

Short-Range Navigation Radio System Simulator

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Abstract

The work is devoted to the description of the key aspects of the development and use of a computer simulator of a short-range radio engineering system. The simulator allows to simulate a wide range of situations of interaction between the beacon and the aircraft on the ground. So, it is possible to link the aircraft and the beacon on a real map of the area at the required scale. Set and change their parameters at the required time. Build separate aircraft flight routes. It is possible to create and use entire flight scenarios. The system has worked out not only algorithms and functionality, but also the interface and visualization system of the simulator. This allows to effectively use the simulator for training purposes. Moreover, the simulator works in real time. And it is fully integrated, that is, it adequately takes into account all the main factors of influence that must be taken into account in the subject area to describe the interaction between the aircraft and the beacon. The simulator was highly appreciated by experts in the subject area.

Keywords

RSBN Simulator, aircraft, beacon, flight route, range, azimuth, visualization

1. Introduction

Currently, the ICT market segment dedicated to the development and use of simulators for a wide range and purposes is actively developing. The best known are driving simulators and biomedical simulators. The main goals of developing such simulators are to provide an opportunity to dive into the process under consideration as realistically as possible, to get a holistic view of it, to learn how to effectively manage an object / process. For example, by plane. The development of modern computer simulators of short-range radio navigation systems (RSBN) is relevant, mainly for the purpose of operational training in working with RSBN.

At the same time, the RSBN simulator must holistically integrate the process of interaction between the aircraft and the beacon on a real terrain (map), in real time. The simulator should provide a better visualization interface and the necessary functionality for simulating a wide range of situations, for a relatively quick understanding of the essence of the process, mastering the basic mechanisms of interaction between the aircraft and the beacon.

In order to achieve these goals, the following main tasks are solved in the work:

- An analysis of the current state of the issue in the subject area is given.
- Requirements for a modern RSBN simulator, basic methods, algorithms and implementation technologies, functionality, requirements for interface and visualization, for using scripts, and much more are described.
- A description of the proposed simulator, experiments with it, the results of experiments is given, their interpretation, recommendations, performance evaluations are given.

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2. Related Works

Analyzing the latest reviews [1-3], one can see that in recent years, technologies for building and visualizing simulators in robotics, medicine, and transport have been dynamically developing. The use of modern information technologies and computer technology makes it possible to simulate real situations in the subject area as accurately as possible when creating simulators. Thus ensuring the maximum learning effect when using modern simulators. In this regard, the development and transfer of technologies in the field of development of computer simulators of RSBN is relevant [4-6].

In this regard, [4] proposes a model for improving positioning efficiency through co-positioning in a partial GNSS environment in special purpose networks. In [6], a description of the model and technologies for modeling scenarios, as well as generating several targets with individual ranges and speeds for radars of a continuous signal with a frequency-modulated sequence is presented (LFM). In [7], the results of research in the field of positioning based on magnetic location are presented – a new tool for modeling the magnetic field is presented, taking into account the specification and the area of localization. The work [8] presents short-range intelligent navigation technologies based on IoT. In [9], a new algorithm is proposed for the localization of a short-range vehicle in order to compensate for the gap in the distance according to the GPS device. This solves the problem of low signal-to-noise ratio. In [10], the problem of using a stationary calibration device for navigation systems to test the DME reception functions and the ATC-1400A DME tester is solved. In [11], a solution is given to the problem of using new software for efficient processing of radio navigation signals, reducing the effect of interference, and increasing the efficiency of spectral signals. A range of computer models is proposed, and the results of laboratory studies of FBMC structures are described. In [12], the problem of constructing a linear flight controller with a variable gain parameter is solved to improve the efficiency of flight simulators (IFS) under conditions of large parameterization. In [13], efficient algorithms and a simulator are proposed for simulating a navigation cycle by waypoints on a terrain map. The paper [14] presents a model of a dynamic low-flying aircraft flight simulator with several degrees of freedom. In [15], a new predictive model based on the back input method was proposed. The paper [16] proposes a new technology for using multi-core platforms to automate onboard data processing, as well as a corresponding test platform for evaluating the efficiency of using the autopilot system. In [17], algorithms and models are presented, on the basis of which a simulator for checking the aircraft take-off warning system, including visualization of the control panel, is built. The paper [18] presents the results of using a genetic algorithm to optimize some processes inside flight simulators. The paper [19] presents the results of simulation modeling of the elements of the navigation system on the time scale to assess the effectiveness of their joint work and mutual influence on each other.

An analysis of the current state of the issue shows significant progress in the field of building a variety of simulators and the relevance of using the models, algorithms and technologies developed in them, including in the field of visualization, to build simulators of short-range navigation radio systems, taking into account the requirements of the time. Including for the short-range navigation radio system [20, 21].

The key requirements for such a simulator are consistent accounting for the entire complex of influencing factors, a high level of visualization, real-time operation on real maps of the area, the ability to quickly correct the situation, work with flight scenarios [20-22].

In terms of the development of such simulators, the most relevant aspects are the introduction of: modern image processing systems and computational intelligence [23, 24] to improve the perception, learning and integrity of data stream processing; latest solutions in the field of network optimization [25] and hardware technologies [26, 27] for high efficiency of network communication; modern methods and tools for implementing the interface and visualization of the simulator to ensure a high level of staff learning in e-learning systems according to modern assessment criteria [28, 29].

3. Methods and materials

The section presents the principles of organization and functioning of the short-range navigation radio system. Short-range navigation systems are designed to determine the navigation parameters that

characterize the position of the aircraft in the polar coordinate system (azimuth, range) relative to the radio navigation point (radio beacon), the position of which on the ground is precisely known [30].

The basis of the system is a network of independent ground-based radio beacons, which determine the navigation parameters. There are azimuth, range finding and azimuth-ranging radio beacons, which are placed at airfields and at points characteristic of airway sections. Parts of the range of meter and decimeter waves have been allocated for work. Therefore, their range is limited by the line-of-sight range [30, 31].

The main purpose of the short-range navigation system is to bring the aircraft to the landing airfield and provide navigation when flying along the route over the continental part of the earth's surface.

According to the classification, short-range radio navigation systems are classified as goniometer-range radio navigation systems, in which the aircraft's position is determined on board by the intersection of position lines equal to its azimuth and range relative to the ground radio beacon. Such systems include an azimuth (goniometer) channel, a ranging channel, and a ground indication channel. All three channels are used by both ground and airborne devices (complex of ground and onboard devices) [32].

