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Evaluation the Quality of Measuring the Coordinates of Air Objects in the Synchronous Information Network of Surveillance Systems

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Abstract

The paper shows that the hereditary transition from asynchronous to synchronous networks of airspace surveillance radar systems in which time is one of the coordinates of the detected air objects, allows to calculate the height of air objects due to long-range measurements with the desired quality.

Keywords

Synchronous information network, information network, surveillance system, radar system, airspace surveillance, accuracy, air object, friend or foe, height measurement, reception center

1. Introduction

In the leading countries of the world, for quite a long time, there have been unified national monitoring systems of the use airspace by both military and civil aviation [1, 2]. Obviously, this achieves the maximum efficiency of the use of airspace with relatively low material, technical and human costs [3].

One of the components of the airspace control system is a unified information network based on existing airspace surveillance systems. Significant attention is currently paid to the network construction of information resources [4-11].

In particular, the existing national unified airspace control systems, as a rule, are implemented on the basis of the network principle using separate information means [3].

The main tasks of these programs are to integrate existing radar surveillance systems of various departments into a common network and centralized management of this network by a higher authority. In this case, the information

network of observation systems, as a rule, is implemented on an asynchronous principle [11-13] and a three-dimensional coordinate system is used [14-15].

The combined information of the considered information network of airspace observation systems is issued to consumers. However, this principle of organizing an information network impoverishes the information support of consumers and does not solve the problems of individual information facilities, in particular, secondary radar systems [16-22], as well as the joint functioning of primary and secondary radar systems [23-30], etc.

The transition to the synchronous principle of building an information network, in which a four-dimensional coordinate system is used, as shown in [31-36], will provide complete and reliable information support for consumers, as well as solve the problems of the functioning of individual information tools, in particular, systems for identifying air objects based on "friend or foe" [9, 22-25].

In addition, the use of a four-dimensional coordinate system in a synchronous information network expands the functionality of such a network, in particular, it becomes possible to implement cooperative reception of signals, measure the height of an aircraft by rangefinder measurements, etc.

The aim of the work is to assess the quality of measuring the height of an airborne object by rangefinder measurements in a synchronous

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information network of radar surveillance systems.

2. Assessment of the accuracy measuring the height of an airborne object in synchronous airspace observation systems

As is known from [8, 9], using measurements of the slant range to an airborne object at several points of the synchronous information network, it is possible to measure the flight altitude of the observed airborne object. It should be noted that such a task is faced by both primary and secondary radars. Indeed, as shown in [7], the synchronous information network of secondary location systems presupposes a transition to requestless systems and, therefore, requires measuring the height of the emitting object. In this regard, we will solve the problem of joint measurement of the height of an air object by systems of both primary and secondary radar.

Consider a synchronous information network that consists of n receiving points. For the primary system, this will be n ground receiving points of echo signals, one of which is emitting, and for the secondary system, these are n ground receiving points of response signals. Thus, the tasks of measuring the height of an airborne object by echo signals and response signals are identical. The accuracy of measuring the height of an airborne object depends on the accuracy of measuring the time of signal reception, the accuracy of synchronization of the time scales of the receiving points, as well as on the relative position of the receiving points and the airborne object, that is, the geometric factor.

Let's assume that an emission or an echo or a response signal occurs from an airborne object at time $T_k(t)$. Let's also assume that there are four ground receiving points.

Consequently, at each of the receiving points at the time $T_i(t) (i = 0, \dots, 3)$ the signal emitted (reflected) by the airborne object is received. Considering the time scales formed at the receiving points of the synchronous information network to be highly stable, we can omit the dependence of time processes on t .

Thus, the time of arrival of the signal of the airborne object at each of the receiving points of the synchronous information network can be written as

$$T_i = T_k + r_i / c, \quad (1)$$

where c is the speed of light.

Subtracting the time of arrival at the base processing point (we consider it to be zero) from the time of the remaining receiving points, we obtain

$$R_i - R_0 = c(T_i - T_0) = r_i, \quad i = 1, 2, 3. \quad (2)$$

Based on the geometry of the location of the receiving and emitting points, it is possible to write

$$R_0^2 = x^2 + y^2 + z^2, \quad (3)$$

$$R_i^2 = (x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2. \quad (4)$$

From (4) it is easy to obtain

$$R_i^2 - R_0^2 = x_i^2 + y_i^2 + z_i^2 - 2(x_i x + y_i y + z_i z) \quad (5)$$

Using expressions (5) and (4), we can write

$$R_i^2 - R_0^2 = (R_i - R_0)(R_i + R_0) = (r_i + 2R_0)r_i \quad (6)$$

Substituting (6) into (5) and performing a permutation, we obtain

$$2(x_i x + y_i y + z_i z + r_i R_0) = x_i^2 + y_i^2 + z_i^2 - r_i^2 \quad (7)$$

Based on the set task, we need to evaluate the effect of errors in synchronization of time scales of reception points, i.e. T_i , for the quality of the height measurement, i.e. to the z coordinate. Differentiation of expression (7) allows writing

$$2 \left(x_i \frac{dx}{dT_j} + y_i \frac{dy}{dT_j} + z_i \frac{dz}{dT_j} + x_i \frac{dR_0}{dT_j} + R_0 \frac{dr_i}{dT_j} \right) = -2r_i \frac{dr_i}{dT_j} \quad (8)$$

for all $i = 1, 2, 3; j = 0, 1, 2, 3$.

