



Methods for the Classification of Radar Objects

Métodos para la Clasificación de Objetos de Radar

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ABSTRACT

Currently, many different algorithms have been developed that implement the classification problem. Of particular interest is the use of automatic classification algorithms in radar systems. In each such system, one has to solve the classification and recognition problem for detected targets. The work of an operator analyzing the information can take place in conditions that hinder assess of the control object's state. This is due to the absence or insufficient amount of reliable information about some radar target properties. A radar target is understood as any material object that can be detected, and its location and movement parameters can be measured using radar methods. We consider air, ground and surface objects as a radar object. Object classification algorithms are used in various fields when analyzing the properties of an object. This paper discusses the main methods for the classification of radar objects.

Keywords: object classification, hyperdimensional vector, radar object, trace information, recognition, tuple.

RESUMEN

Actualmente, se han desarrollado muchos algoritmos diferentes que implementan el problema de clasificación. De particular interés es el uso de algoritmos de clasificación automática en sistemas de radar. En cada uno de estos sistemas, uno tiene que resolver el problema de clasificación y reconocimiento de objetivos detectados. El trabajo de un operador que analiza la información puede tener lugar en condiciones que dificultan la evaluación del estado del objeto de control. Esto se debe a la ausencia o cantidad insuficiente de información confiable sobre algunas propiedades de los objetivos de radar. Se entiende por blanco de radar cualquier objeto material que se pueda detectar, y su ubicación y parámetros de movimiento se puedan medir mediante métodos de radar. Consideramos objetos aéreos, terrestres y de superficie como un objeto de radar. Los algoritmos de clasificación de objetos se utilizan en varios campos cuando se analizan las propiedades de un objeto. Este artículo discute los principales métodos para la clasificación de objetos de radar.

Palabras clave: clasificación de objetos, vector hiperdimensional, objeto de radar, información de trazas, reconocimiento, tupla.

1. INTRODUCTION

Currently, many different algorithms have been developed that implement the classification problem. They are based on various hypotheses about the nature of the objects distribution in a multidimensional space of attributes, and on various mathematical procedures.

Of particular interest is the use of automatic classification algorithms in radar systems. In each such system, one has to solve the classification and recognition problem for detected targets. A situation is possible when it is necessary to classify the detected target into one of several known classes. Automatic classification procedures can help.

The work of an operator analysing the information can take place in conditions that make it difficult to assess the state of a control object. This is usually due to the absence or insufficient amount of reliable information about some properties characterising the control object or factors influencing the formation of the external environment. In practice, solving object classification problems takes place under various kinds of restrictions in presenting initial data, requirements for the algorithmic implementation of functional capabilities and computational tools.

Object classification refers to the type of recognition tasks. A similar problem arises, for example, when classifying radar objects. The radio engineering target classification is one of the most important components of control and information processing systems, automated systems and decision-making systems. A radar target is understood as any material object that can be detected; its location and movement parameters can be measured using radar methods. We will consider air, ground and surface objects as radar object (Manual on MRO for aircraft engineering in Russia and the CIS, 2019; Victor Shunkov, 2018; Osipov, 2004-2017; Afanasyev, 1969). The analysis of such objects is a difficult and time-consuming work for an operator due to the fact that a large number of radar objects and the operating conditions of the operator do not allow correct assessment of the control object due to the lack of reliable information about the properties of the radar object. Object classification algorithms are used in various fields when analysing their properties. This paper will discuss the main methods for the classification of radar objects.

Formulation of the problem

In the course of analysing the track information data, which contains data on radar objects, it is impossible to accurately and quickly say which particular object we are analysing, for example, the Mi-6, Mi-8, Mi-24 helicopters, or, possibly, the RQ-11 Raven unmanned aerial vehicle. The data contains many radar objects with different information: X coordinate, Y coordinate, altitude, time, nationality, azimuth, speed, range, etc. All these parameters represent the behaviour of an object in space. Thus, it is required to conduct a behavioural classification of a radar object according to its parameters.

Let's represent the processed radar information using the set theory. We mean by a track a tuple T , which consists of a tuple of marks t ; it can be represented by the following formula:

$$T = \langle t_1, t_2, \dots, t_n \rangle, \quad (1)$$

Where n is the number of marks.

Each mark t contains a tuple of features s ; we represent it in the form of the formula:

$$\bar{t} = \langle s_1, s_2, \dots, s_m \rangle, \quad (2)$$

Where m is the number of parameters.

Example of a track's T_1 mark t_1 :

$$\bar{t} = \langle \text{Time, Nationality, X Coordinate, Y Coordinate, Speed, Altitude, Azimuth, Course, Range} \rangle.$$

We introduce the operation of intersection over tuples. To do this, we take the same elements that are in both tuples in the same position. Their order is also defined, that is, the result will be a tuple.

