Complex System for Radio Location Field Quality Assessment

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Abstract

In the article designed by authors complex modeling system is presented. The main objective of the developed system is to assess the radar location field (RLF) quality of a specific grouping of radar reconnaissance equipment and a specific air situation. Also, in the manuscript subsystems of complex modeling system such as aerial object movement model, order of battle of the radar group, airspace survey model, processing of radiolocation information, task management and radar location field quality assessment block are presented.

Keywords[1]

Radio location field, radar, radar stations, aerial objects, automation equipment complex

1. Introduction

Radar stations are an important part of modern society. Estimating the effectiveness of the radar field is an important task with numerous advantages and relevance in various fields. In the field of security, radar systems are used to detect, track and identify objects in real-time. Evaluation of the effectiveness of the radar field allows you to identify possible problems and ensure safety at airports, sea and air transport, defense facilities, etc. In the fields of aviation, space and astronomy, radar systems are important for air and space surveillance, help in controlling the movement of aircraft and supersonic aircraft, space exploration, detection and study of planets and other objects. The effectiveness of radar systems directly affects the safety of aviation and space flights. In military applications, radar systems help in the early detection of attacks, the location of artillery firing points, and the determination of enemy troop movements. Assessing their effectiveness is critically important for the defense of national security. Radar systems also play an important role in weather forecasting and natural disaster detection. They make it possible to measure atmospheric parameters, detect radiation and other phenomena affecting the climate and environment. In seafaring, radar systems are used for navigation, helping ships and vessels to avoid obstacles and dangers. Radar systems can be used to monitor and supervise the production, transportation and storage of oil and gas, as well as to detect leaks and environmental pollution.

Given these applications and the need for accuracy and reliability, the evaluation of radar field performance remains critical to ensuring safety, accuracy, and productivity in many areas of our lives.

2. Literature overview

Many scientific works are devoted to the study of radar and the effectiveness of the radar field. The work [1] assembles a micron-scale infrared emitter, a millimeter-scale microwave absorber, and a metal reflector to propose a hierarchical metamaterial that reduces microwave scattering and reflects low-infrared waves. As a proof of concept, laser etching micro-manufactures an upper infrared shielding layer with a periodic metal pattern. At the same time, bottom square frustum metastructure composites are fabricated and optimized based on genetic algorithms. In the paper [2] authors extend the curvilinear

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collocated-grid finite-difference method, which has been developed in the study of seismology, to the 2D electromagnetic simulation of ground penetrating radar (GPR). The method combines curvilinear coordinates and a collocated grid, so it can better describe the geometry of the irregular interfaces than the traditional finite difference method and is more efficient than the finite element method which is suitable for complex geometries. In the article [3] a novel approach to monitor the postural activity of sows in farrowing pen using a millimeter-wave radar imaging system is presented. Three-dimensional images of the scene are obtained from a 77 GHz Multiple-Input Multiple Output radar and the mechanical scanning of the radar beam. In the paper [4] scientists develop a signal processing algorithm for conformal MIMO radar. According to the Least Square (LS) criterion and Maximum Likelihood (ML) criterion, the target Sinclair matrix is estimated. Paper [5] addresses the problem of tensor filters in application to space–time-range clutter suppression for FDA-MIMO radar. The characteristics of space–time-range clutter are discussed to establish the multidimensional signal models. In the paper [6] a novel algorithm for efficiently separating ambient air and precipitation echoes from the Doppler power spectrum is presented. The proposed Mirror-Minimum Algorithm leverages mirror image formation in opposite off-zenith beams to separate the echoes. In the research [7] authors formulate the optimal placement of sensors in the collocated monostatic MIMO radar to improve the sum coarray as well as the difference coarray of the sum coarray. Also, the authors present a mathematical framework to achieve the optimal solution for both problems. In the paper [8] a new radar mixed pulse train deinterleaving algorithm based on the extended Farey dictionary and improved generalized orthogonal matching pursuit is proposed. This method is particularly suitable for the interleaving of the short and highly interleaved missing pulse train in complex electromagnetic environments. In the research [9], an adversarial anti-jamming decision-making network for cognitive radar via multi-agent deep reinforcement learning (MDRL) is proposed, which has good self-learning ability and can meet the requirements of intelligent, dynamic, and real-time in modern electronic warfare. Since competitive decision-makers are considered and these two confrontational sides are not able to obtain completely accurate information about each other, the environment model is specifically constructed as a partially observable Markov decision process. The paper [10] studies a minimum-time trajectory planning problem under radar detection, where a Dubins vehicle aims to approach a target under a limited probability of being detected.

The main point that was not taken into account in the reviewed studies is the lack of assessment of the effectiveness of the radar signal. That is why the presented work is relevant.

3. Problem formulation

The radar field is used to detect and track real targets, build track information and combine it from several sources.

The quality of the radar field is proposed to be evaluated by a vector of indicators that can be divided into temporal, spatial, reliability, accuracy, load and completeness of information. Each of the described characteristics corresponds to the concept of quality. For example, the quality of the time characteristic of target detection is the time of continuous tracking of the target. That is, the longer the system accompanies the target, the higher the quality indicator.

Under the quality of the radar field, we will consider a set of values of indicators of the quality of the functioning of the radar field.