Using the results of differentiation (8), and also proceeding from expression (4), we obtain

$$x \frac{dx}{dT_j} + y \frac{dy}{dT_j} + z \frac{dz}{dT_j} - R_0 \frac{dR_0}{dT_j} = 0. \quad (9)$$

In matrix form, the above expression can be written as the following relation

$$\vec{D} \vec{A} = \vec{R}, \quad (10)$$

where

$$\vec{D} = \begin{bmatrix} x & y & z & -R_0 \\ x_1 & y_1 & z_1 & r_1 \\ x_2 & y_2 & z_2 & r_2 \\ x_3 & y_3 & z_3 & r_3 \end{bmatrix}, \quad (11)$$

$$\vec{A} = \begin{bmatrix} \frac{dx}{dT_0} & \frac{dy}{dT_0} & \frac{dz}{dT_0} & -R_0 \\ \frac{dx}{dT_1} & y_1 & z_1 & r_1 \\ x_2 & y_2 & z_2 & r_2 \\ x_3 & y_3 & z_3 & r_3 \end{bmatrix}, \quad (12)$$

$$\vec{R} = \begin{bmatrix} x & y & z & -R_0 \\ x_1 & y_1 & z_1 & r_1 \\ x_2 & y_2 & z_2 & r_2 \\ x_3 & y_3 & z_3 & r_3 \end{bmatrix}. \quad (13)$$

It should be noted that the speed of light is omitted from expression (10) taking into account the fact that errors in the formation of time scales are given in terms of range.

Based on expression (10), we can write an expression for estimating the required matrix \vec{A} in the following form

$$\vec{A} = \vec{D}^{-1}\vec{R} \quad (14)$$

Thus, for the selected location of the receiving points of the considered synchronous information network of observation systems and the position of the air object, the matrices \vec{D} and \vec{R} are known. This allows solving expression (14). As follows from (14), the third row of the estimated matrix \vec{A} represents the sensitivity of measuring the height of an airborne object to errors in the synchronicity of the formation of time scales of receiving points. If all measured time intervals are equally sensitive to errors in the formation of a synchronous information network, then the sum of square errors is nothing more than the total value of the geometric factor [37]. Some results of calculating the sum of squared errors of range measurement in accordance with expression (14) are shown in Fig. 1 and 2 for different configurations of receiving points and the height of the air object. Fig. 1 is presented for the uniform location of three points at a radius of 45 km around the base receiving point, and Fig. 2 - for triangular. The flight altitude of the airborne object was 5 km.

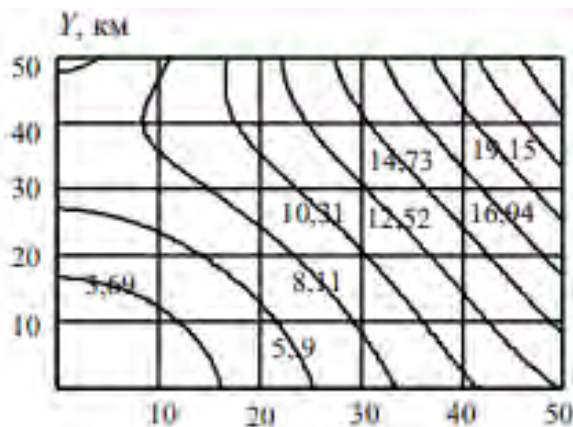


Figure 1: Evaluation the accuracy of measuring the height of an airborne object for the uniform location reception centers of three points at a radius

The presented calculations make it possible to estimate the required synchronization accuracy of the time scales of the receiving points of the synchronous information network of observation systems when calculating the height of an air

object from range measurements carried out at the receiving points of the considered information network of radar observation systems.

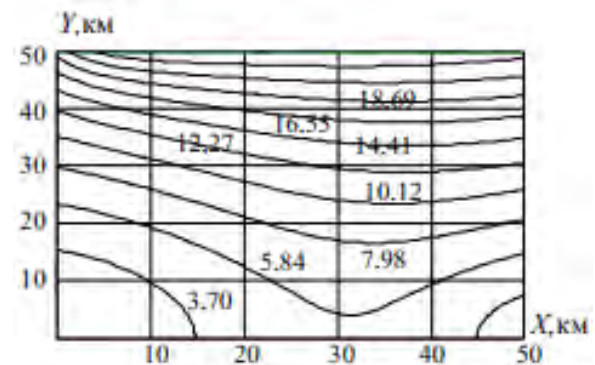


Figure 2: Evaluation the accuracy of measuring the height of an airborne object for reception centers the triangular location

3. Conclusions

The implementation of a synchronous information network of surveillance systems for primary and secondary radars, in which time is one of the coordinates, makes it possible to measure the height of the aircraft with the required accuracy by measuring the slant range at the receiving points of the considered information network of radar surveillance systems for the airspace with an appropriate number of receiving points.

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