There is a tuple U , which includes all tracks, that is:

$$U = T_1 \cup T_2 \cup \dots \cup T_l, \quad (3)$$

Where l is the number of all tracks.

We mean by classes a tuple K , which contains information about all possible classes of a radar object, that is:

$$K = \langle k_1, k_2, \dots, k_p \rangle, \quad (4)$$

Where p – the number of all classes of the radar object.

Thus, it is required to determine to which class of objects K the tuple T belongs, where $T \subseteq U$.

This task has the following features:

- The tuple of tracks T goes to the input of the classifier;
- Due to the large number of parameters of objects \bar{t} , which are interdependent on each other, the process of formalizing the classes K is difficult;
- There is a certain intersection probability between classes of objects and the possibility of assigning a classified object to several classes;
- Due to the large number of tracks and their parameters, the appearance of new objects cannot always be classified even with the participation of an experienced expert; therefore, the need for heuristics appears.

One of the features concerning the presentation of the original data is their displaying in two-dimensional space. In fact, the input data has a large number of parameters and if we try to represent it in the form of a graph, it will represent a hyperplane. Therefore, for easy viewing by human eye, the data will be analysed in two-dimensional space.

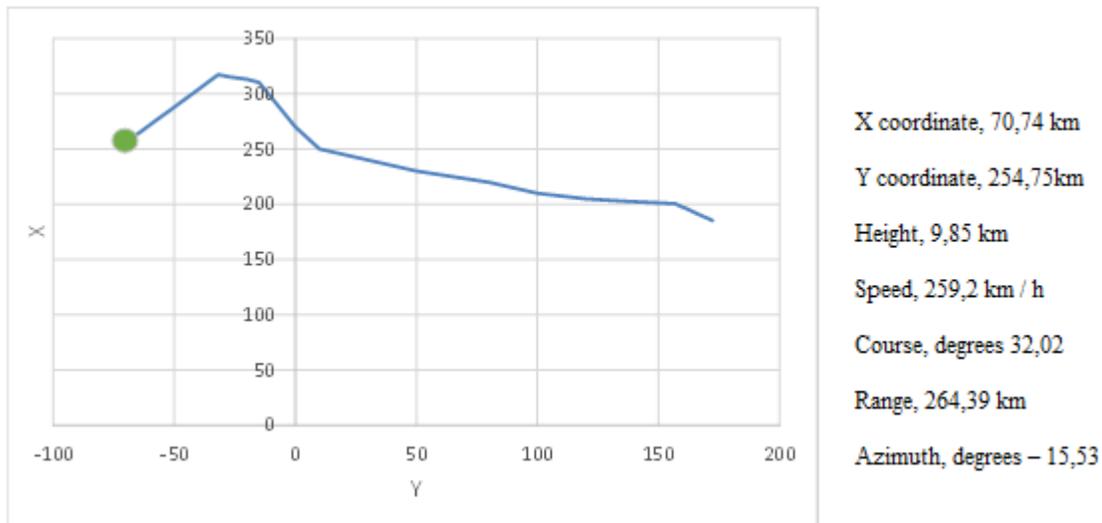


Figure 1. Example of object's track

Figure 1 shows an example of an object's track and its parameters. The bold point marks the analysed track elevation t ; on the right, some of its parameters t are listed. It is very time consuming and not always possible to classify an object manually, even with the participation of an expert, therefore it becomes necessary to automate the process.

Let's consider the fundamental methods of setting images within a class and within the framework of the task.

1. Specifying images by enumerating them

The class is specified by enumerating tracks T with a tuple of features of the images \bar{t} . Automatic pattern recognition assumes comparison with a reference. A tuple of features \bar{t} belonging to the same class K is introduced into the recognition system. In the case of an appearance of new images, they are sequentially compared with the previously introduced images. The recognition system compares the new image with the class K stored in memory. The advantage of this method is the ability to create inexpensive recognition systems, but the method will show a low probability of error only if the sample of images is almost perfect. The disadvantage of this method is that it is impossible to set all values of the tuple T due to the large number of elements (Gonzalez, 1978; Vassiliev, 1983).

2. Assigning images based on their generality

The main task of the method is to select a list of common properties \bar{t} from a sample of images for which it is known that they belong to the class K . The class is specified using common features for all incoming objects. Automatic pattern recognition involves the selection of such features. The advantage of this method are the following: significantly less memory is required to memorize the features of the class \bar{t} than to store all the objects included in this class. The downside of this method is that images that belong to the same class have several properties in common. It is laborious to find a complete set of distinguishing features for a class (Chaban, 2004).