The problem is that, on the basis of the received vector of quality indicators, to identify the weak points of the radar field in order to improve its configuration at different heights.

4. Complex modeling system

The complex modeling system is designed to assess the radar location field (RLF) quality of a specific grouping of radar reconnaissance equipment and a specific air situation.

The complex modeling system consists of the following components:

- the model of the movement of an aerial object (AO), which consists of a certain number of points at which a maneuver can be set according to the course, altitude, speed, and the use of active or passive obstacles. The number of software tracks is limited by the computing capabilities of the computer;

- model of the order of battle of the RL group;
- model of airspace survey by means of radar (radar) reconnaissance (radar station (radar));
- the model of secondary processing of RL information (linking software tracks);
- model of tertiary processing of trace information (generalization of information from several means of secondary processing);
- the task manager, which after a certain time connects the relevant models to exchange data between models;
- block of RLP quality assessment after modeling the air situation and group work;
- graphical interface.

Figure 1: Complex modeling system user interface

4.1. Aerial object movement model

The planning of the trajectory of the aerial object (AO) is carried out in the form of a set of reference points with coordinates in the defined coordinate system and with the specified parameters of movement and the main characteristics of the AO. We consider the movement of an aerial object as the movement of a point on the HOU plane and is represented by a certain function of time $f(t)$. This function is unknown. To construct the trajectory of the object's movement, we fix its position with a certain step in time Δt. That is, the trajectory is a set of points

$$T = \{f(t_0), f(t_0 + \Delta t), \ldots, f(t_0 + \Delta y * n)\},$$

where n – the number of points in the trajectory.

The general view of the trajectory consists of reference points connected by straight lines. When changing the course, the arc of a circle is calculated taking into account the speed, permissible overload, and acceleration of free fall.

The software movement trajectory can be represented by a set of sections of the following types:

- rectilinear movement, with maneuvering according to speed and height;
- curvilinear movement in an arc of a circle (course maneuver);
- curvilinear movement in a spiral (maneuver by course and height).

4.2. Model of the order of battle of the RL group

The model of the order of battle of a radar group determines the organization and interaction of various radar stations (RS) and automation equipment complexes (AEC) within the group to perform specific combat tasks. This model takes into account such aspects as the placement of radars and antiaircraft defenses, their characteristics and functions, communications, information exchange, and joint actions. Here are the main components of such a model:

1. Composition of radars of the group: The model determines which specific radars are part of the group, their types, characteristics, and purposes of use.
2. Placement and coordinates: The geographical location of each radar within the grouping is taken into account, including their coordinates and height of placement.
3. Control system: The model includes control systems for coordination and control of radar actions within the group, synchronization of operations, and information exchange.
4. Communication topology: The topology of the communication system (command hierarchy) is taken into account, which ensures the transmission of data and commands between radars in a grouping and with higher command centers (AEC).

This model can be presented as [Fig. 3].

