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ALGORITHM FOR AUTOMATIC RECOGNIZING OF RADAR SCAN TYPE, BASED ON THE EXTRACTION OF STATICAL FEATURES FROM INPUT ANALYZED PROCESS

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Abstract. An algorithm for recognizing the radar antenna scan type by radio monitoring station is proposed. It is based on the extraction of a set of statistical features from the input radio signal, characterizing the signal amplitude envelope, modulated according to the scan type of radar antenna pattern. For feature extraction, mechanical, one-dimensional electronic and two-dimensional electronic scanning are considered, along with the beam steering schemes of radar antenna pattern used in practice. The essence of the proposed algorithm is the sequential comparison of the features with certain thresholds. The proposed recognition scheme is relevant for tasks of classifying the radio electronic equipment signals in a complex radio electronic environment and resolving ambiguity in recognizing radio signal sources with overlapping regions in the feature space, which characterizes time-frequency parameters of the radio signal. Experimental results are given, showing that the proposed algorithm ensures high recognition quality and is promising for improving existing and developing new radio monitoring equipment.

Keywords: radio emission source recognition, radar systems, antenna pattern, radar scan type, electronic scanning, mechanical scanning

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АЛГОРИТМ ДЛЯ АВТОМАТИЧЕСКОГО РАСПОЗНАВАНИЯ ВИДА РАДИОЛОКАЦИОННОГО ОБЗОРА, ОСНОВАННЫЙ НА ВЫДЕЛЕНИИ СТАТИСТИЧЕСКИХ ПРИЗНАКОВ ИЗ ВХОДНОГО АНАЛИЗИРУЕМОГО ПРОЦЕССА

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Аннотация. Предложен алгоритм распознавания вида радиолокационного обзора станцией радиотехнического контроля, основанный на выделении из входного радиосигнала набора статистических признаков, характеризующих огибающую амплитуду сигнала, модулированную в соответствии с видом сканирования диаграммы направленности антенны радиолокационной станции. Для выделения признаков распознавания рассмотрены механическое, одномерное электронное и двумерное электронное сканирование, а также применяемые на практике схемы перемещения луча диаграммы направленности антенны радиолокационных средств. Суть предложенного алгоритма заключается в последовательном сравнении признаков с определенными порогами. Предложенная схема распознавания актуальна для задач классификации сигналов радиоэлектронных средств в сложной радиоэлектронной обстановке и разрешения неоднозначности распознавания источников радиосигналов с пересекающимися областями в пространстве признаков, характеризующих частотно-временные параметры радиосигнала. Приводятся результаты экспериментов, показывающие, что предлагаемый алгоритм обеспечивает высокое качество распознавания и перспективен для применения в разработке новых и усовершенствовании существующих средств радиотехнического контроля.

Ключевые слова: распознавание источников радиоизлучения, радиолокационные системы, диаграмма направленности антенны, вид обзора радиолокационных систем, электронное сканирование, механическое сканирование

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Introduction

Modern radio monitoring stations are capable of providing prompt and reliable information on the location and parameters of radar system (RS) signals. That is why the improvement of their tactical and technical characteristics is an urgent task.

Among a wide range of tasks in the development of monitoring stations means, the key task is to recognize the type and mode of radar operation. This task is solved by measuring the time-frequency parameters of the radar signal. As a rule, such parameters as carrier frequency, pulse duration, pulse repetition interval, type of pulse modulation are used.

However, many radars performing the same functions, such as space surveillance or weapon control, may have overlapping fields in the feature space. In this case, it is important to have additional information about the radar to resolve the recognition ambiguity. It is known that the received radar series pulses also contain information about the scan type (ST) of radar space scanning [1]. This information instructs on each radar's individual features, so it can be used to make a decision about the radar operating type and mode, linking them to specific positions, monitoring the moving sources. In practice, the visual-manual method is used to solve the problem of recognizing the type of radar. Under these conditions, analyzing the possibility of automating this procedure is of particular importance.

This issue is poorly covered in literature, only some approaches to the formalized description of some types of ST are described in a number of foreign sources [2–10].