3. Specifying Images Using Clustering

This method considers each element of the K tuple as a cluster, when the images of the class are a vector, the components of which are real numbers. Automatic pattern recognition assumes the relative spatial arrangement of individual clusters. Clusters can be located far from each other; in this case, the classification according to the principle of minimum distance is suitable (Kapralov et al., 2004; Barabash & Zinoviev, 1967). There is also an option that the clusters will overlap; this is possible due to incomplete or distorted information. In this case, we can use the method of partitioning the space of images (Fisenko & Fisenko, 2009).

The advantage of this method is that it is possible to split objects by a parameter set, and not by one parameter. Also, this method allows us to consider a large amount of information and reduce arrays, making them more compact and visual. The disadvantages of clusters include the fact that the number of clusters depends on the selected partitioning criteria (Gorelik & Skripkin, 1986). When the data array is reduced, there is a likelihood of distortions, and the properties of objects can also be lost by replacing them with a generalized value (Bureeva, 2007).

To implement the above methods, there are three main types of methodology: mathematical, linguistic (syntactic) and heuristic.

1. *Mathematical methods*

These methods are based on the rules of classification, which are expressed and presented within the framework of a specific mathematical formalism using fundamental methods for specifying images within a class of common properties and clustering. This approach also implies the use of operations on sets.

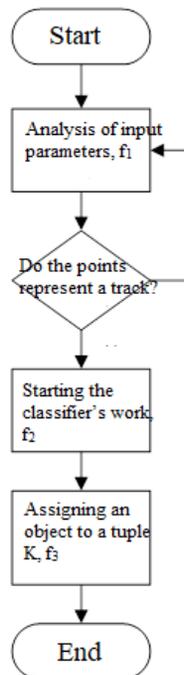


Figure 2. Object classification

Figure 2 shows a functional approach to the classification of radar objects. After starting the system, the input parameters are analysed. The analysed points represent the tuple marks t : the function f_1 for the selection of the required track. The marks are fed to the input of the neural network: the function f_2 of the

neural network triggering includes access to the neural network, which processes information from the track. Function f_3 is assignment of the analysed object to the class K stored in memory.

The main mathematical methods for constructing classification systems are divided into the following classes: deterministic, statistical.

The deterministic approach is based on a mathematical apparatus that does not explicitly use the statistical properties of the analysed classes (Dorogov, 2014). Among these methods, metric diagnostic methods, which are based on the distance between classes, are often used. The advantage of this approach is its ease of use. The disadvantage of this approach is the following: the presence of sets of all possible objects of each image; this is not possible in the absence of reliable information about the objects (Tsipkin, 1978).

The statistical approach is based on mathematical classification rules, which are presented in terms of mathematical statistics. This approach uses Bayesian classification rules and their variations. But in accordance with the task at hand, it is impossible to create membership functions. This is due to the fact that the parameters of the analysed radar object fall within the confidence intervals of the class. In this case, it is necessary to use methods based on enumeration algorithms (Tupikov et al., 2015).

The advantage of the statistical method lies in the relative simplicity of mathematical calculations and the absence of redundancy. The disadvantage is that the classification should be more reliable: a large amount of initial data is required (Gavrilovich & Seitvelieva, 2016).

2. Linguistic approach

Algorithms based on linguistic methods are most suitable for complex objects consisting of several units. The essence of this approach is to construct a concise description of the structure of a complex object; special grammars are used, with the help of which a set of properties of recognized objects can be described.

Let us consider this method within the framework of the task at hand, for example, for objects $T_1, T_2 \subseteq U$. If we replace the mathematical representation of the tuples T_1 and T_2 with a linguistic one, then the elements of the description can be used as features of the object. Thus, the tuples T_1 and T_2 are linked by some grammar.

The difference distinguishing this approach is that the classification of images is a direct tuple T structure use in the process of its recognition. The advantage of the linguistic approach is that the tuple T description is more concise and requires less memory space where it is stored, and the construction of such a description allows us to remove unimportant parameters of an object that could reduce the probability of classification when using correlation methods.

In this approach, difficulties arise when creating a complex object. For example, when formalizing a tuple U , it is difficult to describe the composition of this tuple linguistically because of the large number of traces T with a tuple of marks t , and ranges of values for the tuple of features \bar{t} . Therefore, it is important to pre-process the structure of such an object (Sokolov, 1960).

3. Heuristic methods

The basis of the heuristic approach is considered to be human intuition and experience. It uses such fundamental methods for defining images as enumeration of class members and generality of properties. Systems using such methods include a set of non-standard procedures created for specific classification problems (Zhuravlev, 1978).

In our case, when using this method, we can use a fuzzy set A , where the set is written as follows:

$$(U, f_A(u)), \quad (5)$$

Where $f_A(u)$ is the membership function of the fuzzy set A taking values within the range $[0, 1]$.

The probability distribution coefficients of the function $f_A(u)$ depend solely on the developer.