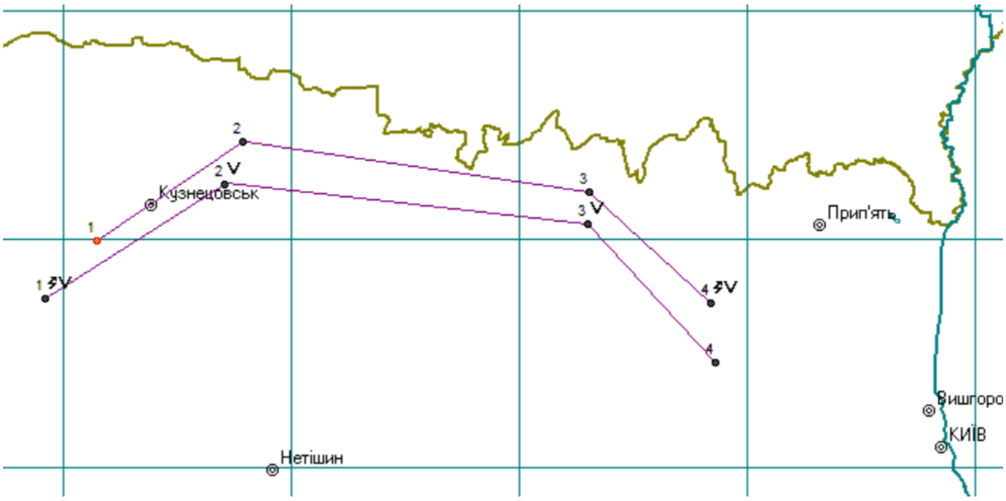

Figure 2: Aerial object movement example

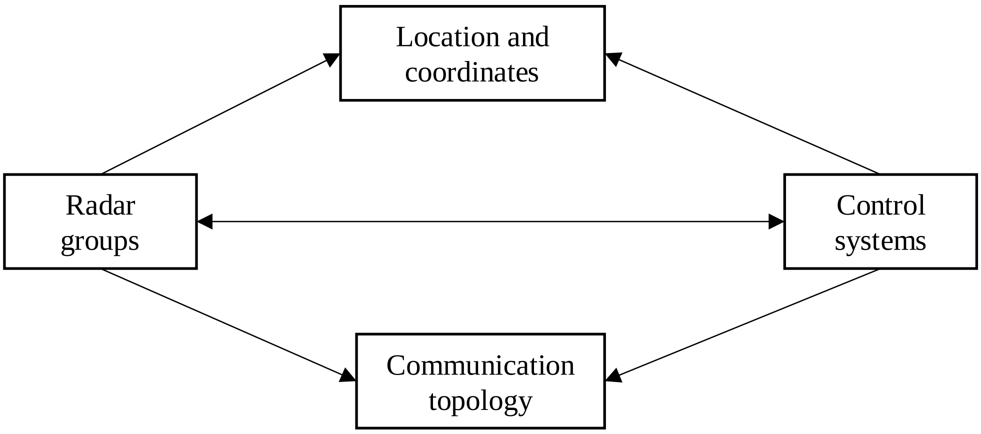

Figure 3: Model of the order of battle of the RL group

4.3. Airspace survey model

The mathematical model of the airspace survey of the radar station (Radar) is used to describe the process of detection, tracking, and identification of objects in the air environment. This model depends on the following parameters:

1. Output data:

Radar parameters: These parameters include operating frequency, transmitter power, antenna pattern, antenna angle, and other characteristics of the radar equipment.

2. Geometric parameters: Height and coordinates of the radar installation, as well as antenna orientation.

3. Atmospheric conditions: Atmospheric parameters, such as air density, temperature, humidity, etc. can affect the propagation of radio waves.

4. Antenna Diagram: Determines how an antenna directs electromagnetic waves into space. The antenna diagram includes the azimuth and angular level (elevation) of the antenna.

5. Equation of signal propagation: The model takes into account the physical laws describing the propagation of radio waves in the atmosphere. This includes diffraction, scattering, and attenuation of the signal.

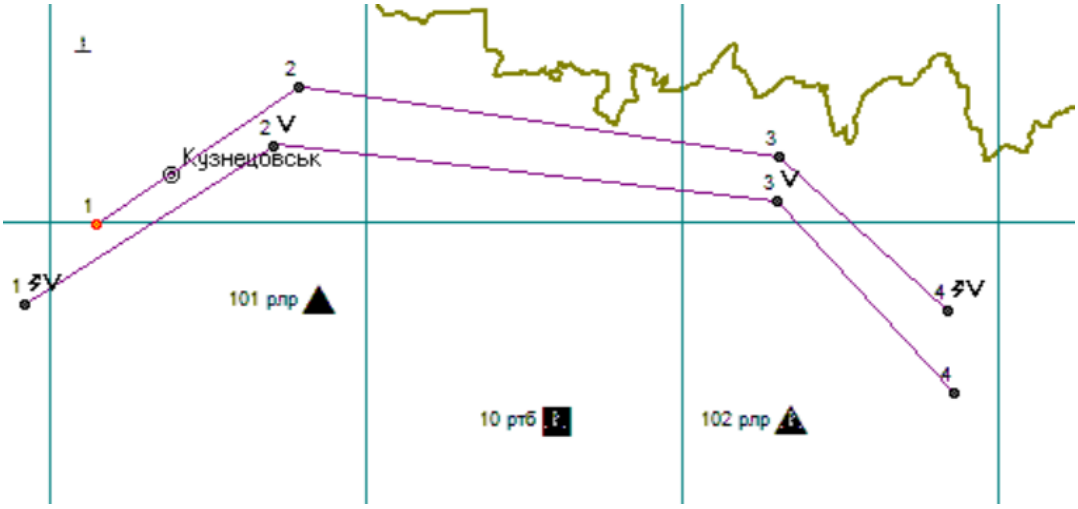

Figure 4: Automation equipment complexes location example

The mathematical model of radar is presented in the form of a system of equations and algorithms that describe all the aspects listed above. In general, the model can be presented as follows:

$$\begin{cases} u(t) = cos\left[2u(t) \cdot \pi \cdot \left(f_0 + \sum_{k=0}^{n-1} b_k \cdot \left(\frac{t}{T}\right)^{2\cdot k+2}\right)\right] \\ P_{ПР} = \frac{P \cdot S_0 \cdot G^2 \cdot \lambda^2}{64 \cdot \pi^3 \cdot D^4} \cdot \left(1 - \frac{\eta}{100\%}\right) \\ F_E(\beta) = \frac{sin\left(\pi \cdot \frac{d_A}{\lambda} \cdot sin\,\beta\right)}{\pi \cdot \frac{d_A}{\lambda} \cdot sin\,\beta} \\ s_{ПР}(t) \approx k \cdot F_E^2(t) \cdot s_П(t - t_3) = k \cdot F_P(t) \cdot s_П(t - t_3) \end{cases},$$

where $u(t)$ – signal propagation equation, $P_{ПР}$ – radar signal strength, $F_E(\beta)$ - antenna orientation in the azimuth-range plane, $s_{ПР}(t)$ – reflected signal function.

This model is used to simulate radar operation, evaluate its characteristics and performance, as well as to optimize and adjust radar systems.

4.4. Model of secondary processing of radiolocation information

The model of secondary processing of radar information describes the processes of processing and analyzing data received from the radar in order to obtain useful information, determine the parameters of targets, identify objects, and make decisions. This model includes several stages and components:

1. Target identification and segmentation: In this step, data is analyzed to identify targets and separate them from the environment. This may include determining the coordinates of the targets, their speed, and other characteristics.

