displaying the following information	Terrain
		Power lines in the flight area
		Up-to-date information on flight restrictions and restricted areas and other AI
		Map of the area for selecting the take-off and landing sites, taking into account the possibility of access to them
	For getting acquainted with the actual and forecast weather information on the day of flights	
	For performing calculations of aeronautical flight elements	
	For making a flight plan	
	For interacting with the main center of unified ATFM	
	For monitoring the parameters of UAV and its flight	
Provider interface	For preparing a daily air traffic plan	
	For interact with other dispatchers	
	For interacting with EP	
	For ensuring the release and reception of UAV	For clarifying the technical condition of the aerodrome of departure and destination
	For assessing the air situation	For the presence of restrictions or a ban on the flight of UAV
	For assessing the meteorological situation	
	For assessing the ornithological situation	
	For UAV flight control	UAV flight path control
	For keeping a log of UAV flights	
External user interface	For analyzing flight data with uploading analytical reports	