3.1. Requirements for the RSBN simulator

The purpose of the developed simulator is to simulate the signals of the radio beacon and the aircraft, emulate the equipment that generates and receive these signals, as well as visualize the navigation equipment on the side of the radio beacon and the aircraft in relation to the terrain map.

Multi-purpose use of the software simulator is planned:

- Construction of aircraft flight scenarios.
- Modeling of radio signals passing in the ranging and azimuth channels.
- Simulation of the receiving-transmitting equipment that performs the formation and selection of signal components.
- Visualization of navigation instruments that control the radio beacon and display the position of the aircraft relative to the beacon: azimuth (bearing) and distance.
- Verification of real signals and equipment of the short-range radio navigation system.

The requirements for the simulator are developed in accordance with the fulfillment of the tasks for the purpose of the RSBN (ensuring the measurement of its azimuth and slant range on board the aircraft relative to the installation site of the ground equipment (radio beacon), which must be identified on the aircraft), the need to ensure the compatibility of the onboard and ground equipment of the RSBN, analysis ICAO requirements [34] for radio navigation aids for aeronautical telecommunications, certification requirements for ground-based radio technical support in civil aviation, requirements of the MIL-STD-291C standard [35], ITU recommendations ITU-R M.2013 [36] and performance analysis modern transponders (responders) RSBN [37].

The ground equipment simulator should simulate operation in the frequency range from 962 to 1213 MHz. The model of the ranging channel of the RSBN systems provides the determination of the slant range to the aircraft relative to the radio beacon, depending on the altitude of the aircraft in the zone. The RSBN azimuth channel provides the determination of the aircraft azimuth relative to the radio beacon. In the horizontal plane, the ground equipment simulator must have a 360° coverage. When determining the width of the coverage area in terms of elevation, it is quite acceptable to perform a review in the vertical plane in the sector of elevation angles from 0° to 45°. The range view area size is determined by the theoretically possible radio communication range, which is defined as the range of the radio horizon for aircraft flight altitudes. For a height of 20 km, the range of the radio horizon is 550 km.

The accuracy of azimuth and slant range measurement is determined by the onboard equipment and the compliance of the RSBN ground equipment signals with the requirements of their characteristics. The ground equipment simulator must ensure the reception, formation and emission of signals. In this case, the deviation of the range response signal delay in the ground transponder (radio beacon) should not exceed $\pm 0.1 \mu\text{s}$, which leads to the introduction of an error of $\pm 15 \text{ m}$ into the total range measurement error on board the aircraft. The accuracy of the azimuth measurement should be 1/3 degree. Slant range accuracy shall be 926 m (± 0.5 miles) or 3% of range, whichever is greater.

For the operation of ground equipment, it is necessary to allocate 252 frequency channels in the range from 962 to 1213 MHz with a step of 1 MHz. This makes it possible to implement 126 X frequency code channels and 126 Y frequency code channels.

3.2. Basic principles and operation algorithms

The researched short-range navigation system has two range-finding and azimuth channels [21]. The RSBN system configuration is shown in Figure 1.

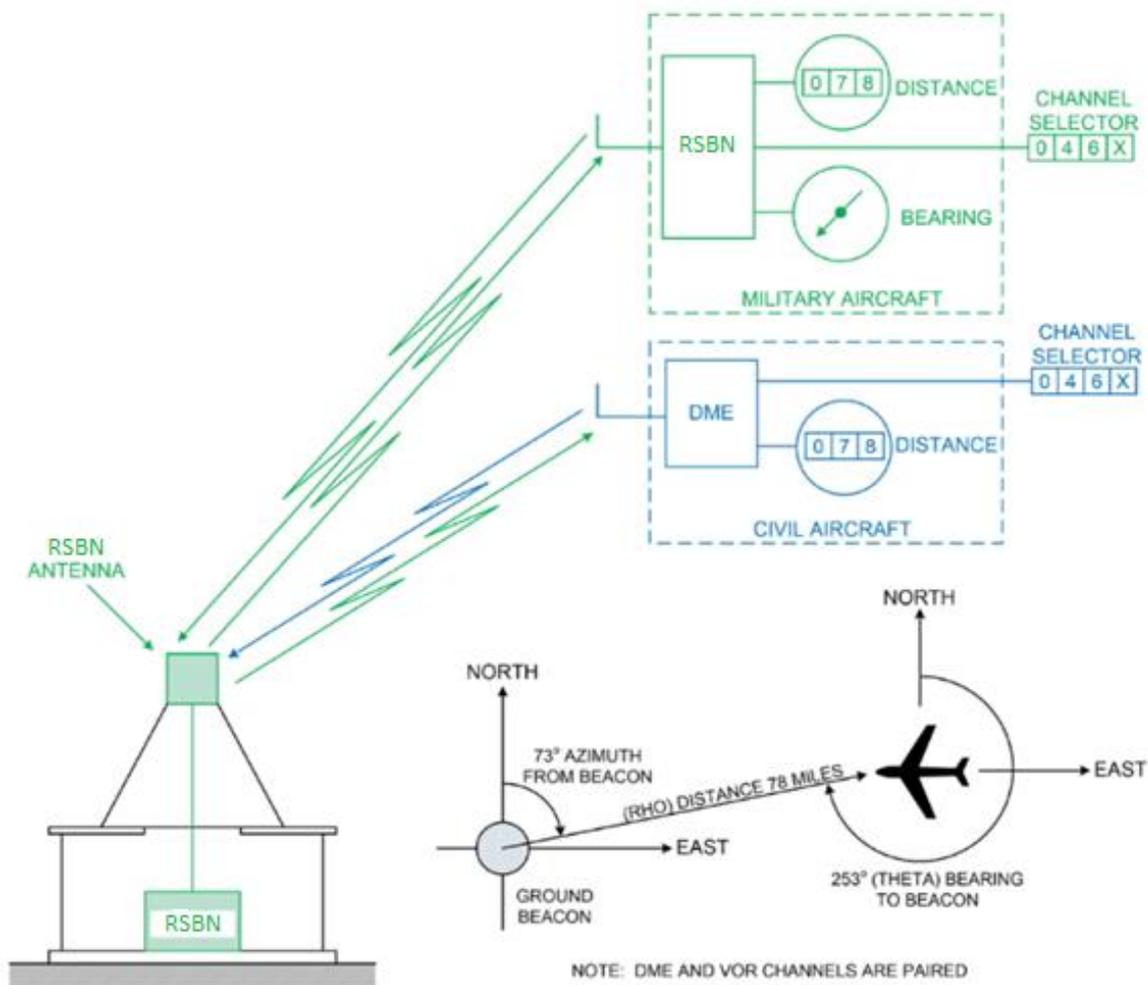


Figure 1: Radio engineering system of short-range navigation [33]