2. Evaluation of target parameters: At this stage, additional target parameters such as course and speed are determined.

3. Tracking and tracking: The model includes tracking algorithms to track the movement and changing parameters of targets over time. This allows you to determine the trajectories of movement and predict the future positions of targets.

4. Exchange of information: The model contains the topology of the communication system for the exchange of processed data with other units and systems of the armed forces.

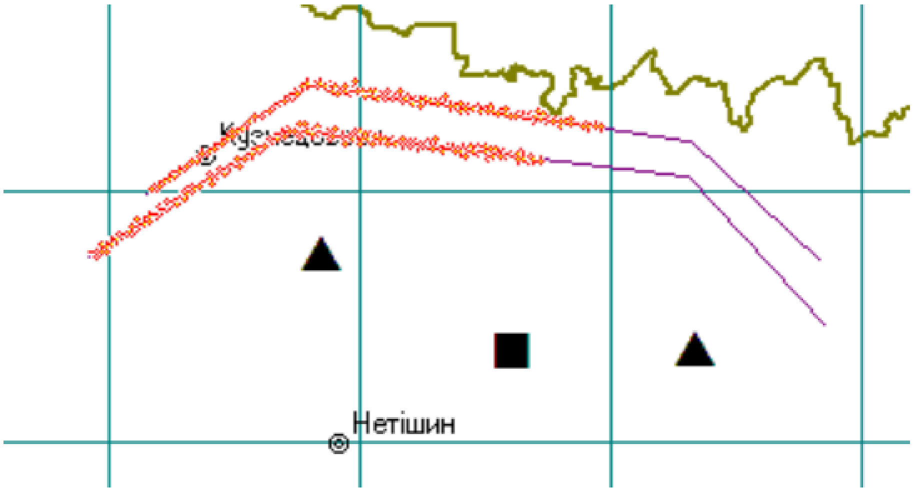

Figure 5: Airspace survey example

Presented model can be described as follows:

Target identification and segmentation

↓

Evaluation target parameters

↓

Tracking target

↓

Information exchange

Figure 6: Steps of secondary processing of radiolocation information

4.5. Model of tertiary processing of trace information

The model of tertiary processing of trace information includes the processes of analysis and interpretation of traces (data on the movement of targets) obtained as a result of secondary processing from subordinate units. This stage of information processing is aimed at highlighting important trends, patterns, and characteristics, as well as making decisions based on this data. Here are the main components of such a model [Fig. 8]:

1. Input track data: This step uses track data, which includes information about coordinates, velocities, azimuths, elevations, and other parameters of targets obtained from several subordinate sub-units.
2. Data integration: The model integrates data from different sources, such as data from subordinate units, to obtain a more complete picture of the situation.
3. Tracking and Prediction: The model can include tracking algorithms to track the movement of targets and predict their future positions and characteristics.
4. Analysis of trends and patterns: At this stage, the data is analyzed to identify trends and patterns in the movement of targets, such as changes in speed, course, altitude, and other parameters.
5. Reporting and Communication: Tertiary processing results can be reported and communicated to operators and commanders for decision-making and follow-up.

6. Feedback and correction: The model can provide mechanisms for correction and updating of data based on new information.

