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MEASUREMENT ERRORS AFFECTING THE CHARACTERISTICS OF MULTI-POSITION SYSTEMS, AND WAYS TO REDUCE THEM

Abstract. *Modern wide development of science and technology causes the growth of information needs in all branches of human development. At present, there are all opportunities to increase information security by combining sources of information into a single system. At the same time, when merging, specific difficulties and features emerge, which together make it difficult to implement the proposed solutions. The paper considers the peculiarity of combining different types* *of radar stations into a single information system. Errors of measurements of separate parameters and their influence on system characteristics are considered. Options for solving the problems that have arisen are proposed.*

Keywords: *information integration, measurement error, multi-position system, primary coordinates, radar station, unified coordinate system.*

Introduction. The integration of different types of radar systems will provide: an unambiguous understanding of the air situation in air traffic control centers and control points, exclude territorial duplication of departmental information systems, the joint use of radio electronic equipment, reduce the type and unify radar facilities, automation and communication systems.

Most of the existing systems for processing radar information from several active sources are a spatially incoherent multi-position system with autonomous signal reception and information integration mainly at the level of single measurements. To estimate the parameters of the movement of airborne objects, information is mainly used on the measured primary spherical coordinates of these objects relative to the "priority source" (selected based on the relative position of the target and system points, the tactical and technical characteristics of radar stations, and other considerations). The information received by the rest of the radar stations of the system is auxiliary and is practically not used in the formation of an estimate of the parameters of the movement of air objects in a single, as a rule, rectangular coordinate system, which makes it possible to abandon the time synchronization of positions, greatly simplifies the processing algorithms and requirements for computing facilities, however leads to a significant loss of measurement accuracy. In the absence of radar stations with sufficient accuracy of measuring three primary coordinates, the system usually uses the results of only high-precision measurements of the corresponding coordinates of air objects of two radar stations (for example, azimuth and distance from one station, elevation angle from another), as a rule, separated from each other by a small distance.

In the works [1-7], the main methods of combining information, problematic issues of creating and operating multi-position information support systems are considered and possible ways of solving them are indicated, but the influence of measurement errors was not taken into account.

Literature review. The potential accuracy of measuring the primary coordinates was estimated in [8-9]. In [9] the issues of estimating the parameters of the movement of an airborne object and the errors of their measurement using the radar information of one radar were studied in detail. In the literature on the joint processing of radar information from several active radar stations [1-5], the issues of determining the parameters of the movement of an airborne object in a single rectangular coordinate system when processing signals received by the system from several sources are highlighted.

In [1] the issues of estimating the coordinates of an airborne object and the errors of their measurement in a single rectangular coordinate system were studied when combining the results of independent primary measurements in an active multi-position system with a synchronous survey of space. In [2-3], the issues of processing radar information from several unequal radar stations at a common receiving point, asynchronous arrival of it, estimation of the parameters of the movement of an airborne object and their measurement errors in a single rectangular coordinate system were studied.

In work [4], algorithms for determining the parameters of the movement of an airborne object are proposed, taking into account the non-synchronicity of obtaining unequal information from individual points of an active multi-position system to the points of the system, the maneuverability of an airborne object is taken into account.

In [10-13] some issues are considered: automation of maintenance processes, improvement of parameter measurement and restoration of multi-position information support systems, optimal composition and placement of measuring instruments, technical diagnostics and recovery in special cases.

The purpose of the work is determination of the main measurement errors affecting the characteristics of multi-position information systems, and the search for possible ways to reduce their influence.

Main material. Let there be a system of N different types of unequally accurate survey radar stations with different rates of space survey, spaced apart in space at a distance significantly exceeding the radius of spatial correlation of the received signals. For the time interval of the trajectory linking $T_{tr\ 0}$, each i radar station $(i = 1...N)$ received $(M_i + 1)$ marks – at the moments of time $t_{i\,j}$, the radar station i evaluates the $(M_i + 1)$ spherical coordinates of the airborne object $\hat{\vec{\mathbf{S}}}_{\mathbf{i\,j}} = \{\hat{R}_{i\,j} \quad \hat{\varepsilon}_{i\,j} \quad \hat{\beta}_{i\,j}\}$ – slant range, elevation angle and azimuth.