The ranging channel of the RSBN system consists of an interrogator installed on board the aircraft and a beacon transmitting responses. Depending on the level of equivalent isotropically radiated power generated and the design of the interrogator, slant ranges of up to 400 nautical miles (740 km) can be measured, but in practice the measurement range is limited by the maximum radio line-of-sight (RLOS) range. The aircraft transmitter emits regular pairs of pulses, the so-called interrogation pulses, which are received by ground-based installations (beacons). The RSBN system pulses have a duration of 3.5 μs at a 50% amplitude level. The time separation between a pair of request pulses is 12 μs (X channel) or 36 μs (Y channel). After receiving a pair of interrogation pulses, the ground station checks the shape of the pulses and the interval between them. If these parameters are within acceptable limits, it transmits a response after a fixed delay with a frequency offset of ± 63 MHz on the interrogation frequency depending on the selected channel on the pulse code. The interval between beacon response pulses is 12 μs (X channel) and 30 μs (Y channel). After receiving the response, the interrogator calculates the

instantaneous range of the oblique beacon from the time elapsed between receiving a pair of request pulses and receiving a pair of response pulses.

The azimuth channel of the RSBN system provides information about the azimuth position of the aircraft. Azimuth information is provided by applying amplitude modulation of the transmitted pulses by the ground beacon. This pulse amplitude modulation (PAM) is created by using a mechanically or electronically scanned beacon antenna. Changing the azimuthal radiation pattern in the form of lobes with a width of 15-135 Hz with a maximum allowable modulation factor of 55 percent reduces the signal level of the response pulses by up to 10.7 dB below the maximum level of the equivalent isotropically radiated pulse power without PAM. In order for the interrogator to decode the northing antenna pattern orientation data from the PAM, the beacon transmits an additional 900 pulse pairs consisting of a North Direction Pulse Group (NRPG) and additional Fine Reference Pulse Groups (RPG). To obtain accurate azimuth information, and to be able to match at least 100 aircraft with 70% response efficiency, at least 3600 pulse pairs must be continuously transmitted.

RSBN range/bearing information is used to support on the route, arrival and departure operations, as well as approach, landing and rendezvous operations. For these applications, RSBN can be used in conjunction with other navigation aids such as precision approach RADAR and instrument landing system (ILS). In addition, pilots use RSBN system azimuth information for published flight procedures and routes for both instrument and visual meteorological conditions (IMC and VMC respectively).

4. Experiment

This section describes the software architecture of the RSBN simulator as an emulation of system, its functionality and visualization modules; describes the planning and conduct of experiments using the proposed simulator in various modes of operation. The experimental results and their interpretation are given in the following two sections.

4.1. Simulator RSBN

According to the problem statement, a RSBN simulator was developed, which we will use to demonstrate and conduct experiments. The proposed simulator (in the form of specialized software) performs software emulation of the operation of real equipment of the RSBN system components, such as RSBN system beacons and aircraft avionics.

The application was developed using Web-technologies according to the principles of client-server architecture. The simulator software architecture is shown in Figure 2.

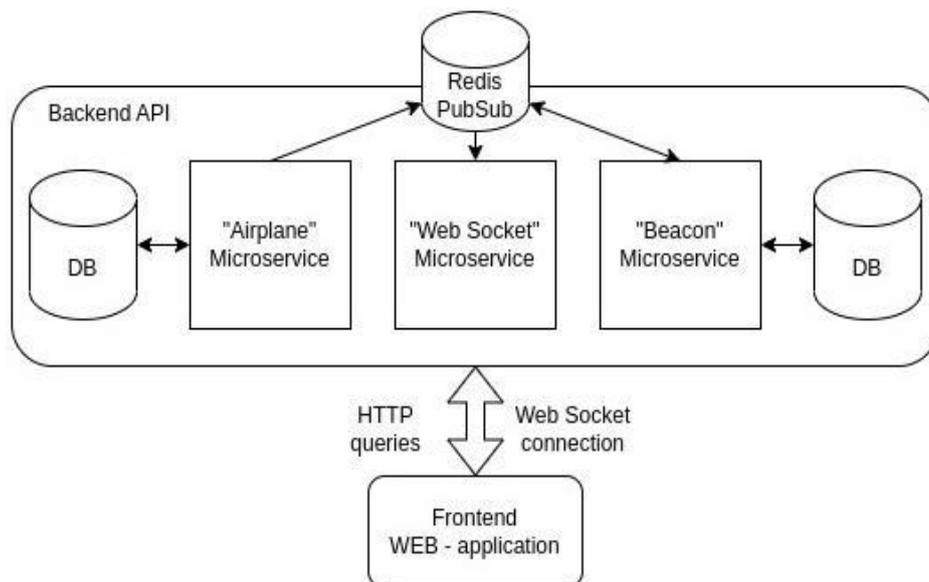


Figure 2: Software architecture

The backend API is built using microservices and is divided into logical parts of aircraft processing and beacon processing in the RSBN system. The microservices work using the Node.js runtime, and the microservices are written using the TypeScript programming language, which is an add-on over JavaScript and has strong typing, and the express library, which provides components for server-side logic.

The “Airplane” microservice is responsible for aircraft processing, it allows you to create and store aircraft flight scenarios and run them on demand.

Microservice "Beacon" allows you to save the arrangement of stations by saving the position of beacons on the map by coordinates and their parameters, as well as further editing the parameters of beacons, for example, visibility radius.

All microservices are interconnected by an event bus implemented by Redis PubSub functionality. So, after launching the flight scenario, every second a signal with information about the position of the aircraft and its parameters such as speed, altitude and direction of flight will be sent to Redis PubSub.

The “Web Socket” microservice is subscribed to information about the position of the aircraft, as well as information from the beacons and serves as a connecting part between the Backend API and the Frontend Web-application for the constant transmission of real-time data for display on the simulator's user interface.

In general, the software interface of the Frontend Web-application part is shown in Figure 3 and represents a real map of the area with target visualization modules and controls.