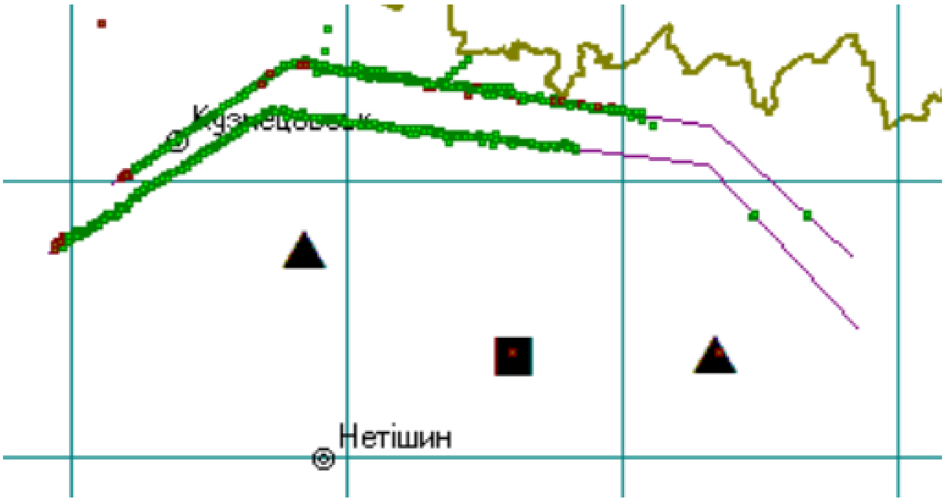

Figure 7: Secondary processing of radiolocation information example

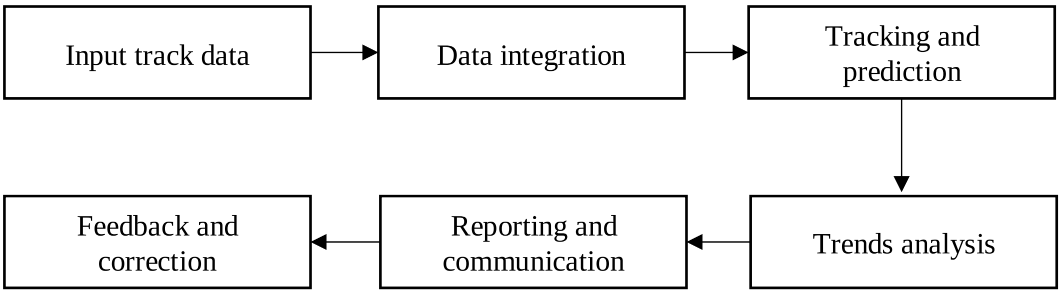

Figure 8: Steps of tertiary processing of radiolocation information

4.6. Task manager

The task manager, which manages the sequential execution of the models and connects them for data exchange, is implemented as a software component. Here is a general outline of how such a task manager works:

1. Definition of tasks and models: The list of tasks to be performed and the models that will be used to solve them are defined. These are models related to data processing, calculations, analysis, and other functions.
2. Organization of the task queue: A queue has been created that will store the tasks that need to be completed. Each task contains information about which model must be run to run it and what data it needs.
3. Execution of tasks: The dispatcher starts the execution of tasks one by one from the queue. It creates processes and execution flows for each task and runs the corresponding models.
4. Connecting models: To perform the task, the dispatcher connects the appropriate model. This includes loading and initializing the model (both tasks are performed before simulation), passing data and parameters to it, performing calculations, and receiving the result.
5. Data exchange: The models exchange data with each other during the execution of the task.

4.7. Radar location field quality assessment block

The block of quality assessment of the (PTB)RTV grouping is the final stage for the purpose of evaluating the effectiveness of the RLF. This block helps determine how well the radars performed their tasks in simulated conditions. Here are the main stages and components of the radar quality assessment unit show in Appendix.

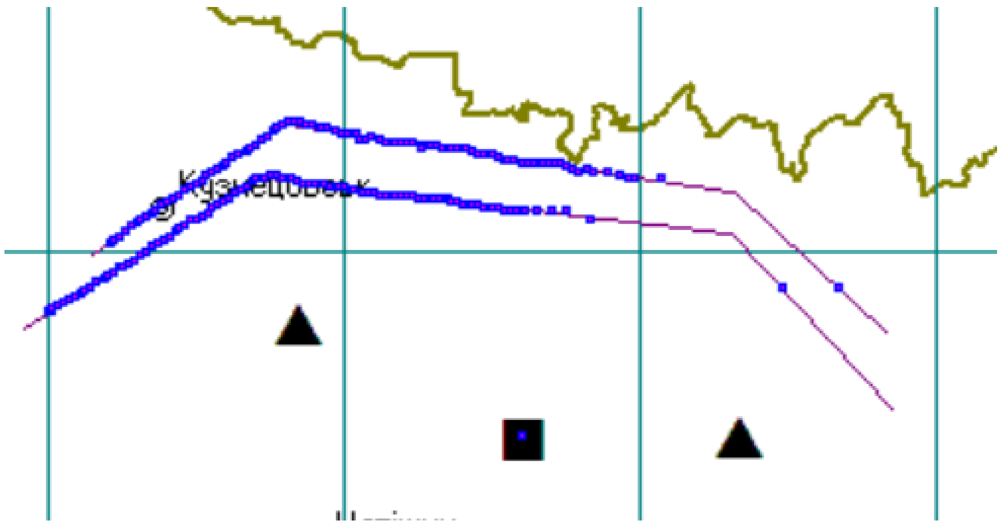

Figure 9: Tertiary processing of radiolocation information example

5. Conclusion

Thus, in this article, the authors introduce a sophisticated modeling system. The primary goal of this system is to evaluate the quality of the radar location field (RLF) for a particular set of radar reconnaissance equipment and a specific aerial scenario. Within the manuscript, various subsystems of the complex modeling system are discussed. These include models for aerial object movement, radar group deployment, airspace survey, radiolocation data processing, task management, and the assessment of radar location field quality. The use of the developed software using real data is presented. The evaluation of the effectiveness of the radar field is also presented, which is positive, that is, the radar field completely covers the required area. Also, examples of the user interface of the designed program are presented.