The purpose of this paper is to develop an algorithm for recognizing radar ST with a recognition probability of 80% or more based on the systematization of available information. The output data of the proposed algorithm will be used in a multi-level recognition system, where the first level is recognition based on the frequency and time parameters of the radar signal, the second level is classification of the radar by ST, and finally, the third level is decision making based on a set of features.

Brief characterization of radar scan methods

A radar scan is the movement of the antenna pattern beam to view a given (monitored) area of space.

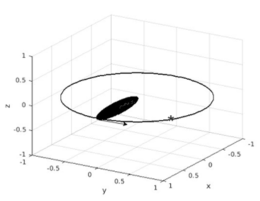
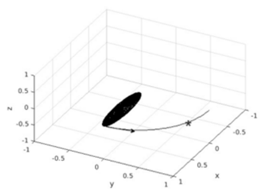
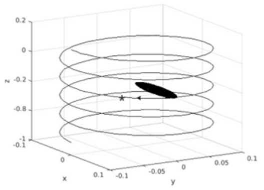
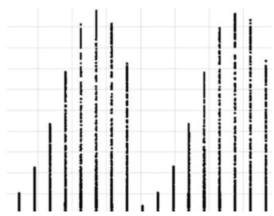
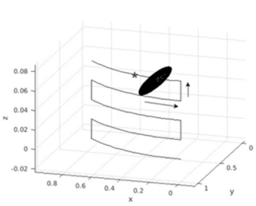
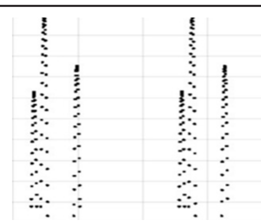
At the receiving and analyzing equipment of the radio monitoring station, the view of ST can be represented in the form of amplitude-time representation (ATR) (Fig. 1).

The ATR is the amplitude envelope of a series of pulses modulated according to the radar ST. Knowledge of this feature can be useful in deciding on the type of radar and its mode of radar operation.

In radiolocation, the following ST are the most popular in practice: circular, sector, helical and raster. The corresponding ATR views are shown in Table 1.

Table 1

ST and their ATRs

ST	Antenna pattern beam movement	ATR
Circular		
Sector		
Helical		
Raster		

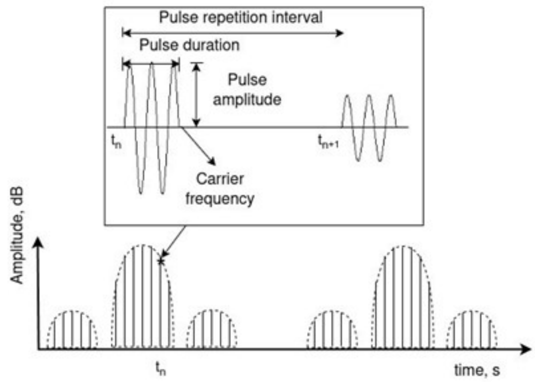


Fig. 1. ATR of the radar signal (the input of radio monitoring station)

In the circular scan, the radar makes a circular rotation in the azimuth plane with a constant velocity Ωα. The ATR of this type of view is characterized by the antenna pattern (AP) width measured at the 3 dB level and the scanning period Ta.

The sector scan of space, in contrast to the circular one, is limited by a certain azimuth angle. The time interval between the main beams of the AP at the receiving point of the monitoring station has two values, except for the case when the AP will be located in the middle of the scanning sector.

In a helical scan, the spatial motion of the AP is a combination of circular rotation of the diagram in the horizontal plane with velocity Ωα and its gradual movement in the vertical plane with velocity Ωβ. In this case, each point of the AP moves along a line close to a helical line.

Raster scan is a type of helical scan with limitation of the scanning sector in the azimuthal plane.

The ST discussed above belong to the class of mechanically scanned radars.

In addition to mechanical scanning (MS), modern radars use electronic scanning (ES) with implemented phased arrays (IPA) to change the spatial orientation of the main beam of the AP. A distinction is made between IPA with one-dimensional and two-dimensional scanning or, in other words, antennas with beam motion in one plane and antennas with beam motion in two planes.

The main difference between MS and ES is that the latter allows the beam direction of the radar antenna to be changed rapidly, almost inertia-free.