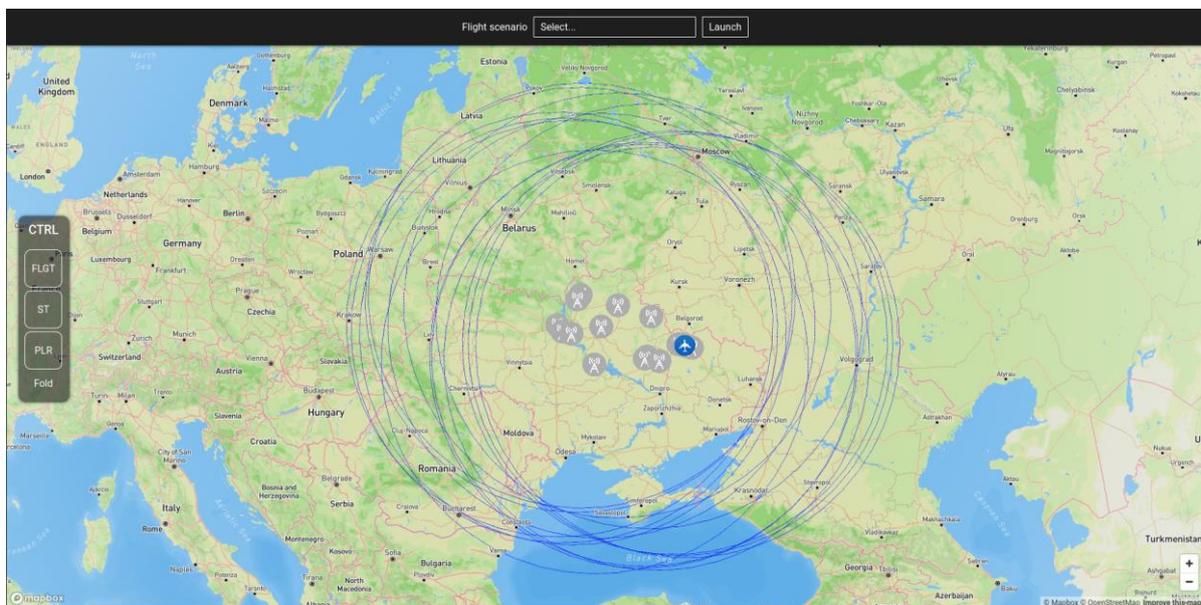


Figure 3: Software interface

Using the user interface, you can place beacons of the RSBN system at any point on the map, where it is necessary, and set or edit their parameters. Stations are displayed by default as gray icons of “inactive” stations with their visibility radius shown as a circle.

Also, the user interface allows you to create aircraft flight routes (scenarios), as in Figure 4.

Creating an aircraft flight route is carried out by simply placing the corner points of the route, for which, in the special form “Plane params”, the instantaneous parameters of the altitude and speed of the aircraft are indicated for this point. The “Scenario Points” table displays information on the corner points of the route, which includes the coordinates of the point, the direction between this and the previous point, the speed and altitude of the aircraft at this point.

Before saving a flight scenario, its name is indicated for further display in the flight scenario selector.

During the saving of the route, the process of interpolation between points takes place, in which the points of the position of the aircraft in every second and the parameters of the aircraft at these points are calculated. Ultimately, all information is saved in a csv file, which, if necessary, can be imported into any other software or in the flight scenario selector for another user.

Using the selector of pre-created scenarios, the required flight scenario is launched, which creates a unique scenario stream, opens a Redis PubSub channel to which the location of the aircraft is sent every second, followed by displaying its marker on the map, as in Figure 5.