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7. Appendix

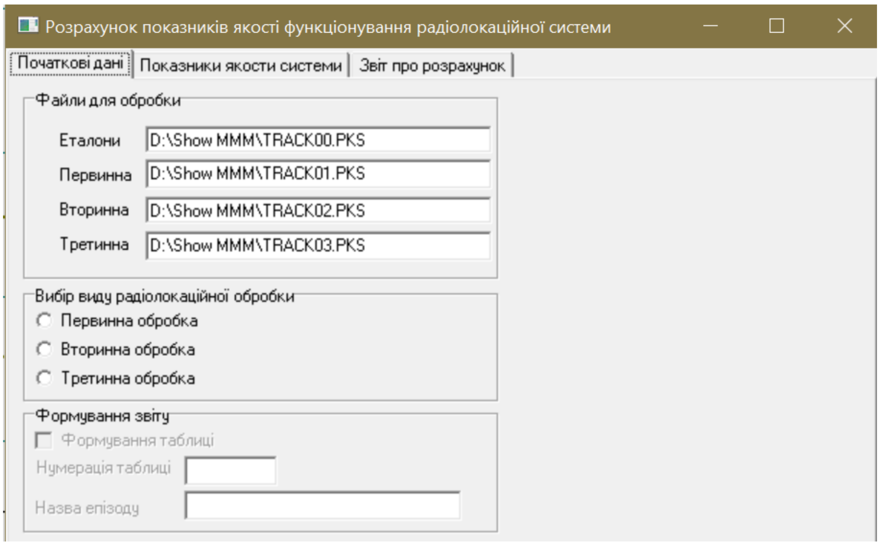

Figure 10: Quality assessment block 1

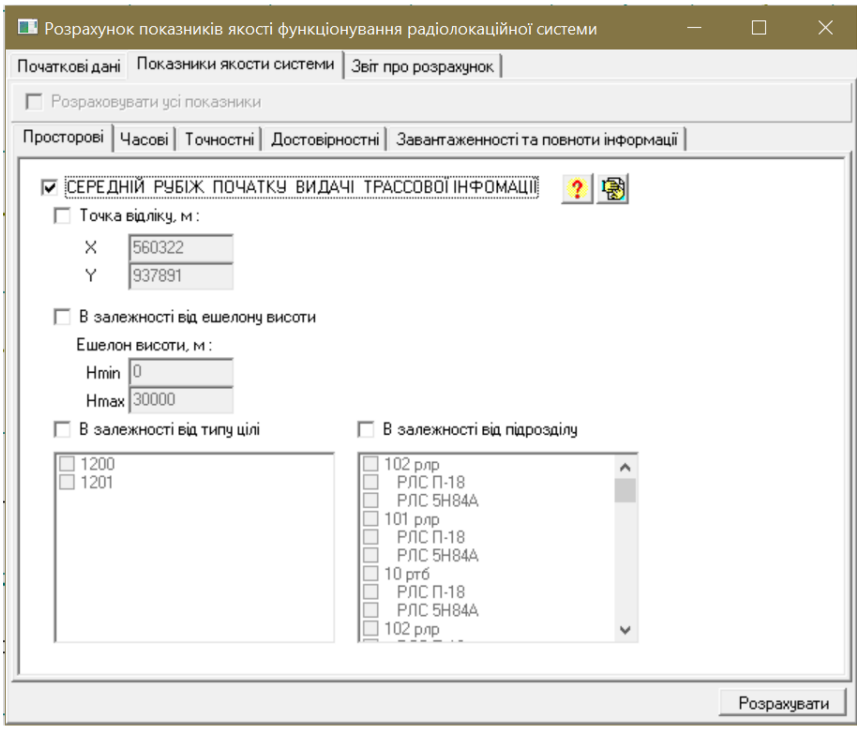