Features for distinguishing radar stations by ST

Let us represent the pulse series amplitude envelope (ATR) at the input of the monitor station as an N-dimensional sample:

$$\mathbf{Y} = \left(\mathbf{y}_1,\ \mathbf{y}_2,\ \ldots,\ \mathbf{y}_n,\ \ldots,\ \mathbf{y}_N\right),$$

where $\mathbf{y}_n = \left(\tilde{a}[n],\ t[n]\right)^{\tilde{a}[n]=\frac{a[n]}{\max(a[n])}}$ is the normalized amplitude of the n-th pulse $a[n]$, t_n is the arrival time of the nth pulse, N is the number of pulses (samples) in the sample Y, $n = \overline{1, N}$.

In this paper, two features are used to classify radars according to the way they scan space: F_1 – the similarity coefficient and F_2 – the amplitude differences wobble $\{\tilde{a}[n]\}$.

The feature F_1, which allows for distinguishing radar with MS from radar with ES, is calculated by the formula:

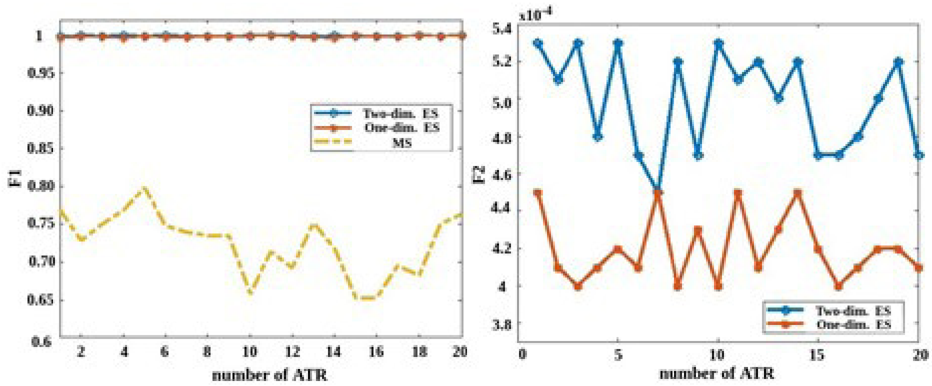


Fig. 2. Result of estimation of informativeness of features F_1 and F_2, allowing for recognizing radars by the method of space scanning into three classes: MS, one-dimensional ES and two-dimensional ES

$$F_1 = \frac{\sum_{j=1}^{N-2} S_1[j] S_2[j]}{\left(\sqrt{\sum_{j=1}^{N-2} S_1^2[j]} \times \sqrt{\sum_{j=1}^{N-2} S_2^2[j]}\right)}, \tag{1}$$

where $S_1[j] = \max\left(|d_1[j+1]|, |d_2[j]|\right)$, $S_2[j] = |d_2[j]|$, …, $j = 1, 2, \ldots, N-2$, $d_1[n] = \tilde{a}[n+1] - \tilde{a}[n]$, $n = 1, 2, \ldots, N-1$ are the amplitude differences of the first order, $d_2[n] = d_1[n+1] - d_1[n]$, $n = 1, 2, \ldots, N-2$ are the second-order amplitude differences $S_1[i] > 0$, $S_2[i] > 0$, $0 \le F_1 \le 1$.

The feature F_2, which allows for distinguishing a one-dimensional ES from a two-dimensional one, is calculated in two steps. First, the sequence $\{d_1[n]\}$ is used to form a series of elements whose values are less than the set value (in this paper, it is assumed to be 0.0003), and then the variance of the series obtained in this way is calculated.

The result of evaluating the informativeness of features F_1 and F_2 by simulation modelling method is illustrated in Fig. 2.

Fig. 2 shows that the feature F_1 allows for distinguishing ES from MS by comparing its value with a certain threshold λ_1. The value of feature F_2 for one-dimensional ES is much larger than for two-dimensional ES, which proves the possibility of its use in classification by comparing it with a certain threshold λ_2.

Decision making on the ST of the MS radar is based on the application of the following three features: F_3 is the number of main AP beams, F_4 is the magnitude of the envelope amplitude wobble of the pulse series and F_5 is the time interval between the main AP beams.