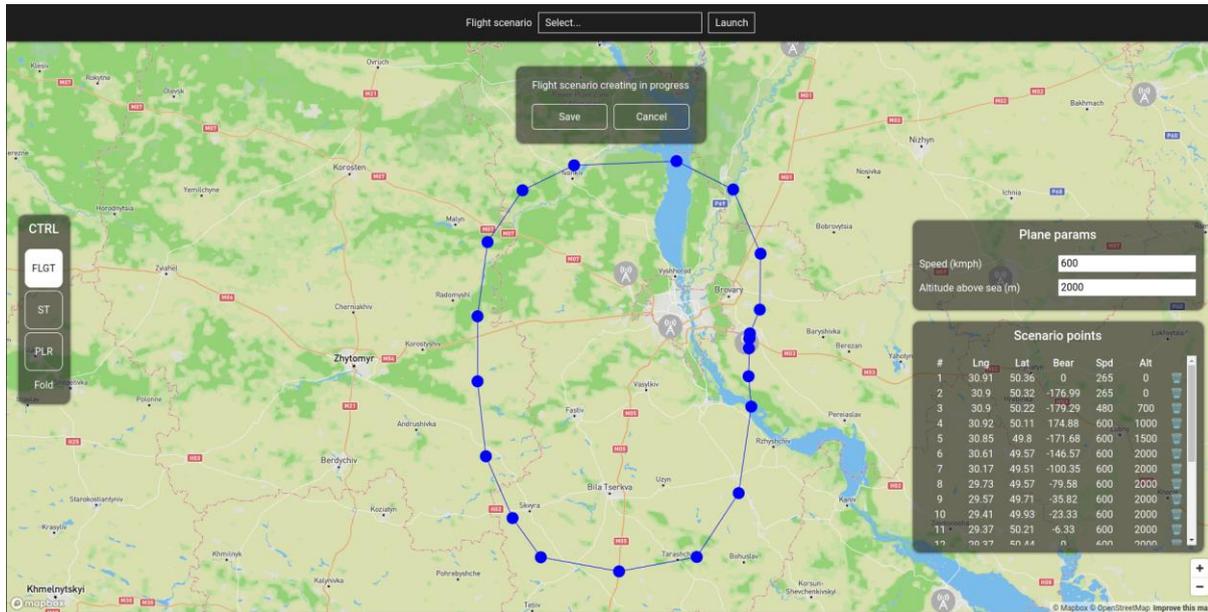


Figure 4: Creating an Airplane Flight Route

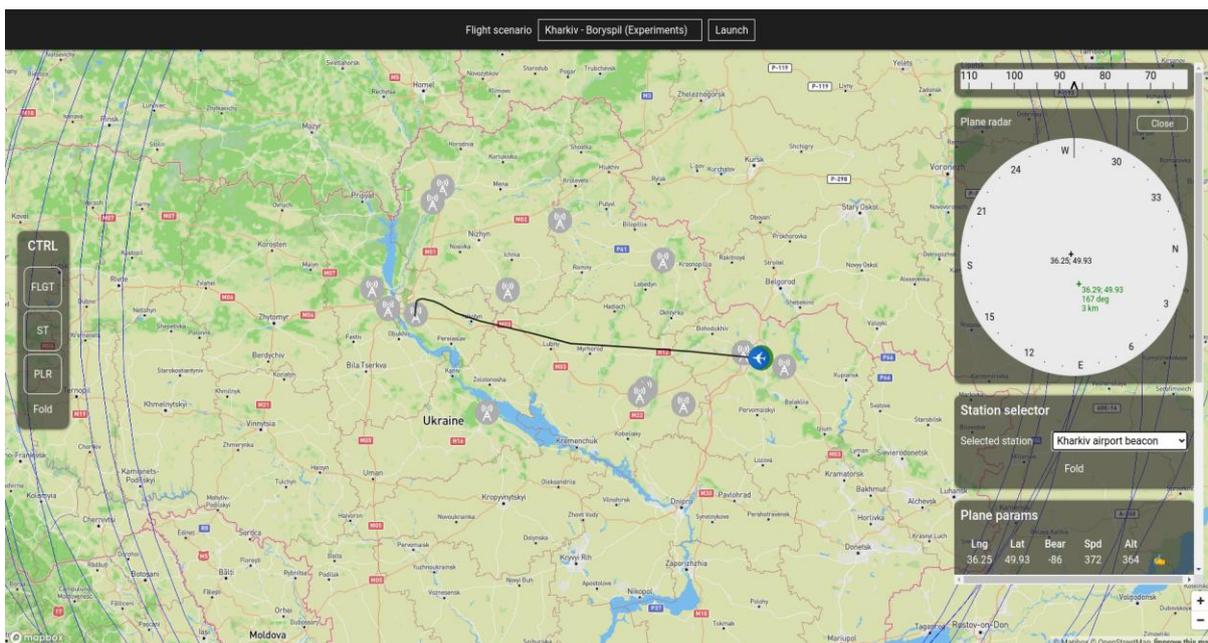


Figure 5: Displaying the enabled flight scenario

In the process of processing each point of the scenario, the operation of the onboard aircraft system is emulated as in Figure 6, aimed at calculating the parameters of beacons in the visibility zone, such as: slant range (km); direction to beacon (degrees).

Programmatically, each radar has a variable radius of action in order to conduct experiments with beacons with different visibility radii. Also, the aircraft radar can programmatically change the radius for the displayed beacons for ease of display and better readability in the interface.

The user interface runs in a web browser environment and is built using TypeScript and the React library, which is used to easily build complex user interfaces. The map uses the Mapbox library, which uses data from the Open Street Map project to display maps.

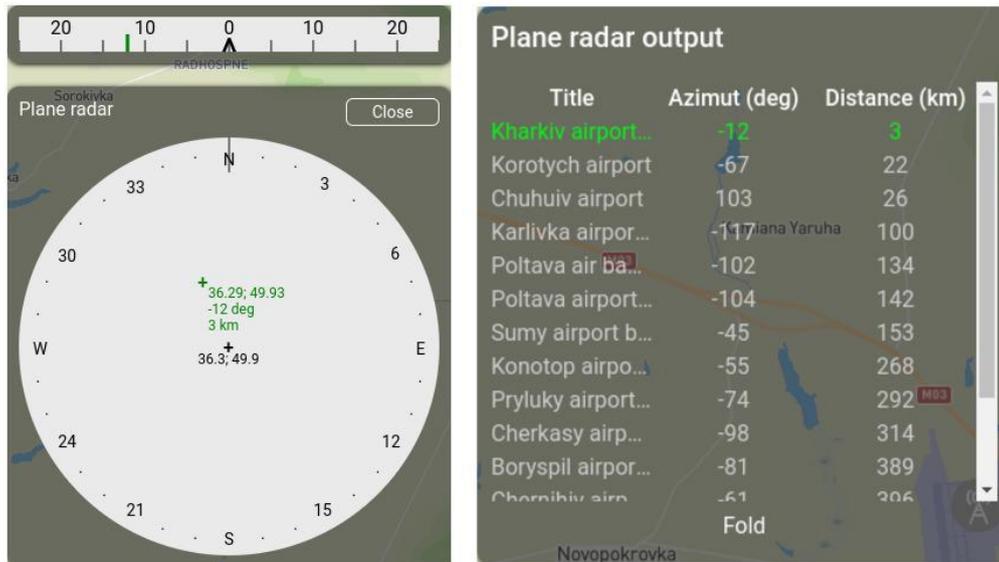


Figure 6: Aircraft radar and list of beacons showing range and direction

A special kind of flight scenarios are scenarios that consist of a single point. This type of scenario is necessary to test the behavior of the radar under fully controlled aircraft parameters. After launching such a scenario and the appearance of the aircraft, the “Plane params” form appears, shown in Figure 7, in which you can edit all the necessary parameters of the aircraft, such as:

- Position on the map, coordinates (lat, lng).
- Aircraft direction (degrees).
- Aircraft speed (km/h).
- Aircraft altitude (m).

Together with the manual beacon selector in the “Station selector” section, such scenarios allow testing the correct operation of all system elements.

Figure 7: Form for changing aircraft parameters and selecting beacons

4.2. Experiment planning

The main way to conduct experiments with the simulator is to run aircraft flight scenarios, in which you can see time-varying indicators from the software-emulated aircraft on-board system. With an assessment of the result in terms of accuracy using expert analysis procedures. There is no time estimate as the simulator is running in real time.

Several experiments are planned to demonstrate three flight modes:

- Aircraft flying in a straight line between two points.
- flight from Kharkiv to Boryspil with the use of a large number of waypoints.
- single point mode, which serves for fine tuning.

Before conducting the experiment, two preparatory stages must be carried out:

- Placement of beacons on the map.
- creation of an aircraft flight scenario.

The placement of beacons is carried out from the “CTRL” control menu by activating the “ST” button, after which it is necessary to place the beacons on the map with the mouse, setting parameters for the beacons such as Distance and Frequency. The result of the placement of RSBN beacons is shown in Figure 8.

