Decision of objective object type recognition on the basis of using the diagram of antenna direction as a sign

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Abstract. The paper presents an algorithm for recognizing the type of an object in aerospace on the basis of a comparison of directional patterns. Attraction of new features to the solution of the recognition problem will increase the probability of correct recognition and will allow the most complete description of recognized objects, which in turn will lead to a decrease in the probability of error in making a decision.

1. Introduction
In the Russian Federation, a complex spatially distributed system for collecting and processing information functions to monitor and control the activities of foreign states in the near-Earth space. One of the indicators of the quality of the work of this system is the probability of correct recognition. This indicator depends on many different factors and in some cases does not reach the level required by the guidance documents.

An increase in the indicator under consideration [1–3] with an unchanged number of types of recognized objects, it is necessary to increase the number of features in whose language these objects are described. This is achieved through the use of new measuring instruments, as well as the improvement of the scientific and methodological apparatus for processing measured information. In turn, as the analysis of recognition algorithms showed, the information coming from the complexes of radio technical control is practically not used in making the decision.

An analysis of the content model considered in [4–6] showed that for a typical recognizable object in the airspace, a certain number of modes of functioning are characteristic. Based on certain conservatism in the design of antenna systems and features of the operation of recognition objects, it is proposed in [7–9] to use as a complementary feature a spectral portrait and a diagram of direction.

This article presents an algorithm for recognizing the type of an object in aerospace space based on the use of the second of the above characteristics. The output data of the proposed algorithm will be used in a multi-level recognition system, where recognition is made on the first level based on various characteristics, on the second level - the computation of informativity and the assignment of weight coefficients, and, finally, the third decision is made on the basis of a set of characteristics using the "weighted voting" [1, 10, 11].
2. Research Method

2.1. Use of the distance function when recognizing on the basis of diagrams of direction

During the analysis of the directional pattern of antenna (DPA) in various modes of functioning of recognized objects [12, 13] it was established that, in contrast to spectral portraits, it is difficult to catalog the DPA sections. This is due, first of all, to the fact that the form of the real DPA has a complex multi-lobe structure (Figure 1). In this regard, it is advisable to use simulation simulation of the DPA to obtain its cross-section for these observation conditions. Simulation is performed for a certain type of recognizable object operating in a given mode of operation.

The decision on whether an object belongs to a particular type is made on the basis of the results of comparing the values of the cross sections of the DPA obtained in the course of the work session at the radio engineering complex and calculated in the course of simulation modeling.

![Figure 1](image1.png)

Figure 1. Directional pattern of a real antenna.

The principle of the minimum distance between the values of amplitudes, simulated and measured DPA is based on the above-described process. The difference in these values will show how much the measured DPA differs from the simulated one. At the same time, the cross section of the DPA is represented by a set of discrete samples, the size of which is advisable to be set as small as possible, which makes it possible to fully describe the entire "fine" structure of the DPA. Dependence of the amplitude difference of the simulated and measured DPA on the corresponding discrete will be called the difference portrait.

Consider the several difference portraits presented in Figure 2.

![Figure 2](image2.png)

Figure 2. Difference portraits of DPA.

The first $R_{i}^{zm}$ difference portrait reflects the degree of difference in the DPA obtained during the measurement session from DPA that obtained for the ideal case with the help of simulation modeling

$$R_{i}^{zm} = A_i - A_{i}^{init \,dl},$$

(1)
where \( A_i \) is a set of discrete, with the help of which the cross section of the DPA obtained during the measurement session is described; \( A_{ii}^{\text{init},ld} \) is a set of discrete, with the help of which the cross section of the DPA obtained in the course of simulation is described; \( i = 1,2,...,N \) is the number of object types; \( l = 1,2,...,L \) is the number of disks with which the DPA is described.

The second \( R_{il}^{\text{sim}} \) difference portrait reflects the degree of difference between the two DPAs obtained with the help of simulation modeling, however, the values of one of them are corrected due to the influence of random factors, as if it were obtained in a real measurement session \( R_{il}^{\text{kat}} = A_{il}^{\text{init},ld} - A_{il}^{\text{init},ld}. \) Evaluation of the influence of random factors should be carried out on the nearest to the recognized object, located in the zone of action of the complex of radio engineering measurements, the radiation parameters of which are known. Thus, the object can act as a "reference" object.

Comparing the difference portraits, one can assume that their mathematical expectations are equal only if the parameters of the DPA are identical. The small value of the discreteness of the difference portrait can be explained by the influence of external factors.

Thus, we propose the following hypothesis:

\[
S_y = \begin{cases} 
1, & H_0 \text{ provided } M(R_{ij}^{\text{sim}}) \approx M(R_{ij}^{\text{kat}}), \\
0, & H_i \text{ otherwise}
\end{cases}
\]

where \( H_0 \) is the hypothesis about the belonging of the recognized object to the \( i \)-type; \( H_0 \) is the hypothesis that the recognized object belongs to the \( k \)-type (\( k \neq i \)).

2.2. Application of the Criteria of the Student for Solving the Objective Type Recognition Object Type

In order to carry out object type recognition based on the antenna pattern, we will use the \( Z \) criterion (Student's criterion) considered in [6, 15]. In this case, when testing the hypothesis put forward, we will use the statistical method for correctness.

The principle of verification of statistical hypotheses is formulated as follows: if the observed value of the \( Z \) criterion belongs to the critical region \( z_{kr} \), then the hypothesis is rejected if the observed value of the criterion belongs to the domain of hypothesis acceptance - the hypothesis is accepted [6, 16]. We divide the entire set of possible values of the criterion into three disjoint sets and form a two-sided domain defined by the inequality \( |Z| > z_{kr} \), where \( z_{kr} \) is a positive number (Figure 3). In the figure, the case is considered when the critical points are symmetric with respect to zero under the assumption that \( z_{kr} > 0 \).