The feature F_3, which allows for distinguishing circular ST from sector ST, is calculated using the normalized mutual correlation function between the signal $\{\tilde{a}[m]\}$ and the signal $\{b[m]\}$, representing the samples of the main AP beam with maximum amplitude:

$$r[k] = \frac{\sum_{n=1}^{V} \tilde{a}[n+k] b[n]}{\sqrt{\sum_{n=1}^{V} \tilde{a}^2[n+k]} \cdot \sqrt{\sum_{n=1}^{V} b^2[n]}}, \quad k = 1, 2, \ldots, N-V, \tag{2}$$

where V is the number of samples of the signal $\{b[n]\}$.

Selection of the main AP beam $\{b[n]\}$ on the signal $\{\tilde{a}[n]\}$ is performed by finding the reference $\tilde{a}[n]$ with the maximum value and the nearest samples (left and right), whose values are greater than the set threshold λ_3.

The feature F_4 is calculated as the difference between the maximum and minimum value of the amplitude of the main beams on the signal $\{\tilde{a}[n]\}$:

$$F_4 = \max(\tilde{a}[n]) - \min(\tilde{a}[n]). \quad (3)$$

The feature F_5 is found as the ratio of the maximum time interval between the maxima of the main beams on the signal $\{\tilde{a}[n]\}$ to the minimum one:

$$F_3 = \Delta T_{\max} / \Delta T_{\min},$$

where $\Delta T_{\max} \Delta T_{\min}$ are the maximum and minimum interval between the maxima of the main beams.

The result of evaluating the informativeness of features F_3–F_5 conducted by simulation modelling method is illustrated in Fig. 3–5.

The figure above shows that the radar with circular ST is characterized by only one beam per period, whereas with the sector ST two beams are observed (Fig. 3). The value of the feature F_4 for sector ST fluctuates around the value equal to zero (Fig. 4). This allows for distinguishing sector and circular scan from raster and helical ones by this feature by comparing it with the threshold λ_4. The feature F_5 is constant for circular and helical ST and varies for raster ST (Fig. 5). Therefore, it can be used to distinguish raster ST from helical ST by comparing it with the threshold λ_5.

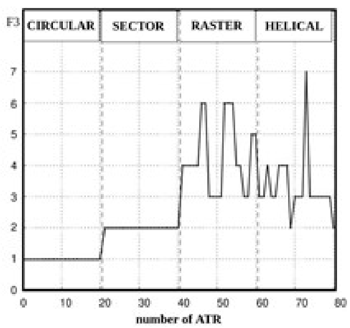


Fig. 3. Result of estimating the informativeness of feature F_3 to distinguish circular ST from sectoral ST

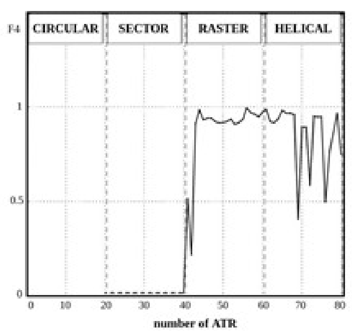
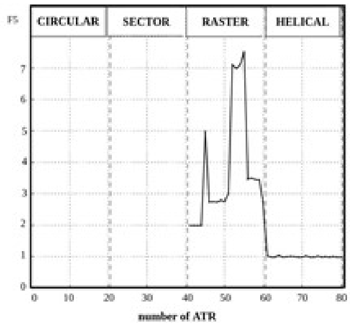


Fig. 4. Result of estimating the informativeness of feature F_4 to distinguish sectoral and circular ST from helical and raster ST



Result of estimating the informativeness of feature F_5 to distinguish raster ST from helical ST

Algorithm for recognizing radar stations by ST

The proposed algorithm includes three main steps: calculating the antenna scan period T_a, extracting the recognition features and deciding on the space scanning method and ST.