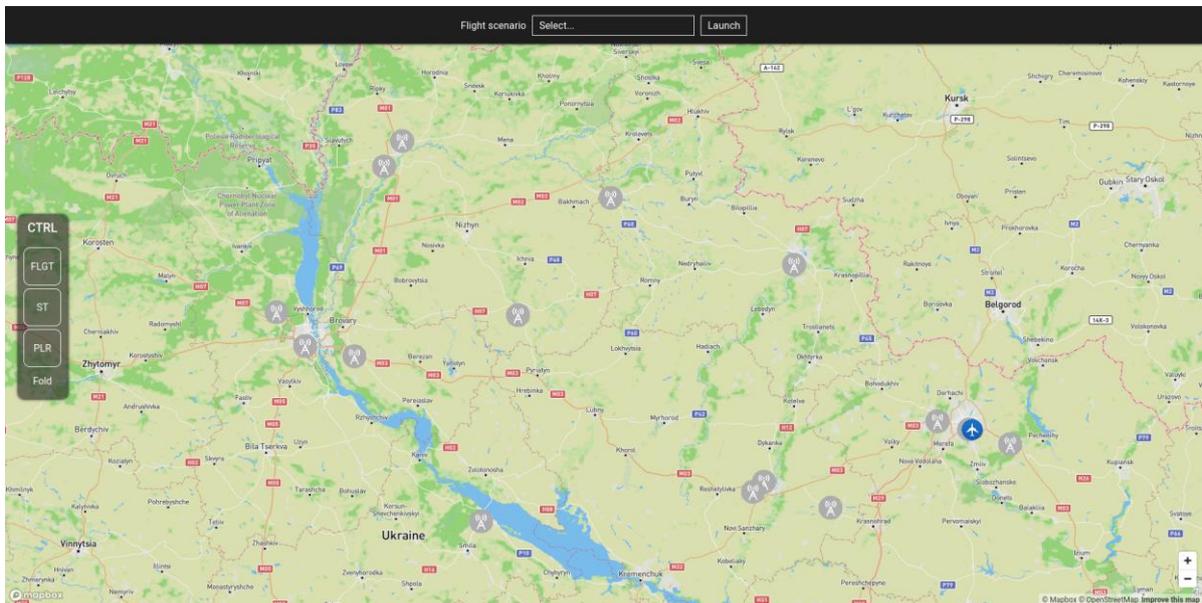


Figure 8: Showing beacons on the map

For already created beacons, you can change their Distance and Frequency parameters using the form from Figure 9, which displays the default parameters.

Figure 9: Editing beacon parameters

The transition to the creation of a flight route is carried out from the “CTRL” menu by activating the “FLGT” button, after which it is necessary to indicate the corner points of the aircraft flight using the mouse on the map. Corner points are those points where there is a change in any flight parameter, for example, a change in heading, a change in altitude and speed. Several options for creating a route are available:

- Set of points.
- Two points.
- One point.

Figure 10 shows the result of creating a route from a set of points. At the bottom, in the “Scenario points” section, a list of points with instantaneous aircraft parameters at a given point is displayed, and in “Plane params” the aircraft parameters for the next point are changed.

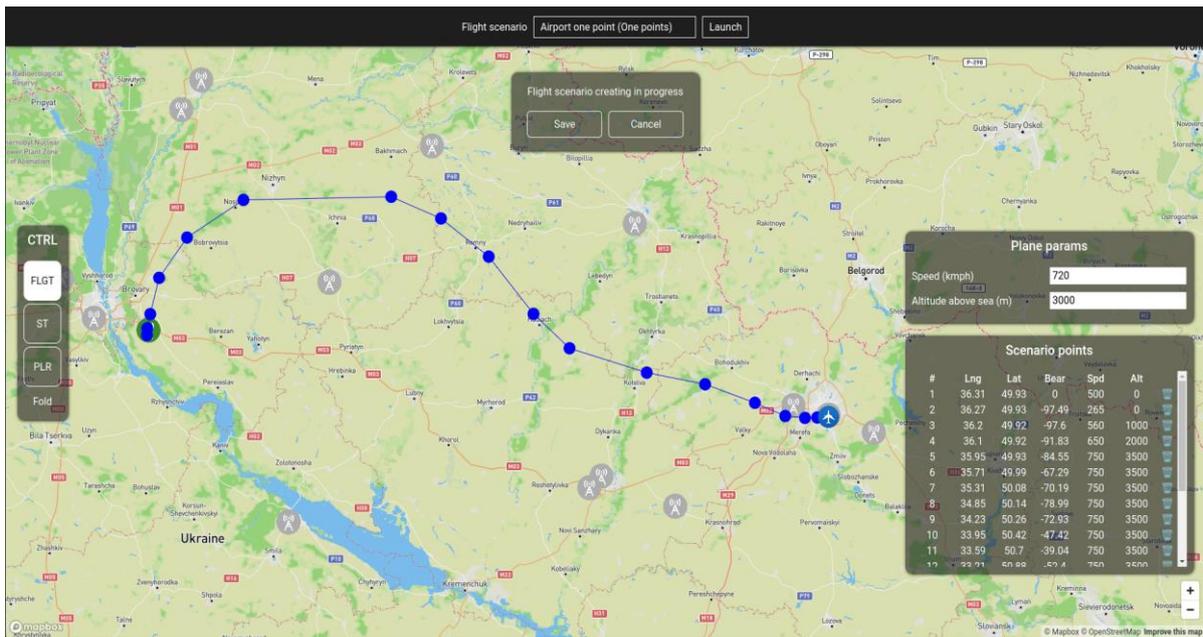


Figure 10: Creating a flight scenario with multiple points

Also was created a flight scenario which consists of two points, with a flight from Chuguev to Boryspil, which is shown in Figure 11 and a single point scenario, which will be used for thin tests.