![Figure 3. Two-sided critical region.](image)

Thus, it is necessary to find a value \( z_{kr} \) that would divide the set of values into three areas indicated above.

Analysis of the difference portraits showed that the values of the samples are random variables and as the number of measurements increases, the law of their distribution tends to normal. In their essence, the difference portraits are general samples of the amplitude values.
In turn, the sample means are unbiased estimates of the general average, i.e. \( M(R_{il}) = M(\overline{R}_{il}) \). In view of the fact that the general samples \( R_{il} \) are normally distributed, then the sample \( \overline{R}_{il} \) means are also distributed normally.

Based on the foregoing, the quantity \( Z \) is a normalized random variable that is normally distributed, since it is a linear combination of normally distributed quantities \( \overline{R}_{il}^{izm} \) and \( \overline{R}_{il}^{kat} \).

Based on the sample mean difference portraits \( \overline{R}_{il}^{izm} \) and \( \overline{R}_{il}^{kat} \), the value \( Z \) is calculated according to the following Equation

\[
Z = \frac{\overline{R}_{il}^{izm} - \overline{R}_{il}^{kat}}{\sigma(\overline{R}_{il}^{izm} - \overline{R}_{il}^{kat})} = \frac{\overline{R}_{il}^{izm} - \overline{R}_{il}^{kat}}{\sqrt{D(R_{il}^{izm})/L_{vyb} + D(R_{il}^{kat})/Q_{vyb}}},
\]

(2)

where \( L_{vyb} \) is the number of discrete differences obtained when compared with the measured cross-section of the DPA; \( Q_{vyb} \) is the number of discrepancies of the difference portrait obtained in comparison with the simulated cross section of the DPA.

By the definition of the standard deviation - \( \sigma(\overline{R}_{il}^{izm} - \overline{R}_{il}^{kat}) = \sqrt{D(\overline{R}_{il}^{izm} - \overline{R}_{il}^{kat})} \). On the basis of the dispersion property of the difference of two independent random variables, we obtain \( D(\overline{R}_{il}^{izm} - \overline{R}_{il}^{kat}) = D(\overline{R}_{il}^{izm}) + D(\overline{R}_{il}^{kat}) \).

In connection with the fact that the variance of the arithmetic mean \( l \) of equally distributed mutually independent random variables is \( L \) times less than the variance \( D \) of each of the quantities, then: \( D(\overline{R}_{il}^{izm}) = D(\overline{R}_{il}^{izm})/L_{vyb} \), \( D(\overline{R}_{il}^{kat}) = D(\overline{R}_{il}^{kat})/Q_{vyb} \).

Consequently,

\[
\sigma(\overline{R}_{il}^{izm} - \overline{R}_{il}^{kat}) = \sqrt{D(\overline{R}_{il}^{izm})/L_{vyb} + D(\overline{R}_{il}^{kat})/Q_{vyb}},
\]

\( l = q \) and \( L_{vyb} = Q_{vyb} = L \) (the sample size is the same), therefore the Equation will take the following form

\[
Z = \frac{\overline{R}_{il}^{izm} - \overline{R}_{il}^{kat}}{\sigma(\overline{R}_{il}^{izm} - \overline{R}_{il}^{kat})} = \frac{(\overline{R}_{il}^{izm} - \overline{R}_{il}^{kat})\sqrt{L}}{\sqrt{D(R_{il}^{izm}) + D(R_{il}^{kat})}},
\]

(3)

The next step is to determine the value of the criterial value \( z_{kr} \), i.e., the boundary of the right-sided critical region based on a given level of significance \( \alpha \). To do this, it is necessary to find the value of the argument of the Laplace function, to which the value of the function equals \((1 - \alpha)/2 \). Then, in accordance with the foregoing, the domain of accepting the null hypothesis is determined by the inequality \( |Z_{sibl}| < z_{kr} \).

Thus, when recognizing different types of objects and their belonging, it is proposed to use the following algorithm as additional features (Figure 4).

3. Results and Discussion

The proposed algorithm was used in recognition of the type of various objects [5], while the following results were given in Table 1.

Analyzing the data it can be concluded that the solution of the problem of object type recognition using a directivity diagram as a sign is possible. The limits of applicability of the considered algorithm are determined based on the requirements to the quality indicators of the recognition system.
Table 1. Results of solving the recognition problem using the Laplace function for different significance levels

| $\varphi_1 - \varphi_2$ | Number of correct hypotheses for different significance levels $\alpha$ (500 experiments), [%] |
|------------------------|-----------------------------------------------------------------------------------------------|
|                        | 0.01 | 0.05 | 0.075 | 0.1 | 0.15 |
| 0.75 - 0.75            | 99   | 94.2 | 91.4  | 88  | 81.6 |
| 0.75 - 0.9             | 5    | 20.4 | 28.2  | 36.6| 46.4 |
| 0.75 - 1.0             | 13.6 | 52.8 | 64.8  | 72.4| 82.6 |
| 0.75 - 1.25            | 50.8 | 93.8 | 97.6  | 99  | 100  |
| 0.75 - 1.5             | 91.2 | 100  | 100   | 100 | 100  |
| 0.75 - 2.0             | 100  | 100  | 100   | 100 | 100  |

Figure 4. Algorithm for recognizing the type of the object based on directional patterns.

4. Conclusion
The considered algorithm allows to carry out the recognition of the type of the object on the basis of the comparison of the directional patterns with the possibility of variation of the threshold values due
to the change in the value of the significance level. The recognition solution, obtained with the help of this algorithm, is one of the elements of the initial data for the realization of the multichannel recognition system with discrete accumulation.

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