In view of the large number of elements of the tuple T being a tuple of features \bar{t} even an expert cannot always classify all objects.

The peculiarity of heuristic methods is that this approach does not imply strict formalization and the optimal solution depends on the human factor.

In the neural network approach to classification, it is problematic to create a training sample within the framework of the set task due to availability of the intersection probability for the ranges of classes (Kaftannikov & Parasich, 2016). Also, due to the large number of radar objects for classification arriving simultaneously and characterized by high computational complexity, the use of heuristic methods is required, since it is impossible to classify them even with the participation of an expert.

Tracks can be built from radar data, but the number of traces T requires a lot of analysis. The analysis will make it possible to be carried out by a neural network synthesized with the direct classification method (Kruglov & Borisov, 2002), which will try to classify this or that object into the class of objects K .

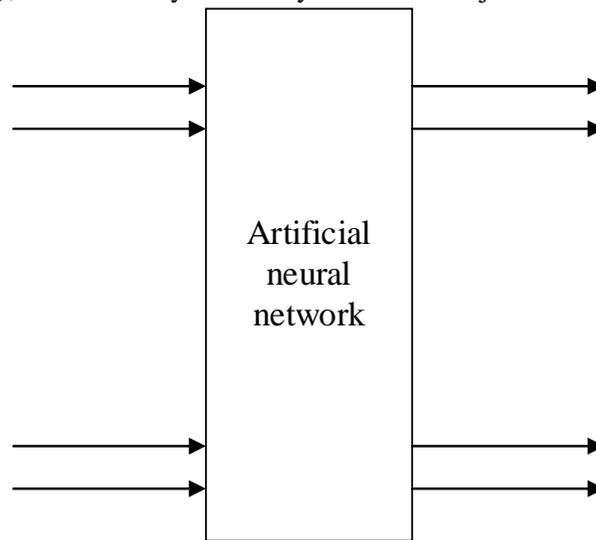


Figure 3. The structure of data coding in a neural network

Track data T is fed to the neural network input, an example of the structure of which is shown in Figure 3; after the learning process, a neural network is created, which will allow us to correlate the probability of belonging to the required class K of an analysed object.

The example of Figure 1 shows that it is impossible to classify an object according to the given parameters of one track mark from the tuple t . After analysing the data of one mark in the relevant literature, it is impossible to say which class the object belongs to, since this is a static value and consideration of further movement of the track point and its parameters is required, automation of the process is necessary for fast and correct classification of the object. In view of this, it is proposed to use the method (Pashchenko et al., 2019) among all the considered methods.

Track information presented in binary form is used as the initial data for classification. Track information contains a large number of radar objects. Information about a radar object is proposed to be represented by a hyperdimensional vector (HD-vector). HD-vector is one of the ways to represent data, in which the data bitness and order does not greatly affect the result. In describing the HD-vector, an important role is played by the relation between objects; it includes the state and transient conditions of the radar object (Sergina, 2020). The hyperspace representation of a target state of the radar object is updated every time a new state transition is created (or updated) by combining all and pre-existing HD vectors representing the state transitions (Associative Synthesis of Finite State Automata Model of a Controlled Object with Hyperdimensional Computing). The use of HD vectors will be more effective than the representation using clusters due to the greater resistance of HD vectors to multiple transformations (Pashchenko et al., 2020).

Field 1	Field 2	...	Field N
010111010101010010	1010111100	...	00000000100101010101010010101010

Figure 4. Classical data structure

Figure 4 shows a classic data structure. Such a structure is a vector where field values are sequentially represented. In this case, the values of the fields are not related to each other, but each field is presented separately. An advantage of the positional structure that we can quickly access the desired field by the array index; it is possible to easily extract / write the value and the developer knows exactly where it is. Presenting data in this way can reduce data redundancy and required storage space.

The HD vector is contrasted with the classic data structure. This method is based on non-positional coding, and represents the value of all parameters as one vector. Within the framework of the problem posed, the parameters are related to each other; therefore, we use precisely the algebra of hyperdimensional vectors. In hyper-sized vectors, each bit contains a small piece of information from each parameter; therefore, the disadvantage of HD vectors is redundancy. But due to the fact that all parameters are encoded, the level of entropy is sufficient to decode them back.

The hyperdimensional vector algebra will make it possible to efficiently analyse the input data of radar objects, and will also allow parallelizing data processing, that is, it will significantly reduce the time in case of using domestic equipment.

2. CONCLUSION

Thus, today the classification of radar objects is an important and urgent task. As part of the study of various methods for solving the classification of objects, various classification methods are considered; the advantages and disadvantages of each of the methods are given. It is proposed to use the method using HD vectors for the classification of radar objects, which will allow an object to be classified by multiple paths. This method requires high computational power, but it will maximize the parallelization of information processing, which will significantly save time in comparison with the considered methods.

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