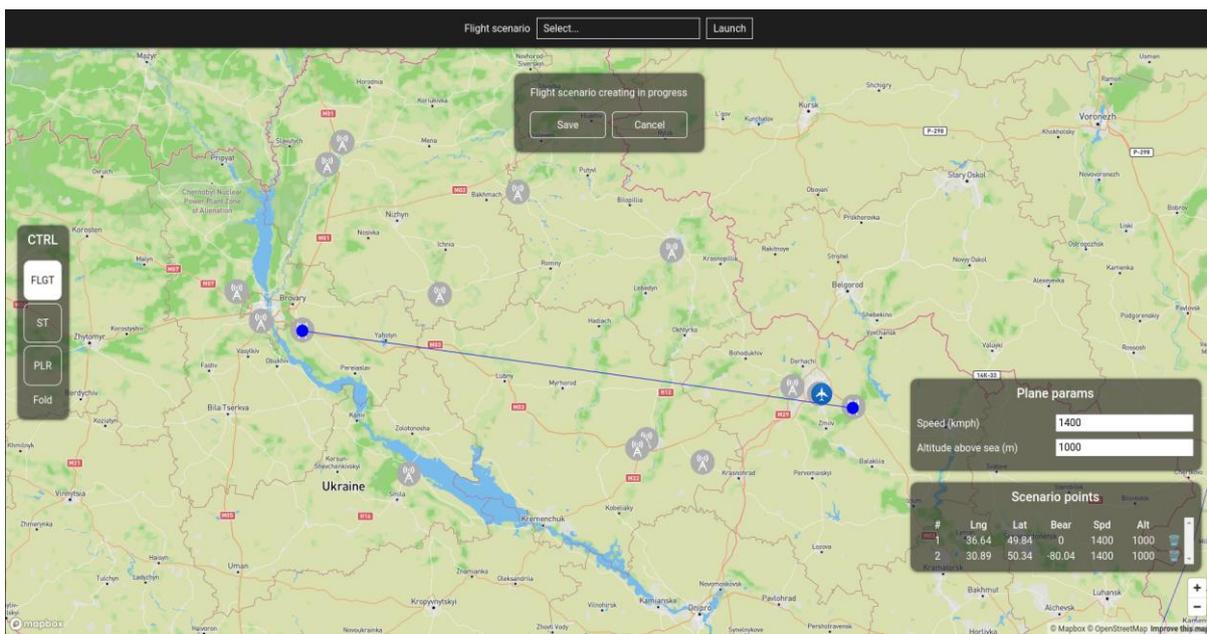


Figure 11: Creating a two-point flight scenario

5. Results

According to the plan, experiments were carried out with the launch of flight scenarios, the removal of parameters at different points in time, and we evaluated the errors by a group of experts.

The created flight scenario between two points was interpolated into a file with 1065 points, that is, the entire scenario takes 17 minutes and 45 seconds at a flight speed of 1400 km/h. Distance from Chuguev to Boryspil. The interface takes on the appearance shown in Figure 12, where you can see the display of the flight route of the aircraft, the station with which the aircraft interacts in the form of a green marker.

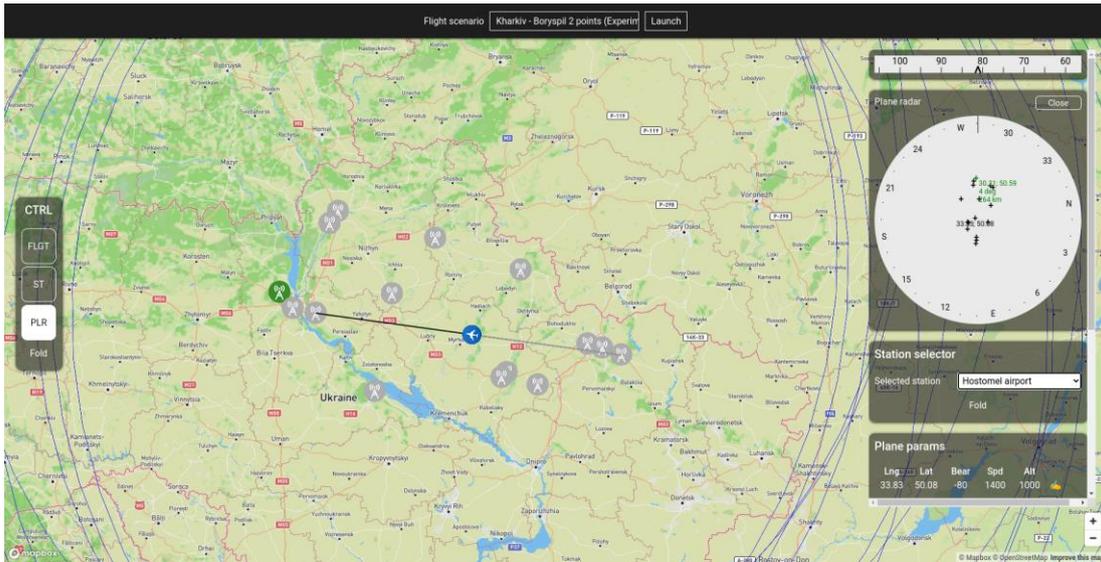


Figure 12: Airplane flight between two points with display of parameters

Figure 13 shows an aircraft radar displaying the beacons in the radar field of view of both the aircraft system and the beacons. The marker of the beacon selected for interaction turns green and next to it appears the display of the beacon coordinates, the direction to the beacon and the slant range to it.

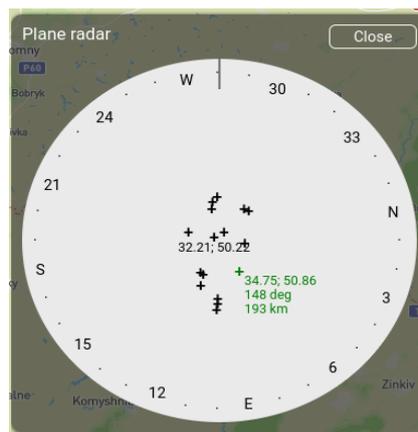


Figure 13: Aircraft radar showing beacons

Table 1 shows the parameters taken at different times of the passage of the two-point scenario from the on-board system of the aircraft, which shows the parameters of the direction and slant range with respect to the beacon “Summy airport beacon”, which is located at the coordinates 34.75,50.86.

Table 1
Values from the aircraft system in a two-point scenario

Aircraft position (lat,lng)	Aircraft direction (degrees)	Distance to beacon (km)	Direction to beacon (degrees)	Altitude (m)
36.34,49.86	-80 (280)	158	35	1000
36.12,49.88	-80 (280)	146	39	1000
35.88,49.90	-80 (280)	133	43	1000
35.52,49.94	-80 (280)	116	52	1000

34.88,50.00	-80 (280)	96	77	1000
34.18,50.05	-80 (280)	98	104	1000
33.59,50.10	-80 (280)	117	124	1000
33.19,50.14	-80 (280)	137	134	1000
32.21,50.22	-80 (280)	193	148	1000
31.77,50.26	-80 (280)	221	151	1000

Table 2 shows the parameters taken at different times of the passage of the scenario with multiple points from the onboard system of the aircraft, which shows the parameters of the direction and slant range with respect to the beacon “Boryspil airport beacon”, which is located at the coordinates 30.89,50.35.