Information about the marks, estimates of spherical coordinates and statistical characteristics of their measurement errors is sent to the centralized station for processing radar information in a single time grid (i.e., the moment of measuring the coordinates of an airborne object by each radar station is known, the information delay time is known or can be neglected).

It is known about the estimates that

$$\hat{\mathbf{S}}_{\mathbf{i\,j}} = \mathbf{S}^{*}_{\mathbf{i\,j}} + \Delta\mathbf{S}_{\mathbf{i\,j}}, \; i \in 1...N, \; j = 0...M_i. \tag{1}$$

where $\mathbf{S}^{*}_{\mathbf{i\,j}}$ *– is the vector of the true value of the spherical coordinates,* $\Delta\mathbf{S}_{\mathbf{i\,j}}$ *– is the vector of normal errors caused by noise, with the following statistical characteristics*

$$M\left[\Delta\mathbf{S}_{\mathbf{ijp}}\right] = 0,$$
$$M\left[\Delta\mathbf{S}_{\mathbf{ijp}}\Delta\mathbf{S}_{\mathbf{nmr}}\right] = \sigma^2{}_{Si,j,p}\delta_{i,n}\delta_{j,m}\delta_{p,r}, \tag{2}$$

where $\delta_{a,b} = \begin{cases} 1, & a = b \\ 0, & a \neq b \end{cases}$ *– is the Kronecker symbol,* $p = 1...3$.

It is believed that the curvature of the earth's surface and the refraction of radio waves are taken into account. Then, in a single rectangular coordinate system, the estimates of the rectangular coordinates of the air object associated with the estimates of the spherical coordinates relative to the radar station of the system by functional dependence:

$$\hat{\overline{\mathbf{K}}}_{\mathbf{i\,jp}} = \hat{\mathbf{K}}_{\mathbf{i\,jp}} + \overline{\mathbf{K}}\mathbf{0}_{\mathbf{i\,p}} = \varphi(\hat{\vec{\mathbf{S}}}_{\mathbf{i\,j}}) + \overline{\mathbf{K}}\mathbf{0}_{\mathbf{i\,p}}, \tag{3}$$

where $\hat{\mathbf{K}}_{\mathbf{i\,jp}}$ *– are the estimates of the corresponding rectangular coordinates of the airborne object relative to the radar station at the time instant* $t_{i\,j}$ *,*

$\overline{\mathbf{K}}\mathbf{0}_{\mathbf{i}}$ *– is the vector of known coordinates of the radar station of the system in a single rectangular coordinate system,,*

$\varphi(\hat{\vec{\mathbf{S}}}_{\mathbf{i\,j}})$ *– functional relationship between coordinate systems.*

The connection of the spherical coordinate system with the rectangular one is shown in Fig.1

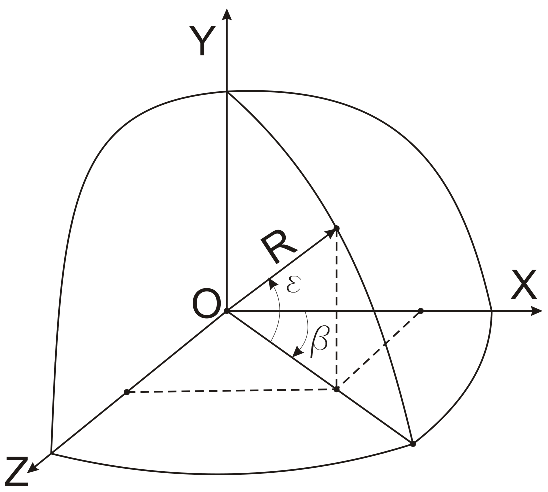

Fig.1. **The connection of the spherical coordinate system with the rectangular**

As an example, the time receipt of marks from the air object for the case of three radar stations is shown in Fig.2