Figure 11: Quality assessment block 2

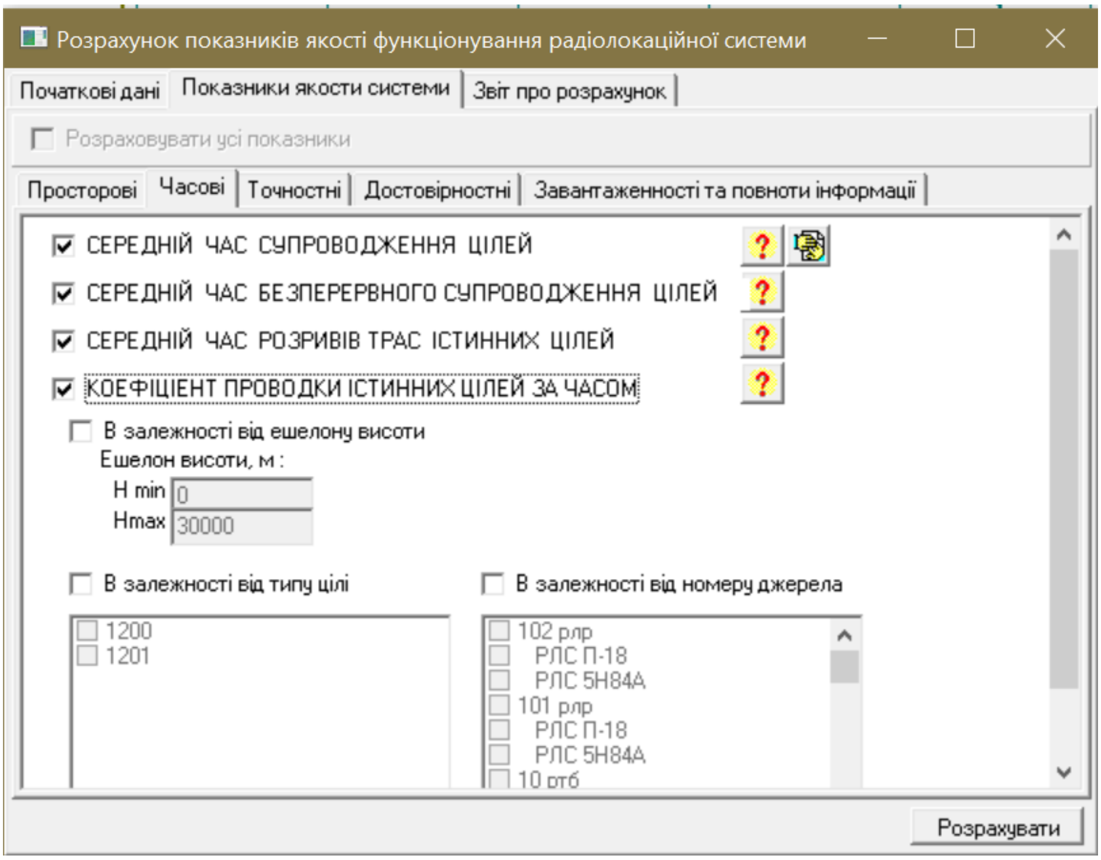

Figure 12: Quality assessment block 3

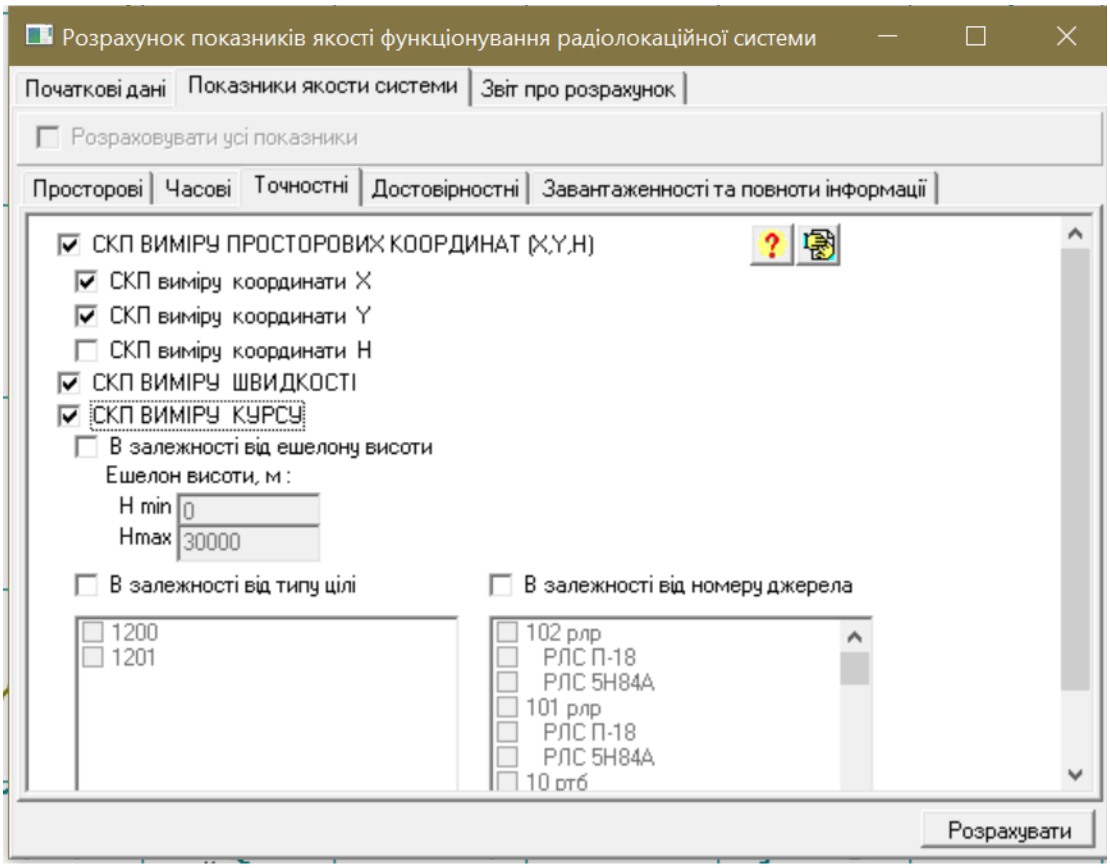