Stage 1. The estimation of the ST period is carried out using the samples of the normalized autocorrelation function, which are calculated by the formula:

$$r[k]=\frac{\sum_{n=1}^{W}a[n]a[n+k]}{\sqrt{\sum_{n=1}^{W}a^2[n]}\cdot\sqrt{\sum_{n=1}^{W}a^2[n+k]}},\quad k=1,2,\ldots,N-W, \tag{4}$$

where $a[n]$ is the envelope amplitude of a pulse series at the moment of arrival of the n-th pulse, k is the serial number of the shift (delay) in time, W is the length of the window, which is chosen based on the requirements of accuracy and computational complexity (in modelling W is taken equal to N/2). As an estimate of T_a (in counts) is taken the value of k at which $r[k]$ is greater than the set value of 0.98.

Stage 2. The features are calculated using formulas (1–3).

Stage 3. Classification of radars by the method of space scanning and recognition of the ST is carried out using the decision tree method. The structure of the decision tree using the features discussed above is shown in Fig. 6.

The scanning method and the ST is represented in a tree structure by finite nodes.

The traversal of the decision tree starts from the root of the tree (feature F_1 is checked), then a sequential traversal of child nodes is performed (features F_2–F_5 are checked) until an appropriate solution is obtained for a given node.

Simulation

To illustrate described processing algorithm, simulation was carried out. As input data, 320 ATR signals of radars with different types of scanning and space scanning methods were modelled. From them, to check the quality of radar classification by scanning method, the following signals were selected: 40 – with MS and 80 (by 40 for each method of electronic scanning) – with ES, and 200 signals (50 for each type of scanning) were selected to check the quality of recognition of ST. The F_1–F_5 features were compared with pre-calculated thresholds, $\lambda_1 = 0.8$, $\lambda_2 = 0.0005$, $\lambda_3 = 1.06$, $\lambda_4 = 1.1$, $\lambda_5 = 1.3$.

Tables 2 and 3 show the results of the simulations.

A value equal to the ratio of the number of trials m in which a given event (radar scan method and ST) appeared to the total number n of trials actually conducted was used as an indicator of decision quality.

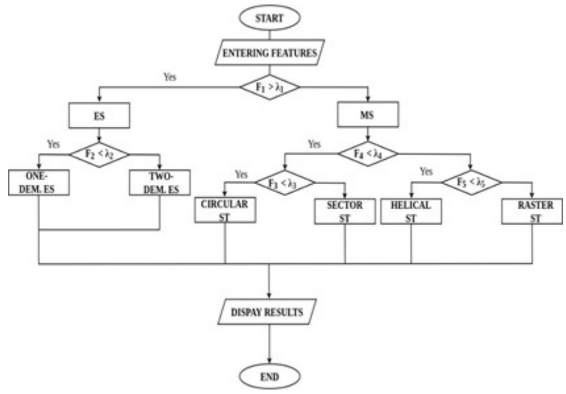


Fig. 6. Algorithm for recognizing the ST

Table 2

Result of the recognition quality evaluation of the space scanning method

Scanning method	One-dimensional ES	Two-dimensional ES	MS	Probability, %
One-dimensional ES	80	18	2	80
Two-dimensional ES	1	95	4	95
MS	1	1	98	98

Table 3

Result of evaluation of the quality of recognition of the ST

Reliability, % / The type of RO is	Circular	Sectoral	Helical	Raster
Circular	97	3	0	0
Sectoral	3	97	0	0
Helical	0	0	85	15
Raster		0	14	86

The recognition quality was assessed at a signal-to-noise ratio R equal to 10 dB. As can be seen from Tables 2 and 3, the percentage of correct decisions in assigning the radar to one of the three classes (Table 2) was at least 80%, and the quality of recognition of the ST was at least 85%.

Conclusion

Circular and sector ST recognition showed a high probability of recognition equal to 97%. The validity for the helical and raster type was 85% and 86%, respectively, provided that there was no false recognition as a sector or circular ST. Since raster scanning is a kind of helical scanning, such results can be justified by the position of the monitoring station in the middle of the radar scanning sector.

The analysis of the available sources of information on the issue of evaluation and selection of features for recognition of the type of scanning can be used in the modernization of existing and development of prospective monitor stations.

The obtained data show that the considered features and recognition algorithm allows to classify radar stations by the method of space scanning and determine their type of radar stations. Further research should be focused on testing the algorithm in real conditions of radio monitoring station operation.

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