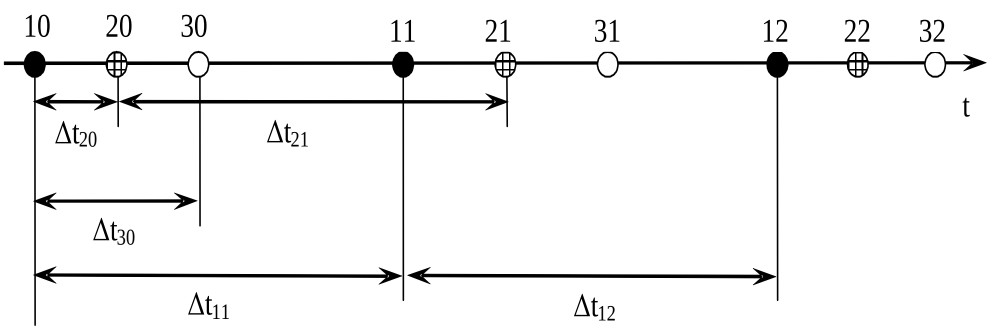

Fig.2. **The receipt of time marks from the air object for the case of three radar stations**

Further processing of information, as a rule, is reduced to the weight integration of the measurement results, taking into account: the accuracy of the data obtained by individual radar stations, the time of its receipt, a priori information about the maneuvering capabilities of an airborne object and other a priori and a posteriori data [1-7].

Thus, the characteristics of multi-position statistics are the following main errors [1-13]:

– errors in accounting for refraction and other functions of radio wave propagation;

– errors in accounting for the curvature of the Earth's surface;

– errors in measuring primary coordinates;

– errors of topographic location and orientation of radar stations;

– errors in estimating the time of measurement of primary coordinates;

– errors (distortions) and delays of information arising in the transmission channels;

– errors when recalculating primary coordinates into a single system, different from the measurement of primary coordinates;

– discretization errors and features of machine counting on digital computing devices.

Errors in accounting for refraction and other features of radio wave propagation can be reduced by: studying the propagation environment of radar signals by conducting periodic control soundings in reference directions, obtaining satellite information, accounting for meteorological data. This leads to the need to make changes to the algorithms for determining the angular arrival of signals to take into account the corresponding corrections. It should be noted that in large-aperture antenna arrays, the signals arriving at individual antenna elements pass practically the same trajectory. Therefore, the entire grid will accompany the air object on a regular basis. In multi-position systems, its individual radar stations can receive signals along significantly curved trajectories, which, when combining information, will lead to the appearance of false targets and an additional load on computing facilities due to the need to identify trajectory measurements.

Errors in accounting for the curvature of the Earth's surface at the present time can be significantly reduced by taking into account the information of digital maps of the area, remote sensing of the Earth, modern methods of surface control [14-15]. Taking into account the fact that the curvature of the Earth's surface significantly affects the accurate estimate of the height in the system, this can be very significant when using information from radar stations with low elevation accuracy. Curvature information is usually used when converting primary coordinates into a single coordinate system.

The errors in the measurement of the primary coordinates mostly depend solely on the signal-to-noise ratio and the steepness of the direction finding characteristic of the radar station according to the measured parameter. To increase the signal-to-noise ratio, the construction of antenna, transmitting and receiving systems on a modern element base is used. This achieves: the characteristics of the antenna directional pattern required in certain operating modes, high stability of the frequency of the generated signal and the required shape of the generated pulses, and a low level of internal noise. The transition to digital and active phased antenna arrays can significantly reduce the requirements for the dielectric strength of the transmission paths and the station cooling system, and increase the useful radiated power. However, at present, the introduction of many technologies, unfortunately, is constrained by the high cost of individual elements. An increase in the slope of the direction finding characteristics is achieved by the introduction of modern, usually digital, methods for processing received signals. Many of these methods, in addition to high accuracy, have the ability to super-Rayleigh resolution. Since many of the proposed solutions require a significant alteration of the transceiver system and (or) replacement of computing devices, they are mainly used in the design of new or deep modernization of existing radar stations.