Figure 13: Quality assessment block 4

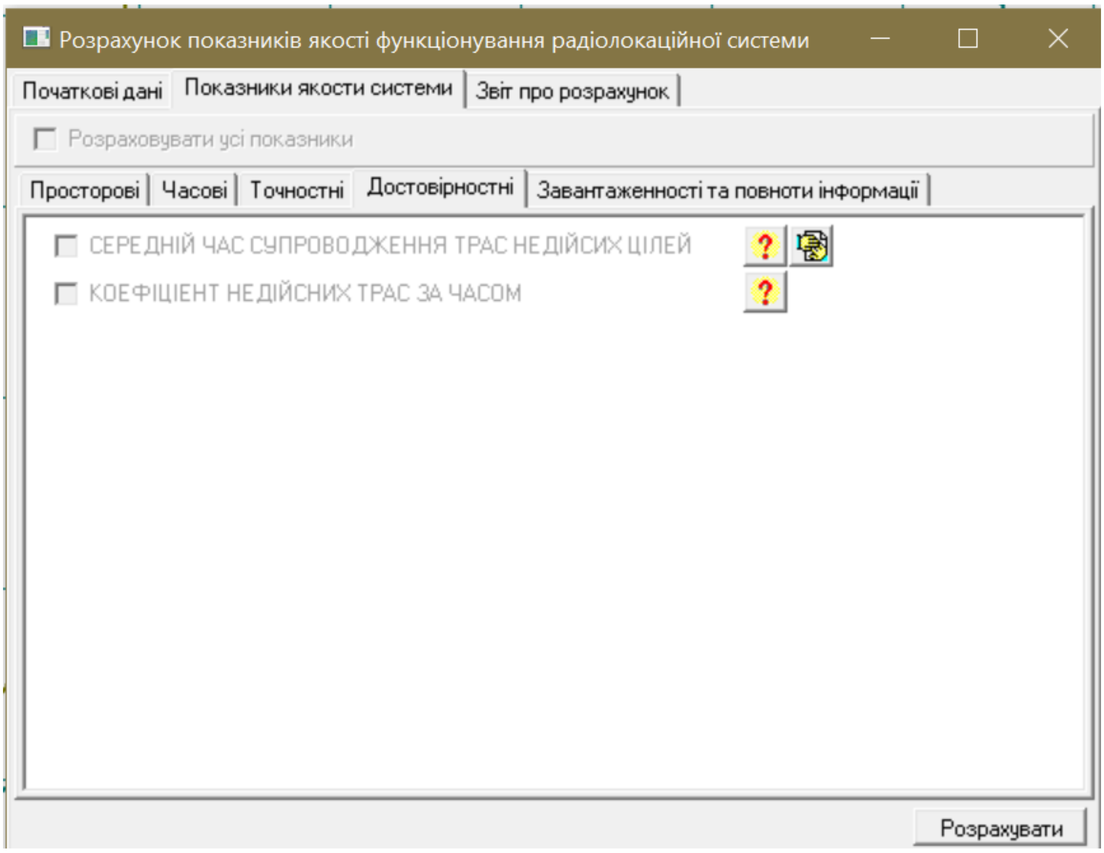

Figure 14: Quality assessment block 5

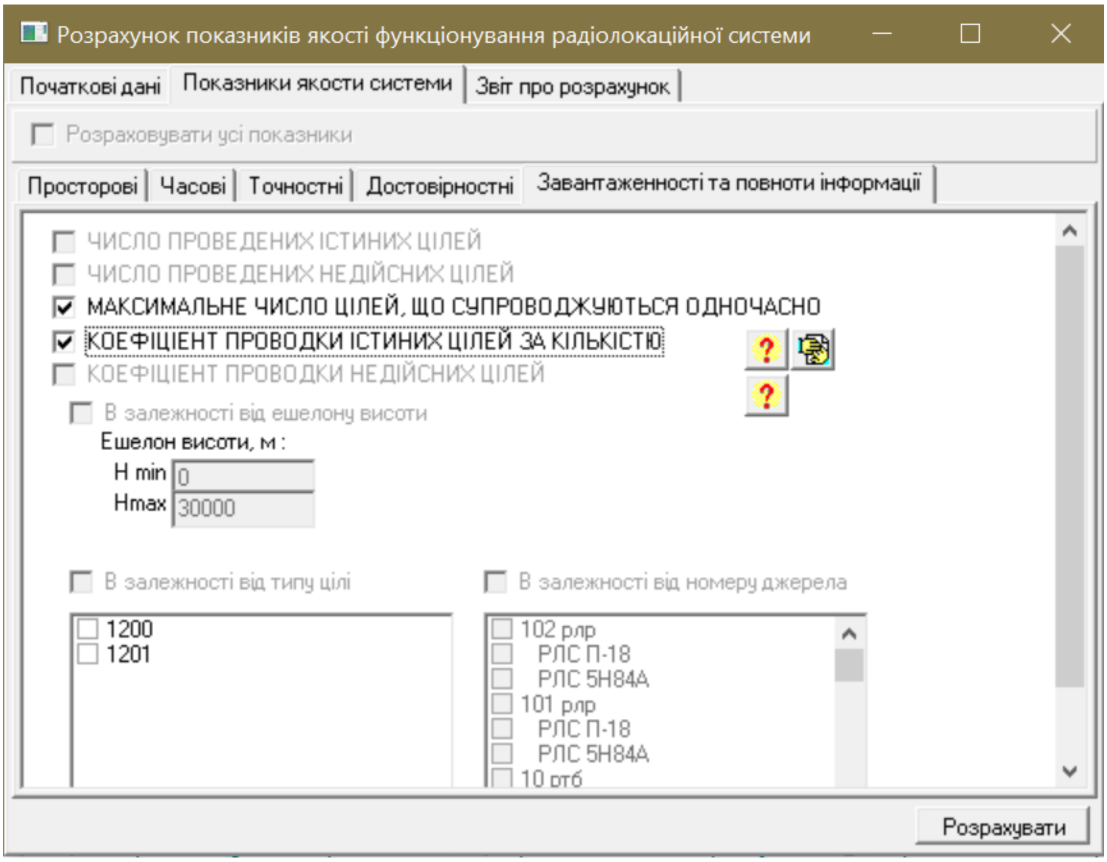

Figure 15: Quality assessment block 6