Table 2
Values from the aircraft system in a multi-point scenario

Aircraft position (lat,lng)	Aircraft direction (degrees)	Distance to beacon (km)	Direction to beacon (degrees)	Altitude (m)
36.15,49.93	-86 (274)	378	5	1727
35.41,49.98	-84 (276)	324	3	3570
34.80,50.01	-86 (274)	281	5	4822
33.24,50.08	-76 (284)	170	-3 (357)	6000
32.48,50.20	-77 (283)	114	-4 (356)	6000
31.71,50.32	-72 (288)	59	-14 (346)	5521
31.38,50.41	-61 (299)	35	-40 (320)	3785
31.08,50.49	-79 (281)	20	-61 (299)	2000
30.92,50.48	-126 (234)	15	-47 (213)	2000
30.90,50.45	-171 (189)	12	-7 (353)	1688

Experiments were also carried out with a scenario consisting of a single point. In this kind of scenario, the aircraft appears at a certain point and remains stationary. The main controls are the form for setting the aircraft parameters, where the coordinates, direction and altitude of the aircraft are set, as well as the beacon selector for switching as in Figure 14. In general, the results of the experiment are similar to the two previous ones.

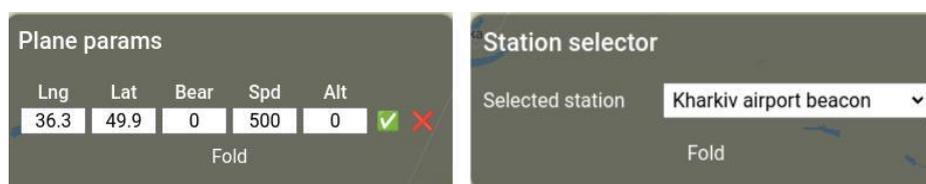


Figure 14: Form of aircraft parameters and selection of beacons

6. Discussions

The main purpose of the software is to carry out computer simulation of the interaction between the aircraft onboard system and RSBN beacons by means of a computer, which will reduce costs and eliminate the need for full-scale experiments with real expensive equipment, which is not even always possible to obtain. Also, with the help of the simulator, it is possible to demonstrate the principles of operation of the RSBN for future or existing pilots and for the maintenance personnel of the stations.

The work carried out on the development and conduct of experiments showed that a computer simulator allows you to quickly and efficiently conduct experiments to study the operation of all components of the RSBN system in a common bundle, while being able to control individual parameters of these components of both aircraft and beacons at any time.

A convenient and simple interface, as well as wide software capabilities, allow you to quickly create flight scenarios and place beacons on the map, change parameters if necessary, and carry out real-time simulation on a real map of the area.

Support for several types of scenarios allows you to simulate both an aircraft flight close to reality by fine-tuning aircraft parameters such as speed and altitude and laying the most accurate route, as well as more experimental ones, such as a flight between two points or even place the aircraft at an arbitrary point and change its parameters, testing the correctness of the processing results in the on-board system of the aircraft. Providing training for employees who can interact with the software is easy.

Evaluation of the results of experiments (simulation) by experts using the procedure for parallel estimation of azimuth and slant range showed that the simulator provides real-time parameter estimates with an error that is not statistically significant. In total, more than 100 simulations of various flight options and interaction between the aircraft and the beacon were carried out.

For such an assessment, a group of 7 experts in the subject area was involved. Experts with the same qualifications individually and independently of each other launched flight scenarios, measured parameters and compared estimates of simulator parameters with observed ones. This was done based on the use of standard tables (such as Table 1, Table 2). Then, the parameter estimates were averaged, outliers were detected by the Grubbs criterion, and the voting procedure was implemented. In more than 99% of cases, the results of the evaluation and voting of experts coincided. Only in one case was a discrepancy found; it was caused by inaccurate data entry. It was corrected upon re-checking. As a result, with an allowable error in engineering calculations, all expert estimates coincided with the simulator estimates.

A comprehensive evaluation of the experimental results showed not only the adequacy of the estimates of the azimuth and slant range parameters, but also the high efficiency of the simulator as a whole. Including scripting capabilities and visualization modules.

The proposed simulator can be used in practice (in online and offline learning systems) to build aircraft flight scenarios and its interaction with beacons on a real-time map. When using it, it is advisable to create and use flight scenarios in relation to the terrain, rather than separate routes.

Further development of the project depends on the demand for the technology in which the simulator works and includes the deployment of the system in a production environment as an MVP to start real testing by users who will use the software in their professional activities. By collecting feedback on the operation of the system and wishes for additional functionality, a further list of functional elements that can be added to the simulator can be formed.

At the moment, such functionality can be offered for development as support for multiple aircraft in a scenario, and integration of new interface elements that simulate the operator's workplace on the ground, as well as some new elements of the aircraft dashboard.

Separately, it can be noted that such an opportunity for development (in close cooperation with experts in the aviation field) is the implementation of support for streaming signals from sensors of real equipment that determine the position of the aircraft, altitude, speed, heading and other parameters for further processing inside the simulator.

7. Conclusions

The paper analyzes the features of the implementation of modern computer simulators, including algorithms and technologies, functionality, implementation of the interface and visualization. On this basis, the requirements were formulated and the specification of the RSBN simulator was developed.

The basic principles of the organization and functioning of the short-range navigation radio system, rangefinder and azimuth channels of the radio beacon and aircraft are considered.

The specification of the proposed implementation of the RSBN simulator software, which simulates the operation of RSBN components such as the aircraft on-board system and beacons in real time, is described. The following architecture and component descriptions provide a brief explanation of how the software works and the technologies used. The stages of planning and conducting experiments based on the use of scenarios are described, where the main possibilities in working with an ordinary user simulator in the process of creating flight templates and placing beacons were shown. The experiments were accompanied by a description of the system's capabilities to derive information from the aircraft's on-board system sensors, and the measurements themselves were carried out with sufficient accuracy, which is the main factor in the effectiveness of the simulator as software that provides emulation of the RSBN system components.

To evaluate the simulation results, a group of experts was involved, which simultaneously estimated the azimuth and slant range, compared them with the simulator estimates, evaluated the interface, capabilities and visual presentation of the results by the simulator. An analysis of the work of experts showed that the simulator provides real-time parameter estimates with an error that is not statistically significant. The simulator can be used in practice (in online and offline learning systems) to build aircraft flight scenarios and its interaction with beacons on a real-time map.

Recommendations are described regarding the use, as well as the prospects for the development of the simulator.

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