Topographic and orientation errors of radar stations have a significant impact on the operation of multi-position systems. This is due to a number of factors. First, each station in this case can introduce a systematic error in the measurement, which can exceed the resolving power of the other stations of the system, which, when combining information, will lead to a large number of false targets even when accompanying one airborne object. Second, when locating several airborne objects in the system, the requirements for identifying the information received will inevitably increase exponentially. Third, the requirements for the system of time synchronization of system elements are increasing to take into account the passage of information from the radar station to the point of joint processing. Fourth, most of the existing algorithms for joint processing of information from several sources include data on the known geometry of the system. These errors are especially significant for systems with non-stationary (constantly changing) position of radar stations. In this regard, in addition to using elements of satellite navigation of several navigation systems, it is expedient to improve and develop inertial navigation systems directly from radar stations. This will ensure the autonomy and sufficiency of the system in a difficult jamming environment. At the same time, topographic reference errors can significantly reduce the coefficient of technical use of the system or lead to a significant increase in the cost of its maintenance and repair, since when solving many logistic problems, information about the remoteness and availability of serviced objects (radar stations) is used [10-11].

Errors in estimating the time of measuring the primary coordinates, depending on its stationarity relative to each station when combining information, can lead to both the appearance of systematic errors and to a complete failure of the system. As the preliminary studies by the authors have shown, the most rational is the organization of synchronization, in which the introduced error will not exceed (and, if possible, be significantly less) the minimum resolving volume of the radar station included in the system. In most cases, synchronization can be carried out using satellite systems, however, when working in a difficult jamming environment and to increase the autonomy of a multi-position system, it is advisable to develop a synchronization system for the system itself. A variant of the synchronization system proposed by the authors is given in [5].

Errors (distortions) and delays occurring in information transmission channels lead both to a complete leveling of information received from individual stations and to the occurrence of systematic errors in information processing. Currently, the performance and speed of computing and communication facilities can significantly reduce this factor. This is achieved by increasing the digitization capacity, using special encryption methods, using specific code-forming sequences and other technical and algorithmic measures. In this case, physical instability of the electrical path length of the transmitted signal can have a significant effect. A variant of its control and compensation by the authors is given in [5].

Systematic errors when recalculating primary coordinates into a single system, different from the system for measuring primary coordinates, arise due to the nonlinearity of the transformation (3). Most of the existing algorithms for converting coordinates use a lianarized transformation model, which was previously justified by the low development of computational means. At the same time, rigorous mathematical expressions were obtained in [9, 16], which make it possible to estimate with high accuracy these errors for individual methods of measuring the coordinates of active and passive location. The carried out modeling confirmed the adequacy of the results obtained, and their introduction into algorithms for joint information processing [1-4, 6-8] showed the possibility of compensating for systematic measurement errors. The currently existing computing facilities make it possible to implement the proposed solution in real time. A distinctive feature of the implementation of the proposed solutions is the need to take into account the signal-to-noise ratio of each measurement and the maintenance and control data on the state and characteristics of each radar station. This can be realized with the introduction of an automated control system and technical diagnostics [5].

Sampling errors and machine counting features on digital computing devices lead to an increase in internal noise due to quantization noise and can cause failures in performing calculations related to the inversion of matrices [1-4, 6-8]. To prevent a decrease in the characteristics of the system at this stage, it is advisable to have mathematically justified restrictions on the structure of the processed data depending on the operating conditions of the system.

The considered measurement errors were studied during modeling on an electronic computer using models of the movement of air objects [17-19]. As a result of research, it was found that the impact of each of the errors significantly depends on the configuration and geometry of the multi-position system, its geographical location and technical characteristics of the radars included in it. Thus, when deciding on the order of reduction of measurement errors, it is necessary to have information about the problems facing the system and the conditions in which they will be solved. The analysis can be useful for substantiation of technical characteristics and feasibility study in the design and construction of appropriate multi-position systems [5, 20-21].

Conclusions.

1. The paper considers the influence of measurement errors on the characteristics of multi-position information support systems.

2. Ways to solve them are considered.

3. A review of their disadvantages and advantages.

4. Recommendations for increasing the information capabilities of multi-position systems are provided.

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